303 Third St6reet

Cambridge, Massachusetts

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AE 481W – Thesis

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Technical Assignment 2

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The purpose of this report is to research possible alternatives to the steel composite floor system of 303 Third Street. This is an eight-story, 485,000 square foot building project currently under construction in Cambridge, MA. This $246 million building will contain primarily residential units with some retail space.

Existing System

The existing floor system is a 3-1/4” lightweight concrete slab on a 3” deep 16 gage metal composite deck and WWF 6x6 W2.1xW2.1 reinforcing. Supporting the slab are W12x16 composite beams which span 18’-1” N-S in a typical bay. The beams frame into composite girders on the interior which are typically W14x30 spanning E-W.

Alternative Systems:

When analyzing the alternative floor systems, criteria such as the overall weight of the system, vibration control, fire proofing, ease of construction and relative cost were considered. These alternative systems were then compared to the criteria performance of the existing floor system.

The following are the alternative floor systems considered:

1. Non-composite floor construction
2. Open web steel bar joists with thinner concrete deck.
3. 2-way flat slab with drop panels
4. Waffle slab

Conclusion:

The main factor taken into consideration in this report was to develop a system that will decrease the amount of lateral bracing elements needed. As designed, 303 Third Street requires exterior moment frames in addition to N-S concentrically braced frames with HSS shapes. Therefore the biggest factor considered was overall weight of each of the systems. Lowering the weight will decrease the seismic loads on the building, thus eliminating the need for the moment frames on the exterior of the building and turning it into a single lateral bracing system with concentrically braced frames. Reducing the cost of the building was also a major factor in comparing the systems. For this reason, I performed a cost per square foot analysis of the typical bay accounting for slab cost, members, and columns. This slimming down of the building weight does have its consequences however in the form of costs, less fire protection and vibration control. It is important to note that elimination of the exterior moment frames will result in the need to carefully investigate any torsional movements of the overall building framing. While this is out of the scope of this particular report, it will be investigated in more detail in Technical Report 3.

The 2-way flat slab and waffle slab systems are ideal for controlling vibration and perform well for fire ratings due to their large mass. However, it is because of their heavy weights that they are almost immediately eliminated as a good alternative compared to the existing system.

The steel bar joists on the other hand, have the advantage of being a less expensive (structural costs) and extremely light system. The downside to open web bar joists, especially with a thinner concrete slab is its vulnerability to vibration, which can be a major issue to ignore when designing an office environment, but not in a residential application such as 303 Third Street. Open web bar joists were found to be the best alternative floor system to eliminate weight, but still require adequate fire protection. In conclusion, the most viable system analyzed in this report is open web steel joists which I will evaluate more carefully in the future.

EXISTING STRUCTURAL SYSTEM

FOUNDATION:

The slab on grade concrete is normal weight (145 pcf dry unit weight) and has a minimum 28-day strength of 3500 psi. The 5” slab on grade is reinforced with 6x6 W2.9xW2.9 welded wire fabric. Column loads are supported by square spread footings (f’c = 4000 psi) ranging from 5’-6” to 14’-0”. The spread footing bear directly on the undisturbed, natural outwash sand, marine clay, or marine sand deposits proportioned utilizing a maximum bearing pressure of 2.5 tons per square-foot. The foundation also contains a few internal and external piers (f’c = 4000 psi) for supporting larger loads. The foundation bears on belled caissons with a typical depth of 20’. The caissons bear on 3 TSF bearing material. A groundwater cut-off at the perimeter is maintained as well as underdraining of the lowest level slab to avoid hydrostatic uplift forces acting on the lowest level slab. The continuous perimeter wall footings are founded at least 12 inches below the surface of the relatively impervious marine clay deposit to provide a groundwater cut-off. The surface of the bedrock deposit was observed to vary from 66.3 to 90 feet below the existing ground surface.

FLOOR SYSTEM:

The sublevel floor system P1 consists of a 4 ½” normal weight concrete (f’c = 5000 psi) slab on a 3” deep 18 gage composite metal floor deck reinforced with #5 rebar at 12”parallel to the deck and #4 rebar at 12” temp for a total slab thickness of 7 ½”. The slab is supported by steel beams with typical sizes ranging from W12 to W18. Wide flange beams typically span 25’ with 8’ spacing. Composite action is created by ¾” diameter shear studs with 5½” length. Girders are also wide flanges sized up to W24 with cambers over 1”. The typical floor system throughout the rest of the building is 3 ¼” light weight concrete slab on a 3” deep 16 gage composite metal floor deck reinforced with 6x6 W2.1xW2.1 welded wire fabric. This slab is supported by steel beams with typical sizes ranging from W12 to W14. Wide flange beams typically span 18-26’ with 12’-6” spacing.

COLUMNS:

The columns are ASTM A992 Grade 50 wide flange steel shapes laid out in a mostly rectangular grid. The columns act as the primary gravity resistance members. The columns that are attached as braced and moment frames are also the main lateral resistant force members. The braces between columns are ASTM A 500 Grade B HSS shapes ranging in size from 7x5x1/2” to 9x7x5/8”. The largest column is a W14x159 and the smallest is a W12x53 on the ground floor.

The maximum unbraced length is 15’ which is the floor to floor height of the ground floor. Column splices occur every 20’ – 25’ at 4’-0” above the floor.

LATERAL FRAMING:

There is a dual lateral system implemented consisting of concentrically braced steel frames in both the N-S and E-W directions and moment frames in the E-W direction. These frames consist of wide flange columns, wide flange beams at each story and two HSS (hollow structural section) diagonal braces between each story and may include moment connections depending on the frame type.

CODES

DESIGN CODES:

Building Code:

Massachusetts State Building Code – 6^{th} Edition

Reinforced Concrete:

American Concrete Institute (ACI) 318 – 1995 Edition

Reinforced Masonry:

American Concrete Institute (ACI) 530 – 2005 Edition

Structural Steel:

American Institute of Steel Construction (AISC)
Load and Resistance Factor Design Specification for Structural Steel Buildings – Latest Edition

Metal Decking:

American Iron and Steel Institute (AISI)
Specification for the Design of Cold Formed Structural Members

Building Design Loads:

Massachusetts State Building Code – 6^{th} Edition

THESIS SUBSTITUTED CODES:

American Society of Civil Engineering (ASCE)
Minimum Design Loads for Buildings and Other Structures – ASCE 7-05

American Institute of Steel Construction (AISC)

Steel Construction Manual – 13^{th} Edition – 2005

The International Building Code – 2006

LOADS

DEAD LOADS:

Metal Deck + Light Weight Concrete	30 PSF Vulcraft Catalog
Steel Beams	AISC Values

Superimposed Dead Loads:

Mechanical, Electrical, Sprinkler	20 PSF
Ceiling Finishes	5 PSF
Floor Finishes	5 PSF

