Technical Report 2

Pro-Con Structural Study of Alternate Floor Systems

Columbia University Northwest Science Building

Broadway & 120th Street, New York, NY

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Executive Summary:

The overall objective of this technical report is to study the existing floor system and three alternative floor systems for the Columbia University Northwest Science Building. The existing design of the building is a composite steel structure. See *Figure 1*, "Typical Structural Floor Plan", below.

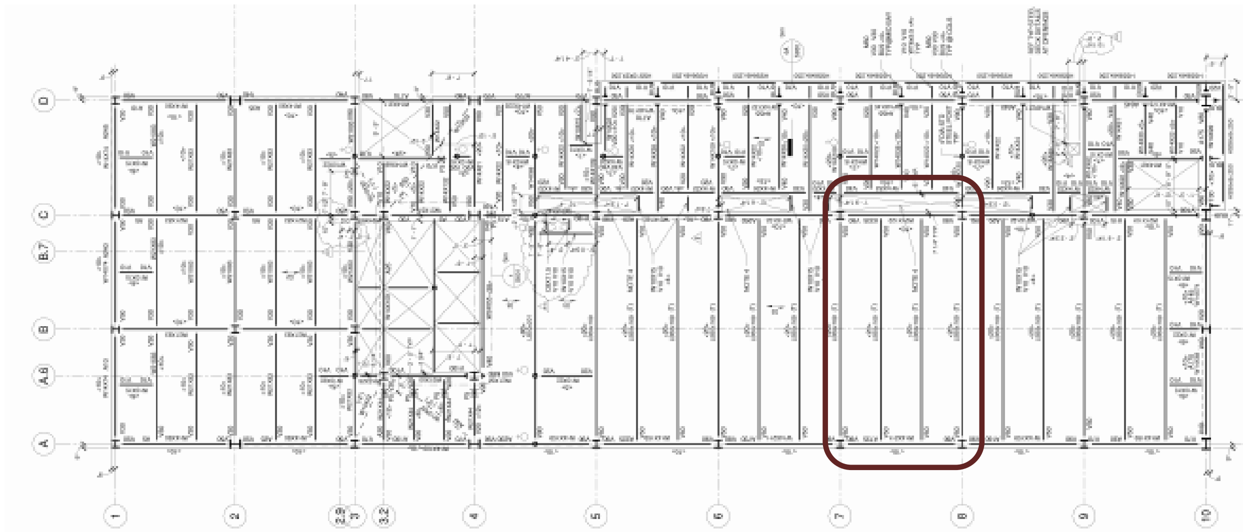


Figure 1: Typical Structural Floor Plan

The red circled area in the figure above represents a typical laboratory bay. These laboratory bays have large 40 foot spans. The spans are made by castellated beams. The slab is a concrete topping on corrugated metal decking. The beams, decking, and concrete topping are all part of the composite structure. This typical laboratory bay will be looked at closely throughout this technical report. Laboratories take up the most area within the building; therefore, the floor system design of these laboratory bays can be a determining design concern. A typical bay is depicted below as *Figure 2*. Take note of the outer bay dimensions.

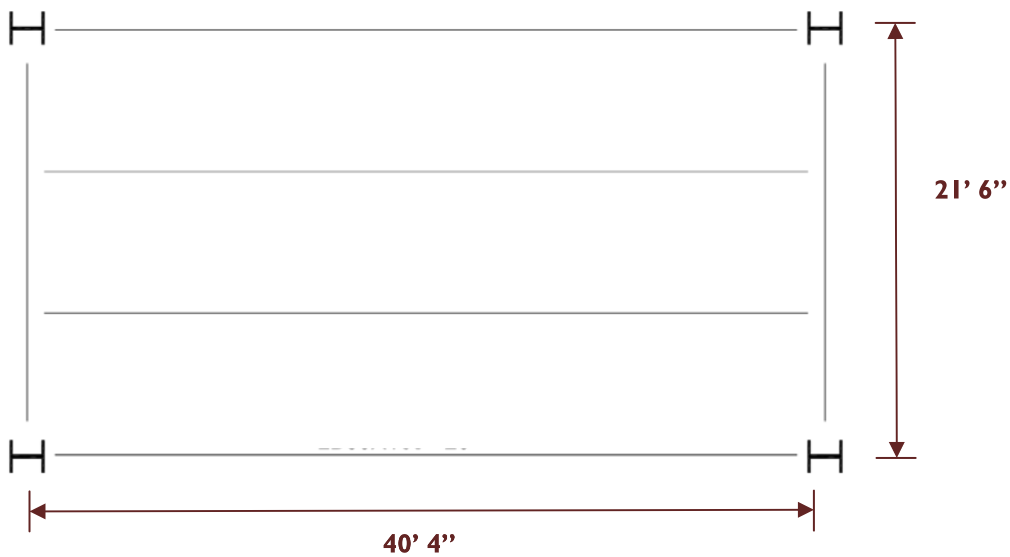


Figure 2: Typical Laboratory Bay

The existing floor design will be discussed and checked, along with three alternative floor systems listed below.

- **Alternative Floor System 1: Composite Joist Floor System**
- **Alternative Floor System 2: Two-Way Post-Tensioned Slab Floor System**
- **Alternative Floor System 3: Precast Hollow-Core Planks on Steel Floor System**

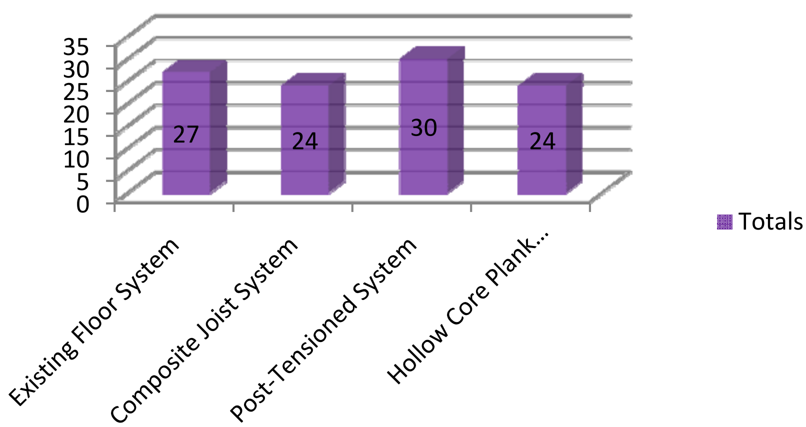
Each floor gravity system was designed based upon preliminary calculations of stresses, moment, shear, and deflection requirements along with common rules of thumb. See *Table 1* below for a summary of design results on each of the floor systems.

Table 1: Floor System Design Results

Floor System	Existing (Composite Steel, Castellated Beams)	Alternative 1 (Composite Joists)	Alternative 2 (Two-Way Post Tensioned Slab)	Alternative 3 (Precast Hollow-Core Planks on Steel)
Slab Depth	8"	6"	11"	8"
Main Member Depth	54" *(42" Opening in Web)	32" *(Provides for 13"x13" Ductwork)	11"	24"
Estimated Cost	$51.02/ft^2	$39.50/ft^2	$30.23/ft^2	$35.50/ft^2
Structure Weight	156.4 PSF	102.0 PSF	145.0 PSF	113.0 PSF
Fireproofing	Spray-On	Spray-On	Provided by Concrete	Provided by Concrete, Steel Needs Fireproofing
Durability	Fair	Moderate	Great	Great
Deflection (D+L)	0.79"	1.06"	Omitted – (Minimal)	1.92" (Camber Needed)
Vibration Concerns	Minimal	Moderate	Minimal	Moderate

The above criteria were all tabulated and researched. Each system was given a point value (1-5), estimated by the author, for each condition. These point values were added to give each floor system a total point value, with a maximum point value of 35. See *Graph 1* below comparing the floor systems' total point values.

Graph 1: Floor System Totals



From research and comparisons, it was determined that the Composite Joist and Hollow Core Plank Floor Systems appear to feasible alternative designs for the Northwest Science Building.

Note: The graph and table results above are further compared, in the "Comparison of Systems" section at the end of this report.

*Thank you to Turner Construction Company for providing the necessary documents, information, and images necessary for this Architectural Engineering Senior Thesis, Technical Report 2.

I. Existing Structural System

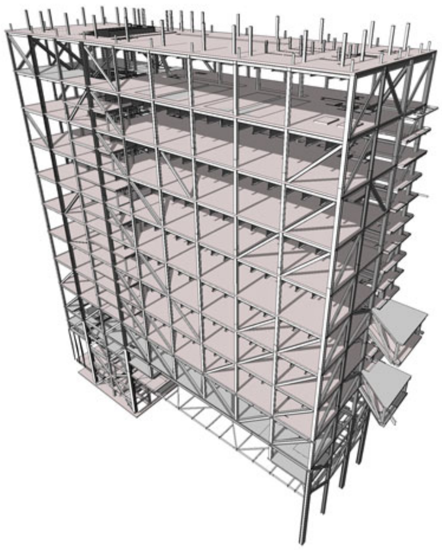


Figure 3: Structure Rendering

Note: For additional descriptions and images on the existing structural system, please see Technical Report 1 on the Columbia University Northwest Science Building.

1. Foundation

The foundation consists of concrete piers, footings, column spread footings, and grade beams.

The concrete piers coincide with the sub-cellar and cellar foundation walls. These piers range in cross sectional size from 2'-0" x 3'-0" up to 5'-0" x 8'-0". These piers are required to be normal weight concrete with a concrete compressive strength (f'c) of 6000 PSI.

The footings support the exterior foundation walls. These footings span the distance between the concrete piers. The column spread footings support mainly interior columns and a few exterior columns. The spread footings vary in size. A large spread footing for this project is considered a 9'-0" x 9'-0" with a 5'-6" depth, while a smaller spread footing is 4'-6" x 4'-6" with a 2'-6" depth.

Two grade beams are used in the foundation of the building. These grade beams are used to provide a resistance to lateral column base movement. One of the grade beams used is 80'-6" long and has a cross section of 3'-0" x 3'-6". The other is smaller in cross section and length and spans in the opposite direction.

2. Floor System

The building's floor system changes dramatically from level 500 to level 600. This is due to the buildings 126 foot clear span. The building spans over an existing structure, the Dodge Physical Fitness Center. This clear span allows for the continued use of the center, with minimum demolition to its existing structure. Due to this dramatic change in floor area from level 500 to level 600, two floor plans of the structure will be discussed. These floor plans will be discussed as Typical Floor Plan 1 and Typical Floor Plan 2.

A. Typical Floor Plan 1 *(Levels 100 to 500)*

This floor system is a composite steel structure. The beam spanning consists of wide flange shapes. Spanning across from beam to beam is corrugated steel decking with concrete topping, both shear studded to the wide flanges. The concrete slabs are designated a concrete compressive strength of 4000 PSI. Slab thickness and the use of normal and lightweight concrete vary throughout the structure.

B. Typical Floor Plan 2 *(Levels 600 to 1400)*

This floor system is also a composite steel structure and also uses wide flange shape spanning. However, another spanning member is introduced because of longer clear spans needed for large laboratory spaces. These members are castellated beams, also known as cellular beams. They are typically about five foot deep and allow for 40 feet clear spans in the labs.

3. Gravity System

As mentioned, the building structure has a clear span of 126 feet occurring at level 5. The structure uses three wide-flange made steel trusses. These trusses are located on the three main longitudinal frames of the structure. See *Figure 4,* "Longitudinal Frame Elevations", below.

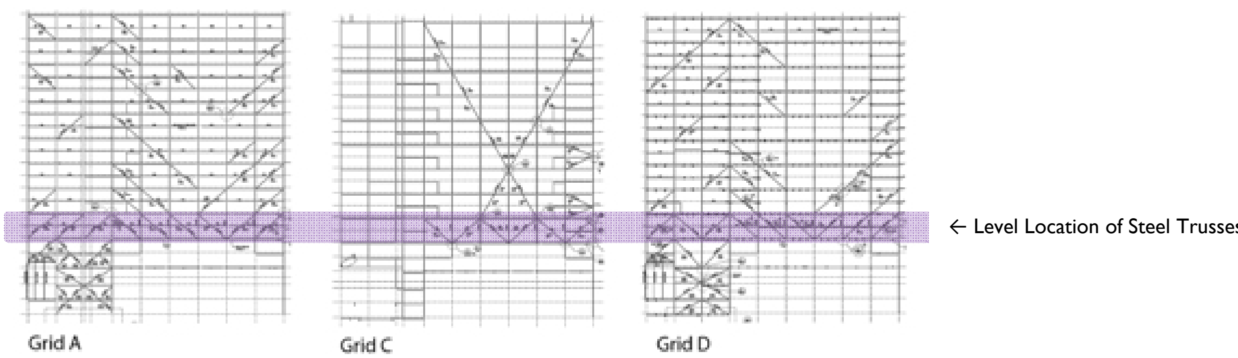


Figure 4: Longitudinal Frame Elevations

Grid A and Grid D are the exterior frames, while Grid C is the middle longitudinal frame. As shown, each frame has a single story truss (purple shaded). These trusses can be comparable in size to most civil, steel-bridge structures. Grid C frame has continuous diagonal members over the full height of the structure. These diagonal tension members, bring the gravity load diagonally up and over to the far edge columns.

