THE Borgata
ATLANTIC CITY

TECHNICAL ASSIGNMENT TWO

christopher m. shipper

Structural Option

Advisor: Dr. Ali Memari

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Executive Summary

The purpose of this report is to investigate the possibility of alternate floor systems of the Borgata Hotel Tower. This is a 43 story, 2.2 million square foot hotel in Atlantic City, New Jersey. The hotel will serve guests for the adjoining low rise casino and spa.

There were a number of floor systems considered, but after preliminary research some of the options were ruled out. A one-way concrete slab was ruled out because the center bay, which is also the largest bay, is almost square and more suitable for a two-system. A non-composite steel framing system was ruled out because the framing size and depths would be much greater that of a composite system. The field was narrowed down to four possible alternative solutions: steel frame with composite deck, Girder-Slab D-Beams with precast hollow core planks, two-way flat plate and two-way flat plate using filigree precast planks. The following is a table with the basic design criteria listed:

System	Slab	Beams	Girders	Columns
Composite Steel	6” Slab on 1 ½” Composite Deck	W12x19	W16x31	W14, Size Varies
Girder-Slab	8” Hollow Core	None	DB 8X35	W14, Size Varies
Two-Way Concrete	10” Cast-In-Place, With Mild Reinforcing	None	None	Concrete, 32”x31”, 22”x22”
Two-Way Concrete Filigree	2 ¼” Precast with 7 ¾” Cast-In-Place Topping	None	None	Concrete, 32”x31”, 22”x22”

Each system analyzed has its advantages and disadvantages. Each system is analyzed based on cost, performance, constructability, lead time, erection time, vibration resistance, depth, weight, durability, grid changes, architectural consideration and lateral system effects.

After analysis and careful consideration, the two-way flat plate filigree system was chosen as an acceptable solution to the original design. This system compared equally in cost with most of the other options, and had the least negative impact on the outcome of the project. The filigree system will speed the construction process while performing similar to the original design.

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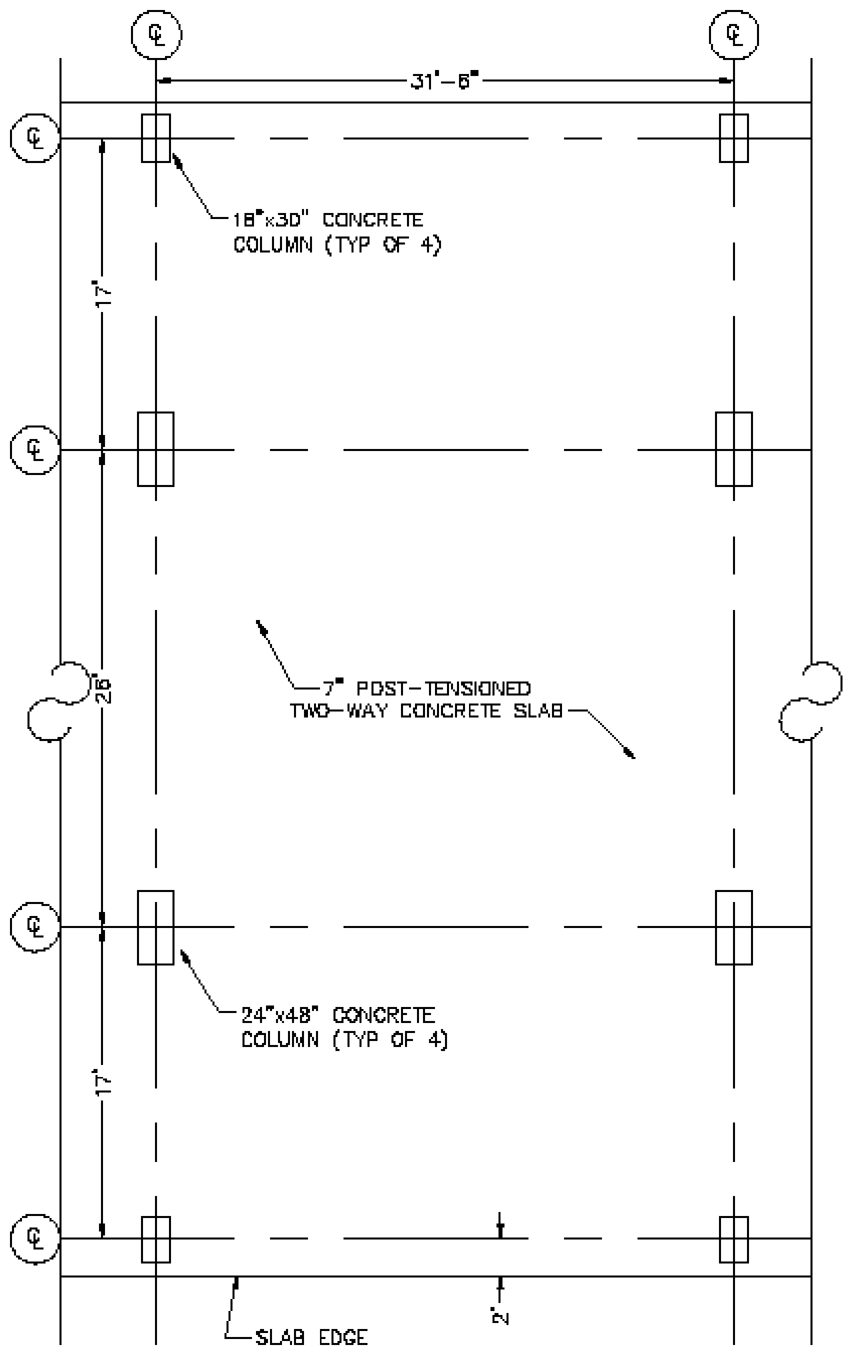
Existing Structural System

Floor System

The typical floor is supported by a post-tensioned concrete slab system. The concrete is normal weight (145 pcf dry unit weight) and has a minimum 28 day strength of 5000 psi. The slab is 7" thick at the center of the building, and 8 ½" thick at each end where the floor plan is circular in shape. The typical bay sizes are 30'-0" X 26'-0" and 30'-0" X 17'-0". There is variation in span sizes at the ends of the building. Post-tensioned cables are to conform to ASTM A-416 and shall be Grade A or Grade B and are loaded with varying forces from 50 to 900 kips. The non typical floors are a mix of post-tensioned systems with a thicker slab, and two way flat slabs with drop panels. The figure to the right shows the typical bay sizes along the building. A full typical floor plan can be found in the appendix.



TWO-WAY POST TENSIONED SLAB

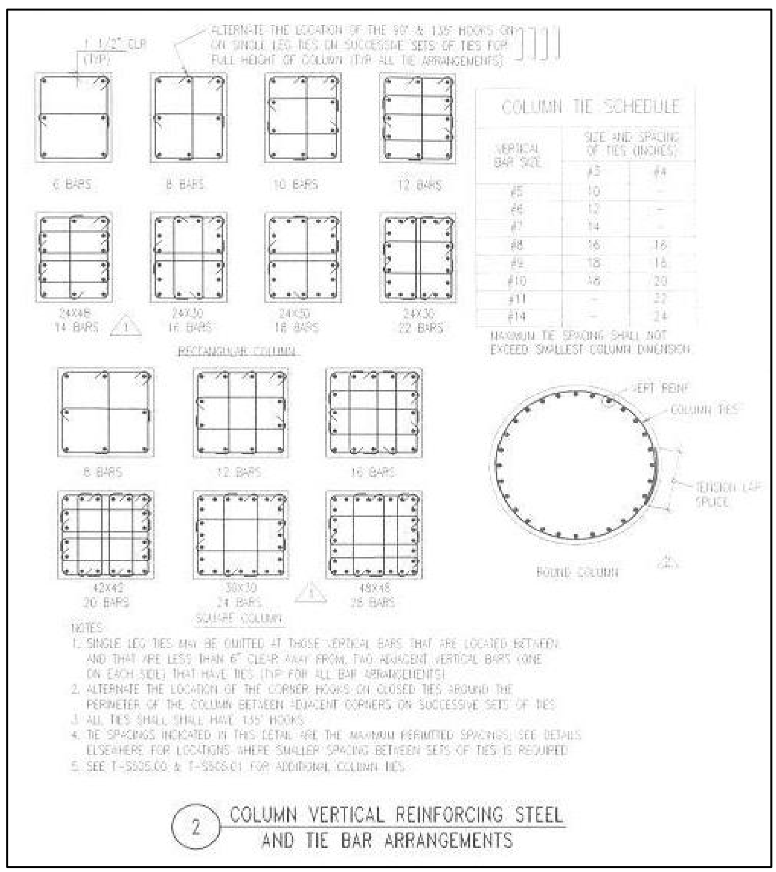
Roof System: The flat roof slab is similar to the typical floor slab. It is a post-tensioned system, but the slab is 8 ½" thick for the entire slab. The roof slab supports most of the buildings mechanical equipment as well as catwalks used to access the mechanical equipment.