LIVE LOADS:	**Design Value**	**ASCE 7 Ch 4**
Floor Live Loads:		
Corridors above 1st floor	80 PSF	100 PSF
First floor lobbies, public areas and corridors	100 PSF	100 PSF
Assembly rooms	100 PSF	100 PSF
Residential	40 PSF + Partition	40 PSF
Retail	100 PSF	100 PSF
Exercise room	100 PSF	100 PSF
Slab on grade	100 PSF	N/A
Storage (light)	125 PSF	125 PSF
Loading dock slab on deck	250 PSF	250 PSF
Framed exterior at ground	100 PSF + Soil	N/A
Fire pump room	150 PSF	N/A
Stairs	100 PSF	100 PSF
Mechanical areas	150 PSF	N/A
Elevator machine room	150 PSF	N/A
Transformer vault	250 PSF	N/A
Parking levels and ramps	50 PSF	40 PSF
Roof Live Loads:		
Roof Live Loads		20 PSF min
Basic Uniform Snow Load (Pf)	30 PSF	

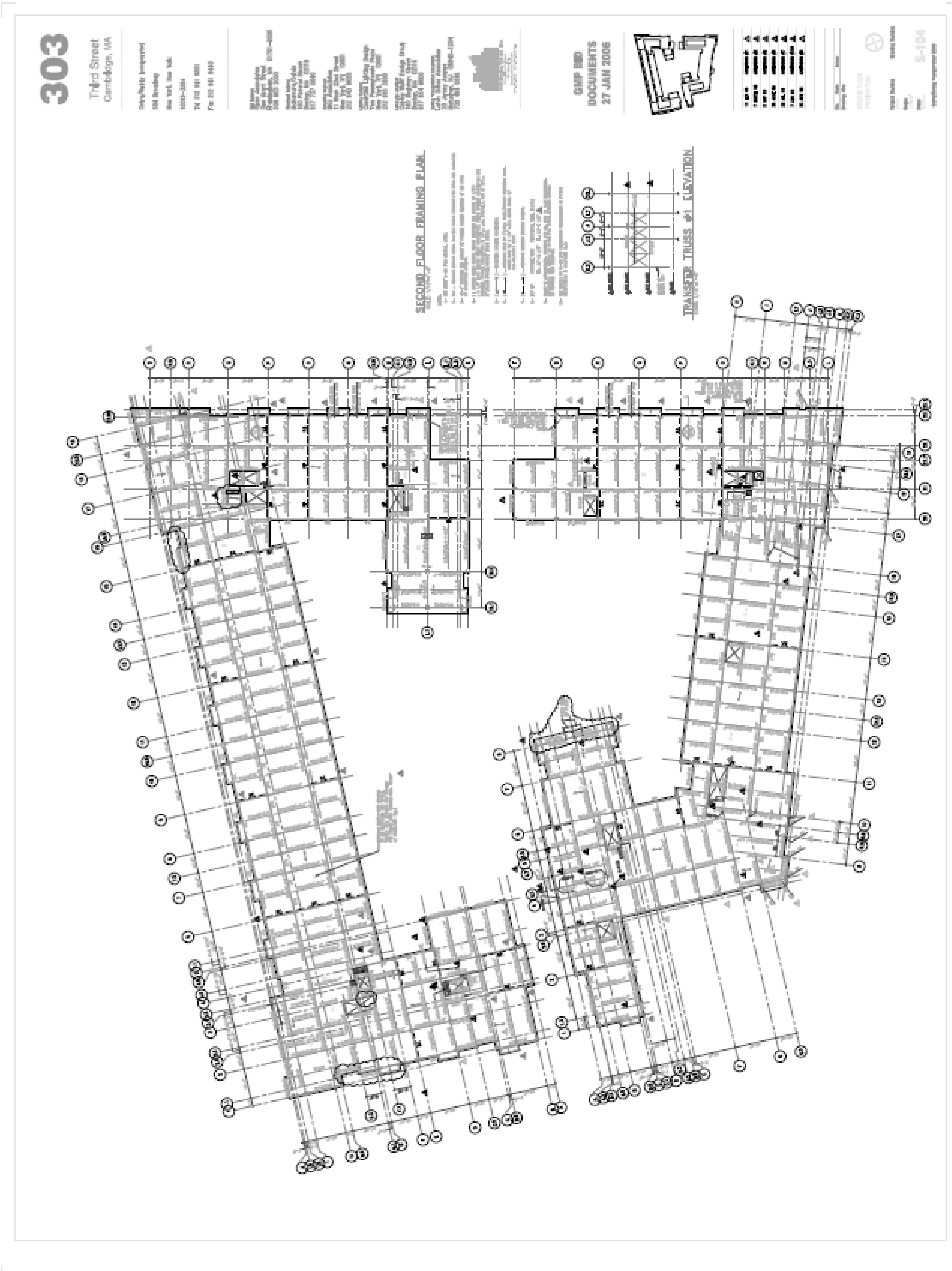

Figure 1: Existing Typical Framing Plan

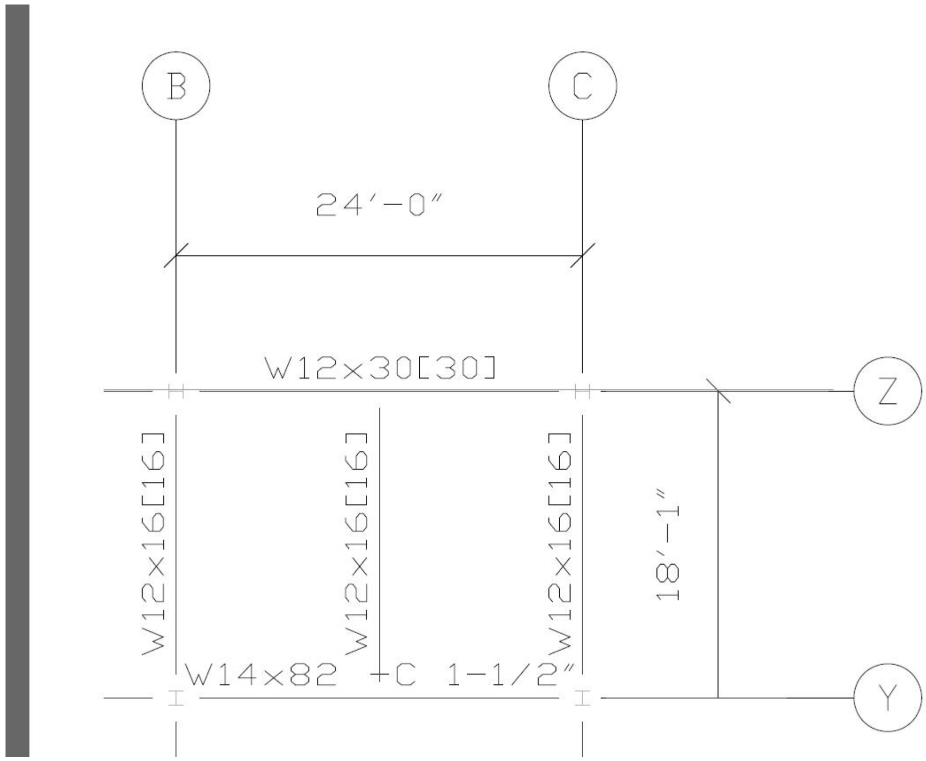

Figure 2: Composite Floor for Typical Bay

Alternative System 1: Non-Composite Floor System

Using RAM Structural System for the typical bay (see Figure 2), I designed a non-composite floor system for the typical bay. The result was predictable, shorter beam spans resulting in more mass and lower deflection values. The disadvantage to this system is that it is more costly due to the extra steel members in raw costs as well as in cost of construction for additional steel connections. Compared to the existing framing plan, the interior girder is slightly larger (W14x30 to W18x40) however the N-S spanning members are increased in number from 3 to 5 while remaining the same size (W12x16). The addition of more members will decrease deflection of the floor and reduce vibration; however it is a much more costly system than the composite system in place. The estimated cost per square foot of the typical bay using the RS Means 2008 catalog is $24.60 per square foot (see Appendix for cost calculation). With the current lead time for steel being a driving factor in construction scheduling and the reasons stated above, I do not believe a non-composite floor system would be a good solution for this building.

