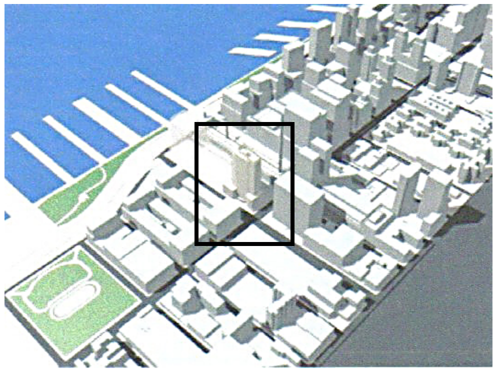
Andrew Covely
Structural
Dr. Linda Hanagan
The Helena
New York City, NY
October 27, 2004



Pictures courtesy of Fox & Fowle Architects

Pro-Con Structural Study of Alternate Floor Systems

Executive Summary

This document will discuss the possible alternatives for a floor system in The Helena. The existing floor system is a 8" flat plate slab on all levels but the ground floor. All levels of the building except the ground floor and sub-floors are for residential use. The existing system seems to be the best choice for the building from a structural standpoint. However, the time it takes to integrate some of the conduit for other systems into the slab creates room for possible alternatives which could be quicker. To determine these issues, four alternative floor systems will be discussed in-depth with other systems also being mentioned. A typical bay area from a residential floor was used as the basis for the design of the alternative systems. The alternative systems were examined on the issues of cost, constructability, and the effects the system had on the other building systems. The four alternative building systems which were considered for in-depth design analysis are:

- One-way concrete slab with beams
- Concrete T-beam
- Open web steel joist
- Composite steel

Other floor systems which were considered are non-composite steel, pre-cast concrete planks, and a waffle slab.

The one-way slab and T-beam showed the best results to being acceptable alternatives to the existing system. Also, pre-cast concrete planks were discussed as a possible alternative and were viewed as being worth the time to perform an in-depth analysis on the system. The open web steel joist and

composite steel systems were not seen as viable alternatives and any further investigation into their design was not considered necessary.

Introduction

The Helena is currently constructed from a flat plate slab floor system. The depth of the slabs varies from 18" on the sub-cellar floor (two stories below grade) to 8" on the residential floors. In this technical assignment, an in-depth analysis of the pros and cons of alternate floor systems will be conducted. Adjustments to the existing floor system as well as new designs using concrete and steel will be considered. Only designs for the residential floors will be calculated since almost all of the building is composed of residential floors. As part of this analysis, four alternate floor systems in addition to the existing system will be examined to determine suitable alternatives. For the four alternate floor systems to be considered, I have selected:

- One-way concrete slab and beams
- Concrete T-beams with integrated slab
- Open web steel joists
- Steel beam with composite concrete slab on metal deck

The variables which need to be considered when evaluating an alternate floor system include fire protection rating, durability, self-weight, vibration resistance, costs, depth, and slab openings. Each system is required to have a 2-hour fire protection rating to ensure enough time for safe evacuation of the building. If the self-weight of the building is too great, it could cause problems for the foundation system of the building. Depending on the type and amount of materials needed for a particular system, the costs required to create the system are much greater than that of other systems.

Existing Structural Floor System

As seen in the figure below, the spacing of the columns is spread out and not typical in any direction. Because of this, I selected an area of the floor plan that was as close to rectangular as possible and adapted its dimensions slightly to use it as a rectangular bay. The typical floor system designed for the building is a two-way flat plate slab supported by columns. A flat plate slab system differs from a regular two-way slab system because the slab is not poured integrally with the columns. The slab is poured separately and sits on top of the columns. The reinforcing for the slab is provided by #4 or #5 bars at 12" throughout the slab with column strips and middle strips providing extra support. Additional bars are also supplied at the columns where needed. Apart from the main floor system in the building, there are a few spots which are designed using beams and one-way slabs. The West end of the building on the second floor is supported in this manner. The lateral loads exerted on the building are absorbed by an intricate arrangement of shear walls which are found on each floor for the entire height of the building.

