Technical Assignment Two:
Pro-Con Study of Alternate Floor Systems

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Structural Option

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Executive Summary

The following report contains a preliminary analysis of the existing floor system and several alternatives. Northside Piers, a 29-story condominium tower located in Brooklyn, New York, is currently being built with a concrete structure. It consists of two-way flat plate slabs, shear walls around the central core, and a pile foundation. The gravity loads for this analysis, determined by the New York City Code, were found to be a 40 psf live load and a 30 psf superimposed dead load. The existing floor system is designed to have an exposed finish over the bedroom and living rooms. It will be held up by columns located sporadically throughout the plan.

Initial considerations of depth, constructability, and serviceability led to the choice of four possible alternative floor systems: flat slab with drop panels, pan joist floor system, post-tensioned slab, and composite beams with metal deck. The analysis for these systems was carried out by looking at two approximate strips in the plan. This is just to get initial ideas about the systems and a more exhaustive analysis should take place at a later stage.

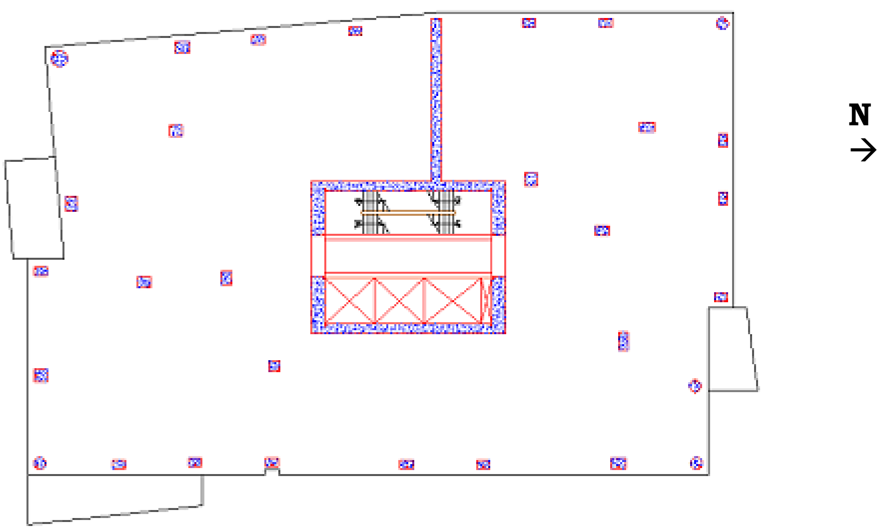
Many factors were considered for each of the possible systems including the estimated cost, weight, depth, constructability, fire proofing, acoustic insulation, vibration, deflection, durability, architectural effects, lateral system effects, and foundation effects. It was determined that all of the concrete structural systems will perform fairly well. The variance between systems is not significant enough to make it obvious which system is the best choice at this point. However, the composite beam system would clearly have the worst performance in terms of serviceability due to its thinner slab and the beams that stick 12” below the ceiling. This protrusion fits awkwardly with the architecture and blocks views out the windows, therefore this system is not a viable solution.

Description of Building

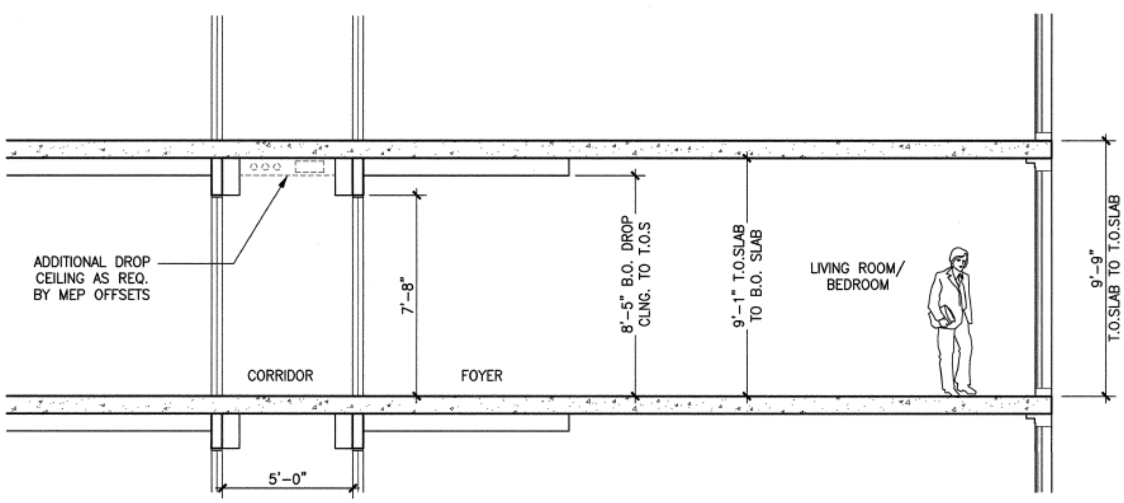
Architecture

Northside Piers is a building currently being constructed on 164 Kent Ave. in the Brooklyn, New York area. It is a 29-story condominium tower built directly off of the East River across from Manhattan Island. The building features a glass cladding system that allows for floor to ceiling windows for uninhibited views of New York City. Transportation throughout the building is provided by a central elevator shaft and stairwell. The 27 floors that are dedicated to the condominium units are all very similar with only minor variations.

Floor System



Almost the entirety of the building is designed with an 8" thick two-way flat plate slab system. Slabs consist of 6000 psi concrete with #5 reinforcing bars at typically 12"o/c or 6"o/c at the top and bottom of the slab going both directions.



The finishes are then attached either directly below the slab or there is an 8" drop that is used for MEP. The floor to floor height is 9'-9" so there is limited space for additional structure. Any additional depth will need to be added to the entire building.

Foundation

The columns sit on top of a foundation of 200 ton piles that are at about ten feet below grade. Grade beams run along the perimeter of the building. The highest concentration of piles is directly underneath the central core of the building in order to transfer the high moments to the ground below. The foundation plan can be found in the appendix.

Columns

The columns in this building do not follow a consistent grid in order to accommodate the floor plans. They are primarily composed of rectangular columns located around the perimeter of the building with a few of them on the interior to break up the large bays. Almost all of the interior columns are hidden behind walls with additional room around them. Columns consist of 8000 psi concrete with usually 8 rebars along their edge varying in size from #7-#11. The bars are held in place with ties. Typical floor to floor height is 9'-9".

Lateral Resisting System

Lateral forces are carried in this building by the central core, which consists of concrete shear walls surrounding the elevator shaft. The walls are 1 ½ foot thick in the long direction and 2 feet thick in the shorter direction. The concrete strength is 8000 psi until the 14^{th} level where it decreases to 6000 psi. The reinforcing is typically #5-#7 at 12 in. o/c. on both faces of the walls.

Gravity Loads

The gravity loads that were used in this analysis are shown below. Applicable loads were taken from the New York City Code, 2003 Edition. Dead loads were taken from manufacturers.

Live Loads:

Multifamily Dwellings	40 psf

*Live Loads may be reduced

Superimposed Dead Loads:

Multifamily Dwellings	30 psf
- MEP	20 psf
- Floor Finishes	5 psf
- Ceiling Finishes	5 psf

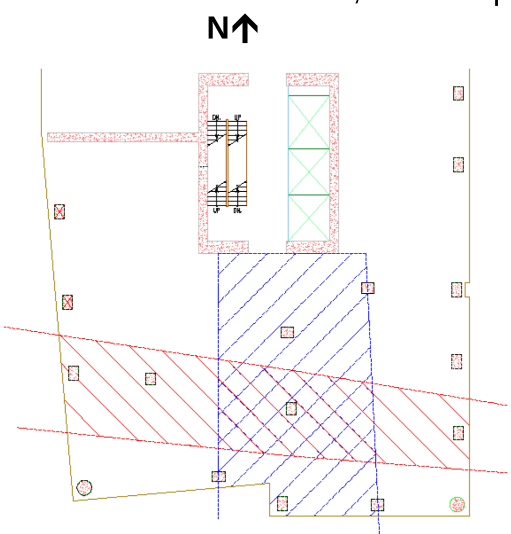
Dead Loads:

Concrete	150 pcf
Glass Cladding	8 psf
Metal Decking	3 psf

System Analysis Overview

Introduction

There are a number of different systems or modifications of systems that could be potentially used for the floor of this building. While many of these alternatives were considered, a thorough analysis was only carried out on the four most likely alternatives. The major initial considerations included depth, constructability, and isolation between condominium units (vibration, acoustics, thermal, fire). Since the building is 29 stories, it is important to keep the depth of the system small because any increase will be multiplied 29 times for the overall height of the building. It is also very important to prevent noise and vibration transmission through the flooring in this high end condominium tower, so a concrete floor was chosen over a wood membrane. These considerations led me to look at four systems in more detail: flat slab with drop panels, pan joist system, post-tensioned concrete slab, and composite beams with metal deck.