Lateral System: The structure is laterally supported by reinforced high strength concrete shear walls in both the North-South and East-West directions. The shear walls also assume gravity load from the floors. The concrete is normal weight and has a minimum strength of 9000psi. Most of the shear walls extend the full height of the building, but a few stop at certain stories because of smaller shears towards the top of the building. The layout of the shear walls can be seen on the typical floor plan in the appendix.

Foundation: The Borgata Hotel is located on the site of a former landfill. The dump was not excavated and the soil below the dump is a combination of marine tidal marsh and clay/sand seams. A deep foundation system was chosen for the building. The transfers gravity and lateral loads to the earth through concrete filled steel tube piles. The piles are 16" in diameter and contain reinforced concrete. Piles are driven to various depths until reaching very dense sand. Columns bear directly on pile caps which vary in size. In some cases at shear walls, the walls and columns bear on 9'-0" concrete pile mats. The slab on grade is a 1'-6" thick structural two-way slab. This slab spans between piles caps since the soil below (landfill) has no bearing capacity.

Columns: Columns are cast-in-place concrete with strengths that vary depending on stories. Below, table one contains the column concrete strengths for the various stories. The figure to the right shows the typical column sizes and common reinforcing arrangements.

Concrete Compressive Strengths		
Stories	f'c	Time
Level B -12	9000 psi	@56 days
Level 12 – 23	7000 psi	@56 days
Level 23 and up	5000 psi	@28 days



Design Loads

<u>Dead Loads</u>

Slab	85, 103 psf
Partitions	15 psf

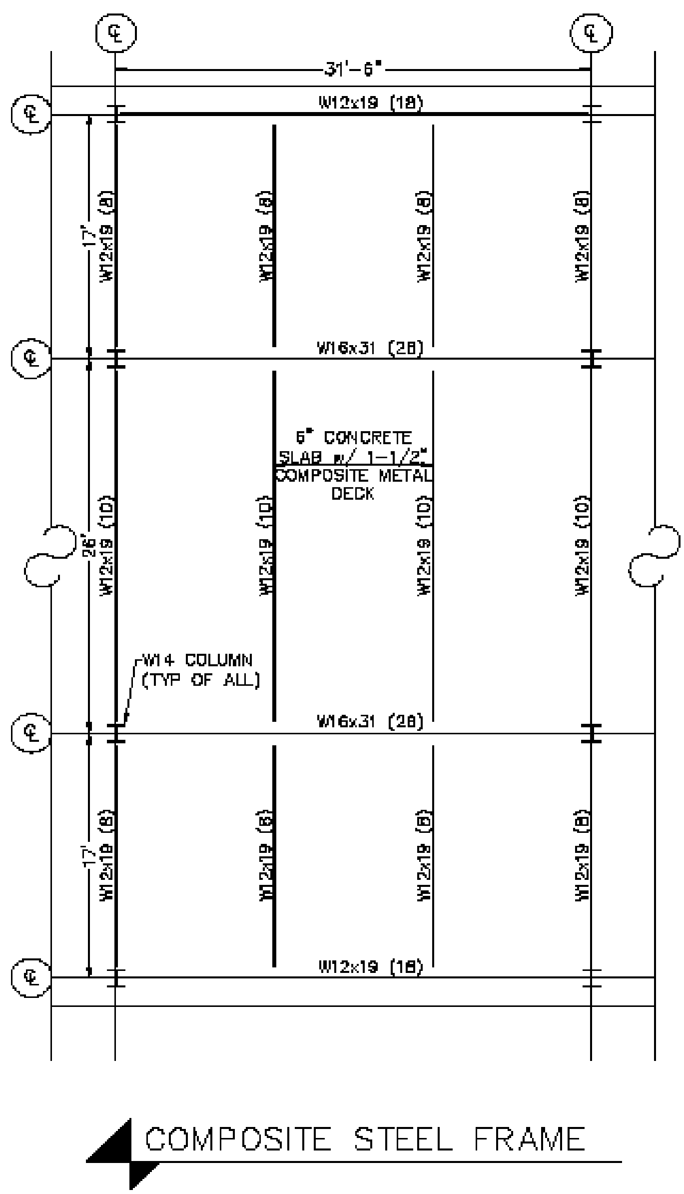
<u>Live Loads</u>

Guest Rooms	40 psf
Guest Hallways	40 psf
Elevators/Stairs/Exits	100 psf
Casino Floor	100 psf
Casino Corridor	100 psf
Mechanical – Basement	150 psf
Mechanical – Roof	150 psf

Alternative Structural Floor System Overview

Steel Composite Floor System

The steel composite floor was designed using the same bay sizing as the original design. A representative three bay model was constructed in RAM Structural System to represent the bay layout in the center of the building. The concrete deck is 6" total with a 1 ½" Vulcraft composite metal deck. The typical beam size is W12X19 and the girders are W12X19 and W16X31. Shear studs are 3/4" diameter by 3 7/8" long. Beams and girders were designed for a minimum of 25 percent composite action and maximum of full composite action.



__Advantages__

Cost: The composite framing proved to have the lowest cost for any of the structural systems (structural system only). The reduced amount of concrete and lack of forming required are factors in the low cost. Most contractors are highly experienced in steel framing, therefore there is also low cost for labor.

Weight: The use of steel framing decreases the distance the concrete has to span, which in effect, decreases the required thickness. This decrease in thickness reduces the weight of the system even with the addition of beams and girders. The weight of the composite system (for the three bays designed) is 135.6 kips versus the original post tensioned system, 165.2 kips. This will result in a decrease of column and foundation sizes, as well as decreased seismic loads.

Construction: Steel composite framing is one of the most commonly used framing systems in the construction industry and is well known by most contractors. This system would prove to be easy to construct which could reduce cost and schedule time.

Disadvantages

Depth: This system results in the largest floor system depth, with a total floor depth of 22”. This depth increases the overall depth of the original design by 15 inches. This depth increase will have drastic effects on the project. Since the building is 43 stories, the total height of the building would increase by about 54 feet. This height increase would require a greater amount of curtain wall to be used. The height increase also affects the cost of construction. The taller the building, the more it costs to construct.

Architectural Considerations: The use of steel framing would require the installation of a finished ceiling system. This would not only increase load on the framing system, but would add significant cost to the project. The original design uses the bottom of the concrete deck as the ceiling.

Fire Protection: The fire rating for structural floor elements in this building is two hours. The deck alone has adequate fire rating, but the steel beams and girders have no fire resistance by themselves. This would require a spray on fireproofing which is expensive and will increase the overall cost of the system.

Lead Time: The amount of steel required for this project will require a large amount of fabrication. The fabrication will cause a long lead time for structural steel and could delay the erection of the frame for months.

Column Sizes: The relatively large size of the bays in the building requires large columns to be used at the base of the building. Assuming only gravity load, preliminary analysis shows the need for W14x311 columns to support interior bays towards the bottom floors of the building. Columns of this size are limited in quantity and expensive. It is unpractical to use columns of this size. If a composite system is to be considered, the use of smaller wide flange shapes with reinforcing or a composite wide flange in concrete must be considered.

Alternative Structural Floor System Overview

Girder-Slab System

The Girder-Slab System was designed using the Girder-Slab Design Guide, provided by Girder-Slab Technologies, LLC. The design guide is available upon request, or can be found at www.Gider-Slab.com. The Girder-Slab System is made from 8" hollow core precast planks that are support by custom made, castellated beams, called D-Beams. The D-Beams used in this design are DB-8X35. The parent beam for the castellated beam is a W10X49 and a 1" x 3" metal rail is welded to the top as the top flange.