4. Lateral System

The lateral system utilizes diagonal wind bracing, wind girts, a composite floor system, moment connections, and wide flange beams and columns.

The diagonal wind bracing elements are made up of W14 members and the wind girts are HSS shaped members. A typical HSS member size used is a 9x3x1/2. The wind girts allow wind to be distributed into the structure at the mezzanine levels, which are in between each main level. The lateral load is first distributed into the building by beams, wind girt members, and the composite floor system. It is then distributed downwards into diagonal bracing, moment connections and columns, until it reaches the foundation of the structure.

II. Codes & Design Requirements:

The following codes were used by the design team engineers of the Columbia University Northwest Science Building.

- "International Building Code 2006" – International Code Council
- "ACI 318-05 Manual of Concrete Practice" – American Concrete Institute
- "Manual of Steel Construction 9th Edition" – American Institute of Steel Construction, Inc.
- "ASCE 7-05 Minimum Design Loads for Buildings and Other Structures" – American Society of Civil Engineers
- "New York City Building Code & Regulations"
- "New York City Construction Code"
- Building Movements
    - Floor Beams
        - D ≤ L/360 (Live Load)
        - D ≤ L/240 (Live Load + Superimposed Dead Load)
        - D ≤ 2" (Live Load + Superimposed Dead Load)

The following codes were used by the author of this technical report.

- "International Building Code 2006" – International Code Council
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        - D ≤ L/360 (Live Load)
        - D ≤ L/240 (Live Load + Superimposed Dead Load)
        - D ≤ 2" (Live Load + Superimposed Dead Load)
- Standard Specifications for Composite Steel Joists – 1st Edition – Steel Joist Institute
- PCI Design Handbook – 6th Edition – Prestressed Concrete Institute

Since, the Northwest Science Building was also designed with New York City Codes, values and member sizes determined can vary slightly. This will depend on the differences of code requirements within the New York City Building and Construction Codes.

III. Dead & Live Loads:

The following gravity loads were determined from ASCE 7-05 by the design team engineers and the author. Note the differences in loads used by the author.

1. Floor Dead Loads:

Table 2: Dead Loads

Load Type	Weight	Used by Design Team	Used by Author
Normal Weight Concrete	150 PCF	Yes	Yes
Lightweight Concrete	120 PCF	Yes	Yes
Steel	490 PCF	Yes	Yes
M.E.P	10 PSF	No (Used 25 PSF for Ceiling and Services)	Yes
Finishes & Miscellaneous	5 PSF	Yes	Yes
Partitions	10 PSF	No (Used 20 PSF for Partitions)	Yes

2. Floor Live Loads:

Table 3: Live Loads

Type of Space	PSF	Used by Design Team	Used by Author
Offices	50	Yes	Yes
Mechanical	150	Yes	Yes
Library – Stack Rooms	150	Yes	Yes
Library – Reading Rooms	60	Yes	Yes
Corridors above 1st Floor	80	Yes	Yes
Lobbies & 1st Floor Corridors	100	Yes	Yes
Roof	20	Yes	Yes
Classrooms	40	Yes	Yes
Laboratories	100	Yes	Yes
Stairs & Exit Ways	100	Yes	Yes

IV. Existing Floor System (Composite Steel Floor System w/ Castellated Beams)

Description:

The laboratory's floor system consists of castellated steel beams. They are 4'-6" deep and span 40 feet long. See *Figure 5*, "Typical Castellated Beam", below.

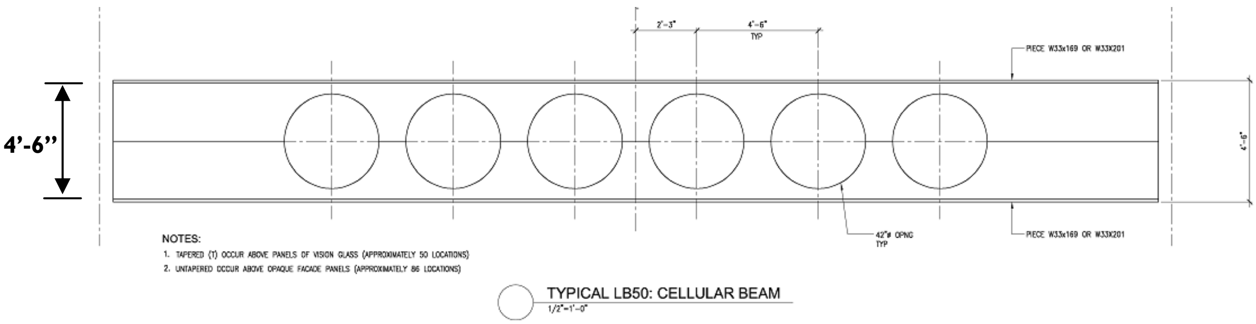


Figure 5: Typical Castellated Beam

Spanning from beam to beam is a 6" normal weight concrete slab topping on 2"-18 GA composite metal decking (8" total slab thickness). This floor system is composite. The shear studs are bonded to the concrete slab and welded to the metal decking and castellated beam members. The 40 foot spans have 20 shear studs used along the length of each castellated beam. The castellated beams require a chemical spray-on substance for adequate fire protection (2 hour rating).

Advantages:

Advantages of this floor system are listed below.

- **Castellated beams are known to be light and strong. They have a great span to weight ratio, which works for this longer span design.**
- **The circular openings in the beams are great for electrical and mechanical systems. Laboratory spaces usually require more mechanical ductwork and electrical conduit. These beams provide an easy access design for the mechanical and electrical engineers, with moderate installation difficulty for the construction crew.**
- **Castellated beams are known to be visually pleasing. Many architects like the aesthetic value of these beams.**
- **Composite floor system provides stiffer spans reducing overall deflections and vibrations.**

Disadvantages:

Disadvantages of this floor system are listed below.

- **In the United States castellated beams are known to have high cost fabrication.**
- **Shear capacity is limited due to the loss in shear area, where the circular openings are located. This may also limit longer spanning and heavier load supporting.**
- **Castellated beams respond poorly in a floor system where there is a large amount of concentrated loads.**
- **Fireproofing is not built into the beam members. Spray-on or concrete fireproofing is needed, which will cause an additional fee.**

Design for Northwest Science Building:

This floor system wasn't designed by the author because it is the existing engineered team design. However, the dead and live load deflection along with an estimated square foot cost was calculated for comparison with the alternative floor systems. Also, moment and shear checks were performed.

*All of the calculations can be found in *Appendix A* at the end of this report.

See *the* "Existing Laboratory Bay Design", *Figure 6*, below.

Figure 6: Existing Laboratory Bay Design

The following *Table 4* reviews the floor system's main characteristics.

Table 4: Existing Floor System Review Table

Design Concern	Notes	Points (1-5)
Beam Deflection (D + L)	0.79"	5
Estimated Floor System Cost	$51.02/ft^2	2
Fire Protection & Rating	Spray-On (Labor Cost Fee)	3
Durability	Fair Durability	4
Average Dead Weight of Bay	156.4 PSF	3
Vibration Concerns	**Limited Vibration Concerns** Long slender steel members are vulnerable to vibrations, however, composite design will stiffen floor reducing overall vibrations.	5
Depth Concerns	**Minimal Depth Concerns** The use of Castellated Steel Beams allows plenty of mechanical and electrical space.	5
	Total Points	27

Design Considerations:

Structural:

Composite steel design is well known and seen within the New York City area. This existing system, with its castellated beams, and composite action (concrete slab compressive strength utilized), provides a system that is fairly light and spans the required 40 feet.

Vibrations of this floor system are complex in nature and therefore were not assessed under the scope of this report. However, with the 4'-6" depth of the castellated beams, along with the 8" slab and composite action, it can be assumed that vibrations will be limited.

Construction:

Composite steel construction is well known and seen throughout the New York City area. This system is quick to construct, however a proper amount of lead time must be determined for the fabrication of the castellated beam members. The fabrication of these castellated members will be costly, along with the required spray-on fireproofing,

Architectural:

As previously stated in the "Advantages" section on the previous page, castellated beams provide an eye pleasing design. The circular openings give a unique feel to the floor system, and are also effective for mechanical ductwork and electrical conduit access.

V. Alternative Floor Systems:

1. Alternative Floor System 1 (Composite Joist Floor System)

Description:

This floor design is a one way system. The top chord of the joists and concrete slab are shear connected to produce composite action. This system works very similarly to the castellated beam existing system. The joists used are CJ-Series, composite joists, which are 32" deep and are spaced 5'-5" apart. The joist depth allows ductwork of 13" x 13" to pass safely through its openings. For the proper amount of composite action, composite metal decking is used, along with 28 – ½" diameter shear studs along the span of each joist.

Advantages:

Advantages of this floor system are listed below.

- **Mechanical and electrical systems can run through joist openings.**
- **Composite design allows for spanning of greater distances.**
- **Composite design creates a stiffer floor system, which limits live load deflections.**

Disadvantages:

Disadvantages of this floor system are listed below.

- **Requires fire proofing (typically spray-on), which requires demanding labor and is costly.**
- **Joist floor systems are known to have vibration issues.**
- **Fabrication of joist members requires lead time.**

Design for Northwest Science Building:

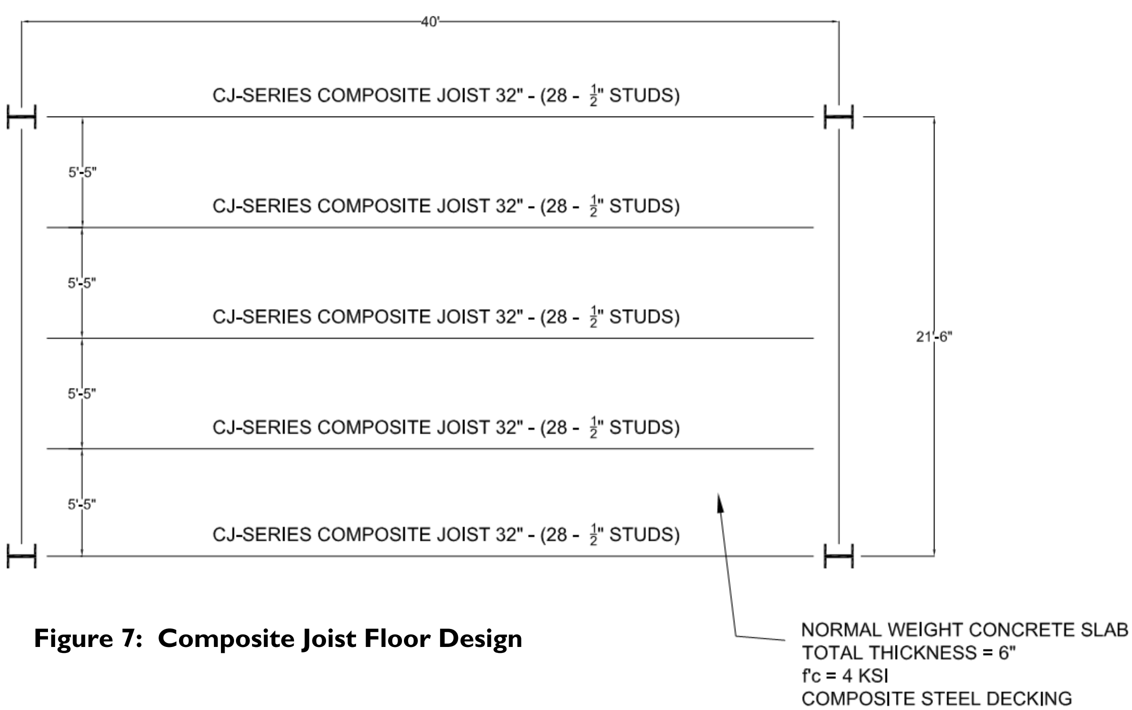


Figure 7: Composite Joist Floor Design

The following *Table 5* reviews the floor system's main characteristics.