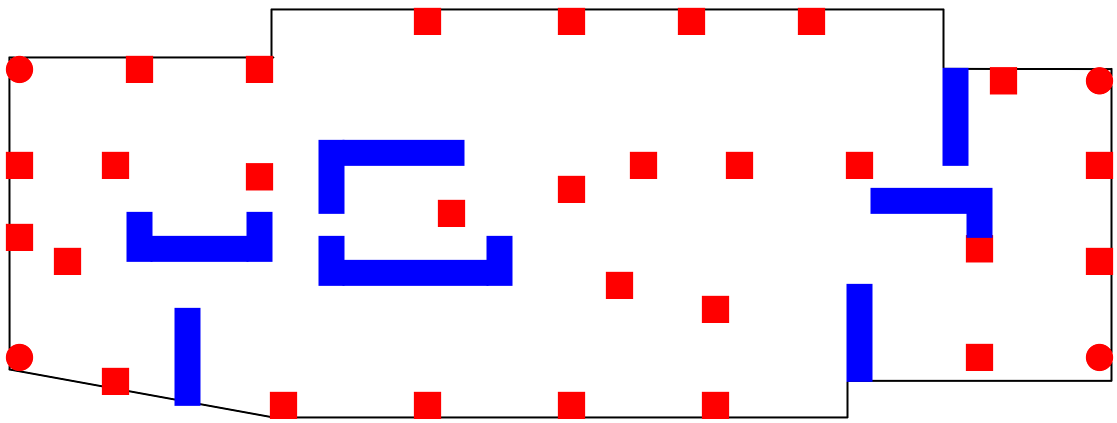


Figure 1. Column layout for floors 12-32, the most typical floor plan in the building

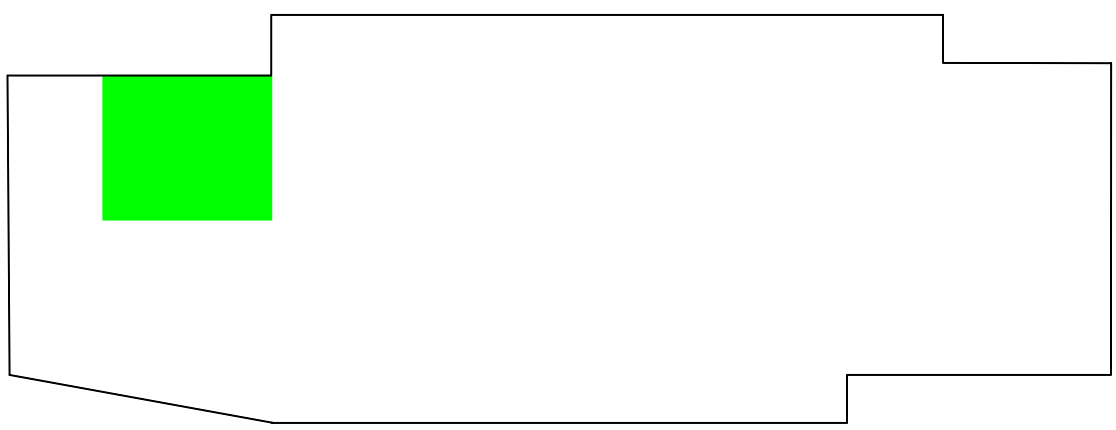


Figure 2. The location of the bay which will be used for the floor system designs

Loads

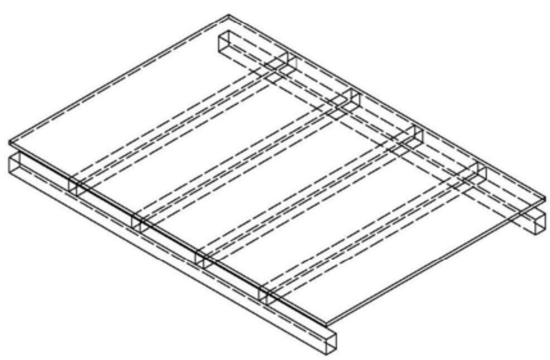
Dead Loads:
- ❖ Partitions: 20 psf
- ❖ MEP/Lighting: 10 psf
- ❖ Finishing: 5 psf
- ❖ Sprinklers: 5 psf
- ❖ Total: 40 psf