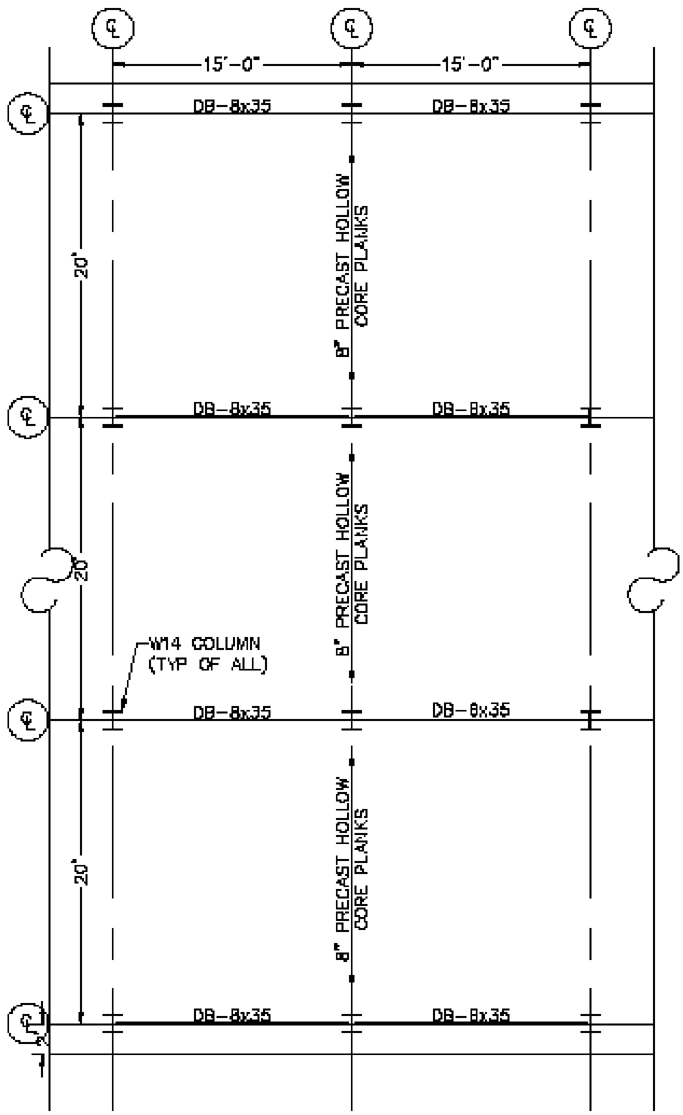
Advantages

Depth: The composite action combined with the unique plank to girder connection provides a system that performs like a steel frame but has the depth of a concrete flat plate. This system has nearly the same depth as the original design.

Construction Time: The use of steel beams and precast panels allow the structure to be erected quickly and efficiently without have to wait for slabs to cure. The system can be erected year round with out worrying about the winter stopping construction if it gets too cold.

Weight: The Girder-Slab System significantly reduces the weight of the floor system. The hollow core planks are rated at 60 psf and the D-Beams are only 35 plf. The total weight of this system is 121.4 kips versus the original system at 165.2 kips (for the three representative bays).

Column Size: The use of the Girder-Slab System and resized bays results in much smaller column sizes that the long span composite system.

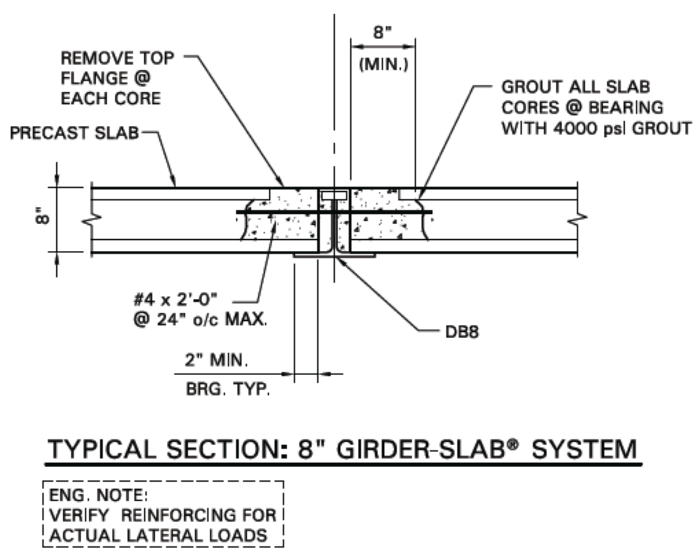


GIRDER–SLAB SYSTEM

Disadvantages

Cost: Cost analysis using RSMeans shows that this system will be the most expensive to construct. No data could be found on the cost of the D-Beams. The D-Beams require extensive fabrication. A fabricator must split a parent beam with castellated cuts and then shop weld a steel bar to act as a top chord. The D-Beams were arbitrarily estimated as costing the full amount of the parent beam.

Grid Changes: The D-Beams have a shallow depth, which in turn gives them low moment capacity. The large spans and moderate load in the Borgata were unforgiving to the D-beam, even when using the largest D-Beam available. To allow the use of D-Beams, the column grid was modified. Since the typical spacing between columns in the East-West direction is 30'-0", and two guest rooms lie in each bay, an extra grid was placed at the center of each bay. The grid in the North-South is governed only by the central hallway, so the grid was changed from 17', 26', 17 to three bays of 20'-0". This layout allowed the use of the smallest D-Beam, DB8x35.

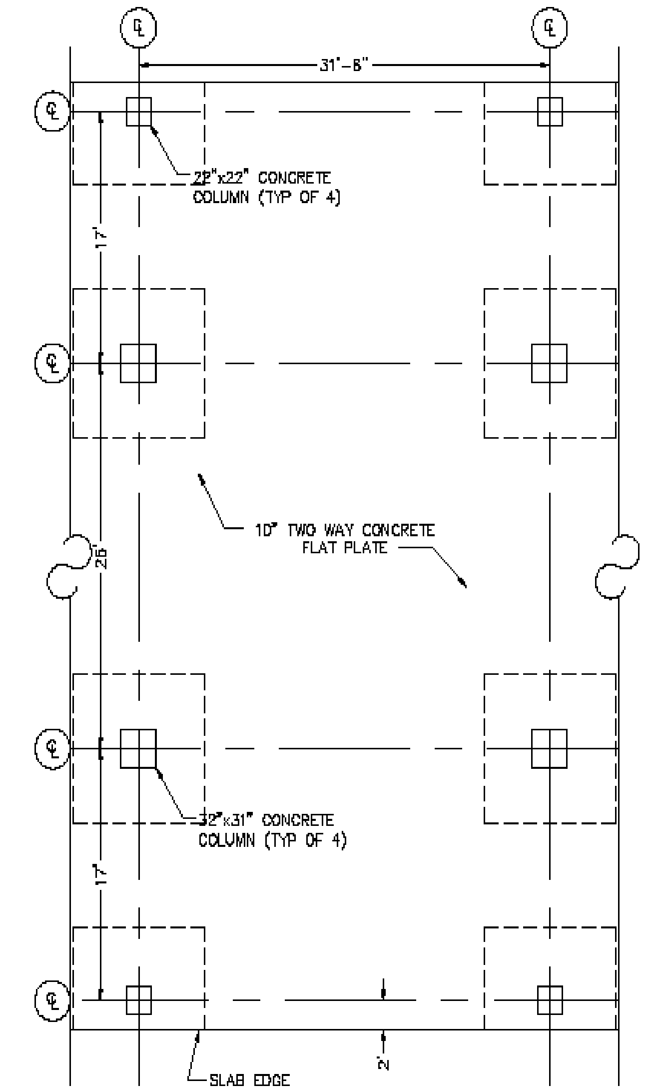


TYPICAL SECTION: 8" GIRDER-SLAB® SYSTEM

Alternative Structural Floor System Overview

Two-Way Flat Plate

The Two-way flat plate system was designed using the Direct Design Method. A minimum slab thickness, governed by deflection control, was found to be 10”. This system adds 2” to the floor depth but a total of 4” since 2” drop panels were used. Though the system adds depth and weight, the two-way slab avoids the use of post-tensioning. The amount of reinforcement necessary was relatively low due to the load floor design loads in spite of the long spans.



TWO-WAY FLAT PLATE w/ DROP PANELS

Advantages

Depth: The use of a reinforced two-way slab keeps depths of the system shallow, but not as shallow as the post-tensioned system. This system adds and extra 2” of depth, which equates to an extra 7’-2” of total building height. This extra height would have minimal effects on construction costs and need for extra curtain wall.

Fire Protection: The two-way system has a total depth of 10”, which does not require any additional fire proofing.