Table 5: Alternative Floor System 1 Review Table

Design Concern	Notes	Points (1-5)
Beam Deflection (D + L)	**1.06"**	**4**
Estimated Floor System Cost	**$39.50/ft^2**	**3**
Fire Protection & Rating	**Spray-On (Labor Cost Fee)**	**2**
Durability	**Moderate Durability**	**3**
Average Dead Weight of Bay	**102 PSF**	**5**
Vibration Concerns	**Moderate Vibration Concerns** Joist Floor Systems known for vibrations.	**3**
Depth Concerns	**Minor Depth Concerns** 13" x 13" ductwork openings provided in joists.	**4**
	Total Points	**24**

Design Considerations:

Structural:

Deflection is limited to 1.06" for dead and live service loads. This deflection was attainable by introducing another joist member in each bay. The tributary area became 5'-5" for the joist system, compared to 7'-2" for the existing system. It was assumed that this composite joist system will have moderate vibration concerns. Joist floor systems are known to have vibration problems. Even though the composite action will make a stiffer floor and reduce vibrations, the author still feels vibrations will occur.

This floor design weighs less than the existing system. With this reduction in weight, there could possibly be a reduction of the overall cost of the structure. A large cost comes from the 126-foot long trusses. These trusses could possibly be reduced in material with less dead load. However, this joist system was designed solely based on gravity load, and it is unknown if lateral loads will cause the design to have an increase in overall dead weight.

Construction:

This floor system can be erected efficiently and quickly by New York City construction workers. It is very similar to wide flange composite construction. The joist members are slightly more difficult to erect into place. Fabrication of these joist members will require proper lead time. Additionally, the joist members will need to be fireproofed. A spray on material or suspended ceiling can be used. Both will increase construction and material costs.

Architectural:

Architecture of the building would be very similar to the existing design. The joist members work similarity to the castellated beam members, allowing mechanical/electrical access. Using joist members introduces more diagonal members which correlates with the rest of the structure.

2. Alternative Floor System 2 (Two-Way Post-Tensioned Slab)

Description:

This system is a two-way flat plate that is post-tensioned. The post tensioning comes from ½", 7-wire tendons. These tendons span in both directions within the typical laboratory bay. The tendons that span in the long direction (40'-4") are uniform throughout the 11" slab, while the tendons in the short direction (21'-6") are banded closer together within the column strip. The purpose of the tendons is to introduce compressive stresses in the concrete to reduce tensile loads on the floor system.

Advantages:

Advantages of this floor system are listed below.

- **Floor depth can be decreased dramatically.**
- **Can design post-tensioning to control defection and vibration control.**
- **Longer spans are possible using post-tensioning rather than just reinforced concrete spanning.**
- **Concrete will provide adequate fire protection and rating.**

Disadvantages:

Disadvantages of this floor system are listed below.

- **New York City contractors are unfamiliar with post-tensioned floor systems.**
- **Field post-tensioning can be very dangerous and extra safety measures must be taken.**
- **Formwork is required with post-tensioned slab construction.**

Design for Northwest Science Building:

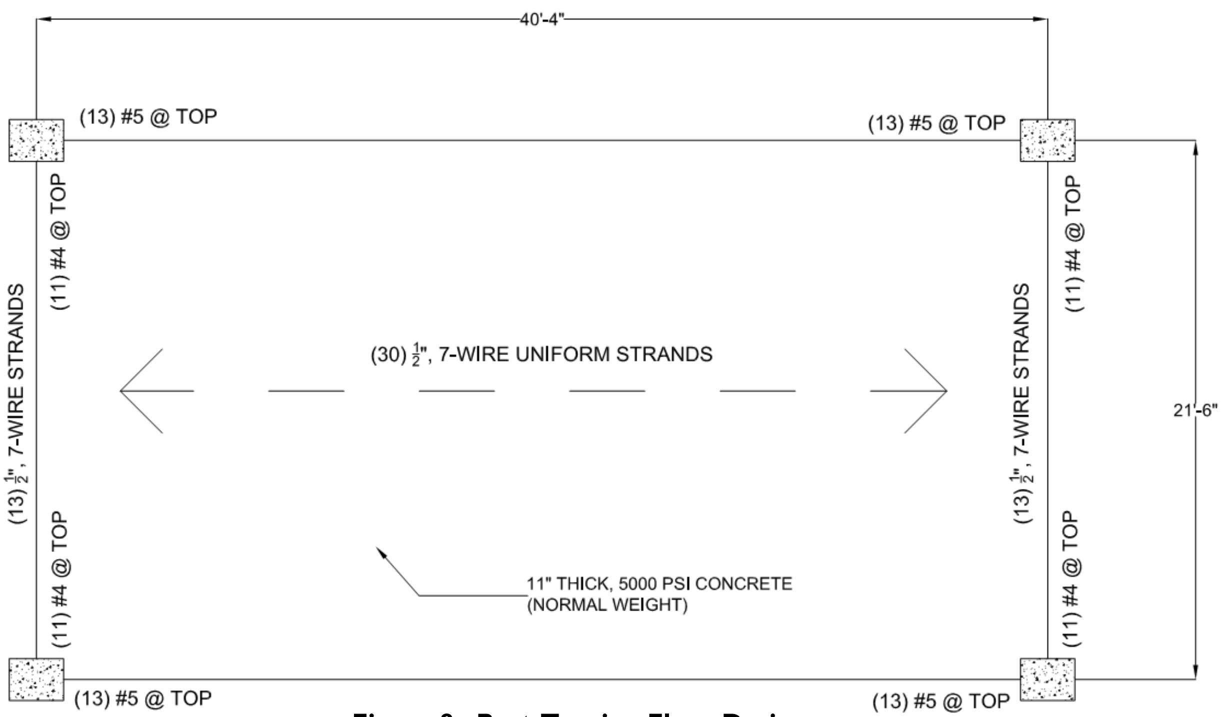


Figure 8: Post-Tension Floor Design

The following *Table 6* reviews the floor system's main characteristics.

Table 6: Alternative Floor System 2 Review Table

Design Concern	Notes	Points (1-5)
Beam Deflection (D + L)	**Minimal Deflections** – (Calculations Omitted) PT floor systems are known to have limited deflections that can be controlled through design.	**4**
Estimated Floor System Cost	**$30.23/ft^2**	**5**
Fire Protection & Rating	**Built-In (Great)** 11" Concrete Slab provides adequate 2 hour fire protection.	**5**
Durability	**Very Durable**	**5**
Average Dead Weight of Bay	**145 PSF**	**2**
Vibration Concerns	**Minimal Vibration Concerns** 11" Slab Thickness (from L/H = 45) should limit vibrations.	**4**
Depth Concerns	**No Depth Concerns** 11" Flat Plate Slab provides a large amount of vertical space.	**5**
	Total Points	**30**

*All of the calculations for this floor system design can be found in *Appendix C* at the end of this report.

Design Considerations:

Structural:

Deflection and vibration calculations have been omitted for this floor system due to its complexity. Vibrations and deflections are assumed to be of minimal concern because of the 11" slab design obtained from design requirements of L/H = 45.

The use of post-tensioned slabs will be more efficient than just a concrete reinforced floor structure. Post-tensioned floor slabs are more efficient for longer spans. They also weigh less than a typical reinforced concrete slab. Dead weight is a very important concern for the Northwest Science Building, due to its long clear span of 126 feet over the existing fitness center. The less the dead weight of the structure, the more economical and cost efficient it will be. However, the building can't be designed entirely of a concrete structure. The 126 foot clear span certainly calls for additional steel spanning and bracing.

Construction:

One main concern of construction is the inexperience of New York City construction crews with post-tensioned floor systems. However, a post-tensioned floor system could be possible with an experienced construction crew, and with a feasible design of steel spanning/bracing at the 126-foot clear span level.

Architectural:

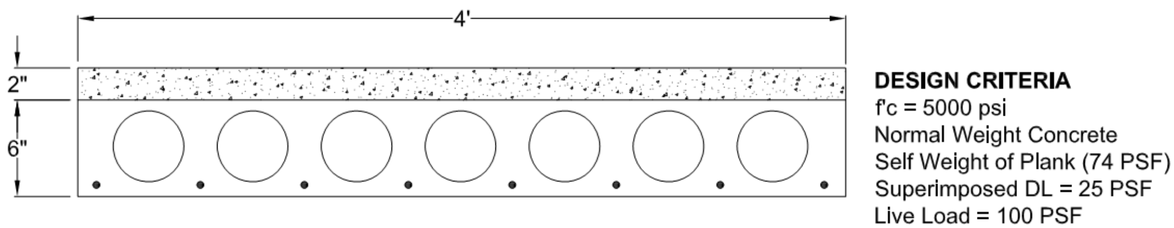
Architecture of the building would change dramatically from the existing design. A post-tensioned system would be a new site to see for New York City residents. It wouldn't fit in with existing structures of Manhattan.

3. Alternative Floor System 3 (Precast Hollow-Core Planks)

Description:

This system uses precast hollow-core planks as the main floor spanning element. Each hollow core is 4 feet wide. These planks will span the short direction of the typical laboratory bay. The 40'-4" long direction of the bay will need to be reduced to 40'-0" to fit 10 planks across. These floor planks will be supported by W24x146 members, spanning in the opposite direction. The precast hollow-core used is depicted below (*Figure 9*).

Figure 9: Hollow-Core Plank Section



Advantages:

Advantages of this floor system are listed below.

- **Planks are prefabricated and can be erected quickly.**
- **Precast concrete can be a very sustainable floor system.**
- **Concrete planks provide adequate fire protection and rating.**
- **Planks can be designed to be fairly thin in depth.**

Disadvantages:

Disadvantages of this floor system are listed below.

- **Prefabrication can require long lead times.**
- **Bay dimensions are dependent upon planks width. (can't design with irregular spanning)**

Design for Northwest Science Building:

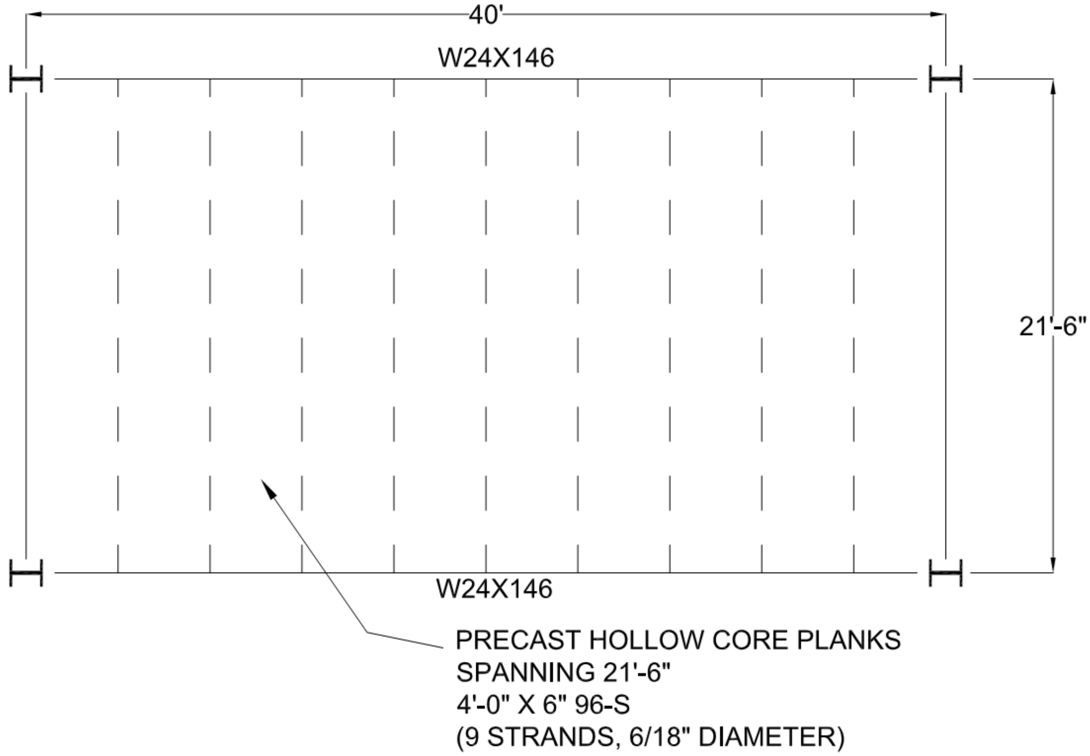


Figure 10: Precast Hollow Core Floor Design

The following *Table 7* reviews the floor system's main characteristics.