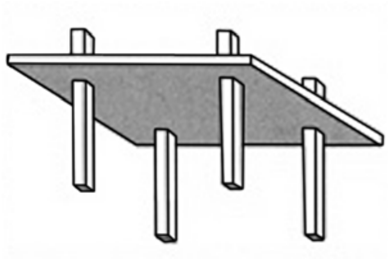
Due to the inconsistent bay size in the floor system, an approximate method was used in order to determine the member sizes. Two strips were analyzed in the floor system: one in the north-south direction and one in the east-west direction. This is shown on the left. While the actual width of the slab supported varies, an estimate was used for this preliminary stage. In the future, the entire slab should be analyzed using a finite element software in order to get a more precise answer. The strips were chosen as a representation of both short spans and long spans.

The member sizes for the concrete systems were determined by making sure they met all of the ACI requirements for strength and deflection. The limit for deflection was determined using ACI 9.5.3.4 which permits you to use Table 9.5b to find the limits. Since the floor slab will be supporting nonstructural elements that may be damaged by deflection (the gypsum ceiling), the limit will be L/480.

The steel was designed to meet AISC requirements for strength, and the deflection limit was determined by IBC 2006 which allows for L/360 for live load and L/240 for dead load.

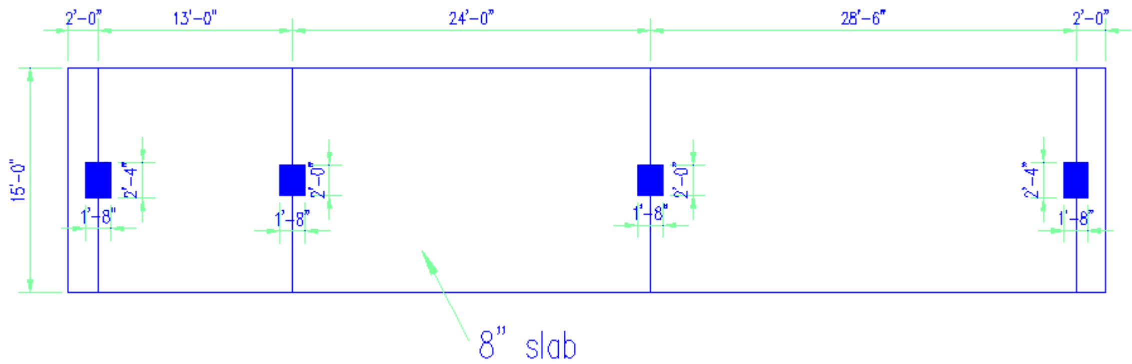
Further details of all the calculations and analyses can be found in the appendix.

Existing System: Two-Way Flat Plate

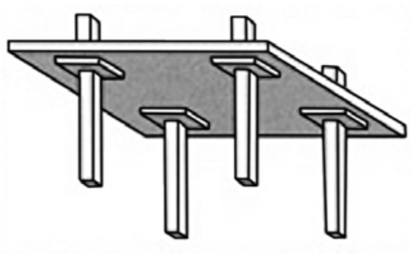


The building is being built using a two-way flat plate system. This system was chosen because of its easy constructability and its ability to fit in well with the architecture and the flat ceilings.

The analysis of this system was carried out using pcaSlab. The 12" thick slab that is being used met all of the strength requirements for moment and shear, but it is obvious that punching shear is the controlling factor in the choice of the slab thickness. The approximate analysis said that the punching shear was at 83% of the slab's capacity. The maximum long-term deflection was found to be 0.53" which meets ACI requirement of 0.71" for that span.

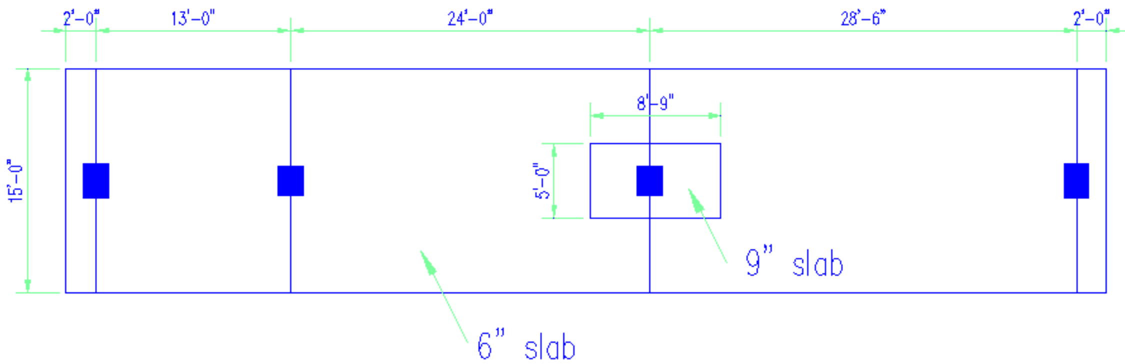


Alternative One: Flat Slab with Drop Panels

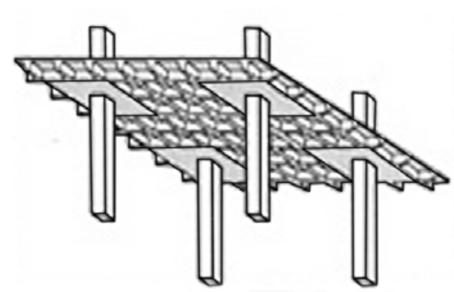


Since the existing system was controlled by punching shear, the next logical system to look at is a flat slab with drop panels. This way concrete can be added only on the columns where the punching shear was critical.

The analysis was done using pcaSlab again. It was found that a 6" slab with 3" drop panels on the critical columns would satisfy the design requirements. When the slab started getting thinner, the long-term deflection became the critical factor for the design. A 2" drop panel was all that was required for strength, but a 3" drop panel was used instead in order to stiffen up the floor. The maximum deflection is 0.70" which just meets the requirement of 0.71" for that span.

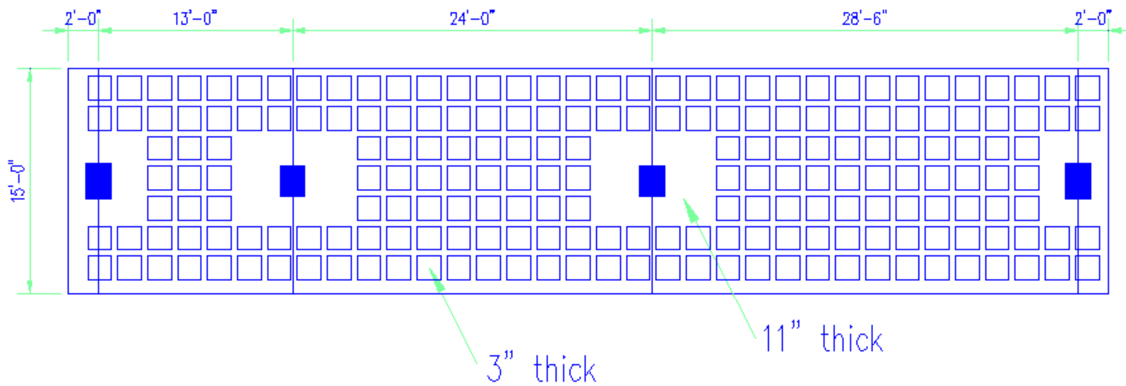


Alternative Two: Pan Joist Floor System

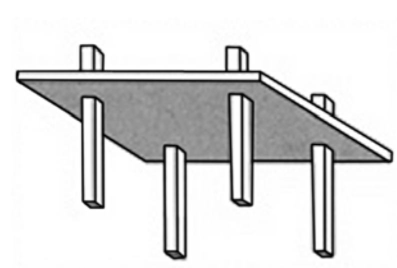


In attempt to create a lighter building, the pan joist floor system was analyzed. The voids in the concrete could potentially decrease the amount of concrete required and thus decrease the size of the columns and the foundation.

This initial sizing of this system was determined using the CRSI Design Handbook. The span length used was 24' which is the longest span in the entire floor. This will give a conservative value for the required reinforcing of the entire slab. 19" pans were chosen because they are better at fitting the non-uniform column plan. It was found that a 3" slab with an 8" rib depth would meet the requirements for this design. The reinforcing for this plan can be found in the appendix.