Constructability: Cast-in-place construction is a common and frequently used method used by contractors. This could save time and money during the construction process.

Performance: Since the loads are relatively moderate, the required amount of reinforcing is not large and the system can easily carry the required design loads.

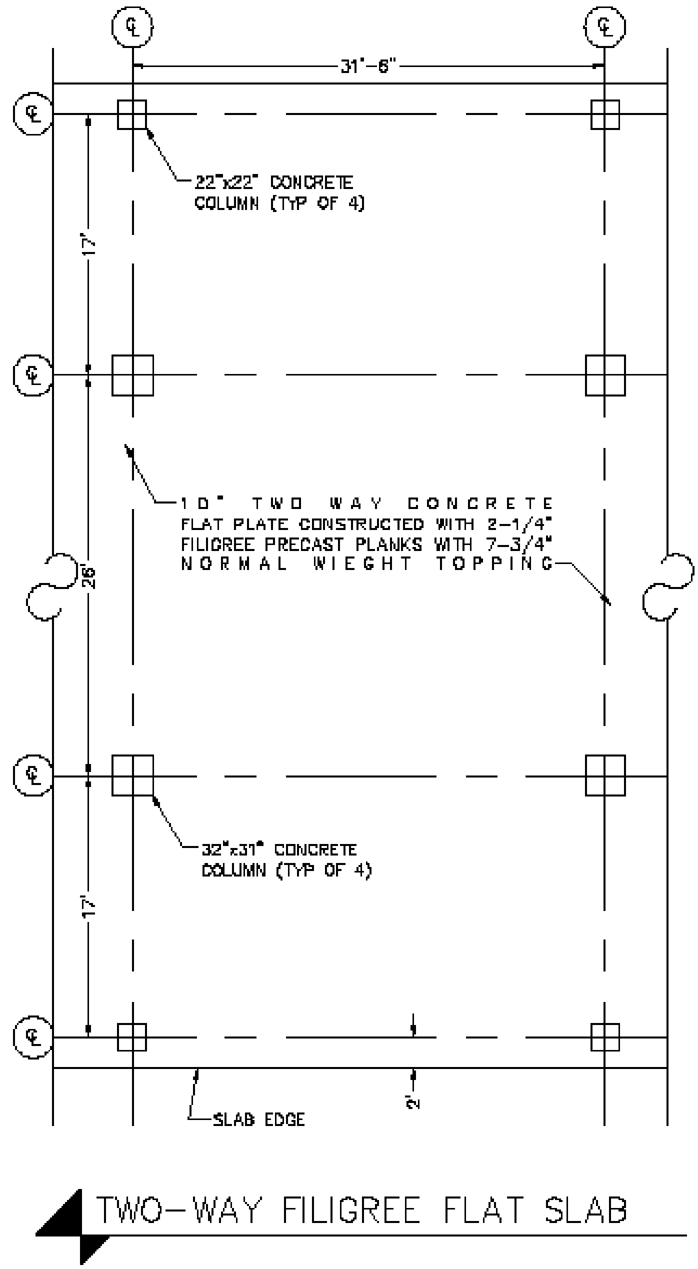
Disadvantages

Weight: The addition of three extra inches of concrete adds an extra 36.3 psf to the system. The overall weight of the two-way system is 236 kips (for the three representative bays).

Alternative Structural Floor System Overview

Two-Way Filigree Flat Plate

The two-way filigree flat plate system was designed using the Direct Design Method. Using filigree eliminates the need for costly formwork and the need to wait for slabs to cure. The filigree system was design using the Direct Design Method for two-way slabs. A slab without voids was chosen so there would be no need for beams and the slab reinforcing could be run in both directions.



Advantages

Depth: The filigree system results in the same depth as the conventional two-way system. This depth is slightly larger than the original post-tensioned design.

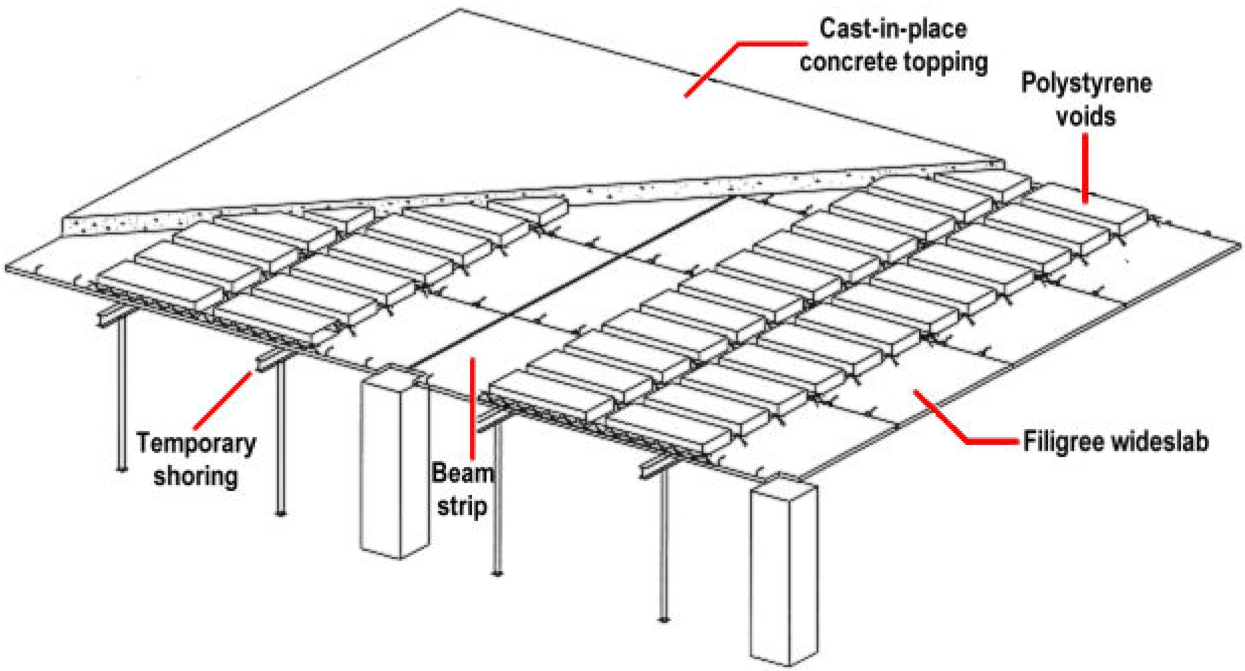
Fire Protection: The filigree system satisfies fire proofing requirements and performs the same as the conventional two-way system.

Constructability: The prefabrication technology in Filigree reduces the need for field skilled and unskilled trades. Although all trades are represented, fewer are needed for each task with a reduction in payroll needs and enhanced cash flow.

Time: Since filigree does not require setting up formwork and stripping it, the erection process goes much quicker. According to Mid-State Filigree Systems, Inc. up to 50,000 square feet of production can be done per week.

Performance: Since the loads are relatively moderate, the required amount of reinforcing is not too large and the system can easily carry the required design loads.

Aesthetics: The filigree planks are manufactured in a controlled environment with more accuracy and attention than possible in the field. The filigree planks are cast in polished steel molds and will enhance the architectural aspects of the project. This is desirable in the Borgata because the bottom side of the slab is the ceiling for the floor below.



Disadvantages

Weight: The addition of three extra inches of concrete adds an extra 36.3 psf to the system. The overall weight of the two-way system is 236 kips (for the three representative bays).

Lead Time: The use of precast planks can result in a long lead time. The time to fabricate the planks may not affect the project if the system is chosen at an early stage in design.

