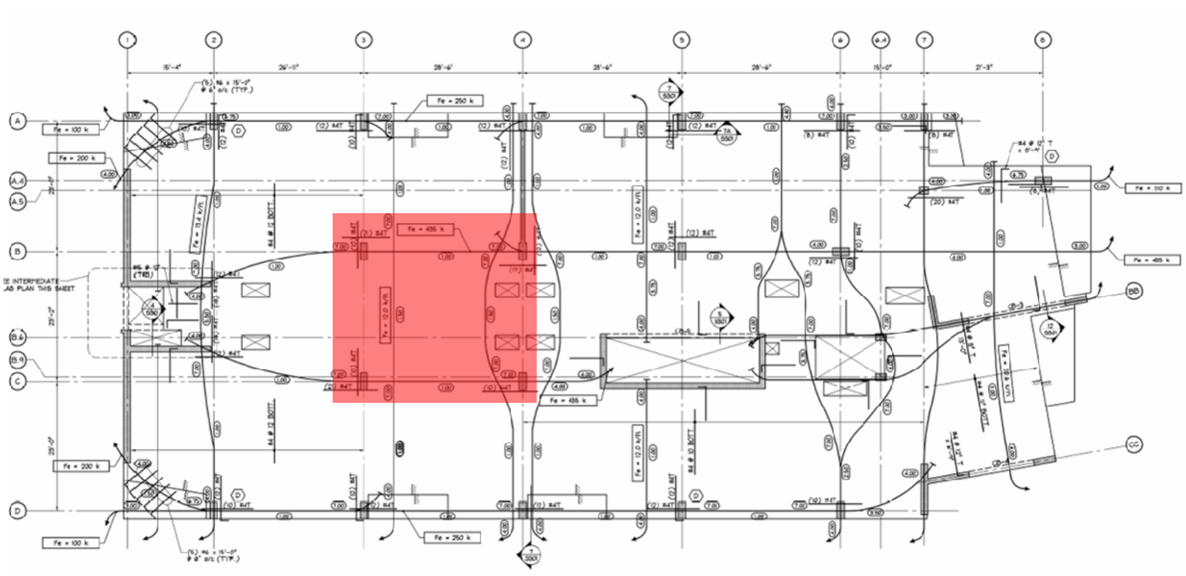
Introduction

This technical assignment presents preliminary research findings for the redesign of a typical floor system for the River Tower at Christina Landing condominium tower. The floor plan, shown below, for Levels 10 through 23 served as the basis for the following research designs. Specifically, an interior bay with consistent dimensions through most floors was used for comparative purposes. This bay, highlighted in the diagram above, lies between column lines 3 and 4 in the West-East direction, and column lines B and C in the North-South direction respectively. The slabs span between columns spaced at 28'-6" in the West-East direction and 23'-0" in the other direction on typical floors. The worst-case live load for a typical floor was determined to be 70 psf in a previous technical assignment, and was determined through a ratio between public and private spaces. The average superimposed dead load of a typical floor was taken as 12 psf to account for ceiling, mechanical and collateral loading. From the structural drawings, this building warrants a 2 hour fire-rating due to its largely residential use.