Table 7: Alternative Floor System 3 Review Table

Design Concern	**Notes**	**Points (1-5)**
Beam Deflection (D + L)	**1.92 in** (will require cambering)	**2**
Estimated Floor System Cost	**$35.50/ft^2**	**4**
Fire Protection & Rating	**Built-In (Great)** Concrete Planks with 2" topping, provides adequate 2 hour fire protection.	**4**
Durability	**Very Durable**	**4**
Average Dead Weight of Bay	**113 PSF**	**4**
Vibration Concerns	**Unknown Vibration Concerns** Plank research and studies on vibrations is limited.	**3**
Depth Concerns	**Minor Depth Concerns** At the W24 girders, mechanical and electrical systems will have to be coordinated appropriately.	**3**
	Total Points	**24**

*All of the calculations for this floor system design can be found in *Appendix D* at the end of this report.

Design Considerations:

Structural:

Composite connections will need to be implemented into this design. The precast slabs will need to be tied appropriately to the wide flange members. If composite floor design is not realistic, a sufficient amount of additional moment connections will need to be designed and constructed.

This design does not change the steel structure dramatically. Steel member spanning still takes place with this design. This floor system design will utilize the steel spanning/bracing at the 126 foot level span with minimal connection differences from the existing structure.

Construction:

Precast hollow planks are quick and easy to construct. The concrete plank design with 2" topping provides adequate fire resistance, and only fire proofing of the wide flange members needs to be applied. This will reduce labor cost and the construction timeline. The planks can also be used as a flat finished ceiling.

Precast hollow plank floor systems are not typically used in New York City. However, there is a lot less variables during construction than with a post-tensioned floor system. New York City construction workers would be able to adjust to this type of construction fairly easy.

Prefabrication of wide flange cambering and planks will need to be coordinated appropriately so construction timeline is not affected.

Architectural:

Column grids need to be placed on 4 ft increments due to the use of 4 foot wide planks. This could cause some architectural space compromising. This design will require substantial structural and architectural coordination.

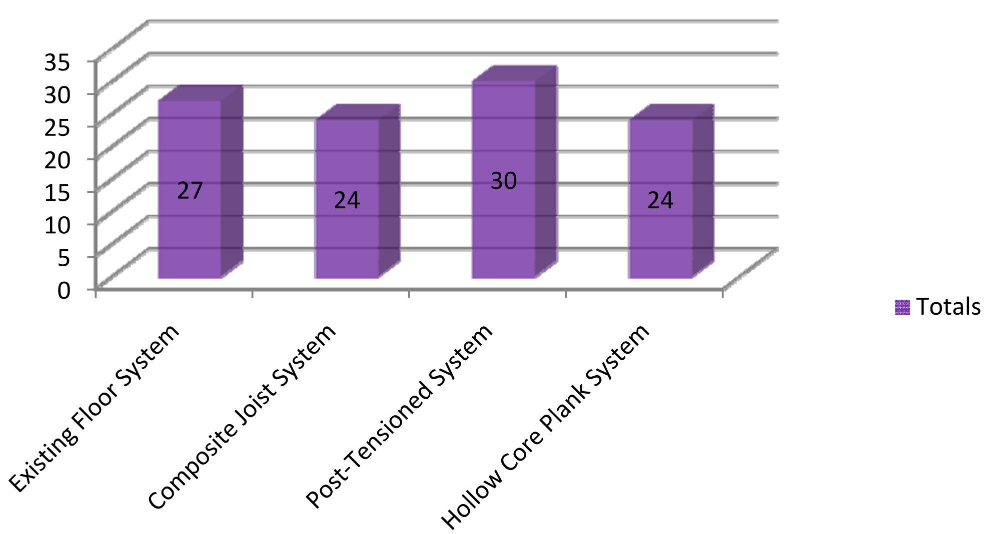
Comparison of Systems

Below is *Table 8,* which reviews each floor system's characteristics. Also below, is *Graph 1*, which summarizes the total point values, obtained by the author. Following the table and graph is a discussion on each characteristic, further explaining how each system compares against one another.

Table 8: Review of Floor Systems

Floor System	Existing (Composite Steel, Castellated Beams)	Alternative 1 (Composite Joists)	Alternative 2 (Two-Way Post Tensioned Slab)	Alternative 3 (Precast Hollow Core Planks on Steel)
Slab Depth	8"	6"	11"	8"
Main Member Depth	54" *(42" Opening in Web)	32" *(Provides for 13"x13" Ductwork)	11"	24"
Estimated Cost	$51.02/ft^2	$39.50/ft^2	$30.23/ft^2	$35.50/ft^2
Structure Weight	156.4 PSF	102.0 PSF	145.0 PSF	113.0 PSF
Effect on Existing Column Grid	N/A	None	None	Minimal
Construction Difficulty	Easy	Medium	Hard	Easy
Lead Time	Long	Medium	Short	Long
Fireproofing	Spray-On	Spray-On	Built-In	Semi Built-In
Beam Deflection (D+L)	0.79"	1.06"	Omitted – (Minimal)	1.92"
Impact on Building Foundations	N/A	No	Yes	No
Floor System Viable?	**Yes**	**Yes**	**No**	**Yes**

Graph 1: Floor System Totals



Slab Depth & Main Member Depth:

Each floor system has comparable slab depths. However, it must be noted that the Post-Tensioned System has a maximum floor depth of 11" (flat plate slab), while the others are governed by main member spanning.

The Existing System and the Composite Joist System have deep members, however these members allow for plenty of plenum space. Also, the mechanical ductwork and electrical conduit can be supported and tied directly to the Joist and Castellated members. While, the Hollow Core System and Post-Tensioned System will require additional structural support for mechanical/electrical.

Estimated Cost:

The Existing System ($51.02/ft^2) and the Composite Joist System ($39.50/ft^2) have the greatest estimated cost per square foot. This is due to prefabrication costs. The Hollow Core System follows with a $35.50/ft^2 estimated cost, which is lower because of material cost, but still higher than the Post-Tensioned System ($30.23/ft^2) due to fabrication cost.

Structure Weight:

Structure weight of the Northwest Science Building is of great concern. Due to its large 126-foot clear span over the Dodge Fitness Center, dead loads must be limited properly. Floor systems will vary in weight depending on the material used. It is important to look at a floor systems dead weight on a structure.

It is surprising that the existing structure currently weighs the greatest (156.3 PSF). However, this is due to large 5 foot deep castellated steel members. These members create reduced weight with circular openings, but there weight is still substantial.

The Hollow Core System weighs the least (113 PSF). This is significant. If hollow cores were used, the structure dead weight would reduce considerably. Also, the Hollow-Core System design utilizes steel beam spanning. This will allow for easy connection and distribution of loads for the 126-foot clear span at level 5 of the structure. The Composite Joist System will also provide easy connection and distribution of loads into the existing trusses at level 5.

Effect on Existing Grid:

The only floor system that has an effect on the existing grid is the Hollow Core Slab. Since, each hollow core plank is 4'-0" wide, the spans will need to be an increment of 4'-0". With additional and proper coordination of the structural engineer and architect, this can be resolved.

Construction Difficulty:

The construction difficulty was considered based upon New York City construction crew experience. Their experience generally falls under steel construction. Therefore, it was assumed an easy construction difficulty of the Existing System along with the Hollow Core System (on steel). A medium difficulty of the Composite Joist System was assumed because this type of construction is still fairly new. Hard construction difficulty was given to the Post-Tensioned system due to New York City construction crew inexperience.

Lead Time:

Long and medium lead times were given to the systems that required fabrication of main floor members. These included the Existing System, Hollow Core System, and Composite Joist System. The only system that requires a short lead time is the Post-Tensioned System.

Fireproofing:

Fireproofing was considered based upon if the system has built-in characteristics of fireproofing, or if additional fireproofing would need to be applied. The Post-Tensioned System and the Hollow-Core System will use their existing concrete for a two hour fire rating. While, the Existing System and the Composite Joist System will require an applied fireproofing, which adds additional material and labor cost to the project.

Deflection (D+L):

All floor systems meet deflection requirements. However, meeting deflection requirements is not enough for the Northwest Science Building laboratories. These laboratories will contain a lot of equipment, and important research will be performed here.

The Existing System has the least amount of deflection. This limited deflection could have been due to an additional owner request. The Composite Joist System and the Post-Tensioned System deflections follow, while the Hollow Core System has the greatest deflection of 1.92".

Impact on Building Foundations:

The Composite Joist and Hollow-Core Systems are assumed to have no impact on the existing foundations. Their estimated dead weights are both 25% less than the Existing System. On the other hand, the Post-Tensioned System is only 7% less than the Existing System. The Post-Tensioned system when designed for lateral loads will most likely increase in dead weight. This increase will cause a need for larger foundations.

Conclusions:

After reviewing all of the floor systems it can be seen why the Existing System was used. Below is a list of 3 main reasons why the author believes this system was chosen by the design team.

- **Composite steel structures are very common to New York City and construction workers.**
- **The castellated beams provide adequate mechanical and electrical space, while limiting some of the dead weight.**
- **The composite action will limit deflections and vibrations within the laboratory spaces, which is critical.**

However, arguments can be made for the use of the Hollow Core System and Composite Joist System.

Hollow Core System:

Below is a list of 3 reasons why the system is feasible for the Northwest Science Building.

- **System dead weight is less than the existing floor system.**
- **Estimated cost is less than the existing floor system.**
- **Hollow Core slabs are very durable and the planks have built-in fire protection.**

Composite Joist System:

Below is a list of 3 reasons why the system is feasible for the Northwest Science Building.

- **System dead weight is less than the existing floor system.**
- **Estimated cost is less than the existing floor system.**
- **Architecture (diagonal members) correlates to rest of existing building design.**

Post-Tensioned System:

The Post-Tensioned System was eliminated as a viable floor system. This was solely due to its dependency on concrete material usage. The Northwest Science Building requires steel spanning for a 126-foot clear span. Transmitting loads and detailing connections of the Post-Tensioned System to steel trusses spanning at level 5 would be extremely difficult for design and costly. Even though the Post-Tensioned system scored the highest total point value (estimated by the author), it is important to note that this system does not fit into overall scope of this building project.

In the future, both an in-depth analysis of the Hollow Core System and Composite Joist System would need to be completed for further comparison.