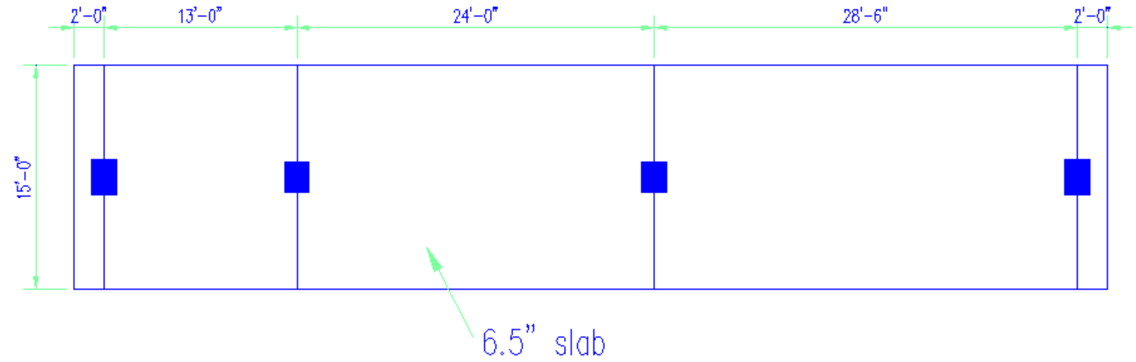


Alternative Three: Post-Tensioned Concrete Slab



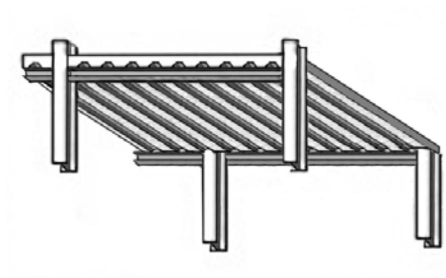
The next system considered was a post-tensioned concrete slab. This system takes care of deflection problems by balancing the dead load using the post-tensioned tendons. This will allow the slab to be thinned to whatever the minimum requirement for punching shear is. It will also have a flat bottom which fits into the architecture better.

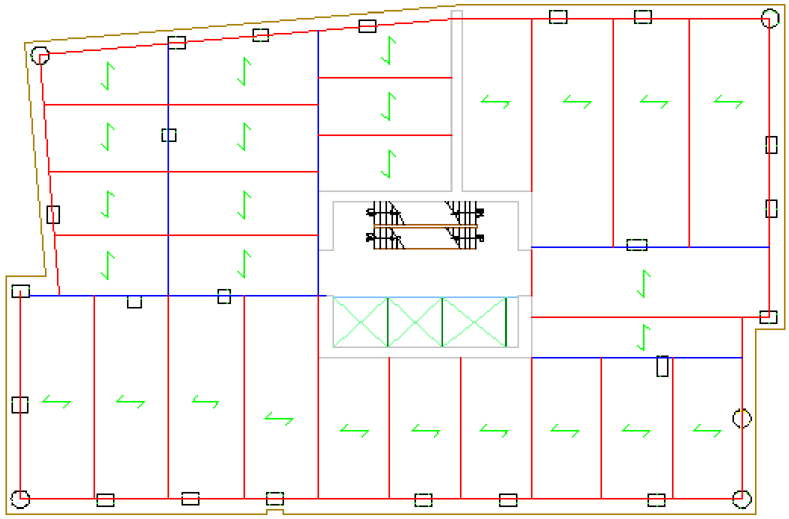
The analysis was carried out using the program RAM Concept. It was found that a flat 6.5" thick slab with 6 tendons stressed to 200 psi will meet the requirements for strength and deflection. The details of the reinforcing can be found in the appendix.



Alternative Four: Composite Beams with Metal Deck

The final system analysis focused on the combination of composite beams with a metal deck. This floor system will give the option of using a completely different structural system with steel columns and a steel lateral system. It was decided that composite beams should be used in order to decrease the depth of the beams. In order to implement this system, an entire system of beams and girders needs to be added to the plan. The columns would be changed to steel and the shear wall would be either changed into just columns with moment frames or braced frames. The new plan can be seen below.





The analysis of the system determined that a 3 ½" slab should be used on a 1.5VL17 deck by Vulcraft. This deck was chosen because it can support an unshored length of over 10 foot. This is important in order to speed up construction. The deck would be supported by composite beams and girders, typically being a W12x22 with 5/8” studs at 6”o/c.

Floor System Comparisons

Cost

Cost is probably one of the most important factors in deciding which system to use. The cheapest structural system that meets all of the design requirements will be the system that is chosen. The estimated costs can be determined using RS Means data. It is important to note that while this data can give an idea of how much systems will cost, there are still other factors that will contribute to the overall cost that are not included in this analysis. Factors excluded are the changes that will be made to other structural elements as well as the interest accrued during construction time.

Since the design of the floor systems is still in the preliminary stage, an assembly estimate will be used rather than a unit estimate. This is also the better choice due to the approximate method of the structural analysis. This will be good enough to get a sense of how the systems relate in price. The following is the prices given from RS Means for a 15x25 foot bay with a superimposed load of 75 psf.

	Cost per Square Foot
Two-Way Flat Plate:	\$13.70/ft^2
Flat Slab with Drop Panels:	\$14.50/ft^2
Pan Joist Floor System:	\$19.10/ft^2
Post-Tensioned Concrete:	–
Composite Beams with Metal Deck:	\$15.45/ft^2

The value for the Post-Tensioned Concrete is not given in the assemblies guide, but it can be estimated that it will be comparable to the two-way flat plate system because it uses the same formwork which is the largest component of the price. Reinforcing it will be more expensive but the decreased amount of concrete should offset this price.

Weight

Dead loads contribute to over half of the gravity loads on the building for the existing system. Having a heavy floor system results in higher loads on the columns and foundation of the building. This means that these members will need to be larger than in a system with a lighter floor. Since the overall structure was not redesigned for the alternative systems, weight can still be an indicator of how much more the other structural components will cost. The equivalent weights for each system were determined and are listed below.

	Equivalent Weight
Two-Way Flat Plate:	100 psf
Flat Slab with Drop Panels:	87.5 psf
Pan Joist Floor System:	71 psf
Post-Tensioned Concrete:	81 psf
Composite Beams with Metal Deck:	35.2psf

Since this building is controlled by wind loads, the lateral system will not need to be adjusted like it would if seismic loads had been the controlling factor.

Depth

Since this building has so many levels, it is important to try to keep the depth of the floors as small as possible. A thinner structure will allow for more occupied space and will keep the overall building height down. There is no limit on the building height, so this will not be the controlling factor. Less depth will save on architectural material required and decrease the wasted volume of the building. The maximum and minimum depth for each system is listed below.

	Maximum Depth	Minimum Depth
Two-Way Flat Plate:	8”	8”
Flat Slab with Drop Panels:	6”	9”
Pan Joist Floor System:	11”	11”
Post-Tensioned Concrete:	6.5”	6.5”
Composite Beams with Metal Deck:	3 ½”	15 ½”

Constructability

All of the systems being designed can easily be built by an experienced contractor. There is nothing atypical about these systems. The construction time, however, will vary depending on which floor is chosen. Construction time will be very important in the design of this building because the owner will have large loans that will be accruing interest while the building is under construction. The owner will not be able to collect final payments for the condominiums until the building is completely finished. It will also be easier to sell the finished units.

The post-tensioned concrete slab will be the quickest concrete construction because you are permitted to remove the formwork quicker than in mild reinforced slabs. The composite beams with metal deck will also be very quick because you do not need to wait for curing.

Fire Rating

The floor systems that were chosen perform very well under fire tests because they are solid concrete slabs. The system that would perform the worst in this criteria is the composite beams with metal deck. The Underwriter’s Laboratory gives the metal deck a 2 hour rating on its own, but the beams would have to have spray-on fire protection in order to become acceptable.

Serviceability Issues

Northside Piers is a very high-end condominium tower so serviceability issues are extremely important. Meeting all of these requirements is essential in order to avoid legal disputes with all of the individual owners of the units and because of the nature of the project, expectations are going to be very high.

Acoustical Insulation:

Since the condominium units are going to be people's homes, noise transmission through the floor system could lead to a lot of complaints from tenants. Since all of the slabs are concrete, the amount of noise reduction will be a function of the slab thickness. The existing slab is the thickest, so it will perform the best in this topic. The slab on metal deck, however, will get additional insulation from the deck. A more in depth acoustical analysis would need to be performed in order to compare this to the others.

Vibration:

Vibration is a function of the weight of the floor and its stiffness. The floor that performs the worst in this matter will probably be the composite beams with metal deck due to its lower stiffness and weight. A more in depth analysis should be performed in order to figure out exactly how much worse in comparison this system is than the others because vibration will be a key aspect for the design of this structure. This is because residents have the lowest allowable value for vibrations of 0.005g.

Deflection:

Deflection is an important issue for the structural design of floors. Deflections are broken down into two groups: deflection due to live load and deflection due to total load. The total load deflection will contribute to the cracking of finishes and the live load deflection is what will be felt by people. All of the systems have been designed in order to meet the serviceability requirements set out by codes. The deflections for the slabs analyzed are listed below.

	Live Load	Total Load
Two-Way Flat Plate:	L/1879	L/647
Flat Slab with Drop Panels:	L/1043	L/490
Pan Joist Floor System:	OK	OK
Post-Tensioned Concrete:	OK	L/2710
Composite Beams with Metal Deck:	L/684	L/267

*Long-term Deflections are listed for concrete slabs

Durability:

All of the systems being used should meet the standards of durability for residences. There is the potential for rust in the steel or rebar of these systems, but because the recommended amount of clear cover of ¾" is used for all of the concrete, the likelihood of rusting is the same for all the systems.