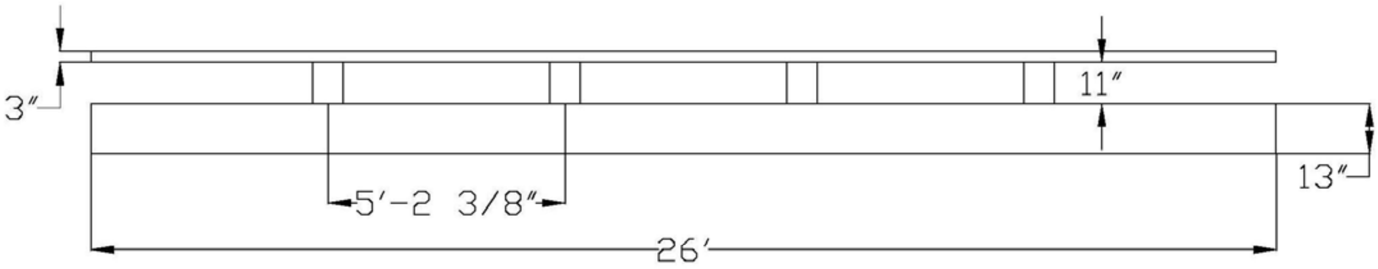
  Self-weight of the members in the systems will not be considered because they are different for each system.

Live Load:
- ❖ 40 psf – As defined by the New York City Building Code

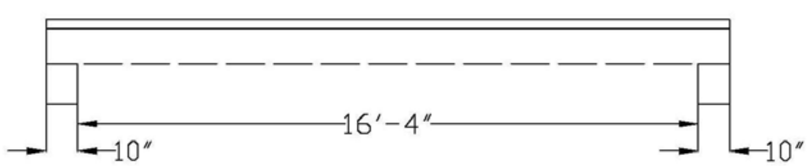
Alternate Concrete Floor Systems

A one-way slab system with beams and girders was the first alternate concrete floor system I chose to consider.