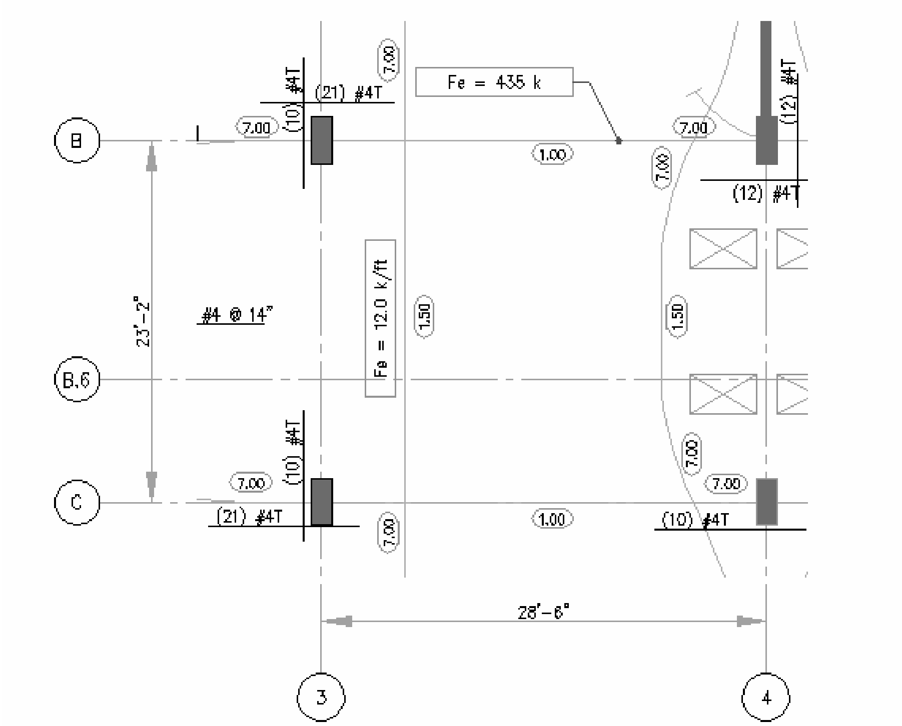


Typical Floor of River Tower Condominium: ***Provided by O'Donnell & Naccarato, Structural Engineers***

Interior bay used for research highlighted in red and enlarged on next page

The following report weighs the benefits and disadvantages of several types of floor systems, including the original flat plate post-tensioned concrete slab. Alternate floor systems included in this analysis are non-composite and composite steel deck/concrete slab systems, a composite steel joist/deck/concrete slab system, and a one-way concrete joist system. Potential factors in determining feasibility include fire protection, system dead weight, and floor-to-floor height. The following pages list the benefits and disadvantages of each system, and a comparative chart lists the conclusions towards their feasibility in River Tower. Alternate column layouts were considered for this assignment, but due to the architectural dependency on the current grid lines, this layout was not changed from the original design.

<u>Existing System</u>: Post-tensioned Flat Plate Concrete Slab

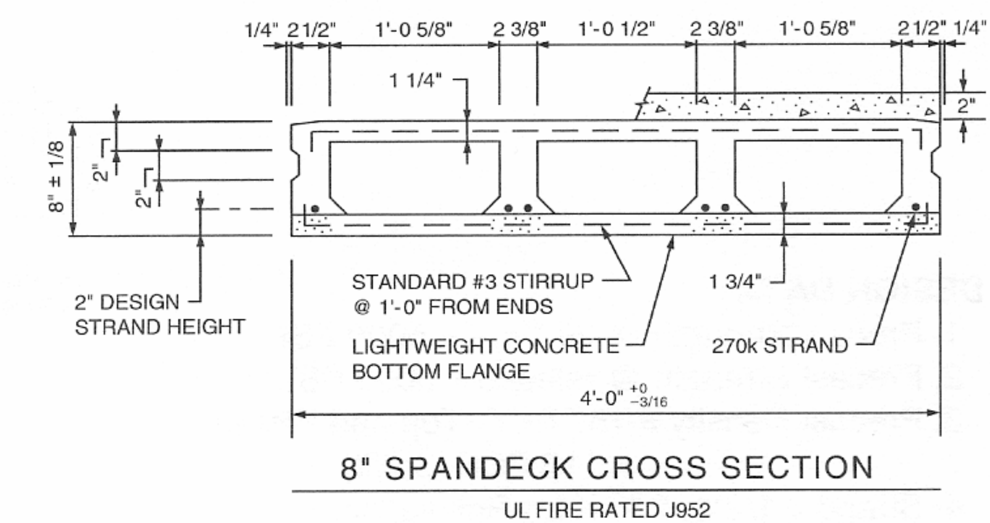


The typical River Tower condominium floors use an 8 inch, 5000 psi thick partially pre-stressed post-tensioned concrete flat plate system. An enlarged view of the interior span used for the preliminary research is shown above. The post-tensioning force in the long-span direction is listed at 12 kip/ft, while in the short-span direction this tensioning is 435 kips. In the banded post-tensioning direction (West-East), #4 tendons are placed every 12 inches, while in the uniform post-tensioned direction (N-S), #4 tendons are placed every 20 inches (omitted on diagram for clarity). At the columns, variable amounts (shown above) of #4 tendons are placed to help prevent punching shear in the flat slab and provide ultimate flexural strength for the slab. Through approximation of R.S. Means *Assemblies Cost Data*, this floor system costs $12.33 per square foot to construct. Please consult Appendix A for more detailed calculations.