Architectural Effect
The existing design leaves the ceiling uncovered above the bedroom and living room. The decision can be made to add gypsum board to cover up the composite deck or even the pan joist system if desired.

The other major architectural effect is that the systems that are not flat will have protrusions in the ceiling. This is an amount of 3" and 12" for the drop panel system and the composite beam system respectively. This is an unavoidable effect for the beam system. It is, however, possible to avoid this in the drop panel system by using shear reinforcing around the column or by increasing the column size itself.

Lateral System Effects
The lateral system will function in the same manner for all of the systems except for the composite beams with the metal deck system. In this case, the lateral system must be changed into a steel system instead of shear walls. This can be done with moment frames or by using bracing. Bracing placed where the shear walls currently are would probably be the more logical choice because there is room for them there and they are better at controlling drift than moment frames. If the composite beam system is chosen, the effects of this will eventually need to be analyzed.

Foundation Effects
The foundation will change based on the weight of the new systems. All of the alternatives consisted of lighter systems so the foundation would certainly be adaptable to this change. If the composite beam system is chosen, the way the steel columns tie into the foundation would need to be altered, but this can be easily done.

	Two-Way Flat Plate	**Flat Slab with Drop Panels**	**Pan Joist Floor System**	**Post-Tensioned Concrete**	**Composite Beams with Metal Deck**
Cost	$13.70/sq.ft	$14.50/sq.ft	**$19.10/sq.ft**	about $14/sq.ft	$15.45/sq.ft
Weight	100 psf	87.5 psf	**71 psf**	81 psf	**35.2 psf**
Depth	8"	6" / 9"	11"	**6.5"**	**3.5" / 15.5"**
Constructability	Very Easy	Easy	Easy	Easy/Quick	Easy/Quick
Fire Proofing	None	None	None	None	**Spray-On**
Acoustic Insulation	**Best**	Good	Good	Good	**Worst**

Vibration	**Best**	Good	Good	Good	**Worst**
Live Deflection	L/1879	L/1043	OK	OK	L/684
Total Deflection	L/647	L/490	OK	**L/2710**	**L/267**
Durability	Good	Good	Good	Good	Good
Architectural Effect	**None**	3" drops	**None**	2" drops	**12" Beams**
Lateral System Effects	None	None	None	None	Braced Frame or Moment Frame
Foundation Effects	None	Smaller	Smaller	Smaller	**Smallest**
Viable Solution?	**Yes**	**Yes**	**Yes**	**Yes**	**No**

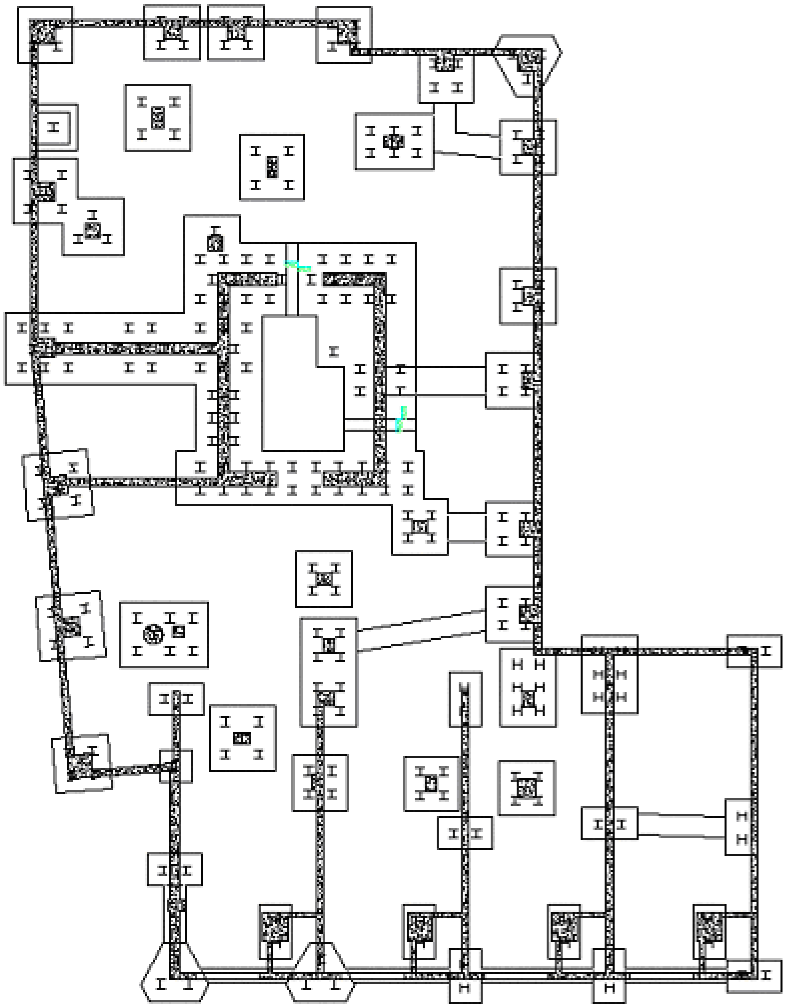
Conclusions

Upon the investigation provided in the report, it is obvious that the composite beam system would have the worst performance in terms of vibration and acoustic insulation. These factors are extremely important factors for a high-end condominium building. This system also contains a major design flaw as it requires beams that are 12” below the bottom of the decking which will be sticking awkwardly into the residential spaces. It will also block some of the view out the floor to ceiling windows which is very undesirable.

All of the concrete systems will perform fairly well in terms of serviceability. Their costs and serviceability effects do not vary enough to make it immediately obvious which system is the best choice. A more exhaustive analysis needs to be carried out in order to determine the system that would be the cheapest and how much of a difference there really is in the serviceability factors.

Appendix

Foundation Plan



Deflection Limits

Deflection Limits

Table 9.5b

l/480 for Floor supporting nonstructural elements likely to be damaged by large deflections

	Span 1 (2')	Span 2 (13')	Span 3 (24')	Span 4 (28.5')	Span 5 (2')
X-direction	0.05	0.33	0.60	0.71	0.05

	Span 1 (2')	Span 2 (16')	Span 3 (13')	Span 4 (14')
Y-direction	0.05	0.40	0.33	0.35

Two-Way Flat Plate System

X-Direction pcaSlab Results

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Punching Shear Around Columns:
==============================
   Units: Vu (kip), Munb (k-ft), vu (psi), Phi*vc (psi)
   Supp           Vu       vu         Munb Comb Pat  GammaV       vu   Phi*vc
   ---- ------------ -------- ------------ ---- ---- ------ -------- --------
      1        21.48     34.9         7.90 U2   S1    0.369     40.5    232.4
      2        62.53     77.9        48.67 U2   All   0.384    107.4    232.4
      3        89.34    111.3        48.90 U2   All   0.384    141.0    232.4
      4        50.41     81.8      -156.78 U2   All   0.369    193.6    232.4

Maximum Deflections:
====================
   Units: Dz (in)
        __________Frame____________  _______Column Strip________  ________Middle Strip_______
   Span Dz(DEAD) Dz(LIVE) Dz(TOTAL)  Dz(DEAD) Dz(LIVE) Dz(TOTAL)  Dz(DEAD) Dz(LIVE) Dz(TOTAL)
   ---- -------- -------- ---------  -------- -------- ---------  -------- -------- ---------
      1    0.001    0.000     0.002     0.003    0.001     0.003     0.000    0.000     0.001
      2   -0.004    0.001    -0.005    -0.006    0.002    -0.008    -0.002    0.000    -0.002
      3   -0.082   -0.039    -0.121    -0.110   -0.053    -0.163    -0.053   -0.026    -0.079
      4   -0.235   -0.123    -0.359    -0.347   -0.182    -0.529    -0.124   -0.065    -0.188
      5    0.020    0.007     0.027     0.032    0.011     0.043     0.008    0.003     0.011