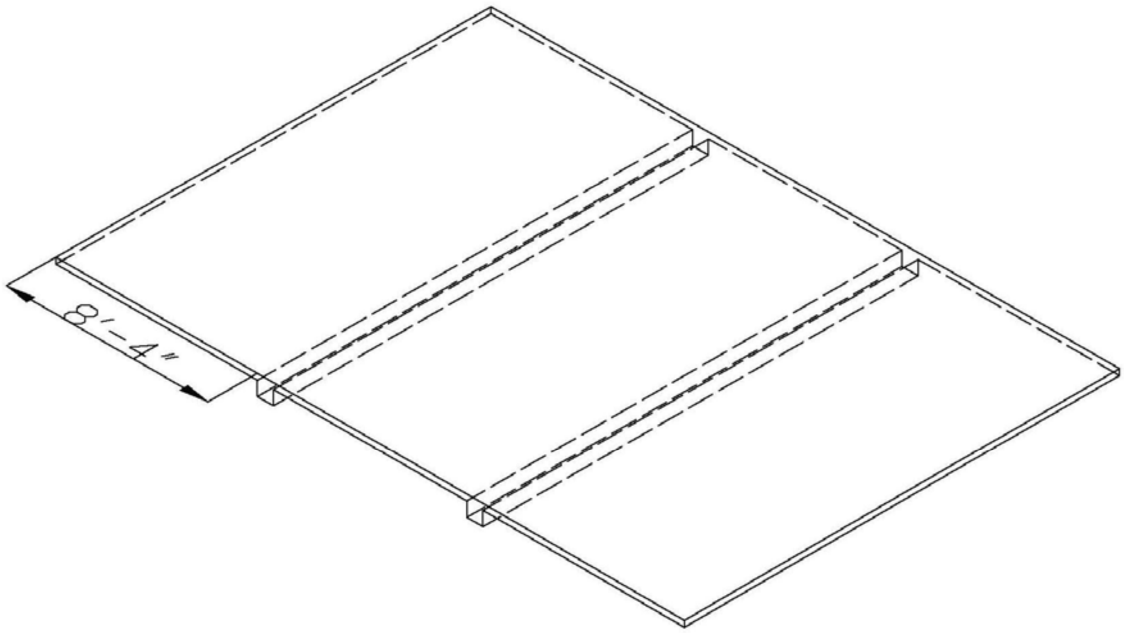




The one-way slab system is designed with a 3" slab with beams and girders. The loads are carried through the slab to 8"x11" beams. 10"x13" girders take the load from the beams and transfer it into the columns from there. A disadvantage to this system is the formwork will take more time to erect since 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 system will be 27" deep, but if the girders are designed to occur inside of a wall, the system's depth can be reduced to 14", increasing the overall building height by 19 feet as opposed to 35 feet. The increased building height would have to be taken into account when calculating the lateral load forces on the building. Also, this increase will mean more materials needed for the envelope of the building to cover the added height. A one-way slab system would also be lighter than the existing system. This provides advantages as well as disadvantages for the design of the building. With the building being lighter, there will not be as much dead load weight to resist the overturning moment due to lateral loads and create an uplift force in the foundation. However, less weight will mean not as much bearing capacity will have to be carried by the foundation.



A concrete T-beam system was the second alternate concrete floor system chosen to be considered for design.



This T-beam system was designed using a 3" slab poured with beams that extend 7" down from the lower face of the slab and are 8" thick. The forms for this system will be more intricate than for that of the flat plate, but as with the one-way slab system, the conduit does not need to be placed prior to pouring the concrete, taking less time than would be needed to embed the conduit in the slab. A fire rated ceiling would be needed to help cover the slab which will not meet the necessary 2 hour fire rating. This is not an issue since a ceiling assembly will be needed to conceal the beams and ductwork which will be run between the beams. The depth of the system is only 2" deeper than that of the existing system making it a viable alternative to the existing system. This system will also be lighter than the existing system requiring a look at the lateral load system which will be required to take more force. The foundations will benefit from the lighter bearing capacity but will be faced with the uplift force from the added stress on the lateral system.

Additional concrete floor systems not considered in full depth which could be considered for alternatives to the existing system are pre-cast concrete plank, post-tension flat plate slab, and waffle slab.

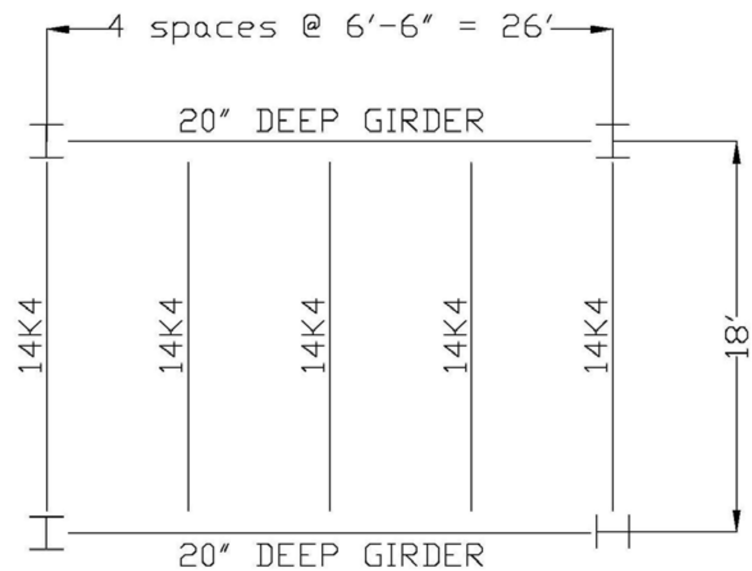
The pre-cast concrete planks could be placed integrally with the girders which would be used to support the load. By these means, the depth of the floor system would not greatly increase from the existing system. One disadvantage would be the need to fireproof the girder to meet the required fire rating. A great advantage for this system is the fact that the pieces are made off-site where they can be precision made. This may slow down the construction process of needing to know the size of the pieces; however, it will make for ease of construction without the need for forms. Constructability may become an issue since there is not much room for on-site storage of the pieces and they would need to be brought in to the site at the time of erection.