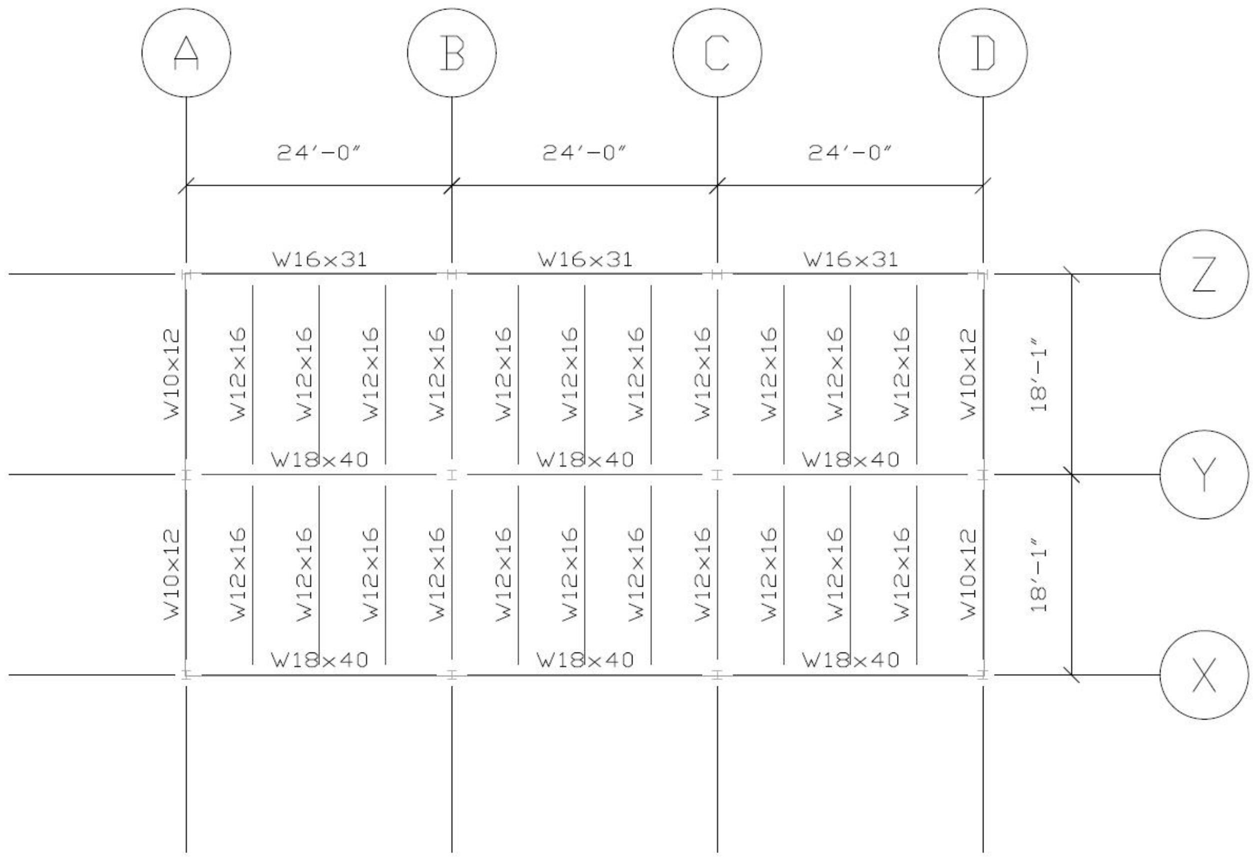

Figure 3: Composite Floor Design of Typical Bay

Alternative System 2: Open Web Steel Joists

From hand calculation, I determined 8 open web steel joists spaced at 24" on center spanning the E-W in the 24' dimension of the typical bay would be the best design. Using the Vulcraft Joist Catalog with my floor loads, I determined the most appropriate K-Series joist to be a 14K4 joist which weighs 6.7 pounds per linear foot of joist. After performing a deflection check on the bay, I determined deflection would not be an issue for this system. From the Vulcraft Deck Catalog, I selected a Type C 9/16" 24 Gage Galvanized form deck with non-composite action with a 3.25" lightweight concrete slab. The resulting load was slightly less than the original design, but not enough to significantly impact the original beams and column sizes. The primary concerns with using an open web steel joist system in any building relate to fireproofing and vibration. Since 303 Third Street is primarily a residential occupancy, I do not believe vibration will be as much of an issue as, say, an office building where there is constant movement. To maintain a 2 hour fire rating on the bar joists, often chicken wire is wrapped around them prior to spraying cementitious fireproofing. The estimated cost per square foot of the typical bay using the RS Means 2008 catalog is $22.54 per square foot (see Appendix for cost calculation).

After this analysis, I believe open web steel joists to be an appropriate floor system for 303 Third Street. Existing bay sizes for the building are such that span length is not an issue. The bar joists also allow for more mechanical space between floors. Joists will also reduce the mass of the building, thus decreasing the seismic loads. Fireproofing of the joists is an issue that would need to be addressed prior to selecting this as the most viable floor system.