Material Takeoff:
=================
   Reinforcement in the Direction of Analysis
   ------------------------------------------
   Top Bars:       892.2 lb   <=>  12.84 lb/ft   <=>  0.856 lb/ft^2
   Bottom Bars:    863.2 lb   <=>  12.42 lb/ft   <=>  0.828 lb/ft^2
   Stirrups:         0.0 lb   <=>   0.00 lb/ft   <=>  0.000 lb/ft^2
   Total Steel:   1755.5 lb   <=>  25.26 lb/ft   <=>  1.684 lb/ft^2
   Concrete:       695.0 ft^3 <=>  10.00 ft^3/ft <=>  0.667 ft^3/ft^2
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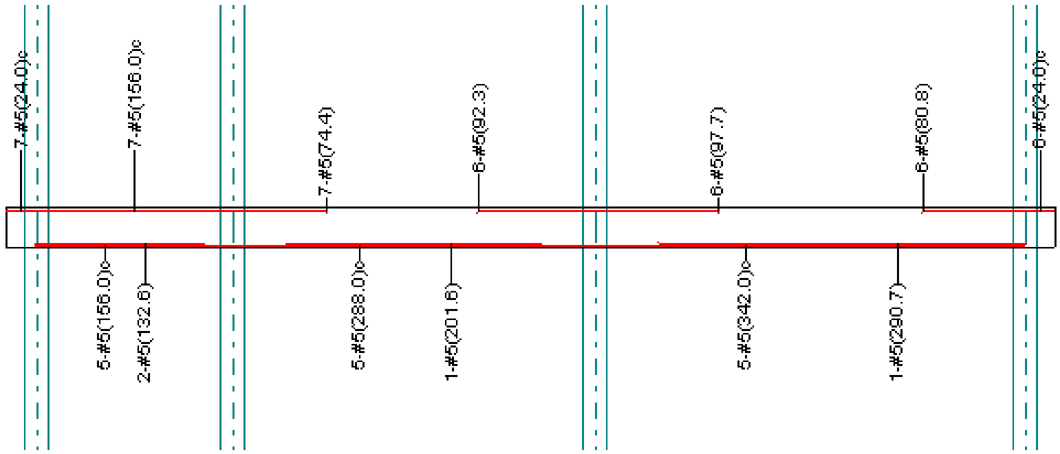
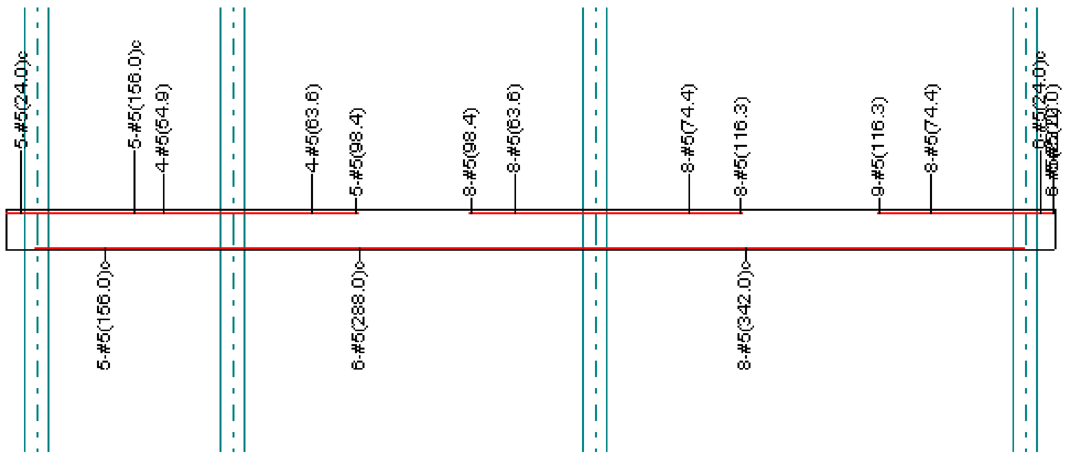


Middle Strip Flexural Reinforcement



Column Strip Flexural Reinforcement

Y-Direction pcaSlab Results

Punching Shear Around Columns:
==============================

Units: Vu (kip), Munb (k-ft), vu (psi), Phi*vc (psi)

Supp	Vu	vu	Munb	Comb	Pat	GammaV	vu	Phi*vc
1	50.14	74.7	39.00	U2	All	0.432	102.2	232.4
2	84.53	105.3	-19.56	U2	All	0.417	117.3	232.4
3	67.79	84.4	4.32	U2	All	0.384	87.1	232.4
4	35.22	18.3	-68.50	U2	All	0.143	85.5	139.4

Maximum Deflections:
===================

Units: Dz (in)

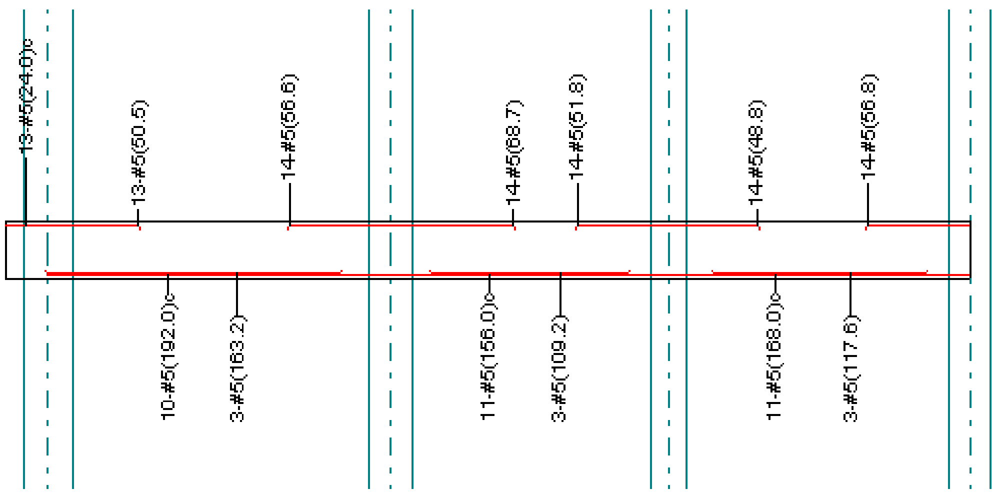
__________Frame____________ _______Column Strip________ ________Middle Strip_______

Span	Dz(DEAD)	Dz(LIVE)	Dz(TOTAL)	Dz(DEAD)	Dz(LIVE)	Dz(TOTAL)	Dz(DEAD)	Dz(LIVE)	Dz(TOTAL)
1	0.008	0.002	0.010	0.020	0.006	0.026	0.002	0.001	0.003
2	-0.027	-0.008	-0.035	-0.062	-0.019	-0.081	-0.010	-0.003	-0.014
3	-0.003	-0.001	-0.004	-0.008	-0.003	-0.011	-0.001	-0.000	-0.002
4	-0.008	-0.003	-0.011	-0.021	-0.006	-0.027	-0.003	-0.001	-0.004

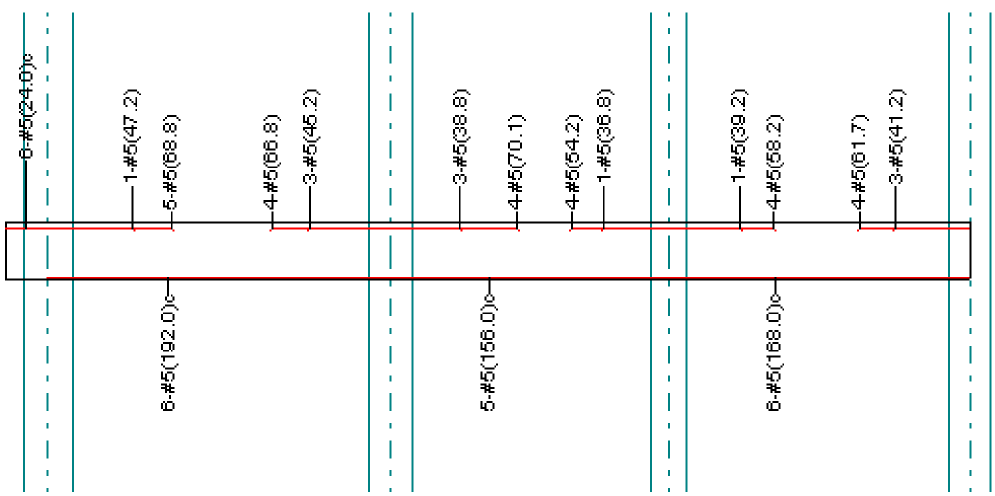
Material Takeoff:
=================

Reinforcement in the Direction of Analysis

Top Bars:	622.1 lb	<=>	13.82 lb/ft	<=>	0.553 lb/ft^2
Bottom Bars:	833.9 lb	<=>	18.53 lb/ft	<=>	0.741 lb/ft^2
Stirrups:	0.0 lb	<=>	0.00 lb/ft	<=>	0.000 lb/ft^2
Total Steel:	1455.9 lb	<=>	32.35 lb/ft	<=>	1.294 lb/ft^2
Concrete:	750.0 ft^3	<=>	16.67 ft^3/ft	<=>	0.667 ft^3/ft^2



Middle Strip Flexural Reinforcement



Column Strip Flexural Reinforcement

Flat Slab with Drop Panels

X-Direction pcaSlab Results

Punching Shear Around Columns:

==============================

Units: Vu (kip), Munb (k-ft), vu (psi), Phi*vc (psi)

Supp	Vu	vu	Munb	Comb	Pat	GammaV	vu	Phi*vc
1	19.11	46.7	9.85	U2	S1	0.367	58.2	220.1
2	51.97	97.7	39.75	U2	All	0.382	137.1	222.7
3	80.26	78.1	40.84	U2	All	0.384	96.5	232.4
4	45.67	58.0	-174.27	U2	All	0.371	151.7	232.4

Maximum Deflections:

====================

Units: Dz (in)

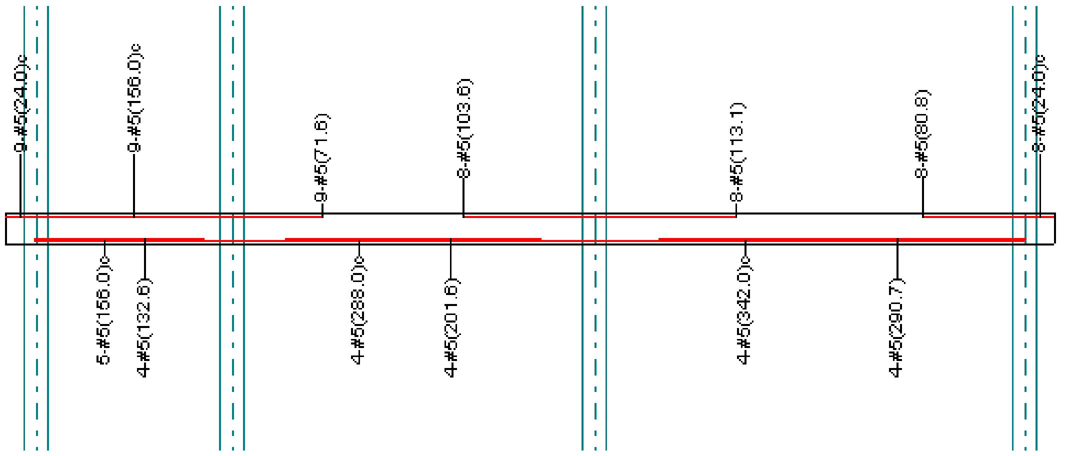
	Frame			Column Strip			Middle Strip		
Span	Dz(DEAD)	Dz(LIVE)	Dz(TOTAL)	Dz(DEAD)	Dz(LIVE)	Dz(TOTAL)	Dz(DEAD)	Dz(LIVE)	Dz(TOTAL)
1	0.003	0.001	0.003	0.005	0.001	0.006	0.001	0.000	0.001
2	-0.008	0.002	-0.010	-0.013	0.004	-0.017	-0.004	0.001	-0.005
3	-0.132	-0.098	-0.230	-0.178	-0.133	-0.311	-0.086	-0.064	-0.150
4	-0.251	-0.222	-0.473	-0.370	-0.328	-0.698	-0.132	-0.117	-0.248
5	0.013	0.005	0.018	0.020	0.008	0.029	0.005	0.002	0.007

Material Takeoff:

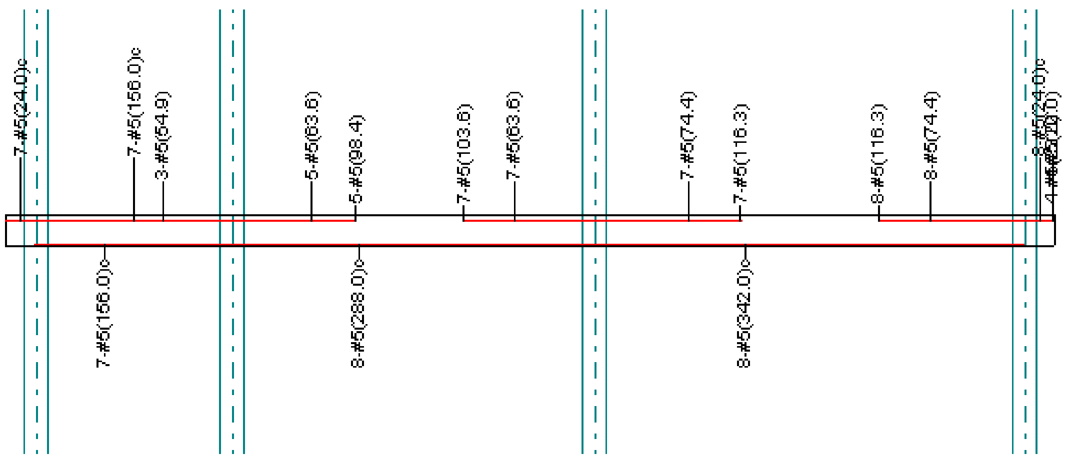
=================

Reinforcement in the Direction of Analysis

Top Bars:	996.9 lb	<=>	14.34 lb/ft	<=>	0.956 lb/ft^2
Bottom Bars:	1037.1 lb	<=>	14.92 lb/ft	<=>	0.995 lb/ft^2
Stirrups:	0.0 lb	<=>	0.00 lb/ft	<=>	0.000 lb/ft^2
Total Steel:	2034.0 lb	<=>	29.27 lb/ft	<=>	1.951 lb/ft^2
Concrete:	543.9 ft^3	<=>	7.83 ft^3/ft	<=>	0.522 ft^3/ft^2



Middle Strip Flexural Reinforcement



Column Strip Flexural Reinforcement

Y-Direction pcaSlab Results

Punching Shear Around Columns:

==============================

Units: Vu (kip), Munb (k-ft), vu (psi), Phi*vc (psi)

Supp	Vu	vu	Munb	Comb	Pat	GammaV	vu	Phi*vc
1	43.61	97.3	36.97	U2	All	0.434	139.6	210.9
2	72.91	137.1	-17.90	U2	All	0.418	155.1	222.7
3	58.72	110.4	3.82	U2	All	0.382	114.2	222.7
4	30.84	22.8	-61.94	U2	All	0.139	127.2	137.1

Maximum Deflections:

===================

Units: Dz (in)

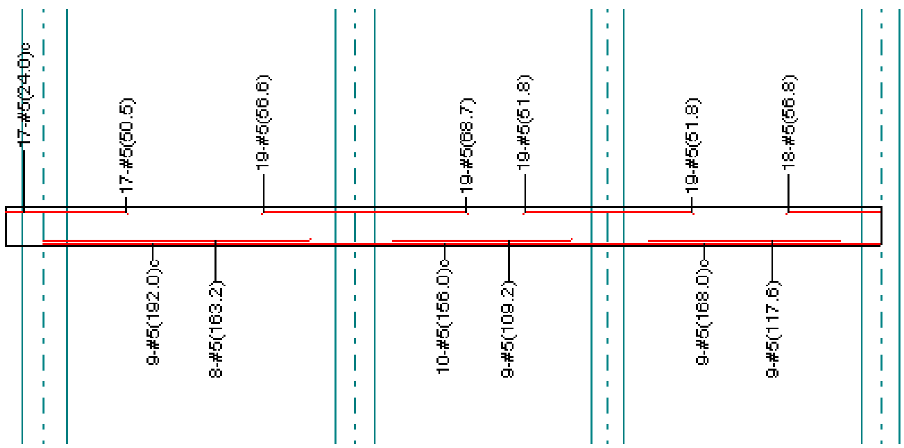
	Frame			Column Strip			Middle Strip		
Span	Dz(DEAD)	Dz(LIVE)	Dz(TOTAL)	Dz(DEAD)	Dz(LIVE)	Dz(TOTAL)	Dz(DEAD)	Dz(LIVE)	Dz(TOTAL)
1	0.014	0.005	0.020	0.036	0.014	0.049	0.004	0.002	0.006
2	-0.050	-0.019	-0.069	-0.116	-0.044	-0.160	-0.019	-0.007	-0.027
3	-0.007	-0.002	-0.009	-0.017	-0.006	-0.023	-0.003	-0.001	-0.004
4	-0.015	-0.006	-0.021	-0.039	-0.015	-0.054	-0.006	-0.002	-0.008

Material Takeoff:

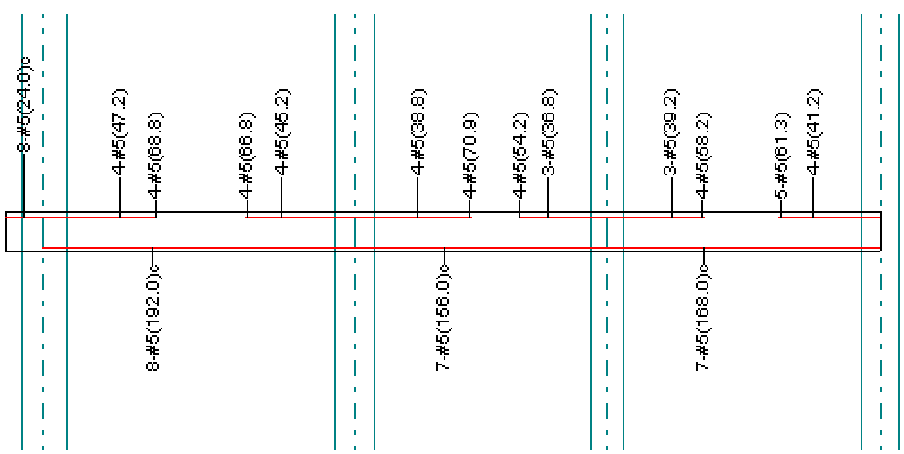
=================

Reinforcement in the Direction of Analysis

Top Bars:	810.8 lb	<=>	18.02 lb/ft	<=>	0.721 lb/ft^2
Bottom Bars:	1038.7 lb	<=>	23.08 lb/ft	<=>	0.923 lb/ft^2
Stirrups:	0.0 lb	<=>	0.00 lb/ft	<=>	0.000 lb/ft^2
Total Steel:	1849.5 lb	<=>	41.10 lb/ft	<=>	1.644 lb/ft^2
Concrete:	562.5 ft^3	<=>	12.50 ft^3/ft	<=>	0.500 ft^3/ft^2



Middle Strip Flexural Reinforcement



Column Strip Flexural Reinforcement

Pan Joist Floor System

WAFFLE FLAT SLAB SYSTEM 19″ X 19″ Voids: 5″ Ribs @ 24″

f'_c = 4,000 psi
Grade 60 Bars

SQUARE EDGE PANELS

Total Depth = 11 in. Rib Depth = 8 in. Total Slab Depth = 3 in.