Post-tensioning a flat plate will make the plate, which is usually a two-way system, act as a one-way system. I feel this could be a benefit to the system given the building's slender dimensions. This system would maintain the advantages of meeting fire rating requirements, decreased depth of the system, and less complicated form design. A disadvantage to this system is the added cost and time of having to post-tension the concrete.

A waffle slab is another system taken into consideration when determining suitable alternative floor systems for this building. The depth of the system will become a consideration as to whether or not it will be of any advantage to use this system instead of the existing system. Also, if drop panels were required in the design, it would be difficult to try to make the drop panel locations coincide with the gaps in the system.

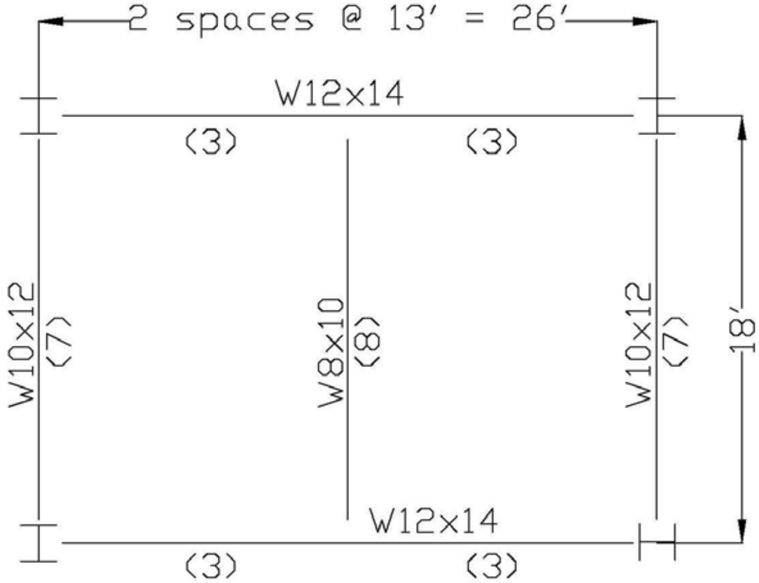
Alternate Steel Floor Systems

An open web steel joist system was the first alternate steel system to be considered.



The system is designed using 4 spans of 6'-6". 14K4 joists were selected to carry the load with no BC bracing required. The deck is composed of 1.5C20 non-composite decking with a 4.5" total slab depth and 4x4-W2.9xW2.9 welded wire fabric reinforcing. The concrete is made of an exposed grid 3" normal weight concrete slab which is able to reach the 2 hour fire rating which is required for such a system. An advantage to this system is the lack of need for forms to pour the concrete which will decrease the amount of time needed to build the structure. A disadvantage to the system is the depth required to get the needed amount of resistance. The joist alone is 14" deep and the girder needed to carry the load of the joists is 20" deep. Also a disadvantage is the need to apply fireproofing to the system. Concrete does not require any additional fireproofing to be used, while a steel system typically requires spray-on fireproofing to give it the needed fire resistant rating. This system is also much lighter than the existing system. While a lighter system sometimes means cheaper, this lighter system can cause a greater affect by the lateral loads on the building. The lateral system will be required to take more force and this could place great stresses on the building. Lateral and foundation systems could have to be re-designed to take on the extra load this system could produce.

A Composite steel beam with metal deck system was the second alternate steel floor system which I took into consideration for the design of The Helena.