System Summary:	Post-tensioned Floor Plate Slab
Advantages	- Post-tensioning saves need for more compressive reinforcement - Low vibration characteristics - Eight inch thickness provides adequate fire resistance - Banded tendon layout speeds construction time, saves on cost - Lack of drop panels reduces cost and floor thickness
Disadvantages	- Cast-in-place construction can lengthen erection process and increase installation costs - Susceptible to punching shear
Feasible for River Tower	(Existing Design System)

<u>Alternate System #1</u>: Hollow Core Slab System

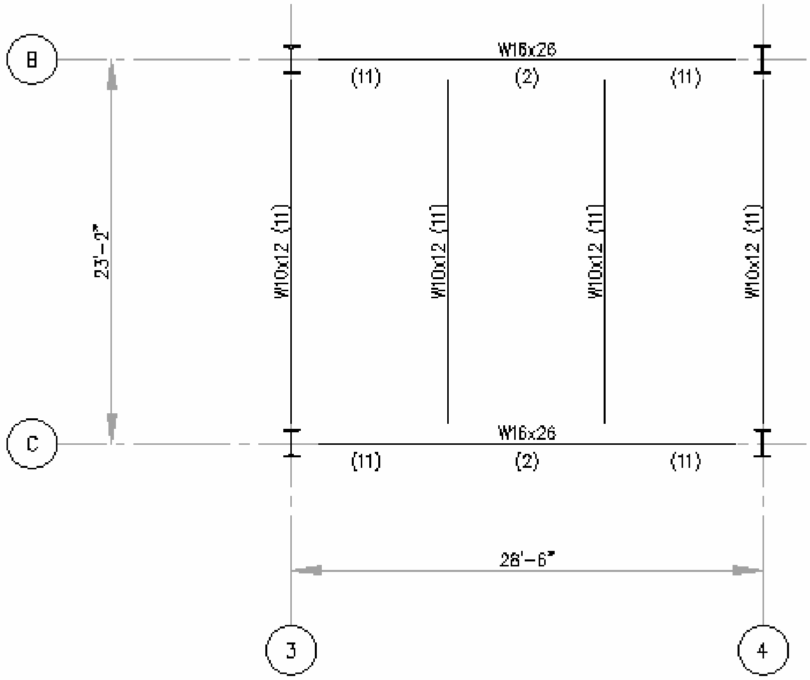
8” × 4’ Prestressed Concrete SpanDeck (U.L. Assembly #J952)



A hollow core slab system saves on material cost and system weight, since only the most necessary materials are used. These systems work similarly to pre-stressed floor slabs, but with voids to save on material cost. For this analysis, the hollow core slab was chosen based on a span of 24 feet, the short direction. Though the hollow core planks could hold the superimposed load without a concrete topping, a 2 inch cast-in-place concrete topping was factored into the design due to fire rating requirements of 2 hours for this condominium building. These planks need to rest on supports at the column lines: steel girders, concrete beams, or other bearing supports at the columns. These members were not analyzed as part of this preliminary report, but the overall depth of the bays would be controlled by the depth of the precast planks. Through approximation of R.S. Means *Assemblies Cost* Data, this floor system costs $10.14 per square foot to construct. Please consult Appendix B for more detailed information and calculations.

System Summary :	Hollow Core Slab System
Advantages	- Excellent Fire Resistance and Sound Attenuation - Precast offers quick and easy constructability, low maintenance - Similar column and column footing type can be used - Can be used as finished ceiling condition - Voids can be used for mechanical or electrical components - Provides basic lateral force-resistant diaphragm
Disadvantages	- Potentially limited competition for materials or labor - Possible constructability issues with contractors and erectors - Must rest on structural supports (not considered in this preliminary report)
Feasible for River Tower	YES