Appendix:

(Hand Calculations)

Appendix A: (Existing Floor System Calculations)

EXISTING
FLOOR SYSTEM. 1

CASTELLATED BEAM SPAN

(A) DEAD LOAD

SLAB → 115PSF
MEP → 10PSF
MEMBER SELF WT (169 lb/FT)

$125(7.2') + 169 = 1070\ \text{lbs/FT} = DL$

(B) LIVE LOAD

$100\text{PSF}(7.2) = 720\ \text{lbs/FT} = LL$

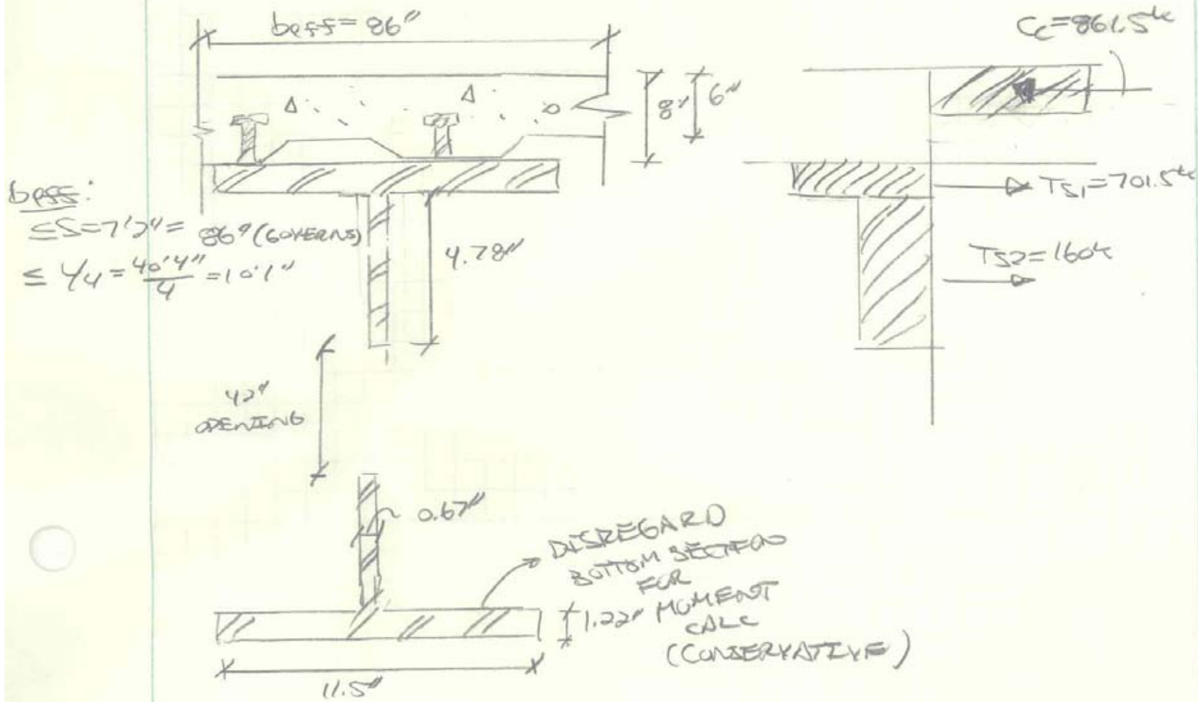
LOAD COMBO

$1.2DL + 1.6LL$

$1.2(1070) + 1.6(720) = 2435\ \text{lbs/FT} = 2.44\ \text{k/FT} = w_u$

(C) MOMENT CAPACITY CHECK:

$$M_u = \frac{w_u l^2}{8} = \frac{2.44(40.33)^2}{8} = 496\ \text{k-FT}$$



2

$C_c = 0.85(6)(86)(4) = 1754.4$

$T_{S1} = 14.03(50) = 701.5^k$
$T_{S2} = 3.2(50) = 160^k$ } 861.5^k (CONTROLS)

$C_c = 861.5^k = 0.85(t)(86)(4)$
$t = 2.95''$

$M_n = 861.5(8 - 2.95/2) + 701.5(1.22/2) + 160(4.78/2 + 1.22)$
$M_n = 552.2^{k \cdot FT}$
$\phi M_n = 0.9(552.2) = 497^{k \cdot FT}$
$\phi M_n > M_u$
$\boxed{497 > 496 \text{ OKAY!}}$ → CLOSE HOWEVER W/ INITIAL CONSERVATIVE ASSUMPTIONS STILL OKAY

(D) SHEAR CAPACITY CHECK:

$V_u = w_u l/2 = \frac{2.44(40.33)}{2} = 49.2^k$

$V_n = 0.6 F_y A_w$ $\quad A_w = (4.78 + 1.22)(0.67)(2) = 8.04\ IN^2$
$= 0.6(50)(8.04\ IN^2)$
$= 241.2^k$

$\phi V_n = (0.9)(241.2^k) = 217^k$

$\boxed{217^k > 49.2^k \text{ OKAY}}$

3

DEFLECTIONS:

$$\Delta = \frac{5wl^4}{384 EI_{EFF}}$$ ASSUME I_{EFF} FOR TOP SECTION AS BEFORE (CONSERVATIVE)

I_{EFF}:

$$n = \frac{29000}{3492} = 8.30$$

$b_{eff} = 86''$

$b_{eff}/n = 86/8.3 = 10.36''$

$I_{STL} = 649 IN^4$ (WT16.5x84.5) → TOP SECTION OF MEMBER.

$$I_{TRANS} = \frac{(10.36)(2.95^3)}{12} = 22.2 IN^4$$

$A_{TRANS} = 10.36(2.95) = 30.6 IN^2$

$A_{ST} = 4.02 IN^2$

FIND ELASTIC NEUTRAL AXIS

$$\bar{y} = \frac{4.02(16.9/2) + 30.6(16.9 + 8 - 2.95/2)}{(4.02 + 30.6)} = 21.69''$$

$$I_{TR} = 649 + 4.02(21.69 - 16.9/2)^2 + 22.2 + 30.6(21.69 - (16.9 + 8 - 2.95/2))^2$$

$I_{TR} = 4681.3 IN^4$

LIVE LOAD Δ = $$\frac{5(0.74)(40.33^4)(1728)}{384(29000)(4681.3)} = 0.32$$

$\boxed{0.32'' \leq l/360 = 1.34'' \text{ OKAY}}$

LL + DL Δ = $$\frac{5(1.79)(40.33^4)(1728)}{384(29000)(4681.3)} = 0.79''$$

$\boxed{0.79'' \leq l/240 = 2'' \text{ OKAY}}$

EXISTING FLOOR SYSTEM COST ANALYSIS

RSMEANS

30X30 BAY → CLOSE TO ORIGINAL

MAT: \$26/SQ.FT
LAB: \$9.05/SQ.FT

X 1.15 ← FOR CASTELLATED BEAM FABRICATION.

=

29.9/SQ.FT

$$\text{TOTAL COST} = (29.9 + 9.05)(1.31)$$

↑ NYC LOCATION FACTOR.

$$= \boxed{\$51.02/\text{SQ FT}}$$

Appendix B: (Composite Joist Floor System Calculations)

COMPOSITE JOIST 1

(SJI – CJ-SERIES SPECIFICATIONS CATALOG 1st EDITION)

DESIGN GUIDE USED

50KSI MAX YIELD STRENGTH

TOTAL LOAD ON JOIST

DEAD LOAD

5PSF (FINISHES + MICELL)
10 PSF (PARTITIONS)
10 PSF (MEP)

25PSF X TRIB AREA (ASSUME 5' 5" SPACING)

DL = 135.42 PLF

LIVE LOAD

100PSF X 5' 5" = 541.67 PLF

LOAD COMBO

1.2DL+1.6LL

1.2(135.42)+1.6(541.67) = 1029.2 PLF

GO TO TABLES

SPAN 40' TL=1030PLF

→ CHOOSE JOIST DEPTH 32" — PROVIDES A 13"x13" DUCT OPENING SIZE

DATA weight of JOIST (13.6PLF)
W360 = 881 PLF
NUMBER OF STUDS – 28 (1/2" DIAMETER)

COMPOSITE MOMENT OF INERTIA = 1310 IN^4

ASSUME W12 OR W14 MEMBER SPANNING IN OPPOSITE DIRECTION

2

DEFLECTIONS

$I_{REQ} = 1310 IN^4$

LIVE LOAD $\Delta = \frac{5(0.542)(40^4)(1728)}{384(29000)(1310 IN^4)} = 0.82''$

$W_{LL} = 100 \times (5 + 5/12) = 541.67 \text{ lbs/FT} = 0.542 \text{ k/FT}$

$L/360 = 1.33''$

$\boxed{0.82'' \leq 1.33'' \text{ OKAY}}$

DEAD+LIVE LOAD $\Delta = \frac{5(0.70)(40^4)(1728)}{384(29000)(1310)} = 1.06''$

$W_{LL+DL} = 0.542 + 0.15 = 0.70$

$W_{DL} = 13.6 PLF + (135.4) PLF = 150 PLF = 0.15 \text{ k/FT}$

$L/240 = 2''$

$\boxed{1.06'' < 2'' \text{ OKAY!}}$

COST ANALYSIS:

2009 RSMEANS

BAY SIZE
ASSUME 35×30
SUPERIM LOAD → 125PSF
DEPTH 38" (CLOSE)

MAT	INST
$21/SQFT	$6.45/SQFT
×	×
1.05 (ADDED COMP. MAT)	1.25 (ADDITIONAL COMPOSITE LABOR)
=	=
$22.05/SQFT	$8.10/SQFT

NYC LOCATION FACTOR

TOTAL = $30.15/SQFT (1.31)

$\boxed{\text{TOTAL} = \$39.50/\text{SQFT}}$

NORMAL WEIGHT CONCRETE

DESIGN GUIDE LRFD WEIGHT TABLE FOR COMPOSITE STEEL JOISTS, CJ-SERIES

Based on a 50 ksi Maximum Yield Strength

BEARING HEIGHT	2 1/2"	5"	7 1/2"

Concrete Slab Parameters
Normal Weight Concrete (145 pcf) f'c = 4.0 ksi

Joist Span (ft.)	Joist Depth (in.)										
		hr (in.)	1	1	1	1	1	1	1	1	1
		tc (in.)	2	2	2	2	2	2	2	2	2
		Js (ft.)	3	3	3	3	3	3	3	3.5	4
		Total Safe Factored Uniformly Distributed Joist Load in Pounds Per Linear Foot									
		TL	300	400	500	600	700	800	900	1000	1200
40	16	Wt(plf)	8.0	9.6	11.9	12.5	14.0	16.1	18.0	19.8	24
		W360(plf)	146	192	231	253	295	318	362	409	477
		N-ds	24-3/8"	32-3/8"	24-1/2"	28-1/2"	34-1/2"	36-1/2"	42-1/2"	34-5/8"	40-5/8"
		Ieff(in4)	218	286	344	376	440	474	540	610	710
		Bridging	(1)X+(3)H	(1)X+(3)H	(1)X+(2)H	(1)X+(2)H	(3)H	(3)H	(3)H	(3)H	(3)H
	18	Wt(plf)	6.9	7.8	9.0	10.2	11.9	13.1	14.3	16.3	18.1
		W360(plf)	150	186	226	263	298	329	366	411	455
		N-ds	22-3/8"	28-3/8"	36-3/8"	42-3/8"	30-1/2"	34-1/2"	40-1/2"	44-1/2"	46-1/2"
		Ieff(in4)	224	277	337	391	444	490	546	612	678
		Bridging	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(3)H	(3)H	(3)H	(2)H	(2)H
	20	Wt(plf)	6.1	7.0	8.1	8.8	10.2	12.4	13.2	14.5	17.5
		W360(plf)	165	212	256	282	332	381	402	458	550
		N-ds	20-3/8"	26-3/8"	32-3/8"	38-3/8"	46-3/8"	32-1/2"	34-1/2"	40-1/2"	48-1/2"
		Ieff(in4)	246	315	382	420	495	567	598	682	820
		Bridging	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(3)H	(3)H	(3)H	(2)H
	22	Wt(plf)	6.4	6.8	7.7	8.6	9.7	11.2	12.4	13.2	16.3
		W360(plf)	196	235	285	323	365	412	455	490	612
		N-ds	20-3/8"	24-3/8"	30-3/8"	36-3/8"	40-3/8"	28-1/2"	32-1/2"	34-1/2"	44-1/2"
		Ieff(in4)	293	350	424	481	544	614	678	729	912
		Bridging	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(3)H	(3)H	(3)H	(2)H
	24	Wt(plf)	6.1	6.9	7.5	8.3	9.3	10.9	11.9	12.4	15.6
		W360(plf)	199	275	311	358	401	465	509	544	674
		N-ds	20-3/8"	24-3/8"	28-3/8"	32-3/8"	38-3/8"	26-1/2"	30-1/2"	32-1/2"	40-1/2"
		Ieff(in4)	297	410	464	533	598	692	758	810	1000
		Bridging	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(3)H	(3)H	(3)H	(2)H
	26	Wt(plf)	6.2	6.7	7.3	8.0	9.1	10.7	11.6	12.0	14.8
		W360(plf)	229	290	340	384	443	512	558	597	732
		N-ds	20-3/8"	22-3/8"	26-3/8"	30-3/8"	36-3/8"	24-1/2"	28-1/2"	30-1/2"	36-1/2"
		Ieff(in4)	342	432	506	572	660	763	831	889	1090
		Bridging	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(2)H	(2)H	(2)H	(2)H
	28	Wt(plf)	6.1	6.5	7.2	8.0	8.9	10.4	11.4	11.6	14.3
		W360(plf)	234	301	360	436	477	545	610	645	787
		N-ds	20-3/8"	20-3/8"	24-3/8"	30-3/8"	32-3/8"	22-1/2"	26-1/2"	28-1/2"	34-1/2"
		Ieff(in4)	348	449	537	650	710	812	909	960	1170
		Bridging	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(2)H	(2)H	(2)H	(2)H
	30	Wt(plf)	6.3	6.7	7.3	7.9	9.0	10.1	11.1	11.4	14.0
		W360(plf)	263	339	405	458	535	587	654	696	835
		N-ds	20-3/8"	20-3/8"	24-3/8"	28-3/8"	32-3/8"	22-1/2"	24-1/2"	26-1/2"	30-1/2"
		Ieff(in4)	391	504	603	682	797	874	975	1040	1240
		Bridging	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(2)H	(2)H	(2)H	(2)H
	32	Wt(plf)	6.2	6.4	7.0	7.6	8.2	9.0	10.9	11.2	13.6
		W360(plf)	292	342	412	481	543	594	681	738	881
		N-ds	20-3/8"	20-3/8"	22-3/8"	26-3/8"	30-3/8"	32-3/8"	22-1/2"	24-1/2"	28-1/2"
		Ieff(in4)	435	509	613	717	809	885	1010	1100	1310
		Bridging	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(1)X+(2)H	(2)H	(2)H	(2)H