Alternative System Comparison Chart				
	Composite Steel	**Girder-Slab**	**Two-Way Concrete**	**Two-Way Filigree**
Cost[1]	\$22,900,000[2]	\$34,410,000	\$34,450,000	\$34,230,000
Depth	22”	8”	10”	10”
Weight	135.6 kips	121.4 kips	236 kips	236 kips
Deflection	1.42” total load deflection = L/266	0.3” total load deflection = L/600	Deflection not calculated per ACI 318-05 Table 9.5(c)	Deflection not calculated per ACI 318-05 Table 9.5(c)
Constructability	Easy construction, common method	New technology, not common	Easy construction, common method	Less common construction method
Lead Time	Long, up to 6 months	Long, up to 6 months	Little to none	Long, up to 6 months
Erection Time	Moderate	Short	Long	Short
Vibration	Average	Good	Excellent	Excellent
Durability	Steel fatigue, corrosion	Steel fatigue, corrosion	Concrete spalling	Concrete spalling
Fire Proofing	Spray On	Minimal Required at beam	Non required	Non required
Grid	No changes	Major Changes	No Changes	No Changes
Architectural	Ceiling finish needed, More curtain wall needed	Minor Changes	No Changes	Superior Quality
Lateral System	Change to steel lateral system, braced frames	Change to steel lateral system, braced	No changes	No changes
Viable Alternative?	**No**	**No**	**No**	**Yes**

Footnotes:
1. Cost of the systems was estimated using RSMeans Building Cost Data 2008. A representative three bay model was used to construct the cost. The total cost of this system was divided by the square footage of the model, and multiplies by the total building square footage.
2. The steel system cost was estimated for the cost of the structural system only. No costs for additional curtain wall, fire proofing, ceiling finishes or the effects that the additional building height would have on the construction cost were calculated, but taken into consideration when choosing viable solutions.

Conclusion

Analysis of all the systems has only narrowed the choices of systems by one. The steel composite system was ruled out due to the enormous column size requirements, total building height effects, fire proofing requirement and interior finish changes it would require. These monetary costs were not calculated but assumed as a defining factor in the decision.

The Girder-Slab system may be a possible alternative system to be used, but was ruled out because of the major changes it would require for the architectural gird. These grid changed would effectively double the number of columns in the building. Another factor in the decision to rule out Girder-Slab was the lack of industry experience with a project of the Borgata's scope. Girder-Slab has been used in many low-rise apartments and other housing projects, but nothing to the scale of the Borgata has been completed using this system, according to my research.

The two-way concrete system was removed from consideration for the alternative system because it is basically a less effective system than the original design, but has the same construction. The lack of post-tensioning cables requires the slab to have a greater depth, which in turn increases the weight of the system by 43 percent. Using a conventional concrete slab would be wasteful in materials and would not affect cost drastically versus the current system.

The two-way filigree systems were chosen as the best alternative system out of the four possible candidates. Though this system is almost identical to the performance of the two-way flat plate, it implements a completely different construction process. The filigree requires a larger amount of reinforcing due to the decreased effective depth of the reinforcing in the short span direction, but the effects on the construction process should greatly outweigh the cost of extra reinforcing steel. The filigree slab system will allow the building to be erected faster than the conventional two-way slab which will allow other trades to complete work sooner, thus allowing the building to open earlier. This building is a hotel to an already existing and open casino. The sooner the building opens, the more revenue the owner can collect.

Appendix 1 – Composite Steel Frame

Calculations

AE 481 | TECH ASSIGNMENT 2 | SHIPPER | 1/3

COMPOSITE STEEL FRAME

- SPOT CHECK

TYPICAL BEAM SPAN = 26'

TRIB WIDTH = $\frac{21.5}{2}$ = 10.5 ft

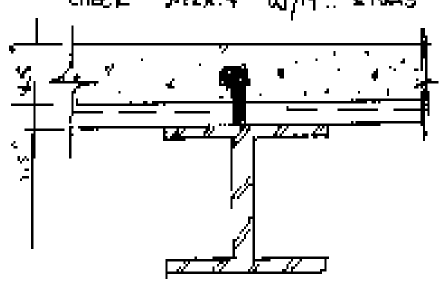
w_u = 1.2D + 1.6L = 10.5(1.2(15 + $\frac{5.25}{12}$(145)) + 1.6(40)) = 1.66 KLF

$W_{DEAD + LIVE}$ = 1.16 KLF

$M_u = \frac{w_u l^2}{8} = \frac{(1.66)(26)^2}{8}$ = 140.3 K·ft

W_{LIVE} = 0.42 KLF

CHECK W12x14 w/14 studs



f'_c = 5000 psi

f_y = 50 ksi

b_{eff} = least { 0.5' = 12" ; $\frac{26}{4}$ = 6.5' = 66" }

ASSUME a = 1" ∴ $Y_2 = t_s - \frac{a}{2}$ = 6 − 0.5 = 5.5

$Q_n = 0.5 A_{sc} \sqrt{f'_c E_c}$ $E_c = 145^{1.5}\sqrt{5000}$ = 3904.2 ksi

= 0.5(0.442)$\sqrt{(5000)(3904.2\times10^3)}$ = 30.9 kips

ΣQ_n = 7 × 30.9 = 216.3 K > ΣQ_n @ TOP FLANGE

↳ ϕM_n @ TFL = 179 K·ft

↳ ϕM_n > 179 K·ft > 140.3 K·ft OK

DEFLECTION

w_{LL} = 40(10.5) = 0.42 KLF

I_{LB} = 361 in⁴ $\Delta_{LL} = \frac{5(0.42)(26)^4 1728}{384(29000)(361)}$ = 0.4" < $\frac{26\times12}{360}$ = 0.87 OK

w_{TL} = 1.094 KLF $\Delta_{TL} = \frac{5(1.28)(26^4)1728}{384(29000)(361)}$ = 1.2" < $\frac{26\times12}{240}$ = 1.3" OK.

AE481 | TECH ASSIGNMENT 2 | C. SHIPPER | 2/3

COMPOSITE STEEL FRAME

INTERIOR COLUMN

A_T = 677 sf

DEAD LOAD – 15 psf + $\frac{5.25}{12}$ × 145 + 2 = 78.4 psf

LIVE LOAD – REDUCTION

L_o = 40 psf

$L = \left(0.25 + \frac{15}{\sqrt{K_{LL} A_T}}\right) L_o$

FLOOR	
40	$0.4L_o$
34	$0.4L_o$
28	$0.4L_o$
22	$0.4L_o$
16	$0.4L_o$
10	$0.4L_o$
3	$0.4L_o$

FULL LIVE LOAD REDUCTION ALLOWED ON ALL FLOORS BELOW 40

FLOOR LOAD: 677 psf × (1.2(78.4) + 1.6(16)) = 81.0 kips

ROOF LOAD: 677 psf × (1.2(64) + 1.6(350)) = 214.5 k

FLOOR	LOAD, P_u	COLUMN DESIGN	ϕP_n
40	214.5 + 4(81) = 538.5	W14×53	557
34	538.5 + 6(81) = 1024.5	W14×90	1120
28	1024.5 + 6(81) = 1510.5	W14×122	1640
22	1510.5 + 6(81) = 1996.5	W14×176	2210
16	1996.5 + 6(81) = 2482.5	W14×211	2650
10	2482.5 + 6(81) = 2968.5	W14×257	3230
3	2968.5 + 7(81) = 3535.5	W14×311	3930

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COMPOSITE STEEL FRAME

EXTERIOR COLUMN

A_T = 268 sf

DEAD LOAD: $W_D = 15 + \frac{5.25}{12}(140) = 78.4$ psf

LIVE LOAD:

REDUCTION

L_o = 40 psf

$L = L_o\left(0.25 + \frac{15}{\sqrt{K_{LL} A_T}}\right)$

FLOOR	L	w_u	FS
40	0.58 L_o	130.6	35
34	0.45 L_o	122.9	32.9
28	0.41 L_o	120.3	32.2
22	0.40 L_o	119.7	32.1
16	0.40 L_o	↓	↓
10	0.40 L_o		
3	0.40 L_o		

ROOF LOAD: w_u [1.2(64) + 1.6(150)] 268 = 84.9

WALL = 1.2(0.015)(315)(8.75) = 5K

FLOOR	LOAD	COLUMN DESIGN	ϕP_n
40	84.9 + 4(35 + 5) = 244.9	W14x43	447
34	84.9 + 10(32.9 + 5) = 463.9	W14x53	557
28	84.9 + 16(32.2 + 5) = 680.1	W14x61	700
22	84.9 + 22(32.1 + 5) = 901.1	W14x82	942
16	84.9 + 28(32.1 + 5) = 1123.7	W14x99	1230
10	1123.7 + 6(32.1 + 5) = 1345.7	W14x109	1360
3	1345.7 + 7(32.1 + 5) = 1605.4	W14x132	1640

Appendix 1 – Composite Steel Frame

Cost Analysis

Steel Beams	Length	Cost/foot	Amount	Studs/Beam	Total Studs	Cost/stud	Total Cost
W12X19	26	$26.72	4	10	40	$2.31	$2,871.28
W12x19	17	$26.72	8	8	64	$2.31	$3,781.76
W12X19	31.5	$26.72	2	18	36	$2.31	$1,766.52
W16X31	31.5	$41.84	2	28	56	$2.31	$2,765.28