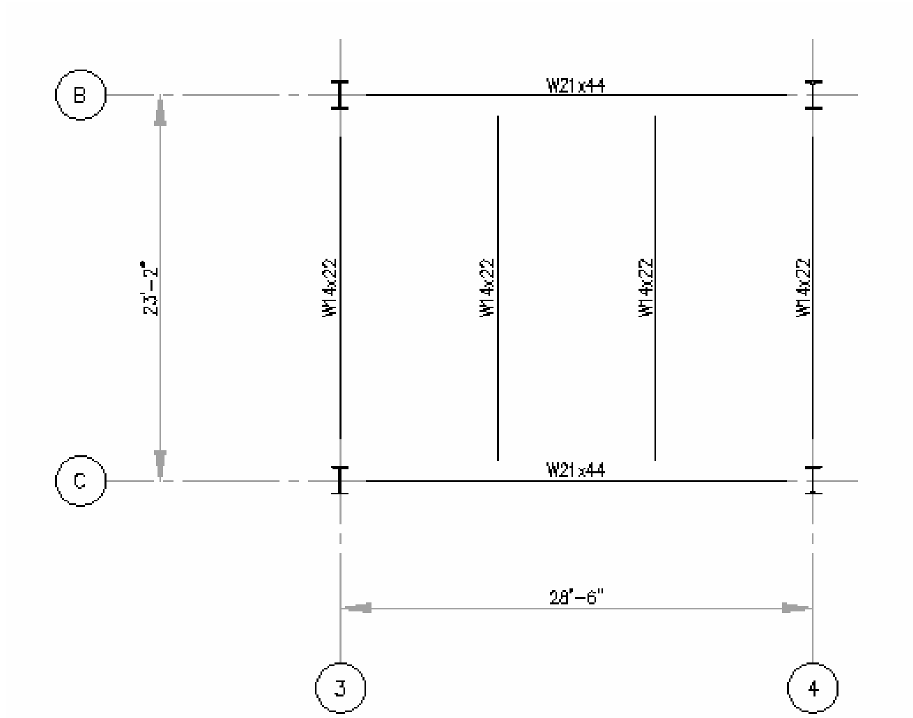
<u>Alternate #2:</u> Composite System: Steel Beams, Girders, and Deck with 3" Concrete Slab



The beam and girder sizing were determined using RAM Structural Analysis software and had the following results. The largest depth in this configuration is the 15.7" depth of the W16×26 girder, but this occurs only in the 5.5" width of the flange. Primarily, the floor depth is controlled by the 10.2" deep W10×12 beams, which together with the 5" slab depth results in a difference of nearly seven inches from the existing floor system. The dead weight of this system, which includes the 3" concrete floor slab, 2" USD Lok-Floor metal decking, and structural steel components, is 44.8 psf. This system sacrifices floor depth and inherent fire protection, but has clear advantages in system weight and overall system cost, despite the expenses of steel procurement. Through approximation from R.S. Means *Assemblies Cost Data*, this system costs $19.37 per square foot to construct. Please consult Appendix C for more detailed information.

System Summary:	Composite Metal Deck/Concrete Slab System
Advantages	- Excellent stiffness – minimizes vibration issues - Structural shapes need fireproofing, slab/deck assembly do not - Lightens building weight considerably - Smaller column footings needed - Thinner/smaller column size minimizes architectural intrusion
Disadvantages	- Additional fireproofing necessary on structural supports (spray-on fiber or gypsum board) - Larger floor depth by almost seven inches - Change in lateral resistance system necessary - Ceiling finishing required underneath structural members
Feasible for River Tower	YES

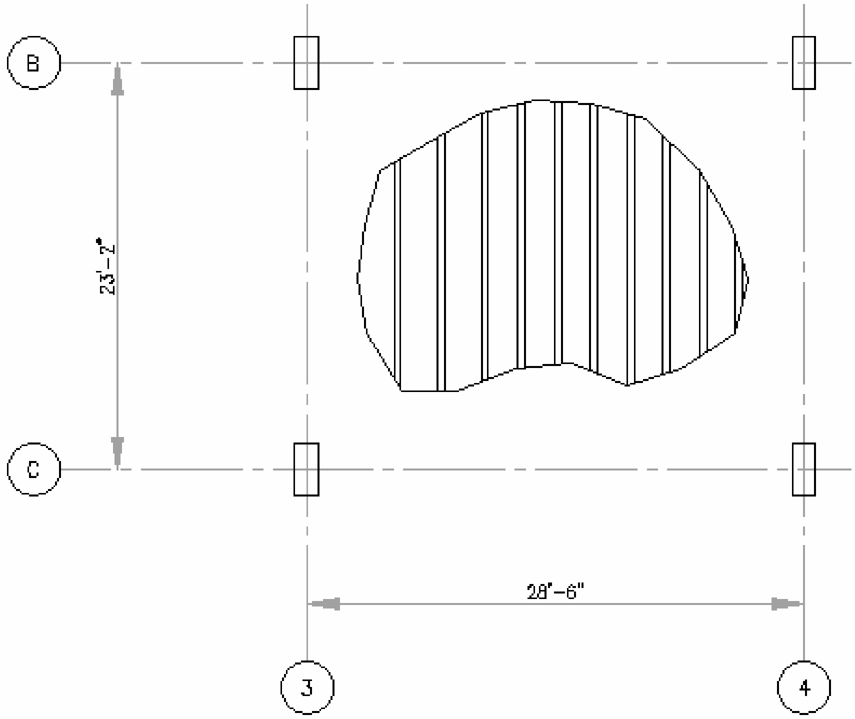
<u>Alternate #3:</u> Non-composite System: Steel Beams, Girders, and Deck on 3" Concrete Slab