DESIGN GUIDE LRFD
NORMAL WEIGHT TABLES

STEEL JOIST SJI INSTITUTE

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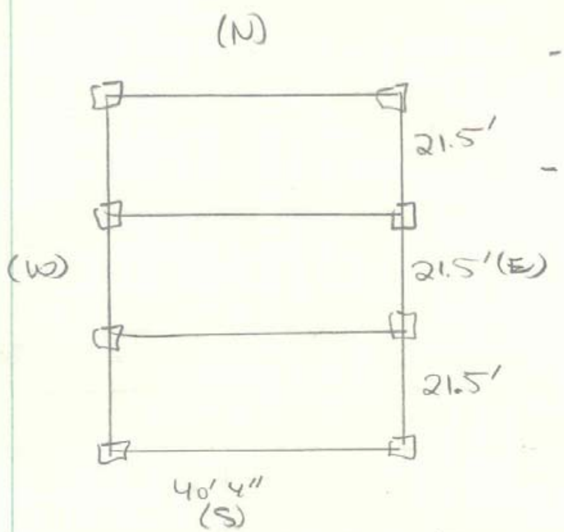
Appendix C: (Post-Tensioned Floor System Calculations)

1

POST TENSION

40'4" x 21'6" FRAME $\qquad f'_c = 5000$ PSI



- IN N-S DIRECTION WILL USE BANDED TENDONS ALONG COL STRIP
- IN E-W DIR., UNIFORM TENDONS

35'-48' (BEAM SPAN)
18'-25' (SLAB SPAN) } TWO-WAY FLAT PLATE

RECTANGULAR SPANS
- BANDS IN SHORT DIRECTION OVER COLS.
- UNIFORM IN LONG DIRECTION.

LOADS:

FRAMING DEAD LOAD = SELF WEIGHT
SDL = 25 PSF (PART, M/E, MISC.)
LL = 100 PSF (LABS)

* ASSUME 2HR FIRE RATING.

MATERIALS:

CONCRETE NORMAL WT → 150 PCF

$f'_c = 5{,}000$ PSI $\qquad f'_{ci} = 3{,}000$ PSI

REBAR: $f_y = 60{,}000$ PSI

PT: UNBONDED TENDONS

1/2" Φ, 7-WIRE STRANDS, ($A = 0.153\ IN^2$)

$f_{pu} = 270$ KSI $\qquad$ EST. PRESTRESS LOSSES = 15 KSI

$f_{SE} = 0.7(270) - 15 = 174$ KSI

$P_{eff} = A * f_{se} = 0.153(174 KSI) \approx \boxed{26.6^k/\text{TENDON}}$

2

DETERMINE PRELIM SLAB THKNESS:

$L/h = 45$ (LONGEST SPAN → 40.33')

$h = (40.33)(12)/45 = 10.75'' \rightarrow 11''$

$\boxed{11'' \text{ PRELIM SLAB THKNESS}}$

LOADING

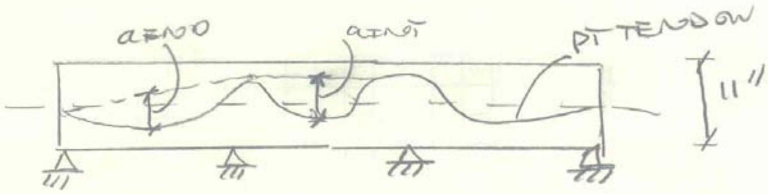
DL → $\frac{11}{12}(150) = 137.5$ PSF

SDL → 25 PSF

LL REDUCTION

EXT + INT BAYS
$A_T = (40.33)(21.5) = 867.1\ FT^2$
$K_{LL} = 1$

→ $LL = 0.76(100) = 76$ PSF



$a_{INT} = 10 - 1 = 9''$, $a_{END} = \frac{(5.5+9)}{2} - 1.75 = 5.5''$

E-W DIRECTION:

PRESTRESS FORCE TO BALANCE 60% OF SELFWT.

$w_b = 0.60(137.5)(21.5) = 1.77\ ^k/FT$

$P = \frac{w_b L^2}{8 a_{END}} = \frac{1.77(40.33^2)}{8(5.5/12)} = 785.2^k$

$785.2/26.6 = 29.5 \rightarrow \boxed{30 \text{ TENDONS}}$

$P_{ACT} = 30(26.6) = 798$

BAL LOAD:
$\frac{798}{785.2}(1.77) = 1.80\ ^k/FT$

ACTUAL PRECOMPR. STRESS
→ $798/(11 \cdot 258) \cdot 1000 = \boxed{281.2 \text{ PSI}}$
> 125 PSI (MIN) ✓
< 300 PSI (MAX) ✓

3

N-S DIRECTION

PRESTRESS FORCE REQ'D TO BAL 95% SELFWT.

$w_b = 0.95(137.5)(20.17) = 2.63^{k}/FT$

$P = \frac{2.63(21.5)^2}{8(5.5/12)} = 331.60^{k}$

→ CALCULATING P → FOR JUST COL. STRIP

$331.6/26.6 = 12.5 \rightarrow \boxed{13 \text{ TENDONS}}$

$P_{ACT} = 26.6(13) = 345.8^{k}$

BAL LOAD:

$\frac{345.8}{331.6}(2.63) = 2.74^{k}/FT$

ACT PRECOMPR. STRESS → $345.8/(20.17 \times 12)(11) \cdot 1000 = \boxed{130 \text{ PSI}}$

> 125 (MIN) ✓

< 300 (MAX) ✓

(FRAME A) → N-S DIR
(FRAME B) → E-W DIR

→ SEE SAP PRINTOUTS.

CALC OF MOMENTS

$\boxed{\text{FRAME A}}$

STAGE 1: STRESSES IMMEDIATELY AFTER JACKING (DL+PT)

MIDSPAN STRESS

$f_{TOP} = (-M_{DL} + M_{BAL}) - P/A$

$f_{BOT} = (+M_{DL} - M_{BAL}) - P/A$

$S = bh^2/6$

$242(11)^2/6 = 4880 \text{ IN}^3$

INT SPAN

$f_{TOP} = (-36.7 + 30.7)(12)(1000)/(4880) - 130 \text{ PSI}$

$= -145$ PSI COMPRESSION $< 0.6 f'_{CI}$ ok

$f_{BOT} = (36.7 - 30.7)(12)(1000)/4880 - 130 \text{PSI}$

$= -115$ PSI COMPRESSION $< 0.6 f'_{CI}$ ok

4

FRAME A CONT:

END SPAN

$f_{TOP} = (-120.4 + 100.6)(12)(1000)/4880 - 130PSI$

$= -178.7$ PSI COMPRESSION $< 0.6 f'_{ci}$ OKAY

$f_{BOT} = (120.4 - 100.6)(12)(1000)/4880 - 130PSI$

$= -81.3$ PSI COMPRESSION $< f'_{ci}$ OKAY.

SUPPORT STRESSES

$f_{TOP} = (151.2 - 126.3)(12)(1000)/4880 - 130PSI$

$= -68.8$ PSI COMPRESSION $< f'_{ci}$ OKAY.

$f_{BOT} = (-151.2 + 126.3)(12)(1000)/4880 - 130PSI$

$= -191.2$ PSI COMPRESSION $< 0.6 f'_{ci}$ OKAY.

STAGE 2: STRESSES AT SERVICE (DL+LL+PT)

MIDSPAN STRESSES

INT SPAN

$f_{TOP} = (-36.7 - 17.12 + 30.7)(1000)(12)/4880 - 130PSI$

$= -186.9$PSI COMPRESSION $< 0.45 f'c$ OKAY.

$f_{BOT} = (36.7 + 17.12 - 30.7)(1000)(12)/4880 - 130PSI$

$= -73.1$ PSI COMPRESSION $< 0.45 f'c$ OKAY

END SPAN

$f_{TOP} = (-120.4 - 56.18 + 100.6)(12)(1000)/4800 - 130PSI$

$= -320$ PSI COMPRESSION $< 0.45 f'c$ OKAY

$f_{BOT} = (120.4 + 56.18 - 100.6)(12)(1000)/4800 - 130PSI$

$= 57$ PSI TENSION $< 6\sqrt{f'c}$ OKAY.

5

FRAME A CONT: (N-S)

SUPPORT STRESSES

$f_{TOP} = (151.2 + 70.55 - 126.3)(12)(1000)/4880 - 130\ PSI$

$= 105\ PSI$ TENSION $< 6\sqrt{f'c}$ OKAY.

$f_{BOT} = (-151.2 - 70.55 + 126.3)(12)(1000)/4880 - 130\ PSI$

$= -365$ COMPRESSION $< 0.45 f'c$ OKAY.

NOTE:
— ALL STRESSES ARE WITHIN CODE LIMITS.

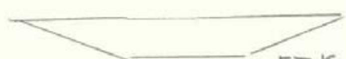
ULTIMATE STRENGTH:

$M_1 = P \cdot e$

$= 345.8(3")/12 = 86.5^{FT \cdot K}$

$M_{SEC} = M_{BAL} - M_1$

$= 126.3 - 86.5 = 39.8^{FT \cdot K}$ (AT THE INT SUPPORTS)



M_u @ MIDSPAN $= 1.2(120.4) + 1.6(56.2) + 1.0(19.9) = 254.3^{FT \cdot K}$

M_u @ SUPPORT $= 1.2(151.2) + 1.6(-70.6) + 1.0(39.8) = -254.6^{FT \cdot K}$

DETERMINE MIN BONDED REINFORCEMENT:

POS. MOM REGION:

INTER SPAN: $f_T = 15\ PSI < 2\sqrt{f'c} = 2\sqrt{5{,}000} = 141\ PSI$

∴ NO POSITIVE REINF. REQ

EXT SPAN $f_T = 57 < 2\sqrt{f'c}$

∴ NO POSITIVE REINF. REQ.

NEG MOMENT REGION.

$A_{SMIN} = 0.00075\ A_{CF}$

INT SUPPORTS $= (11)[(21.5) \times (12)] = 2838$

$A_{SMIN} = 0.00075(2838) = 2.13\ IN^2 \rightarrow \boxed{11-\#4\ TOP\ (2.2\ IN^2)}$

6

FRAME A CONT:

EXT SUPPORTS $A_{S MIN} \rightarrow \boxed{11-\#4 \text{ TOP } (2.2 IN^2)}$

- MUST SPAN A MIN OF 1/6 THE CLEAR SPAN ON EACH SIDE OF SUPPORT
- AT LEAST 4 BARS REQ. IN EACH DIR.
- PLACE TOP BARS WITHIN 1.5h AWAY FROM FACE OF SUPPORT = 16.5"
- MAX BAR SPACING 12"

CHECK MIN REINF FOR ULT STRENGTH SUFFICIENCY.