Steel Deck	Cost Per Square Foot	Square Feet	Total Cost
1.5VL	$1.79	1953	$3,495.87

WWF	CSF	Cost per CSF	Cost
6x6-W2.1x2.1	$19.53	53.5	$1,044.86

Concrete Slab	Thickness	Square feet	Total CY	Mat'l Cost/cy	Labor Cost/cy	Total
	5.25	1953	31.65	$120.00	$25.50	$4,604.47

Estimated Total Cost	$20,330
Cost per square foot	**$10.41**
Total Building Cost	**$22,901,216**

Column Designs

Floor	Interior	Exterior
40 - 43	W14x43	W14x43
34 - 40	W14x90	W14x53
28 - 34	W14x132	W14x61
22 -28	**W14x176**	W14x82
16 - 22	**W14x211**	W14x99
16 - 10	**W14x257**	W14x109
3 - 10	**W14x311**	W14x132

Appendix 2 – Girder-Slab Calculations

[redacted]

AE 481 | TECH ASSIGNMENT 2 | C. SHIPPER | 1/5

GIRDER SLAB

BAY SIZE: 26'x31.5'

LOADS: PLANK - 60 PSF

SUPERIMPOSED - 25 PSF

LIVE - 40 PSF

Δ_{LL} ALLOWED $= \frac{L}{360} = \frac{26 \times 12}{360} = 0.867"$

INITIAL LOAD: PRECOMPOSITE

$W_{DL} = (31.5')(60 PSF) = 1.89 KLF$

$M_{DL} = \frac{1.89(26)^2}{8} = 159.7 K\text{-}FT > 84 K\text{-}FT$

- TRY TO REDUCE DEAD LOAD

SUPERIMPOSED LOAD IS CONSERVATIVE WAS CALCULATED BEFORE DESIGN LOADS WERE AVAILABLE

FROM ENG. DWGS DL = 15 PSF.

- LOOK FOR LIGHT WEIGHT PLANKS

SPIRAL CORE

NO TOPPING - 56 PSF

2" TOPPING - 80 PSF

INITIAL LOAD:

$W_{DL} = 31.5(56) = 1.76 KLF$

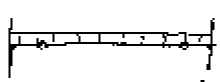
$M_{DL} = \frac{1.76(26 - 7/12)^2}{8} = 142 K\text{-}FT > 84 K\text{-}FT$

WHAT SPAN IS OK?

$84 = \frac{1.76 L^2}{8}$

$L = \sqrt{\frac{84 \cdot 8}{1.76}} = 19.5'$

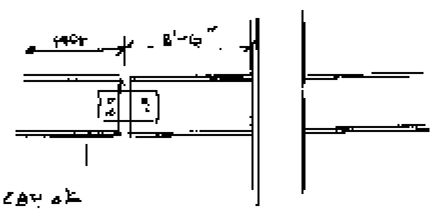
USE TREE COLUMN CONNECTION

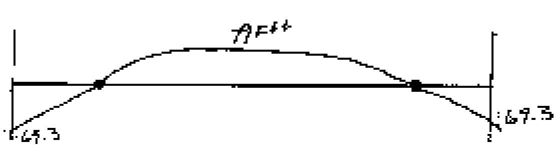


$M_{center\ span} = \frac{1.76(19)^2}{8} = 79 K\text{-}FT < 84$ OK

$M_{cant} = \frac{w\ell^2}{2} + P\ell$

$= \frac{1.76(3.5)^2}{2} + 16.72(3.5) = 69.3 K\text{-}FT < 84$ OK





* DB 9x46 OK TO CARRY PRECOMPOSITE LOAD

DB 9x46

$w = 46.8$ plf

$A = 13.4 in^2$

$d = 9.145$

$t_w = 0.375$

PARENT BEAM = W14x61

$a = 2.375$

$b = 5.75$

T (CHORD) = 3x1.5

DB 9x46 PROPS.

STEEL ONLY

$I = 251 in^4$

$C_{bot} = 3.84 in$

$C_{top} = 5.79 in$

$S_{bot} = 50.8 in^3$

$S_{top} = 33.7 in^3$

$M_u = 84 K\text{-}FT$ $f_b = 0.66 F_y$

TRANSFORMED

$I = 356 in^4$

$C_{bot} = 4.43$

$C_{top} = 5.26$

$S_{bot} = 80.6$

$S_{top} = 68.6$

GIRDER SLAB

TOTAL LOAD COMPOSITE

$W_{DL} = (15psf + 80psf)(31.5ft) = 2.99 KLF$

- LIVE LOAD REDUCTION

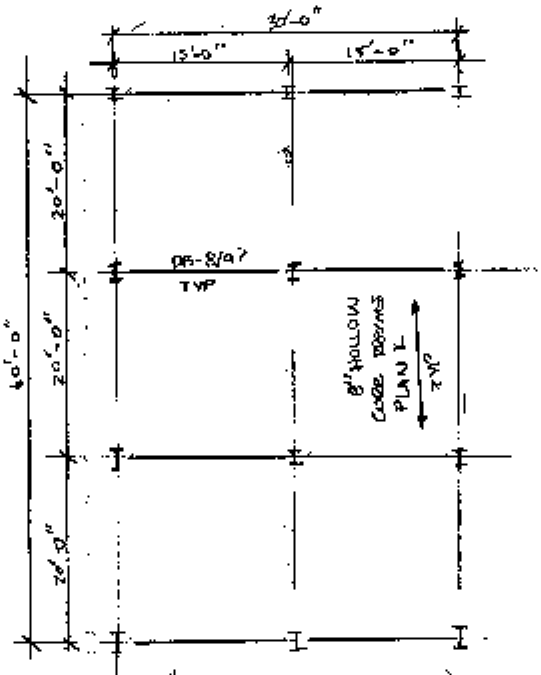
$L = L_o\left(0.25 + \frac{15}{\sqrt{2 \cdot 819}}\right) = 0.62 L_o = 0.62(40) = 24.8 psf$

$W_{LL} = (24.8 PSF)(31.5) = 0.78 KLF$

$M_{TL} = \frac{(2.99 + 0.78)(26^2)}{8} = 318.6 \text{ K-ft}$

$S_{req} = \frac{318.6 \times 12}{0.6(50)} = 127.4 in^3$ 76#/ft NO GOOD.

- ANALYSIS SHOWS GIRDER SLAB IS NOT A VIABLE FOR THIS BAY LAYOUT
  - FROM ARCH DWGS, TWO GUEST ROOMS PER BAY, PARTITION LOCATED "ABOUT" CENTER SPAN
  - ∴ MAKE NEW BAY SIZE, MODIFY ARCH PLANS MINIMALLY.



NEW FRAMING PLAN

GIRDER SLAB

* PLANK SPANS 20 ft – GIRDER SPANS 15 ft

DEAD LOAD

PLANK – w_{PL} = 60 PSF × 20 ft = 1.2 KLF

SUP – w_{st} = 15 × 20 = 0.300 KLF

* LIVE LOAD

REDUCTION – $L = \left(.25 + \frac{15}{\sqrt{2(20)(15)}}\right) \cdot L_o = 0.848 L_o$

w_{LL} = 0.848 (40) = 33.9 PSF

PRECOMPOSITE – CAN STEEL BEAM SUPPORT PLANKS DURING CONSTRUCTION

$M = \frac{wl^2}{8} = \frac{1.2 KLF (15)^2}{8} = 33.75$ K ft USE DB 8×35 M_{ALL} = 49 K ft

$\Delta_{DL} = \frac{5(1.2)(15)^4(1728)}{384(102)(29000)} = 0.46''$

COMPOSITE – TOTAL LOAD

$w_{TL} = 1.2 + 0.3 + \frac{33.9 \times 20}{1000} = 2.178$ KLF

$M_{TL} = \frac{2.178(15)^2}{8} = 61.3$ K ft

$S_{req} = \frac{61.3(12)}{.66(50)} = 24.5 in^3 < 63.5 in^3$ OK

$\Delta_{TL} = \frac{5(2.178)(15)^4 1728}{384(282 in^4)(29000)} = 0.30 in < \frac{15(12)}{240} = 0.75$ OK

CHECK SUPERIMPOSED COMPRESSIVE STRESS IN CONCRETE

$N = \frac{29000000}{57000\sqrt{5000}} = 7.20$ $S_{tc} = 7.20(63.5) = 456.9$

$M_{SI} = (0.015 + 0.024)(20)(15^2)\frac{1}{8} = 27.5$

$f_c = \frac{(27.5)(12)}{456.9} = 0.72 ksi < F_c = 0.45(5) = 2.25 ksi$ OK

CHECK BOTTOM FLANGE TENSION STRESS (TOTAL LOAD)

$f_b = \frac{(61.3 K ft)(12)}{36.5} = 20.2 < 0.9(50) = 45 ksi$

CHECK SHEAR

TOTAL LOAD = 60 + 15 + 33.9 = 108.9 PSF

w = 108.9 (20) = 2.18 KLF

$V = \frac{2.18(15)}{2} = 16.35$

$f_v = \frac{16.35}{(0.34)(8)} = 16.03$ ksi

$F_v = 0.4(50) = 20 > 16.03$ OK.