Span c.-c. Columns $\ell_1 = \ell_2$ (ft)	Factored Super-imposed Load (psf)	(1) Steel (psf)	Square Edge Column: $c_1 = c_2$ (in.)	Square Edge Column: γ_f	Square Edge Column: (2) Stirrups	Column Strip: Top Edge No.-size +	Column Strip: Bottom No. Ribs	Column Strip: Bottom Bars per Rib	Column Strip: Top Interior No.-size	Middle Strip: Bottom No. Ribs	Middle Strip: Bottom Long Bars	Middle Strip: Bottom Short Bars	Middle Strip: Top Interior No.-size	Moments: −M Edge (ft-k)	Moments: +M Bot. (ft-k)	Moments: −M Int. (ft-k)
24'- 0" D= 8.417 RIB ON COLUMN LINE 0.571 CF/SF	50	2.26	12	0.855		18-#5+ 0	5	2-#4	18-#5	7	#4	#4	7-#5	67	135	181
	100	2.39	12 *	0.889		18-#5+ 0	5	2-#5	18-#5	7	#4	#4	7-#5	88	182	237
	150	2.54	12 *	0.926		18-#5+ 1	5	1-#5 and 1-#6	18-#5	7	#4	#4	7-#5	109	251	292
	200	2.96	13 *	0.629		18-#5+ 0	5	1-#6 and 1-#7	21-#5	7	#4	#5	7-#5	129	315	347
	300	3.73	18 *	0.623	3 S 4 1	18-#5+ 0	5	1-#7 and 1-#8	19-#6	7	#5	#5	9-#5	166	417	446
26'- 0" D=10.417 RIB NOT ON COLUMN LINE 0.585 CF/SF	50	2.32	13	0.863		19-#5+ 0	6	1-#4 and 1-#5	19-#5	7	#4	#4	8-#5	86	173	233
	100	2.40	13 *	0.911		19-#5+ 2	6	2-#5	19-#5	7	#4	#4	8-#5	113	227	303
	150	2.85	14 *	0.936		19-#5+ 4	6	2-#6	22-#5	7	#4	#5	8-#5	138	315	373
	200	3.31	17 *	0.624		19-#5+ 2	6	1-#6 and 1-#7	26-#5	7	#5	#5	8-#5	163	393	439
28'- 0" D=10.417 RIB NOT ON COLUMN LINE 0.577 CF/SF	50	2.39	14 *	0.881		21-#5+ 1	6	2-#5	21-#5	8	#4	#4	8-#5	107	215	289
	100	2.55	14 *	0.931		21-#5+ 4	6	1-#5 and 1-#6	22-#5	8	#4	#4	8-#5	140	280	377
	150	3.14	17 *	0.624		21-#5+ 0	6	1-#6 and 1-#7	20-#6	8	#4	#5	9-#5	171	378	461
	200	3.45	23 *	0.619		21-#5+ 2	6	2-#7	23-#6	8	#4	#5	10-#5	198	414	533
30'- 0" D=10.417 RIB NOT ON COLUMN LINE 0.571 CF/SF	50	2.50	15 *	0.893		22-#5+ 2	6	1-#5 and 1-#6	22-#5	9	#4	#4	9-#5	132	263	354
	100	2.77	16 *	0.934		22-#5+ 6	6	2-#6	28-#5	9	#4	#4	9-#5	171	343	461
	150	3.37	23 *	0.619		22-#5+ 1	6	2-#7	24-#6	9	#4	#5	11-#5	207	417	556

SQUARE INTERIOR PANELS

Total Depth = 11 in. Rib Depth = 8 in. Total Slab Depth = 3 in.

Span c.-c. Columns $\ell_1 = \ell_2$ (ft)	Factored Super-imposed Load (psf)	(1) Steel (psf)	Square Interior Column: $c_1 = c_2$ (in.)	Square Interior Column: (2) Stirrups	Column Strip: Bottom No. Ribs	Column Strip: Bottom Bars per Rib	Column Strip: Top Interior No.-size	Middle Strip: Bottom No. Ribs	Middle Strip: Bottom Long Bars	Middle Strip: Bottom Short Bars	Middle Strip: Top Interior No.-size
24'- 0" D= 8.417 RIB ON COLUMN LINE 0.571 CF/SF	50	2.23	12		5	2-#4	18-#5	7	#4	#4	7-#5
	100	2.23	12		5	2-#4	18-#5	7	#4	#4	7-#5
	150	2.35	12 *	3 S 4 1	5	1-#4 and 1-#5	18-#5	7	#4	#4	7-#5
	200	2.53	12 *	3 S 4 1	5	2-#5	19-#5	7	#4	#4	7-#5
	300	3.21	14 *	3 S 4 2	5	2-#6	18-#6	7	#4	#4	8-#5
26'- 0" D=10.417 RIB NOT ON COLUMN LINE 0.585 CF/SF	50	2.23	13		6	2-#4	19-#5	7	#4	#4	8-#5
	100	2.23	13		6	2-#4	19-#5	7	#4	#4	8-#5
	150	2.52	13 *	3 S 4 1	6	2-#5	20-#5	7	#4	#4	8-#5
	200	2.94	13 *	3 S 4 1	6	1-#5 and 1-#6	18-#6	7	#4	#4	8-#5
28'- 0" D=10.417 RIB NOT ON COLUMN LINE 0.577 CF/SF	50	2.23	14		6	2-#4	21-#5	8	#4	#4	8-#5
	100	2.35	14 *	3 S 4 1	6	1-#4 and 1-#5	21-#5	8	#4	#4	8-#5
	150	2.81	14 *	3 S 4 1	6	1-#5 and 1-#6	26-#5	8	#4	#4	8-#5
	200	3.13	17 *	3 S 4 2	6	1-#5 and 1-#6	22-#6	8	#4	#4	10-#5
30'- 0" D=10.417 RIB NOT ON COLUMN LINE 0.571 CF/SF	50	2.33	15		6	1-#4 and 1-#5	22-#5	9	#4	#4	9-#5
	100	2.60	15 *	3 S 4 1	6	2-#5	26-#5	9	#4	#4	9-#5
	150	3.06	16 *	3 S 4 2	6	1-#5 and 1-#6	23-#6	9	#4	#4	10-#5

See the notes on Page 11-19.

Table 11-3 Waffle Flat Slabs (19″ x 19″ Voids at 2′-0″)—Equivalent Thickness and Maximum Load Based on $L/360$ Deflection

Rib+ Slab Depths (in.)	Equiv. Thickness t_e* (in.)	Max. Span in Tables (ft)	Maximum Span Limited by $L/360$ Deflection for Load Shown Below						
			L/t_e=30	L/t_e=31	L/t_e=32	L/t_e=33	L/t_e=34	L/t_e=35	L/t_e=36
8 + 3	8.89	30	22′-3″	23′-0″	23′-8″	24′-5″	25′-2″	25′-11″	26′-8″
8 + 4½	10.11	34	25′-3″	26′-1″	27′-0″	27′-10″	28′-8″	29′-6″	30′-4″
10 + 3	10.51	36	26′-3″	27′-2″	28′-0″	28′-11″	29′-9″	30′-8″	31′-6″
10 + 4½	11.75	38	29′-5″	30′-4″	31′-4″	32′-4″	33′-4″	34′-3″	35′-3″
12 + 3	12.12	38	30′-4″	31′-4″	32′-4″	33′-4″	34′-4″	35′-4″	36′-4″
12 + 4½	13.38	38	33′-5″	34′-7″	35′-8″	36′-10″	37′-11″	39′-0″	40′-2″
14 + 3	13.72	38	34′-4″	35′-5″	36′-7″	37′-9″	38′-10″	40′-0″	41′-2″
14 + 4½	15.02	38	37′-7″	38′-10″	40′-1″	41′-4″	42′-7″	43′-10″	45′-1″
16 + 3	15.31	38	38′-3″	39′-7″	40′-10″	42′-1″	43′-5″	44′-8″	45′-11″
16 + 4½	16.64	38	41′-7″	43′-0″	44′-4″	45′-9″	47′-2″	48′-6″	49′-11″
Maximum Load (psf) for Immediate (Elastic) Deflection of $L/360$**			504	457	416	379	346	318	292

* Based on gross moment of inertia.