The beam and girder sizing were determined using RAM Structural Analysis software and had the following results. The largest depth in this configuration is the 20.7" depth of the W21×44 girder, but this occurs only in the 6.50" width of the flange. Primarily, the floor depth is controlled by the 13.7" deep W14×22 beams, which combined with a 5" slab depth results in a difference from the original floor system by almost eleven inches. The dead weight of this system, which includes the 3" concrete floor slab, 20 gage 2" USD Lok-Floor metal decking, and structural steel components, is 48.11 psf. Through approximation from R.S. Means *Assemblies Cost Data*, this system costs $14.30 per square foot to construct. Please consult Appendix D for more detailed information and calculations.

System Summary:	Non-Composite Metal Deck/Concrete Slab System
Advantages	- Structural shapes need fireproofing, slab/deck assembly do not - Lightens dead weight of structure - Smaller column footings needed - Thinner/smaller column size minimizes architectural intrusion
Disadvantages	- Additional fireproofing necessary on structural supports (spray-on fiber or gypsum board) - Less stiffness compared to composite steel/slab system - Larger floor depth by nearly eleven inches - Change in lateral resistance system necessary - Ceiling finishes required underneath structural members
Feasible for River Tower	NO

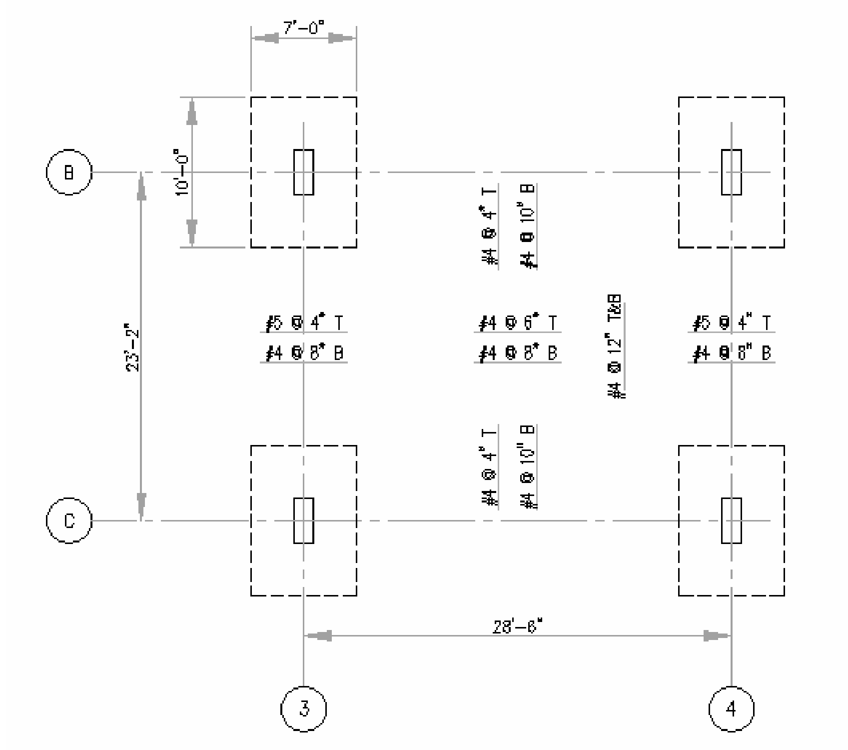
<u>Alternate #4:</u> One-Way Concrete Joist Floor System



Standard square-end one-way concrete joists were designed using the CRSI Handbook. Because BOCA 1996 was referenced in the original floor design, the 1996 version of the CRSI Handbook edition was used to maintain design consistency. A 20" form system with 5" thick ribs spaced at 25" center-to-center was designed based on the typical loading configuration. This alternate system contains a 10" deep rib with a 3" top slab, making its total depth only 13 inches. To gauge a system with the minimum necessary depth, these joists were designed to span the short-span direction, taken at 24 feet to be conservative. The dead weight for this system is given as 67 psf from Table 8-1 of the CRSI Handbook. Through approximation from R.S. Means *Assemblies Cost Data*, this system costs $14.64 per square foot to construct. Please consult Appendix E for more detailed information and calculations.