[redacted]

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GIRDER SLAB

COLUMNS - INTERIOR

A_T = 15' x 20' = 300 SF

LOADS - FLOOR

DEAD - PLANK - 60 PSF, PARTITION - 15 PSF } 75

LIVE - L_o = 40 PSF

REDUCTION	FLOOR	$L = L_o(0.25 + \frac{15}{\sqrt{K_{LL}A_T}})$	w_u	P_u
	40	0.47 L_o	120.1	36.0
	34	0.4 L_o	115.6	34.7
	28	0.4 L_o	↓	
	12	0.4 L_o		
	16	0.4 L_o		
	10	0.4 L_o		
	3	0.4 L_o		

LOADS - ROOF -

DEAD - PLANK - 60, SUP - 20 w_u = 1.2(80) + 1.6(150) = 336

LIVE - 150 PSF P_u = 336 x 300 = 100.8

FLOOR	LOAD, P_u	COLUMN	ϕP_n
40	4(36.0) + 1(100.8) = 244.8 K	W14x43	447
34	10(34.7) + 100.8 = 447.8 K	W14x48	509
28	447.8 + 6(34.7) = 656 K	W14x61	700
22	656 + 6(34.7) = 864.2	W14x82	942
16	864.2 + 6(34.7) = 1072.4	W14x90	1120
10	1072.4 + 6(34.7) = 1280.6	W14x109	1365
3	1280.6 + 7(34.7) = 1523.5	W14x132	1640

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GIRDER SLAB

COLUMNS – EXTERIOR
A_T = 15' × 1/2 · 20' = 150SF

LOADS:
FLOOR: DEAD – 15+60 = 75
LIVE –
REDUCTION

FLR	$L = L_o\left(0.25 + \frac{15}{\sqrt{A_T K_{LL}}}\right)$	w_u	P_u
40	0.68 L_o	135.5	20
34	0.52 L_o	123.3	18.5
28	0.47 L_o	120.1	18
22	0.43 L_o	117.5	17.6
16	0.41 L_o	116.2	17.4
10	0.4 L_o	115.4	17.3
3	0.4 L_o	115.4	17.3

ROOF – w_u = 336
P_u = 50.4

WALL: w_D = 15(0.75)(15) = 176.9
w_u = 1.2(176.9) = 2.41k

FLOOR	LOAD	COLUMN	ϕP_n
40	50.4 + 4(20+2.4) = 140	W14×43	447
34	50.4 + (10)(18.5+2.4) = 259.4	W14×43	447
28	50.4 + 16(18+2.4) = 376.8	W14×43	447
22	50.4 + 22(17.6+2.4) = 470.4	W14×53	557
16	50.4 + 28(17.4+2.4) = 604.8	W14×61	704
10	50.4 + 34(17.3+2.4) = 720.2	W14×68	781
3	50.4 + 41(17.3+2.4) = 857.8	W14×82	942

Appendix 2 – Girder-Slab

Cost Analysis

Beams	Length	Cost Per Linear Foot	Amount	Total Cost
DB-8x35	15	$75.25	8	$9,030.00

Precast Plank	Cost Per Square Foot	Square Feet	Cost
8" x 96"	$10.20	1953	$19,920.60

Grout	Length	Area	Cubic FT	Cost/CF	Total Cost
	120	1.33	159.99996	$10.00	$1,600.00

Estimated Total Cost	$30,551
Cost Per Square Foot	**$15.64**
Total Cost	**$34,414,398**

Column Designs

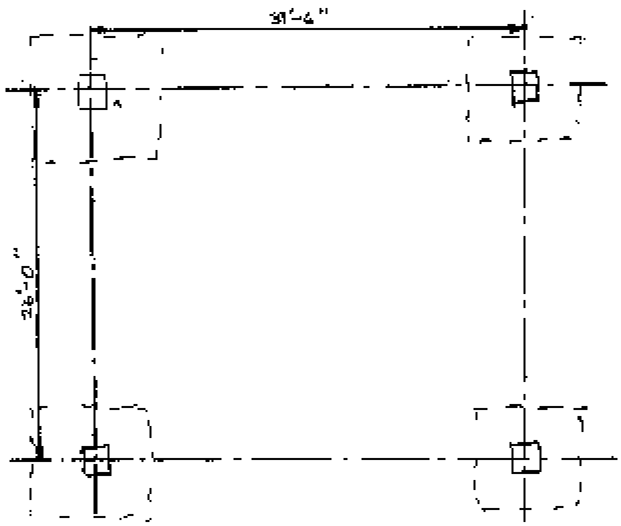
Floor	Interior	Exterior
40 - 43	W14x43	W14x43
34 - 40	W14x48	W14x43
28 - 34	W14x61	W14x43
22 -28	W14x82	W14x53
16 - 22	W14x90	W14x61
16 - 10	W14x109	W14x68
3 - 10	**W14x132**	**W14x82**

Appendix 3 – Two-Way Flat Plate with Drop Panels

Calculations

AE481 | TECH ASSIGNMENT TWO | C. SHIPPER | 1/5

TWO WAY CONCRETE FLAT SLAB



SLAB THICKNESS
ASSUME DROP PANEL
$t_{min} = \frac{(31.5 - \frac{20}{12})(12)}{36} = 9.47"$

USE $t = 10"$

DROP PANEL $- \frac{l_1}{6} = \frac{26}{6} = 4.3'$

$\frac{l_2}{6} = \frac{31.5}{6} = 5.25$

USE 12 x 10 DP
$t_{dp} = 2.5"$
$t = 10 + 2.5 = 12.5"$

COLUMNS

$A_{T,int} = (31.5)(\frac{26+17}{2}) = 677.3$ SF

$A_{T,ext} = (31.5)(\frac{17}{2}) = 268$ SF

FLOOR LOADS: DEAD – SUPERIMPOSED = 35 PSF
– SLAB
$t = 10"$ $\frac{10}{12} \times 145 = 121$ PSF

LIVE – 40 PSF

$w_u = 1.2(121 + 15) + 1.6(40) = 227$ PSF

ROOF LOADS: DEAD – SAME

LIVE – 150 PSF FOR MECH + OCCUPANCY

CHECK COL. SIZE @ LEVEL 3 (START OF TOWER)

$L_o = 40$ PSF

$L = L_o\left(0.25 + \frac{15}{\sqrt{K_{LL}A_T}}\right) = L_o\left(0.25 + \frac{15}{\sqrt{4(677.3)\times 40}}\right) = 0.36L_o \leq 0.4L_o$

$\therefore L = 0.4L_o$

$= 0.4(40) = 16$ PSF

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TWO WAY CONCRETE FLAT SLAB

FACTORED LOAD @ LEVEL 3 (1ST COLUMNS)

FLOOR: $1.2(15+121) + 1.6(16) = 188.8$ psf $\times 677.3$ sf $= 127.9$ kips / flr

ROOF: $1.2(121) + 1.6(150) = 342 \times 677.3 = 260.9$ K

$\therefore P_u = 127.9 \times 41$ flrs $+ 266.9 = 5504.8$ kips

SIZE COLUMN – ASSUME COL. ACTS AS SHORT COLUMN
– FOR EFFICIENCY USE SQUARE SECTION

$\phi P_n = 0.8\phi[0.85 f'_c (A_g - A_{st}) + f_y A_{st}]$ FIND A_g

$A_{st} = \rho A_g$ ASSUME $\rho = 0.04$

$\phi P_n \geq 5504.8 \times 10^3 = 0.8(0.65)[0.85(9000)(A_g - 0.04 A_g) + 0.04 A_g (60000)]$

$5504800 = 3818.88 A_g + 1248 A_g$ $A_g = 1086.4$ in^2 $= 33'' \times 33''$ ← PRETTY BIG

TRY $\rho = 0.05$

$5504800 = 0.8(0.65)[0.85(9000)(A_g - 0.05 A_g) + 0.5 A_g 60000]$

$5504800 = 3779.1 A_g + 1560 A_g$ $A_g = 1031$ in^2 $= 32 \times 32$

TRY $\rho = \rho_{max} = 0.06$

$5504800 = 0.8(0.65)[0.85(9000)(A_g - 0.06 A_g) + 0.06 A_g 60000]$

$5504800 = 5611.3 A_g$ $A_g = 981$ in^2 $\rightarrow 31 \times 32$

SPIRAL TIES?