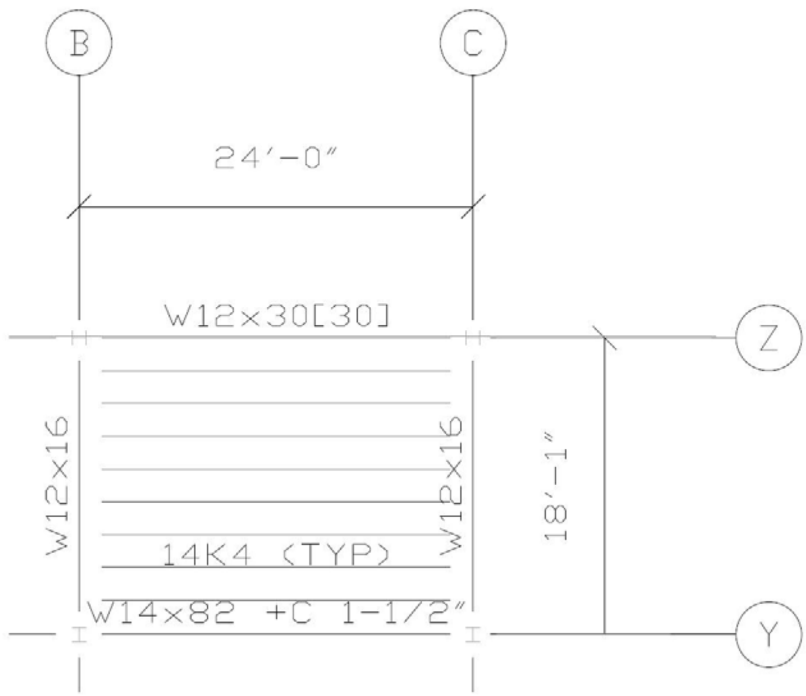

Figure 4: Open Web Steel Joist Typical Bay

Alternative System 3: Waffle Slab

The third alternative floor system to evaluate is the waffle slab. While waffle slabs are typically not chosen for residential occupancies, they are very durable, have excellent fire ratings, do not have vibration issues, and are suitable for the spans of the typical bay for this project. When designing with concrete, typically square bays are optimal. As the typical bay for 303 Third St is 18'-1" x 24' a new column grid would need to be designed, which would throw off the organization of residential units and corridor space. The new column grid would likely interrupt corridors and other open spaces as the architectural plans are laid out.

Using the CRSI Handbook, 30"x30" voids were chosen over 19"x19" because they provided the necessary capacity and use a little less material. The capacity needed was 170 psf superimposed, using the 1.4D+1.7L combination on which the table is based. The smallest system in the table capable of supporting this load at a 24' span has a 4 ½" slab and 6" ribs. See Appendix for reinforcement. Since the table values are to limit deflections in a square bay, the reinforcement and concrete will probably be a little conservative. Also, the slab will need to be changed to 5" in order to achieve the desired 2-hour fire rating. The estimated cost per square foot of the typical bay using the RS Means 2008 catalog is $30.46. per square foot (see Appendix for cost calculation).

Another major drawback to this system is the weight. Obviously, a concrete waffle slab system will increase the weight of the system drastically from the original composite design. This will cause increased seismic loads, and since the foundation quality of the soils in urban Cambridge, MA are suspect at best (Site Class E), the substitution of a massive waffle slab system will likely cause headaches for the foundation design as well as in the design of the lateral bracing system.

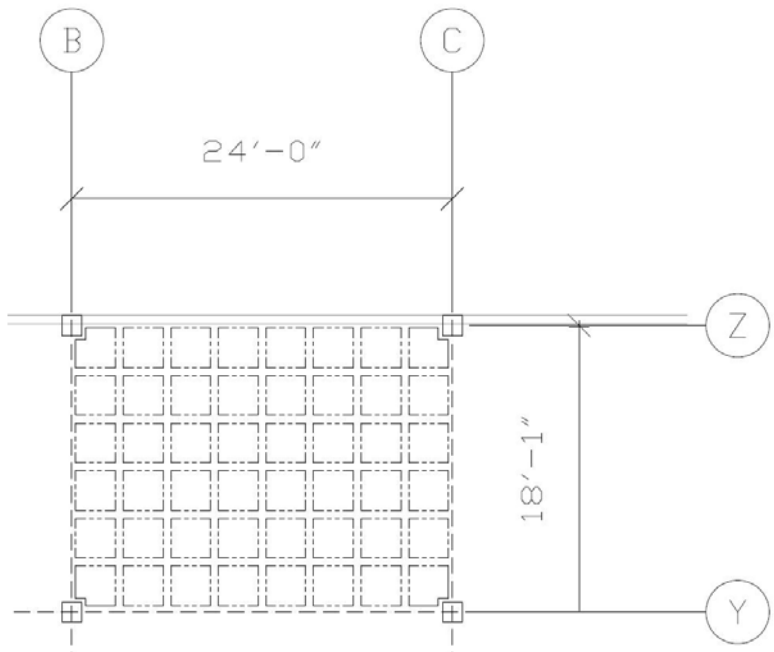

Figure 5: Waffle Slab for Typical Bay

Alternative System 4: 2-Way Flat Slab with Drop Panels

The fourth alternative floor system to evaluate is the two way flat slab with drop panels. Two way flat slabs are very durable, have excellent fire ratings, do not have vibration issues, and are suitable for the spans of the typical bay for this project. As stated before, when designing with concrete, typically square bays are optimal. As the typical bay for 303 Third St is 18'-1" x 24' a new column grid would need to be designed, which would throw off the organization of residential units and corridor space. The new column grid would likely interrupt corridors and other open spaces as the architectural plans are laid out.

Using the CRSI Handbook, h=8.5” total slab depth between panels was chosen with 8’ square drop panels. The capacity needed was 170 psf superimposed, using the 1.4D+1.7L combination on which the table is based. The smallest system in the table capable of supporting this load at a 24’ span has a drop panels 8’ square with a depth of 7”. See Appendix for reinforcement. Since the table values are to limit deflections in a square bay, the reinforcement and concrete will probably be a little conservative. Also, the slab thickness (8.5”) is sufficient for fire rating. The estimated cost per square foot of the typical bay using the RS Means 2008 catalog is $31.36 per square foot (see Appendix for cost calculation).

Another major drawback to this system is the weight. Obviously, a concrete system will increase the weight of the system drastically from the original composite design. This will cause increased seismic loads, and since the foundation quality of the soils in urban Cambridge, MA is suspect at best (Site Class E), the substitution of a two way flat slab system is not likely.