System Summary:	One-Way Concrete Joist Floor System
Advantages	- Excellent stiffness criteria, meaning little deflection concern - Inherent fire protection - Voids between ribs can be used to place mechanical or electrical components - Original column and column footing type can be used - Original concrete shear walls can still be used
Disadvantages	- Expensive pour – cast-in-place concrete - Difficult construction – long spans and continuous pours - Needlessly deep floor depth compared to advantages of flat plate system properties
Feasible for River Tower	NO

<u>Alternate #5</u>: Two-Way Flat Plate Reinforced Concrete Slab



For a two-way flat plate with reinforcing steel, a 9.25" thick, 5000 psi concrete slab was designed with 2.5" thick, 7 ft by 10 ft drop panels around the columns. For the short-span direction, #4 rebar is required at the following spacing: 12" at the top and bottom of the middle strip, 4" at the top of the column strip, and 10" at the bottom of the column strip. For the long-span direction, #4 rebar is used at 8" spacing for all bottom reinforcement. #4 bars are spaced at 6" for the top reinforcement of the middle strip, and #5 bars are used at 4" spacing for column strip top reinforcement. The system dead weight was determined to be 113.13 psf, neglecting the weight of the drop panels, which was judged to be negligible compared to the overall weight. The system cost was determined to be $14.07 through approximation of R.S. Means *Assemblies Cost Data*. Please consult Appendix F for more detailed information and calculations.

System Summary:	Two-Way Flat Plate Reinforced Concrete Slab
Advantages	- Low vibration characteristics - 9.25 inch thickness provides adequate fire resistance - Excellent stiffness = low deflection - Original column and column footing type would be similar - Original concrete shear walls can still be used
Disadvantages	- Susceptible to punching shear - Drop panels add additional floor thickness near supports - Difficult constructability – cast-in-place concrete
Feasible for River Tower	NO

Details of Cost Analysis

Through approximation from the 2005 R.S. Means *Assemblies Cost Data*, the existing and alternate systems were compared using 25 foot spans, and in some cases 25 ft by 30 ft bays, for comparative purposes. While this assemblies cost data is not totally applicable, such as in the case of concrete strength, this data provides a valuable preliminary estimate of the building cost concerns of these proposed systems. The values are compared in the following overall comparison chart.

Overall Comparison

Floor System	System Depth	Dead Weight	System Cost (per sq. ft.)	Further research?
Post-tensioned flat plate slab system	8”	98 psf	$12.33	**Existing**
Hollow Core Slab System	8” ± 1/8” precast + 2” topping	82.5 psf	$10.14	**YES**
Composite Steel Framing System	10.2” steel + 5” slab depth	44.8 psf	$19.37	**YES**
Non-Composite Steel Framing System	13.7” steel + 5” slab depth	48.11 psf	$14.30	**NO**
One-Way Concrete Joists	10” Deep Rib + 3” Top Slab	67 psf	$14.64	**NO**
Two-Way Flat Plate Slab with Drop Panels	9.25” + 2.5” at drop panels	113.31 psf	$14.07	**NO**

Conclusion

While each alternative system offered unique benefits to the overall building system, floor depth, dead weight, and building cost were deciding factors. The composite steel framing system provides both the lowest system weight and highest system cost. The non-composite steel framing system provides nearly the same system weight at a much lower cost, but at a greater floor depth. Budget would certainly control in most cases, but in this preliminary structural analysis, floor depth controlled overall. With this in mind, the non-composite system was judged to not warrant further analysis. The one-way composite joist system’s poor overall cost and depth does not offset its benefits of dead weight to merit further research as well. The flat plate slab system with drop panels does not offer any significantly better results, particularly with self weight, than the original partially prestressed flat plate slab.

It is important to note that the potential change in floor system would affect the type of column footings used, but not the overall deep pile cap foundation system. Concrete columns would be supported with wooden column base connections, while steel columns would need steel base plates. The instabilities of the riverfront soil of the River Tower site would necessitate using deep piles regardless of floor system type. Lighter building weights would affect sizing of footings, however, and would potentially alleviate overturning capacities.