AT SUPPORTS

$$M_N = (A_s f_y + A_{ps} f_{ps})(d - a/2)$$

$d = 11 - 3/4 - 1/4 = 10$

$$A_{ps} = 0.153(13) = 1.99$$

$$f_{ps} = f_{se} + 10{,}000 + (f'_c bd)/(300 A_{ps})$$

$$= 174{,}000 + 10{,}000 + (5000)(40.33)\cdot(12)d / 300(1.99)$$

$$= 184{,}000 + 4053.3d = 224{,}533 \text{ PSI}$$

$$a = [2.2(60) + 1.99(224.533)] / 0.85(5)(40.33 \times 12)$$

$$a = 0.281$$

$$\phi M_N = 0.9[2.2(60) + 1.99(224.5)][10 - 0.281/2]/12$$

$$= 340.3^{FT\cdot K} > 254.6^{FT\cdot K}$$

$$\frac{340.3(12)}{0.9} = [A_s(60) + 1.99 \times 224.5][9.25 - \frac{A_s(60) + 1.99(224.5)}{0.85(5)(40.33 \times 12)}]$$

$\hookrightarrow A_s = 1.75 IN.$

$\therefore$ (9) #4 BARS $\rightarrow$ $A_{S MIN}$ CONTROLS 11-#4 BARS

SUMMARY FRAME A: (N-S DIR)

@ NEG MOMENT — 11-#4 BARS
(13) 1/2" DIAMETER, 7-WIRE STRANDS
(ACTING ALONG COL. STRIPS)

7

$\boxed{\text{FRAME B}}$ (E-W DIRECTION)

$w_b = 1.8^{k}/\text{FT}$
$w_D = 3.5\ ^{k}/\text{FT}$
$w_L = 1.6\ ^{k}/\text{FT}$

STAGE 1 (DL+PT)

MIDSPAN STRESS

$S = (21.5)(12)(11^2)/6 = 5203\ \text{IN}^3$

END SPAN

$f_{TOP} = (-400.71 + 206.08)(12)(1000)/5203 - 281.2\ \text{PSI}$

$= -730$ PSI TENSION $> 3\sqrt{f'_{ci}}$ (NOT OKAY → IGNORE NOW FOR PRELIM DESIGN)

$f_{BOT} = (400.71 - 206.08)(12)(1000)/5203 - 281.2\ \text{PSI}$

$= 167.7$ PSI COMPRESSION $< 0.60 f'_{ci}$ OKAY

SUPPORT STRESSES

$f_{TOP} = (710.47 - 365.58)(12)(1000)/5203 - 281.2\ \text{PSI}$

$= 514$ PSI COMPRESSION $< 0.60 f'_{ci}$ OKAY

$f_{BOT} = (-710.47 + 365.58)(12)(1000)/5203 - 281.2\ \text{PSI}$

$= -1076.64$ PSI TENSION $> 3\sqrt{f'_{ci}}$ NOT OKAY

IGNORE NOW FOR PRELIM DESIGN

STAGE 2 STESSES AT SERVICE (DL+LL+PT)

MIDSPAN STRESSES

END SPAN

$f_{TOP} = (-400.71 - 183.18 + 206.08)(12)(1000)/5203 - 281.2\ \text{PSI}$

$= -1153$ PSI $> 6\sqrt{f'_c}$ (NOT OKAY → IGNORE FOR PRELIM DESIGN)

$f_{BOT} = (+400.71 + 183.18 - 206.08)(12)(1000)/5203 - 281.2\ \text{PSI}$

$= 590$ PSI $< 0.45 f'_c$ OKAY.

SUPPORT STRESSES

$f_{TOP} = (710.47 + 324.79 - 365.38)(12)(1000)/5203 - 281.2\ \text{PSI}$

$= 1263$ PSI $< 0.45\sqrt{f'_c}$ OKAY.

$f_{BOT} = (-710.47 - 324.79 + 365.38)(12)(1000)/5203 - 281.2\ \text{PSI}$

$= -1826$ PSI $> 6\sqrt{f'_c}$ NOT OKAY → IGNORE FOR PRELIM DESIGN

8

NOTE: ALL COMPRESSIVE STRESSES ARE WITHIN CODE LIMITS.

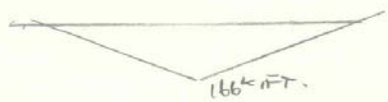
MOST TENSION STRESSES ARE NOT WITHIN CODE LIMITS
↳ DUE TO 2 SPAN ANALYSIS
↳ ASSUME OKAY FOR PRELIM DESIGN, IN FUTURE LOOK AT ADDING 3 SPAN TO REDUCE TENSION STRESSES.

ULTIMATE STRENGTH

$M_1 = P \cdot e$

$= 798(3)/12 = 199^{FT \cdot K}$

$M_{SEC} = M_{BAL} - M_1 = 365.38 - 199 = 166^{K \cdot FT}$ (AT THE INT SUPPORTS)



M_u @ MIDSPAN $= 1.2(400.71) + 1.6(183.18) + 1.0(83) = 857^{FT \cdot K}$

M_u @ SUPPORT $= 1.2(-710.47) + 1.6(-324.79) + 1.0(166) = -1206^{FT \cdot K}$

DET MIN BONDED REIN.

NEGLECT INT SPAN FOR PRELIM DESIGN.

END SPAN

$S_T = 590\,PSI > 2\sqrt{f'_c}$

$y = 590/(590 + 1153)(11)$ $y = 3.72$ IN

$N_c = (400.71 + 183.18)(12)/5203 \cdot (0.5)(3.72)(21.5)(12)$

$N_c = 646^K$

$A_{S\,MIN} = N_c / 0.5 f_y = 646/0.5(60) = 21.5\ IN^2$

$A_{S\,MIN} = 21.5^{IN^2}/21.5^{FT} = 1\ IN^2/FT.$

USE #6@5" $= 1.01\ IN^2/FT$

→ USE #6@5" OC BOTTOM.

→ MIN LENGTH SHALL BE 1/3 CLEAR SPAN & CENTERED IN POSITIVE MOMENT REGION

9

FRAME B CONT.