** For long-term (creep) deflection limited to $L/360$, multiply the long-term loads, including the waffle slab weight, times 2; deduct from loads shown above. Result is maximum superimposed service live load.

Long Term Deflection

To change $\frac{L}{360}$ to $\frac{L}{480}$ multiply loads by $\frac{3}{4}$

$318psf \cdot \frac{3}{4} = 238psf$

For Long-Term Deflection

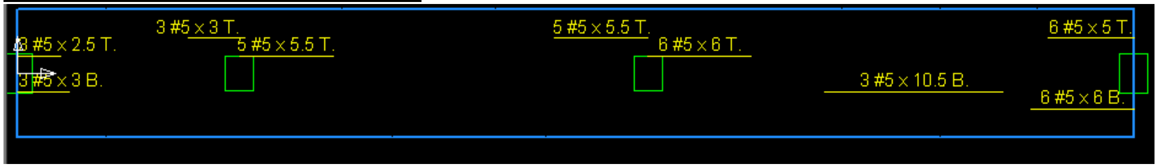
Dead Load = $71psf + 30psf = 101psf$
Slab + Super

$238psf - 2(101psf) = 36psf \approx 40psf$

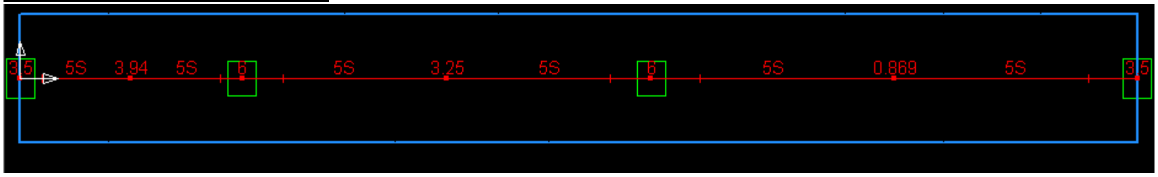
25′-11″ is max span for L/480 long-term deflection

Post-Tensioned Concrete Slab

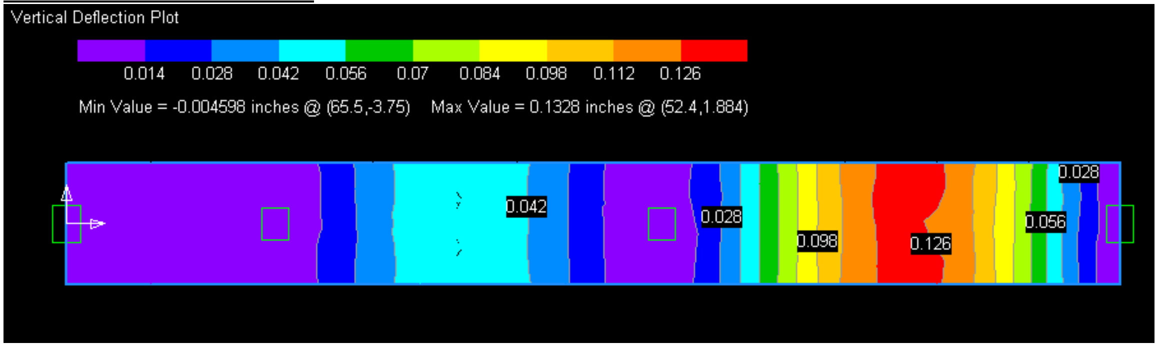
X-Direction Reinforcement Plan



X-Direction Tendon Plan



X-Direction Deflections

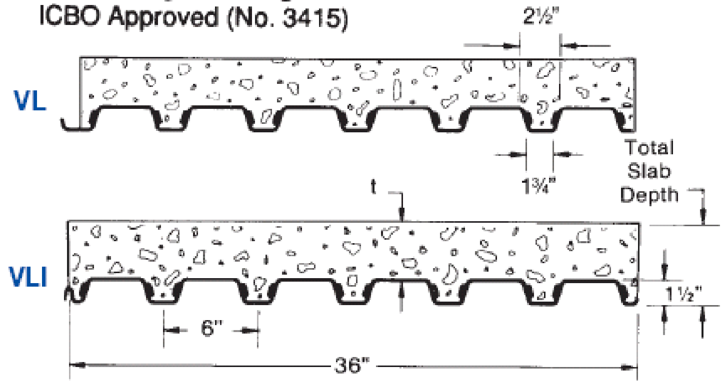


Composite Beams with Metal Deck Design

VULCRAFT

1.5 VL, VLI

Maximum Sheet Length 42'-0
Extra Charge for Lengths Under 6'-0
ICBO Approved (No. 3415)



STEEL SECTION PROPERTIES Fy= 40 KSI

Deck Type	Design Thick.	Weight PSF	Ip in4/Ft	In in4/Ft	Sp in3/Ft	Sn in3/Ft
1.5VL22	0.0295	1.78	0.150	0.182	0.178	0.186
1.5VL21	0.0329	1.97	0.174	0.205	0.209	0.215
1.5VL20	0.0358	2.14	0.195	0.222	0.231	0.240
1.5VL19	0.0418	2.49	0.239	0.260	0.274	0.288
1.5VL18	0.0474	2.82	0.282	0.295	0.315	0.327
1.5VL17	0.0538	3.19	0.331	0.335	0.361	0.371
1.5VL16	0.0598	3.54	0.373	0.373	0.404	0.411

(N=9) NORMAL WEIGHT CONCRETE (145 PCF)

Total Slab Depth	Deck Type	SDI Max. Unshored Clear Span			Superimposed Live Load, PSF Clear Span (ft.-in.)														
		1 Span	2 Span	3 Span	5'-0	5'-6	6'-0	6'-6	7'-0	7'-6	8'-0	8'-6	9'-0	9'-6	10'-0	10'-6	11'-0	11'-6	12'-0
	1.5VL22	5'-2	6'-11	7'-0	314	259	230	206	186	169	154	141	130	120	111	100	87	76	67
3 1/2"	1.5VL21	5'-9	7'-8	7'-9	331	294	243	218	197	179	163	150	138	127	118	104	91	80	70
	1.5VL20	6'-2	8'-3	8'-4	345	306	275	228	206	187	171	157	144	133	124	108	94	82	73
(t=2")	1.5VL19	6'-10	9'-2	9'-4	372	330	296	268	223	203	186	171	157	145	134	116	101	88	78
	1.5VL18	7'-6	9'-11	10'-2	395	351	315	285	260	238	199	182	168	156	142	123	107	94	82
33 PSF	1.5VL17	8'-2	10'-6	10'-10	397	353	316	286	261	239	221	183	169	157	145	131	114	99	87
	1.5VL16	8'-8	11'-0	11'-5	397	353	316	286	261	239	221	205	169	156	145	135	119	105	92
	1.5VL22	4'-11	6'-6	6'-7	342	301	267	240	216	196	179	164	151	139	129	119	111	103	96
4"	1.5VL21	5'-5	7'-3	7'-4	385	318	283	253	229	208	190	174	160	148	137	127	118	110	102
	1.5VL20	5'-10	7'-9	7'-11	400	356	295	264	239	217	198	182	167	155	143	133	124	116	108
(t=2 1/2")	1.5VL19	6'-6	8'-8	8'-10	400	383	344	311	259	235	215	197	182	168	156	145	135	126	115

ITE

Composite Beam Design

Spacing:	10	ft	f'c:	6000	ksi
Span:	28.75	ft	Sigma Qn:	324	kip
Live Load:	40	psf	beff:	7.19	ft
Super:	30	psf	a:	0.74	in.
Dead:	33	psf	Slab Thickness:	3.5	in.
Factored Load:	139.60	psf	Y2:	**3.13**	in.
Construction Live Load:	40	psf			

Max Moment:	**144.24**	ft-kip	
Live Load Deflection <	0.96	in.	L/360
Dead Load Deflection <	1.44	in.	L/240
Composite Moment of Inertia >	**379.81**	in.^4	
Construction Moment:	**107.04**	ft-kip	
Construction Deflection <	1.44	in	L/240
Moment of Inertia >	**269.19**	in^4	

W12x22

Construction Moment Capacity:	110	ft-kip	
Construction Moment of Inertia:	156	in^4	**Must Camber Beam**
Composite Moment Capacity:	223	ft-kip	
Composite Moment of Inertia:	428	in^4	
Live Load Deflection:	0.50	in.	
Total Load Deflection:	1.28	in.	

Stud Requirement

Length:	172.5	in.	
Spacing:	6	in. o/c	
Qn:	12.0	kip	(Deck Perpendicular, 1 weak stud per rib, 5/8" diameter)
Sigma Qn:	345	kip	