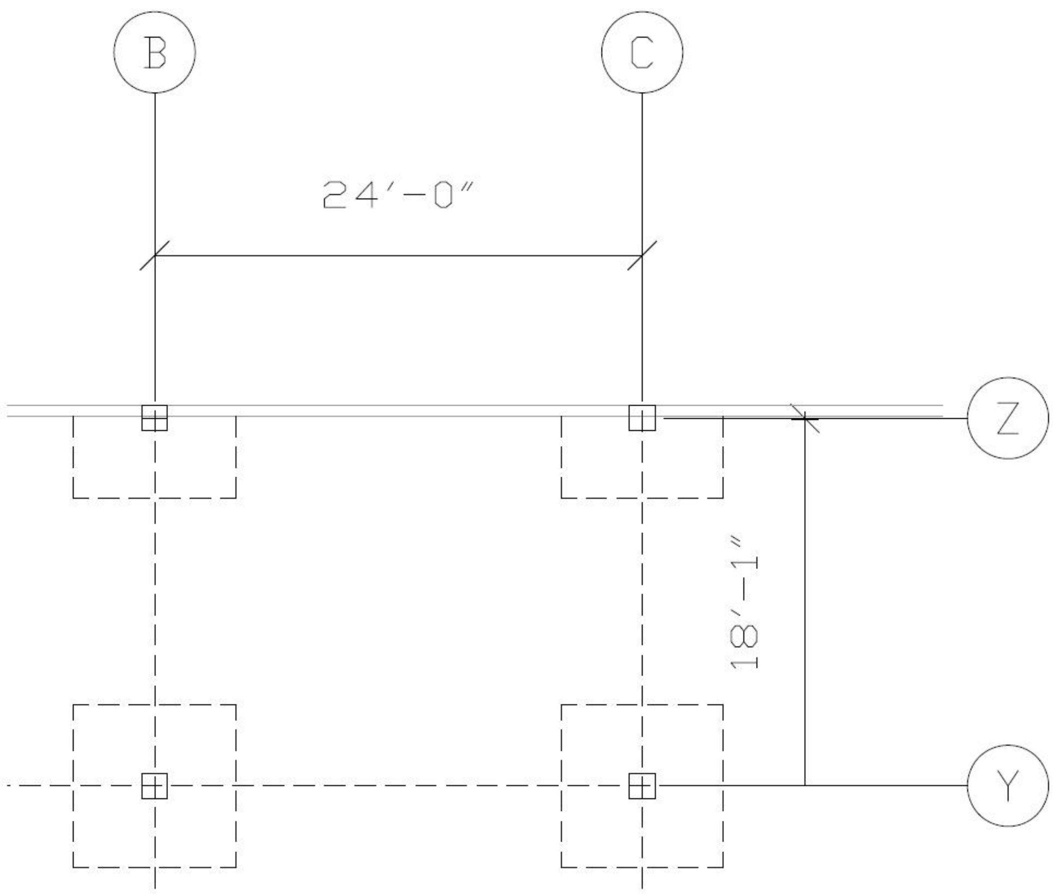

Figure 6: 2-Way Flat Slab for Typical Bay

Summary and Conclusions

ALTERNATIVE SYSTEM COMPARISON:

The results of the alternative floor system analysis and preliminary design for 303 Third Street are shown in the comparison chart that follows (Figure 7).

Criteria	Composite	Non-Composite	Steel Joist	Waffle Slab	2-Way Flat Slab
Cost/SF	$27.25	$24.60	$22.54	$30.46	$31.36
Fireproofing	Spray On	Spray On	Special Detail	None Extra Reqd	None Extra Reqd
Constructability	Medium	Medium	Easy	Labor Intensive	Relatively Easy
Deflection Issues	None	None	None	None	None
Vibration Resistance	Average	Average	Below Average	Above Average	Above Average
Slab Width	6.25"	6.25"	6.25"	5"	8.5"
Total Depth	20.25"	20.25"	20.25"	12.5"	15.5" (Incl Drops)
Weight relative to Orig Design	As Designed	Slightly Heavier	Slightly Lighter	Heavier	Much Heavier
Durability Issues	Steel Fatigue	Steel Fatigue	Steel Fatigue	Concrete Spalling	Concrete Spalling
Column Grid Changes	No	No	No	Yes	Yes
Lateral System Effects	No	No	Minor	Yes	Yes
Viable Solution?	Yes	Yes	Yes	No	No

Figure 7: Alternative System Comparison Chart

CONCLUSION:

All four systems analyzed in this report would in fact work for 303 Third Street given the right circumstances and requirements. The main criterion which resulted in the largest effect was the weight of each system. Given the condition of the soil in Cambridge, MA, reducing seismic shear by decreasing weight could reduce the overall cost of the building by decreasing the amount of lateral bracing necessary. The existing system of composite W shapes, and concrete on composite metal deck already requires the use of moment frames on the exterior of the building in conjunction with braced frames in the N-S direction with HSS bracing elements system. Thus, any system that produces substantially higher dead weights was immediately recognized as at a disadvantage and quickly eliminated from the list of viable alternatives.

The 2-way flat slab does have the advantage of thinner floors and ease of constructability with no need for additional fire protection. However the addition of columns to create larger, square bays creates the need for retrofitting the foundation as well as reorganizing the architectural layout of the spaces. This in addition to the heavy weight of the 2-way flat slab eliminates it as an option.

The waffle slab also has the advantage of thinner floors, no additional fireproofing, and great durability. However, like the 2-way flat slab, the column grid would need to be altered to create square bays, which causes issues with the spacial arrangement of the building and the foundation plan already designed. The increased weight of the concrete system would also be of special concern. Waffle slabs are also labor intensive as they require special forms and shoring. For these reasons, the waffle slab was eliminated as a viable option.

The non-composite floor system performs similarly to the designed composite floor, however, more structural steel members of smaller size are needed to decrease spans. I do not believe the relatively small cost savings over the composite sytem ($27.25 vs $24.60) justifies the extra connections that would be necessary in connecting 3 extra steel members per bay.

One alternative system that is extremely light is the open web joist system. The substantial decrease in dead weight of the system makes the open web joists ideal for the goal of decreasing lateral bracing. One of the main reasons open web steel joists are often eliminated is due to the susceptibility of vibration in such a system. Since 303 Third Street is primarily residential units, I do not believe vibration to of serious concern as it would be in an office building. Along with resistance to vibration is the disadvantage of fireproofing. Spray on fireproofing for open web joists is not only costly but difficult to do. Given the bay dimensions as designed, the short spans allow for a 14” deep K-Series joist, which does not cause any issues in the interstitial space between floors for mechanical equipment, as 14” deep members were used in the existing composite design. Open web steel joists certainly have potential for a more in depth investigation as a viable candidate floor system.