NEG MOMENT REGION

INT SUPPORTS & EXT SUPPORTS

$A_{cf} = (11)(40.33)(12) = 5320$

$A_{S\,MIN} = 0.00075(5320) = 3.99\ in^2$

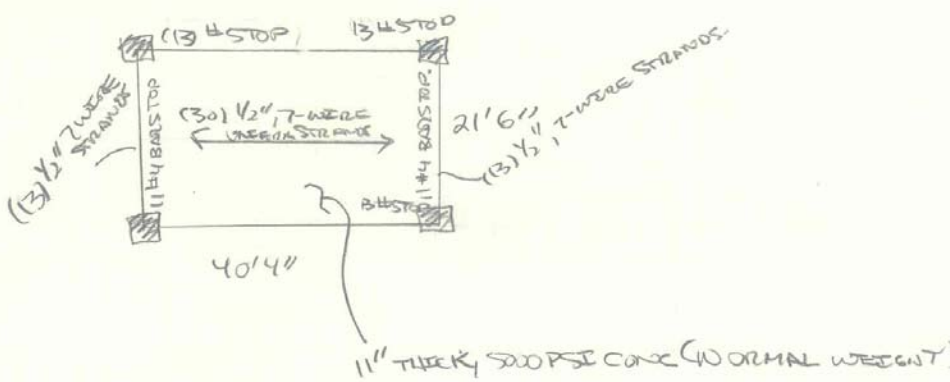
EXT SUPPORTS

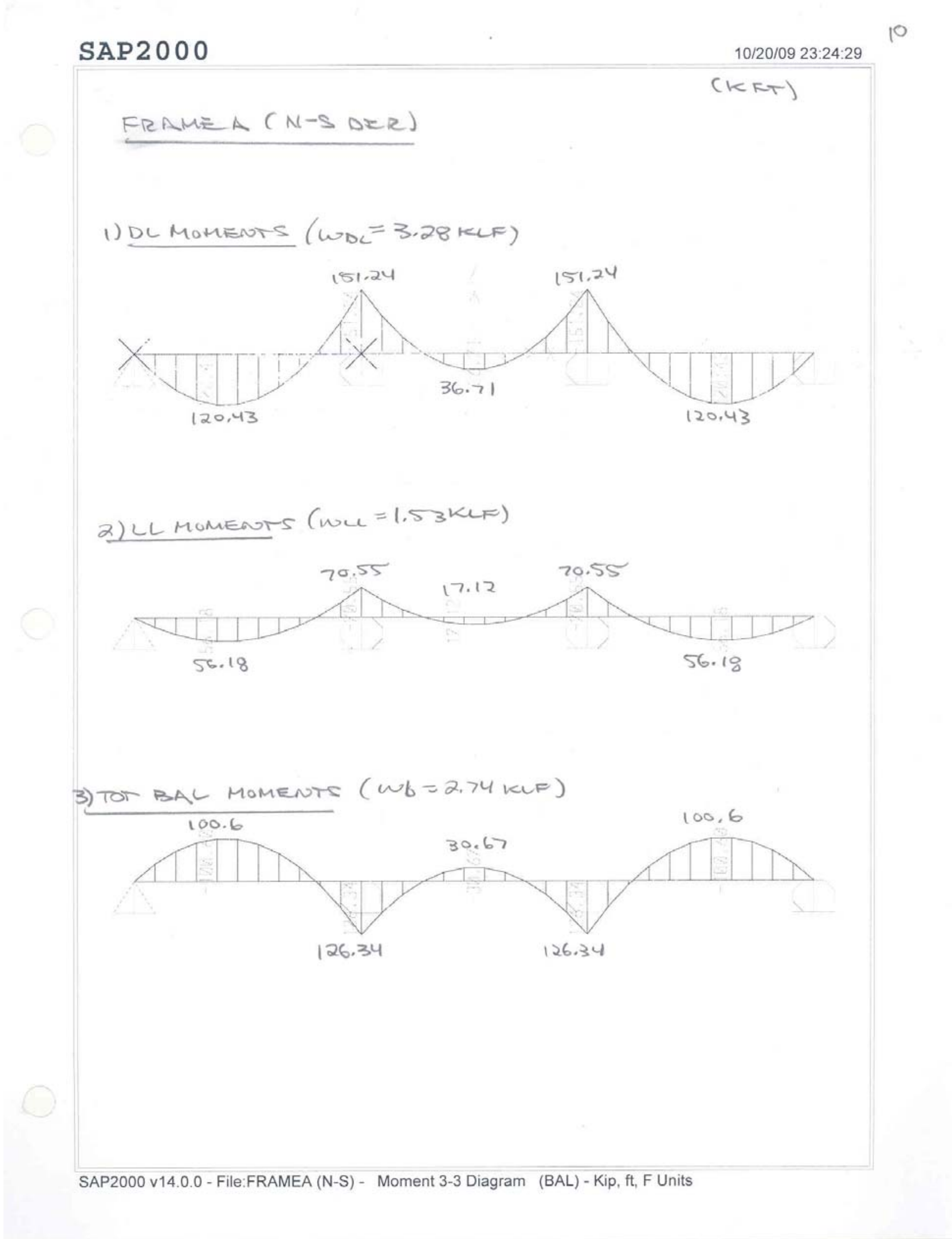
$= 13 - \#5$ TOP $(4.03\ in^2)$

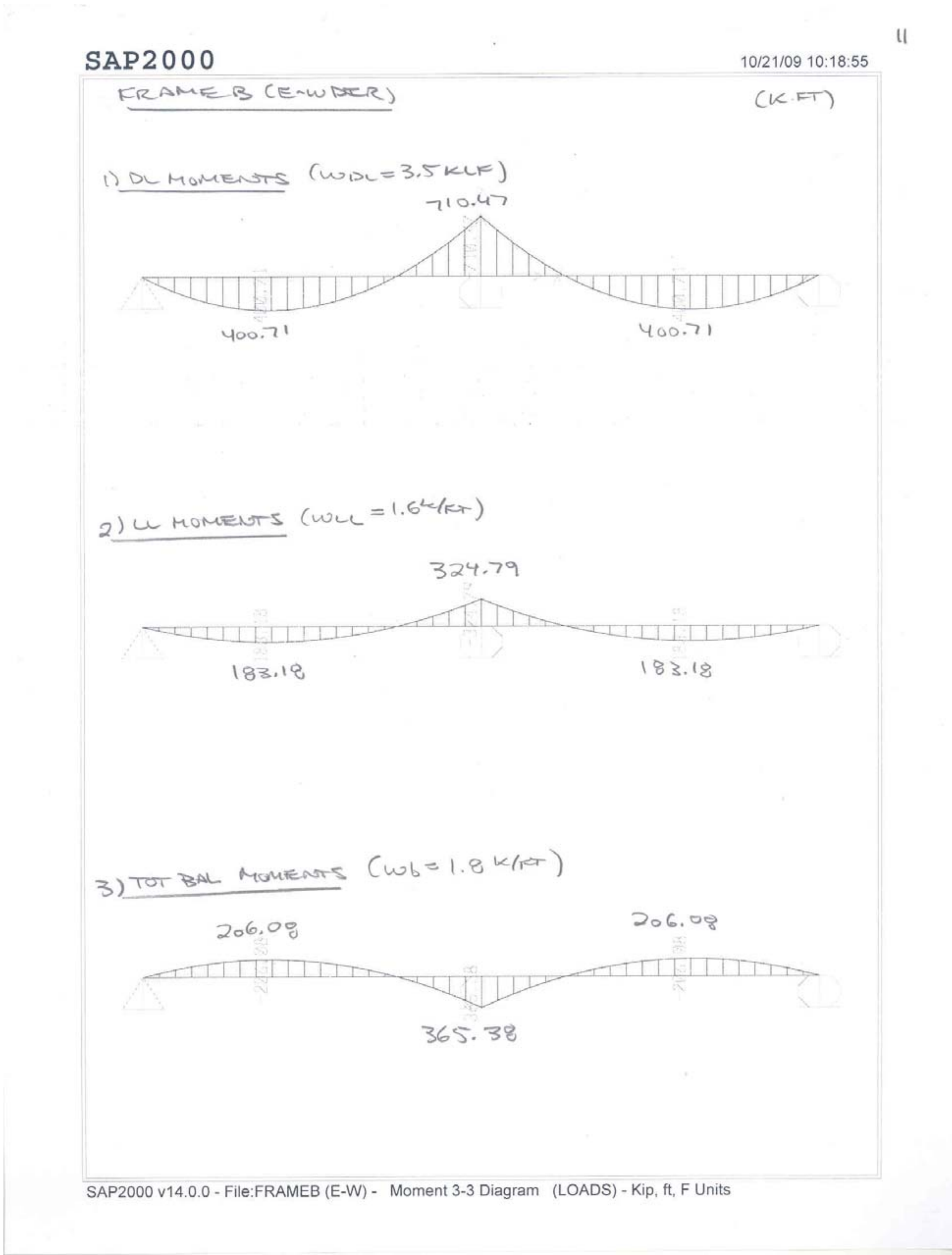
SUMMARY FRAME B (E-W DIR)

13 – #5 TOP BARS

(30) 1/2" DIAMETER, 7-WIRE STRANDS




10
SAP2000
10/20/09 23:24:29
(K FT)
FRAME A (N-S DIR)
1) DL MOMENTS (w_{DL} = 3.28 KLF)
151.24
151.24
36.71
120.43
120.43
2) LL MOMENTS (w_{LL} = 1.53 KLF)
70.55
17.12
70.55
56.18
56.18
3) TOT BAL MOMENTS (w_b = 2.74 KLF)
100.6
30.67
100.6
126.34
126.34
SAP2000 v14.0.0 - File:FRAMEA (N-S) - Moment 3-3 Diagram (BAL) - Kip, ft, F Units


11
SAP2000
10/21/09 10:18:55
FRAME B (E-W DIR)
(K-FT)
1) DL MOMENTS (WDL = 3.5 KLF)
710.47
400.71
400.71
2) LL MOMENTS (WLL = 1.6K/FT)
324.79
183.18
183.18
3) TOT BAL MOMENTS (Wb = 1.8 K/FT)
206.08
206.08
365.38
SAP2000 v14.0.0 - File:FRAMEB (E-W) - Moment 3-3 Diagram (LOADS) - Kip, ft, F Units

12

POST TENSION FLOOR SYSTEM COST ANALYSIS

RS MEANS 2009

STEEL PRESTRESSING $\$3.33/LB$

$0.52 lb/FT \rightarrow 1/2''$ STRAND

$$0.52 \frac{lb}{FT}(30 \cdot 40.33 + 26(21.5)) = 920^{lb}$$

$$\frac{\$3.33}{lb} \times 920^{lb} = \frac{\$3063.6}{(40.33)(21.5)} = \$3.55/SQFT$$

CAST IN PLACE CONCRETE

$$\$575/yd^3 \left(\frac{1 yd^3}{27 ft^3}\right)\left(\frac{11''}{12''}\right) = \$19.52/SQFT$$

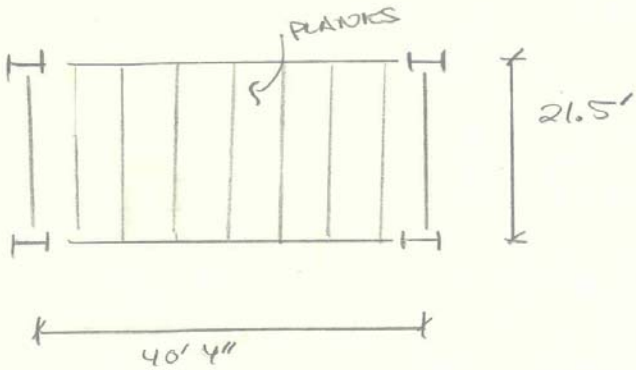
$$\text{TOTAL COST} = \left(\frac{\$3.55}{SQFT} + \frac{\$19.52}{SQFT}\right)(1.31)$$

↳ NYC LOCATION FACTOR

$$\boxed{\$30.23/SQFT}$$

Appendix D: (Hollow Core Plank Floor System Calculations)

HOLLOW CORE PLANK 1



SDL = 25 PSF
LL = 100 PSF > 125 PSF SERVICE LOAD

1.2(25) + 1.6(100) = 190 PSF → WHEN USING PCI, USE UNFACTORED LOADS.

PCI DESIGN HANDBOOK:

SPAN 22' (125 PSF) ⟹ 9 − 6/16THS STANDS (STRAIGHT)
(4'0" x 6" w/ 2" TOPPING)
2HR FIRE RESISTANCE

SAFE SUPERIMPOSED SERVICE LOAD
= 166 PSF > 125 PSF (OKAY)

DL = 74 PSF (PLANK)
= 74 + 25 (SDL) = 99 PSF, LL = 100 PSF

1.2(99) + 100(1.6) = 279 PSF

TRIB WIDTH = 21.5'

278(21.5) = $\underline{6^{k}/FT = w_u}$

$M_u = w_u l^2/8 = 6(40.33)^2/8 = \underline{1220^{FT \cdot K} = M_u}$

2

$$\Delta_{LL\,MAX} = \frac{\ell}{360} = \frac{(40.33)(12)}{360} = 1.34'' = \frac{5(100)(21.5)(40.33)^4 1728}{384(29000)I_{MIN}}$$

$$I_{MIN} \geq 3293.3\ IN^4$$

$$\Delta_{D+L(MAX)} = \frac{\ell}{240} = \frac{(40.33)(12)}{240} = 2.01 = \frac{5(100+99)(21.5)(40.33)^4(1728)}{384(29000)I_{MIN}}$$

$$I_{MIN} \geq 4355\ IN^4 \text{ (GOVERNS)}$$

FOR W24X146 ($I = 4580\ IN^4$)

$\phi M_N = 1570 > M_u = 1220$ OKAY

$I_{W24X146} = 4580 > 4355$ OKAY

∴ USE W24X146 GIRDERS W/ HOLLOW CORE PLANK (4'0" × 6" W/ 2" TOPPING, 96-S)

– NOTE – FOR BEAMS PARELLEL TO PLANKS, NO SIGNIFICANT GRAVITY LOADS ACTING ON MEMBER.
∴ WOULD LIKELY SEE W12 – W14 SECTION.

COST ANALYSIS:

- RSMEANS 2009 SQUARE FOOT COSTS

MAT	INST	TOT		
9.05	4.41	\$13.46/SQ.FT	[PLANKS]	(P6264)
10.70	2.94	(+) \$13.64/SQ FT	[W SHAPE] IN 30X35 BAY	

NYC LOCATION FACTOR

$\$27.1/SQ\ FT\ (1.31) = 35.50$

$\boxed{\$35.50/SQ\ FT}$

3

Strand Pattern Designation
76-S

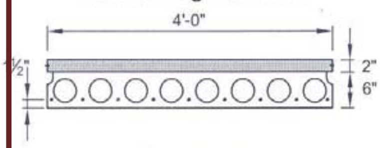
- S = straight
- Diameter of strand in 16ths
- No. of Strand (7)

Safe loads shown include dead load of 10 psf for untopped members and 15 psf for topped members. Remainder is live load. Long-time cambers include superimposed dead load but do not include live load.

Capacity of sections of other configurations are similar. For precise values, see local hollow-core manufacturer.

Key
444 – Safe superimposed service load, psf
0.1 – Estimated camber at erection, in.
0.2 – Estimated long-time camber, in.

HOLLOW-CORE
4'-0" x 6"
Normal Weight Concrete



$f'_c = 5{,}000$ psi
$f_{pu} = 270{,}000$ psi

Section Properties

		Untopped		Topped	
A	=	187	in.^{2}	283	in.^{2}
I	=	763	in.^{4}	1,640	in.^{4}
y_b	=	3.00	in.	4.14	in.
y_t	=	3.00	in.	3.86	in.
S_b	=	254	in.^{3}	396	in.^{3}
S_t	=	254	in.^{3}	425	in.^{3}
wt	=	195	plf	295	plf
DL	=	49	psf	74	psf
V/S	=	1.73	in.		

4HC6

Table of safe superimposed service load (psf) and cambers (in.) — **No Topping**

Strand Designation Code	Span, ft 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
66-S	444	382	333	282	238	203	175	151	131	114	100	88	77	68	59	52	46	40	33	28	
	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.0	–0.1	–0.2	–0.4	–0.5	–0.7		
	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.0	–0.1	–0.3	–0.5	–0.7	–0.9	–1.2	–1.5	–1.9	
76-S		445	388	328	278	238	205	178	155	136	120	105	93	82	73	65	57	49	42	36	31
		0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.1	0.1	0.0	–0.1	–0.3	–0.4	–0.6
		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.1	0.0	–0.1	–0.2	–0.4	–0.7	–0.9	–1.2	–1.6	–2.0
96-S		466	421	386	338	292	263	229	201	177	157	139	124	110	99	88	78	68	60	53	46
		0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.3	0.3	0.1	0.0	–0.1
		0.3	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.4	0.3	0.2	0.1	–0.1	–0.3	–0.6	–0.9	–1.3
87-S		478	433	398	362	322	290	264	240	212	188	167	149	134	119	107	95	85	76	68	60
		0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.6	0.5	0.4	0.3
		0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.7	0.7	0.6	0.5	0.3	0.2	0.0	–0.3	–0.6
97-S		490	445	407	374	346	311	276	242	220	203	186	166	148	133	119	107	96	86	78	70
		0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.8	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.8	0.7	0.6
		0.5	0.6	0.6	0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.0	1.0	0.9	0.9	0.8	0.7	0.5	0.3	0.1	–0.2

4HC6 + 2

Table of safe superimposed service load (psf) and cambers (in.) — **2 in. Normal Weight Topping**

Strand Designation Code	Span, ft 12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
66-S	470	396	335	285	244	210	182	158	136	113	93	75	59	46	34				
	0.2	0.2	0.2	0.2	0.2	02	0.2	0.2	0.2	0.2	0.1	0.1	0.0	–0.1	–0.2				
	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.0	–0.1	–0.2	–0.3	–0.5	–0.7	–0.9	–1.2				
76-S		461	391	334	287	248	216	188	163	137	115	95	78	63	50	38	27		
		0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.1	0.1	–0.0	–0.1	–0.3		
		0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.0	–0.2	–0.3	–0.5	–0.7	–0.9	–1.2	–1.5		
96-S			473	424	367	319	279	245	216	186	160	137	116	98	82	68	55	43	33
			0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.3	0.3	0.1	0.0	–0.1
			0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.2	0.1	–0.1	–0.3	–0.5	–0.7	–1.0	–1.4	–1.7
87-S			485	446	415	377	331	292	258	224	195	169	147	127	109	94	80	67	55
			0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.6	0.5	0.4	0.3
			0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.4	0.4	0.2	0.1	–0.1	–0.3	–0.5	–0.8	–1.2
97-S			494	455	421	394	357	327	288	251	219	192	168	146	127	110	95	82	70
			0.5	0.6	0.7	0.7	0.8	0.8	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.8	0.7	0.6
			0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.5	0.4	0.2	0.0	–0.2	–0.5	–0.8

Strength is based on strain compatibility; bottom tension is limited to $7.5\sqrt{f'_c}$; see pages 2–7 through 2–10 for explanation.

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