This system was designed and checked through a RAM model. It consists of 2" USD lok-floor composite steel deck with a 3.5" lightweight concrete which covers two spans of 13 feet. The composite beams are designed from A992 steel with 7 shear studs transferring the load for the W10x12 beam and 8 shear studs transferring the load for the W8x10 beam. The W12x14 girders then take the load from the composite beams using 6 shear studs. As designed, the total slab depth of 5.5" satisfies the 2 hour fire rating requirement. Although the deck satisfies the fire rating requirement, the steel structure itself would need to be fireproofed. This will add time and cost to the construction which would offset the time gained by not having to create forms for the concrete pours. Another disadvantage to this system is the depth it will add to the overall height of the structure. The combination of this problem and the lighter weight of this system will cause problems with the lateral system. The decrease in dead load will not allow for as much resistance of the building to the overturning moment caused by the lateral loads. To redesign the lateral system, braced frames could be used in the building in place of the shear walls to avoid re-designing the floor plan of the building.

Another steel floor system considered for the design of this building is the use of non-composite beams with metal deck. This system is almost identical to a composite system, but without the use of the shear studs to transfer the load, the members used in the design would be deeper and heavier than that of the composite system. The larger members would increase the overall depth of the system and the extra material needed probably would not compensate for the lack of shear studs used in the composite system.

RESULT SUMMARY

System	Add’l Fire Protection	Depth Change	Slab Openings	Vibration	Self Weight	Suitable
Flat plate (Current)	None	None	Easily Used	No issues	Current	Yes
One-way slab	Fire rated ceiling	19 ft increase	Easily Used	No issues	Lighter	Further Explore
T-beams	Fire rated ceiling	6 ft increase	May require add’l support	Light weight could cause issues	Lighter	Further Explore
Open web steel joist	Spray-on fireproofing	19 ft increase	May require add’l support	No issues	Lighter	No
Composite steel	Spray-on fireproofing	51 ft increase	May require add’l support	Composite will stiffen the system	Lighter	No

Conclusions

Reviewing the summary of possible alternatives for this building, I believe the best choice was made by using the existing two-way flat plate slab. This building has the right combination of self-weight which will be able to resist the lateral loads being applied, but will not exceed the allowable bearing capacity for the foundation and soil. Also, this system does the best job of keeping the building height to a minimum which keeps the lateral loads in check.

The one-way slab with beams system is a lighter system and will increase the building by 19 feet. The lighter system will not create as much of a bearing stress on the foundation, but the lack of dead load weight on the system along with the greater building height will create the need for a review of the lateral load resisting system. Having to embed the conduit in the slab prior to pour will take longer to make the pour and delay the time of moving the formwork to the next level. If this time is more important than the cost of the extra exterior cladding and reinforcing needed for the shear walls, then this could be a better alternative for the building.

The T-beam system did not have much of an affect on the overall building height, but the need to strengthen the slab with extra members around an area which would require slab openings would be an issue. This system is also lighter than the existing system which would have the problems of less dead load to resist the overturning moment placed on the building by the lateral loads. The formwork will be a little more complicated than for that of the flat plate but the conduit will not need to be embedded in the slab and can be fastened underneath the slab between the beams. This system could prove to be a good alternative.

The open web steel joist system did not prove to be an acceptable alternative floor system. The combination of the increase in building height with the cost and time required to perform the fireproofing made this system a bad choice for an alternative system. The system is also lighter which would combine with the height increase to cause problems with the design of the building's lateral load resisting system.

The composite steel system also proved to be an unacceptable alternative. This system created the greatest increase in building height. Also, the cost and time required to perform the spray-on fireproofing does not make this system a good alternative choice. The extra framing members needed to support slab openings also adds to the disadvantages of the composite steel system.

The pre-cast concrete plank system is one which I think should be considered in more detail. The ability to create the slabs off-site gives them the ability to be created in optimal conditions with less possibility of problems. This system also eliminates the need for formwork which will cut the time of construction. The only issue would be where the planks would be kept until the time of erection. If the building height is not too greatly affected by this system, it could prove to be an acceptable alternative.