APPENDIX

WAFFLE FLAT SLAB SYSTEM 30″ X 30″ Voids: 6″ Ribs @ 36″

f'_c = 4,000 psi
Grade 60 Bars

SQUARE EDGE PANELS

Total Depth = 12½ in. Rib Depth = 8 in. Total Slab Depth = 4½ 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.)	γ_f	(2) Stirrups	Reinforcing Bars—Each Direction: 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)	+M Bot. (ft-k)	−M Int. (ft-k)
18'- 0" D= 6.500 RIB ON COLUMN LINE 0.648 CF/SF	50	1.86	12	0.688		13-#5+ 0	3	2-#4	13-#5	3	#4	#4	5-#5	30	60	81
	100	1.86	12	0.713		13-#5+ 0	3	2-#4	13-#5	3	#4	#4	5-#5	39	78	104
	150	1.92	12	0.737		13-#5+ 0	3	1-#4 and 1-#5	13-#5	3	#4	#4	5-#5	47	107	127
	200	1.98	12	0.761		13-#5+ 0	3	2-#5	13-#5	3	#4	#4	5-#5	56	134	150
	300	2.34	12	0.809		13-#5+ 0	3	2-#6	13-#5	3	#5	#5	5-#5	72	187	195
	400	2.61	12	0.858		13-#5+ 0	3	1-#6 and 1-#7	13-#5	3	#5	#6	5-#5	89	239	241
	500	3.02	12 *	0.633	3 S 4 1	13-#5+ 0	3	1-#7 and 1-#8	14-#5	3	#6	#6	5-#5	106	289	286
21'- 0" D= 9.500 RIB NOT ON COLUMN LINE 0.680 CF/SF	50	1.84	12	0.759		15-#5+ 0	4	2-#4	15-#5	3	#4	#4	6-#5	50	99	134
	100	1.84	12	0.787		15-#5+ 0	4	2-#4	15-#5	3	#4	#4	6-#5	63	129	171
	150	2.01	12	0.816		15-#5+ 0	4	2-#5	15-#5	3	#4	#5	6-#5	77	177	207
	200	2.23	12	0.844		15-#5+ 0	4	1-#5 and 1-#6	15-#5	3	#5	#5	6-#5	91	221	244
	300	2.70	12 *	0.906		15-#5+ 1	4	1-#6 and 1-#7	16-#5	3	#6	#6	6-#5	118	306	318
	400	3.30	12 *	0.633		15-#5+ 0	4	1-#7 and 1-#8	14-#6	3	#7	#7	7-#5	145	389	391
	500	3.81	15 *	0.629		15-#5+ 1	4	2-#8	23-#5	3	#7	#8	8-#5	170	460	457
24'- 0" D= 9.500 RIB NOT ON COLUMN LINE 0.661 CF/SF	50	1.92	12	0.823		18-#5+ 0	4	1-#4 and 1-#5	18-#5	4	#4	#4	7-#5	74	149	200
	100	1.98	12	0.854		18-#5+ 0	4	2-#5	18-#5	4	#4	#4	7-#5	95	193	256
	150	2.32	12 *	0.885		18-#5+ 0	4	2-#6	18-#5	4	#5	#5	7-#5	116	264	311
	200	2.64	12 *	0.921		18-#5+ 1	4	2-#7	18-#5	4	#5	#6	7-#5	136	330	367
	300	3.44	14 *	0.630		18-#5+ 0	4	2-#8	17-#6	4	#6	#7	8-#5	176	456	474
	400	4.19	18 *	0.626		18-#5+ 2	4	2-#9	16-#7	4	#7	#7	7-#6	212	546	569
27'- 0" D= 9.500 RIB NOT ON COLUMN LINE 0.648 CF/SF	50	2.06	13	0.847		20-#5+ 0	4	1-#5 and 1-#6	20-#5	5	#4	#4	8-#5	105	211	284
	100	2.22	13 *	0.889		20-#5+ 1	4	2-#6	20-#5	5	#4	#5	8-#5	135	270	363
	150	2.65	13 *	0.931		20-#5+ 3	4	2-#7	23-#5	5	#5	#5	8-#5	164	368	442
	200	3.26	15 *	0.629		20-#5+ 0	4	2-#8	19-#6	5	#6	#6	9-#5	192	458	518
	300	4.10	20 *	0.624		20-#5+ 1	4	2-#9	18-#7	5	#6	#7	8-#6	244	590	658
30'- 0" D=12.500 RIB ON COLUMN LINE 0.670 CF/SF	50	2.12	15 *	0.861		22-#5+ 1	5	1-#5 and 1-#6	22-#5	5	#4	#5	9-#5	146	292	393
	100	2.53	15 *	0.917		22-#5+ 5	5	1-#6 and 1-#7	25-#5	5	#5	#5	9-#5	186	372	501
	150	3.19	17 *	0.933		22-#5+ 8	5	1-#7 and 1-#8	22-#6	5	#6	#6	10-#5	225	484	606
	200	3.88	20 *	0.624		22-#5+ 4	5	1-#8 and 1-#9	20-#7	5	#6	#7	12-#5	263	604	708
33'- 0" D=12.500 RIB ON COLUMN LINE 0.658 CF/SF	50	2.45	16 *	0.900		25-#5+ 4	5	1-#6 and 1-#7	26-#5	6	#5	#5	10-#5	193	386	520
	100	2.99	17 *	0.937		25-#5+ 8	5	1-#7 and 1-#8	24-#6	6	#5	#6	11-#5	246	493	663
	150	3.71	23 *	0.622		25-#5+ 2	5	1-#8 and 1-#9	22-#7	6	#6	#6	10-#6	295	608	794

SQUARE INTERIOR PANELS

Total Depth = 12½ in. Rib Depth = 8 in. Total Slab Depth = 4½ 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.)	(2) Stirrups	Reinforcing Bars—Each Direction: 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
18'- 0"	50	1.84	12		3	2-#4	13-#5	3	#4	#4	5-#5
	100	1.84	12		3	2-#4	13-#5	3	#4	#4	5-#5
	150	1.84	12		3	2-#4	13-#5	3	#4	#4	5-#5
	200	1.84	12		3	2-#4	13-#5	3	#4	#4	5-#5
	300	2.05	12	3 S 4 1	3	2-#5	13-#5	3	#4	#4	5-#5
	400	2.28	12	3 S 4 1	3	1-#5 and 1-#6	13-#5	3	#4	#5	5-#5
	500	2.53	12 *	3 S 4 1	3	2-#6	13-#5	3	#5	#5	5-#5
21'- 0"	50	1.82	12		4	2-#4	15-#5	3	#4	#4	6-#5
	100	1.82	12		4	2-#4	15-#5	3	#4	#4	6-#5
	150	1.82	12		4	2-#4	15-#5	3	#4	#4	6-#5
	200	2.01	12		4	1-#4 and 1-#5	15-#5	3	#4	#5	6-#5
	300	2.35	12 *	3 S 4 1	4	1-#5 and 1-#6	15-#5	3	#5	#5	6-#5
	400	2.73	12 *	3 S 4 1	4	2-#6	18-#5	3	#5	#6	6-#5
	500	3.29	13 *	3 S 4 1	4	1-#6 and 1-#7	15-#6	3	#6	#6	7-#5
24'- 0"	50	1.86	12		4	2-#4	18-#5	4	#4	#4	7-#5
	100	1.86	12		4	2-#4	18-#5	4	#4	#4	7-#5
	150	2.05	12	3 S 4 1	4	2-#5	18-#5	4	#4	#4	7-#5
	200	2.25	12 *	3 S 4 1	4	1-#5 and 1-#6	18-#5	4	#4	#5	7-#5
	300	2.97	12 *	3 S 4 1	4	1-#6 and 1-#7	16-#6	4	#5	#6	7-#5
	400	3.64	15 *	3 S 4 1	4	2-#7	20-#6	4	#6	#6	9-#5
27'- 0"	50	1.94	13		4	1-#4 and 1-#5	20-#5	5	#4	#4	8-#5
	100	2.02	13	3 S 4 1	4	2-#5	20-#5	5	#4	#4	8-#5
	150	2.38	13 *	3 S 4 1	4	2-#6	21-#5	5	#4	#5	8-#5
	200	2.84	13 *	3 S 4 1	4	1-#6 and 1-#7	25-#5	5	#5	#5	8-#5
	300	3.74	16 *	3 S 4 2	4	1-#7 and 1-#8	23-#6	5	#5	#6	8-#6
30'- 0"	50	1.94	15		5	1-#4 and 1-#5	22-#5	5	#4	#4	9-#5
	100	2.28	15 *	3 S 4 1	5	1-#5 and 1-#6	23-#5	5	#4	#5	9-#5
	150	2.84	15 *	3 S 4 1	5	2-#6	21-#6	5	#5	#5	10-#5
	200	3.50	15 *	3 S 4 1	5	2-#7	25-#6	5	#5	#6	12-#5
33'- 0"	50	2.16	16	3 S 4 1	5	1-#5 and 1-#6	25-#5	6	#4	#4	10-#5
	100	2.65	16 *	3 S 4 1	5	2-#6	23-#6	6	#4	#5	10-#5
	150	3.36	16 *	3 S 4 1	5	2-#7	28-#6	6	#5	#5	13-#5

See the notes on Page 11-19.

$f'_c = 4,000$ psi
Grade 60 Bars

FLAT SLAB SYSTEM

SQUARE EDGE PANEL With Drop Panels
No Beams

SPAN c.-c. $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	Square Drop Panel Depth (in.)	Square Drop Panel Width (ft)	Square Column[(3)] Size (in.)	Square Column[(3)] γ_f	Reinforcing Bars (E. W.) Column Strip[(1)] Top Ext. +	Column Strip[(1)] Bottom	Column Strip[(1)] Top Int.	Middle Strip Bottom	Middle Strip Top Int.	Total Steel (psf)	Moments Edge (−) (ft-k)	Moments Bot. (+) (ft-k)	Moments Int. (−) (ft-k)
h = 8.5 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS														
22	100	4.00	7.33	12	0.676	11-#4 1	10-#5	11-#5	10-#4	11-#4	2.01	79.1	158.2	213.0
22	200	4.00	7.33	15	0.746	11-#4 4	10-#6	15-#5	9-#5	8-#5	2.57	107.1	214.2	288.4
22	300	5.50	7.33	17	0.638	12-#4 2	18-#5	25-#4	12-#5	10-#5	3.08	135.1	270.1	363.6
22	400	7.00	7.33	18	0.629	13-#4 2	9-#8	18-#5	14-#5	12-#5	3.70	163.8	327.7	441.1
22	500	8.50	8.80	20	0.629	14-#4 1	12-#8	14-#6	8-#8	10-#6	4.67	192.3	415.9	517.8
23	100	4.00	7.67	12	0.786	12-#4 4	18-#4	19-#4	12-#4	12-#4	2.13	90.8	181.5	244.4
23	200	5.50	7.67	15	0.697	12-#4 4	16-#5	15-#5	16-#4	9-#5	2.64	123.3	246.7	332.1
23	300	7.00	7.67	17	0.630	13-#4 3	11-#7	12-#6	10-#6	17-#4	3.40	155.6	311.2	418.9
23	400	7.00	9.20	19	0.738	15-#4 5	18-#6	20-#5	9-#7	10-#6	4.00	187.3	374.5	504.2
23	500	8.50	9.20	20	0.658	16-#4 3	13-#8	12-#7	20-#5	16-#5	4.83	220.6	451.7	593.8
24	100	5.50	8.00	12	0.706	13-#4 2	21-#4	19-#4	9-#5	13-#4	2.27	103.9	207.7	279.6
24	200	7.00	8.00	15	0.633	13-#4 3	19-#5	15-#5	12-#5	10-#5	2.80	140.6	281.3	378.7
24	300	7.00	8.00	17	0.722	15-#4 4	17-#6	14-#6	11-#6	13-#5	3.71	177.9	355.7	478.9
24	400	8.50	9.60	19	0.630	16-#4 2	16-#7	15-#6	10-#7	16-#5	4.43	214.8	429.5	578.2
– 25	100	5.50	8.33	12	0.766	13-#4 4	23-#4	14-#5	10-#5	13-#4	2.34	117.8	235.6	317.2
25	200	7.00	8.33	15	0.686	13-#4 4	15-#6	12-#6	10-#6	12-#5	3.11	159.8	319.5	430.1
25	300	8.50	8.33	17	0.643	15-#4 3	15-#7	14-#6	10-#7	15-#5	4.08	202.5	405.0	545.2
25	400	8.50	10.00	20	0.723	18-#4 5	14-#8	13-#7	9-#8	10-#7	5.01	243.4	486.8	655.3

SQUARE INTERIOR PANEL

With Drop Panels[(2)]
No Beams

SPAN c.-c. $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	Square Column[(3)] Size (in.)	Reinforcing Bars (E. W.) Column Strip Top	Column Strip Bottom	Middle Strip Top	Middle Strip Bottom	Total Steel (psf)	Concrete $\left(\frac{\text{cu. ft}}{\text{sq. ft}}\right)$
h = 8.5 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS								
22	100	12	16-#4	11-#4	11-#4	11-#4	1.94	0.745
22	200	17	14-#5	9-#5	11-#4	11-#4	2.31	0.745
22	300	20	15-#5	18-#4	9-#5	8-#5	2.71	0.759
22	400	21	16-#5	14-#5	8-#6	14-#4	3.16	0.773
22	500	22	17-#5	13-#6	13-#5	12-#5	3.84	0.822
23	100	12	12-#5	12-#4	12-#4	11-#4	2.01	0.745
23	200	17	14-#5	16-#4	13-#4	11-#4	2.33	0.759
23	300	20	11-#6	21-#4	16-#4	9-#5	2.91	0.773
23	400	23	28-#4	16-#5	19-#4	16-#4	3.35	0.802
23	500	23	14-#6	20-#5	15-#5	13-#5	4.09	0.822
24	100	12	12-#5	9-#5	13-#4	12-#4	2.09	0.759
24	200	18	14-#5	18-#4	14-#4	12-#4	2.38	0.773
24	300	20	18-#5	11-#6	12-#5	10-#5	3.22	0.773
24	400	23	14-#6	10-#7	22-#4	12-#5	3.76	0.822
– 25	100	12	13-#5	10-#5	13-#4	12-#4	2.12	0.759
25	200	18	16-#5	21-#4	16-#4	9-#5	2.65	0.773
25	300	20	18-#5	18-#5	10-#6	12-#5	3.43	0.787
25	400	23	12-#7	9-#8	9-#7	10-#6	4.32	0.822

NOTES: (1) 50 percent of these bars may be placed in the middle third of column strip. (2) Drop panels same size as for edge panels. (3) Same column size above and below slab.

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CLASS:
DATE:
ASSIGNMENT:

PAGE: ___ of ___

JOIST DESIGN

24' X 18'-1"

- JOISTS SPAN LONG DIRECTION
- MAX SPACING = 2.5'

$\frac{18.0833'}{2.5'} = 7.23 \rightarrow$ USE 8 JOISTS

$\frac{18.0833}{10} = 1.81'$ SPACING

LL = 100 PSF
DL = 50 PSF
TL = 150 PSF

1.8' TRIBS $\Rightarrow$ LL = 181
DL = 90.5
24' SPAN

TL = 271.5 PLF

K MEMBERS

12K5 (7.1 PLF) 282^k
14K4 (6.7 PLF) 295^k ← USE THIS ONE LIGHT AND DEPTH WILL NOT CAUSE MEP ISSUES WITH ORIGINAL DESIGN
14K5 (7.7 PLF) 362^k
16K3 (6.3 PLF) 283^k

CHECK DEFLECTION

$I_s = 26.767(295)(24'-0.33)^3(10^{-6}) = 104.72 \text{ in}^4$

$\Delta = \frac{5}{384} \frac{(.181)(24)^4(1728)}{29000(104.72)} = 0.44'' < \frac{l}{360} = 0.8''$ ✓ok

TYPE C NON-COMPOSITE DECK

USE TYPE C 9/16" 24 GAGE GALVANIZED DECKING

2 SPAN TL = 342 > 150 PSF ✓ok

USING HIGHER GAGE DECK FOR SERVILIBILITY REASONS

CLASS:
DATE:
ASSIGNMENT:

PAGE: ___ of ___

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NON COMPOSITE DESIGN

DL = 50 + 20 = 70 PSF   6' BEAM SPACING
LL = 100 PSF ← CONS.

$\boxed{\text{DECK TYPE 2" C FORM 3 SPAN CONDITION 20 GA}}$

TL = 173 > 170 PSF ✓OK

RAM SUMMARY:

4 W12x16 BEAMS @ 6'
2 W12x16 EXT BEAMS
1 W16x31 EXT GIRDER
1 W18x40 INT GIRDER
4 W10x33 COLUMNS

SEE FIGURE

WAFFLE SLAB COST ANALYSIS

CAST-IN-PLACE CONCRETE

0.661 CF/SF → 0.661 (434) = 286.9 CF CONC

18'-1" × 24' = 434 SF

$286.9\,(ft^3)\left(\frac{1\,yd}{3\,ft}\right)^3 = 10.63$ CY

MARK UP CY BY 10% FOR CONSTRUCTION WASTE

∴ 11.7 CY OF CONC

FROM RSMEANS, WAFFLE, 30" DOMES, 20' SPAN: $770/CY

COST = 11.7 (770) = $ 9,009

INCLUDED IN

~~FORMS IN PLACE, ELEVATED SLAB~~

~~FLOOR SLAB, 20" METAL PANS, 1 USE ← CLOSEST TO WAFFLE CONST~~

~~$13.50 /SFCA~~

~~$13.50 (434 SF) = $4630.5~~

~~REINFORCING STEEL, ELEVATED SLAB #4-#7~~

~~$1875 /TON~~

~~2.64 PSF (434) = 1145.76 lb (ton / 2000 lb) = 0.573 TONS~~

~~COST = $1875 (0.573 TONS) = $ 1074.15~~

COLUMNS (4) 12"×12"

CAST-IN-PLACE CONCRETE, COLUMNS, AVERAGE REINFORCING

$1850/CY

no. cols

1 SF COL (10') = 10 CF (4) = 40 CF / 27 = 1.48 CY

COST = $1850 (1.48 CY) = $ 2740.74

FORMS, 12"×12", 3 USE

$ 9.20 /SFCA

no sides, no cols

10' × 1' × 4 × 4 = 160 SFCA

COST = $9.20 (160 SFCA) = $1472

TOTAL ESTIMATED BAY COST = $13,221.74

APPROX COST/SF = $30.46/SF

2 WAY FLAT SLAB W/DROP PANELS COST ANALYSIS

CAST IN PLACE CONC

8.5" SLAB DEPTH BTWN DROP PANELS
7" DEEP SQUARE DROP PANELS
8' WIDE DROP PANELS

24' x (18'-1") = 434 SF x 8.5" = 307.42 CF

+ 8' x 8' x 7" = 37.33 CF

344.75 CF / 27 = 12.77 CY CONC

x 1.1 (WASTE) = 14.05 CY CONC

ELEVATED SLABS, FLAT SLAB W/DROPS, 20' SPAN (CONT)

$635/CY

COST = $635 (14.05 CY) = $8918.90

INCLUDED IN

FORMS IN-PLACE, ELEVATED SLAB
FLAT PLATE, JOB-BUILT PLYWOOD to 15', 3 USE $7/SF

COST = $7 (434) = $3038

REINFORCING STEEL, ELEVATED SLAB #4-#7
$1875 / TON

2.8 PSF (434 SF) = 1215.2 lb / 2000 → 0.6076 TONS

COST = $1875 (0.6076) = $1139.25

COLUMNS (4)

CAST-IN-PLACE CONC, COLUMNS, AVG REINFORCING

$1525/CY 15" x 15"

$\frac{15}{12}\left(\frac{15}{12}\right)$ = 1.5625 SF (10' HT)(4 ~~10 COLS~~) = 62.5 CF / 27 = 2.31 CY

COST = $1525 (2.31) = $3522.75

FORMS, 16" x 16", 3 USE

$8.85/SFCA

10' (15/12) x 4 x 4 = 200 SFCA

COST = $8.85 (200) = $1770

TOTAL ESTIMATED BAY COST = $15,611.65
APPROX COST/SF = $35.361

NON-COMPOSITE COST ANALYSIS

W16x31 (24') = \$48/LF (24') = \$1152

(5) W12x16 (18'-1") = \$26.50/LF (18'-1") = \$479.2(5) = \$2396

W18x40 (24') = \$61/LF (24') = \$1464

FORM DECK: \$3.50/SF 20 GA (BY INTERPOLATION) 2" DEEP UNCOATED

COST = \$3.50 (434 SF) = \$1519

CAST-IN-PLACE CONC

3.5" CONC

$\frac{3.5}{12}(434) = \frac{126.50}{27}$ CF = 4.69 CY

\$291/CY

COST = \$2.91 (434) = \$1262.94

WWF

\$61/CSF (434/100) = 264.74

COLUMNS W10x33

\$65.50 (10')(4) = \$2620

TOTAL ESTIMATED COST = \$10,678.68

COST/SF = \$24.60/SF

STEEL JOIST COST ANALYSIS

(8) 14K5 JOISTS = 5($10.3/LF)(24) = $1236

W16x31 = $1152

W18x40 = $1464

W 12x16 = $479.2

W 12x16 = $479.2

CAST-IN-PLACE CONC

COST (FROM PREV) = $1262.94

DECK

$2.2/SF (434) = $954.8

WWF (FROM PREV)

264.74

COLUMNS (FROM PREV) = $2620

TOTAL COST = $9912.88

COST/SF = $22.84/SF

AS DESIGNED (COMPOSITE) COST ANALYSIS

BEAMS W12X30 = \$46.50/LF (24') = \$1116

(3) W12X16 = \$36/LF (18'-1")(3) = \$1952.96

W14X82 = \$128/LF (24') = \$3072

COLUMNS (4)

(4) W14X61 = \$104/LF (10')(4) = \$4160

CAST-IN-PLACE CONC + WWF

\$1262.94 + \$264.74 ← FROM PREV

TOTAL COST = \$11828.64

COST /SF = \$27.25