$5504800 = 0.8(0.70)[0.85(9000)(A_g - 0.6 A_g) + 0.6 A_g (60000)]$

$5504800 = (4737.6 + 2016) A_g$ $A_g = 815.1$ in^2 $= 28 \times 29$

* TO JUSTIFY SPIRAL TIES, MUST ANALYZE SAVED CONCRETE MATERIAL PLUS INCREASED COST FOR SPIRAL REINFORCEMENT.

FOR TIME BEING – ASSUME NORMAL TIES
USE $\rho = 0.06$
31 × 32 COLUMNS.

[redacted]

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TWO-WAY CONCRETE FLAT SLABS

EXTERIOR COLUMN

$A_{TRIB} = (2' + \frac{17}{2})(31.5) = 330$ SF

$L = L_0 \left(0.25 + \frac{15}{\sqrt{K_{LL} A_T}}\right) = \left(0.25 + \frac{15}{\sqrt{2(330.8)41}}\right) L_0 = 0.34 L_0 < 0.4 L_0$

FLOOR LOAD : $[1.2(18+121) + 1.6(40)]\,330.8 = 62.5^K$ / floor

ROOF LOAD : $(1.2(121) + 1.6(150))\,330.8 = 127.4$ K

WALL LOAD : $(1.2(8.75')(31.5')(15\,psf)) = 5.0^K$ / flr

$P_u = 127.4 + 41(62.5 + 5) = 2894.9$ KIPS $\leq \phi P_n$

$2894900 = 0.8(0.65)[0.85(7000)(0.94A_g) + 0.06A_g(60000)]$

$2894900 = 5962.0 A_g \qquad A_g = 485.6\ in^2 = 22 \times 22''$

SLAB MOMENTS – INTERIOR SPAN

$w_u = 1.2(18 + 121) + 1.6(40) = 227$ PSF

SHORT DIRECTION – $M_o = \frac{.227(31.5)(26 - \frac{31}{12})^2}{8} = 490.1$ KFT

LON DIRECTION – $M_o = \frac{.227(26)(31.5 - \frac{32}{12})^2}{8} = 616.9$ KFT

\# 6 BARS
$d = 10 - 0.75 - 0.375$
$= 8.875$

DISTRIBUTE MOMENT AND DESIGN STEEL

LONG DIRECTION

$M^- = 0.65(616.9) = 401$ KFT CS GETS 75%

$M^+ = 0.35(616.9) = 216$ KFT MS GETS 60%

ITEM	DESCRIPTION	M^-_{CS}	M^-_{MS}	M^+_{CS}	M^+_{MS}
1	MOMENT	301	101	130	87
2	WIDTH	156	156	156	156
3	DEPTH	8.875	8.875	8.875	8.875
4	$M_n = M_u/\phi$	335	113	145	97
5	$R = M_n/bd^2$	328	111	142	95
6	ρ	0.0057	0.002	0.0025	0.0018
7	$A_s = \rho bd$	7.89	2.77	3.46	2.49
8	$A_{s,min} = 0.0018bt$	3.12	3.12	3.12	3.12
9	$N = A_s/A_{s,bar}$	18	8	8	8
10	$N_{min} = w/2t$	8	8	8	8

NEGATIVE MOMENT CS – (18) #6 BARS
MS – (8) #6 BARS

POSITIVE MOMENT CS – (8) #6 BARS
MS – (8) #6 BARS

[redacted]

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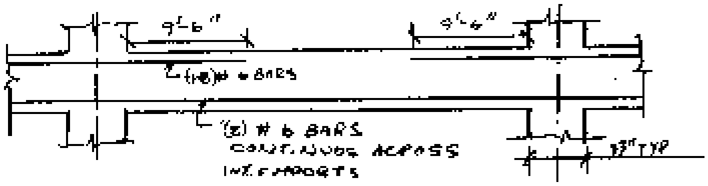
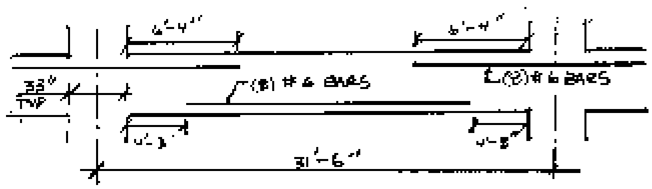
TWO-WAY CONCRETE FLAT SLABS

REINFORCEMENT LOCATION & CUTOFF

* COLUMN STRIP



* MIDDLE STRIP



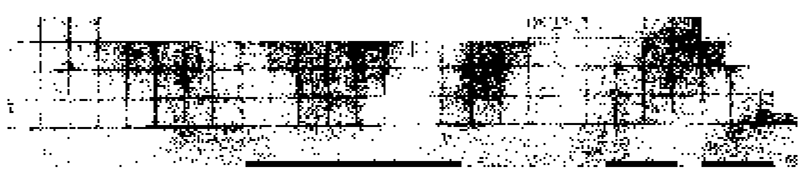
SHORT DIRECTION

$M^- = 0.65(490) = 319$ $M^+ = 0.35(490) = 172$ $d = 10 - .75 - 6/8 - 6/16 = 8.125$

ITEM	DESCRIPTION	M^-_{cs}	M^-_{ms}	M^+_{cs}	M^+_{ms}
1	MOMENT	240	60	104	69
2	WIDTH	189	189	189	189
3	DEPTH	8.125	8.125	8.125	8.125
4	$M_n = M_u/\phi$	267	89	116	77
5	$R_n = M_n/bd^2$	257	80	112	74
6	ρ	0.0045	0.0015	0.0022	0.0013
7	$A_s = \rho bd$	6.91	2.30	3.07	2.00
8	$A_{s,min} = 0.0018bt$	3.78	3.78	3.78	3.78
9	$N = A_s/A_{bar}$	16	9	9	9
10	$N_{min} = w/2t$	10	10	10	10

NEGATIVE MOMENT CS – (16) # 6 BARS
MS – (10) # 6 BARS

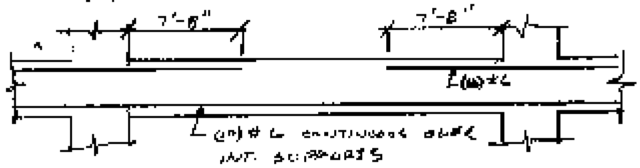
POSITIVE MOMENT CS – (10) # 6 BARS
MS – (10) # 6 BARS



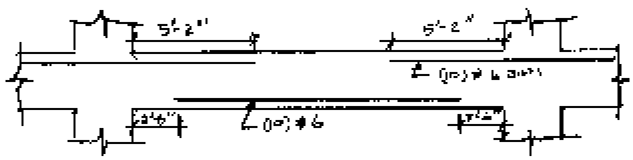
TWO WAY CONCRETE FLAT SLAB

REINFORCEMENT LOCATION & CUTOFF – SHORT DIRECTION

- COLUMN STRIP



- MIDDLE STRIP



SHEAR – PUNCHING

$V_u = (31.5')\left(\frac{26+17}{2}\right) \times 251.2\,psf + (10)(10)\frac{2.5}{12}(145)\frac{1}{1000} \times 2 = 173.8\,k$

$V_c = 4\sqrt{f'_c}\,b_o d$ $\qquad d = 12 - 0.75 - 6/8 = 10.5$

$b_o = 4(33 + \frac{10.5}{2}) = 153''$

$V_c = 4\sqrt{5000}\,(153)(10.5) = 454\,k >> 173.8\,k$ ok

SHEAR DUE TO TENSION DIAG CRACKS

$V_u = \frac{wl}{2} = \frac{(251.2)}{1000} \times \frac{31.5 \times 26}{2} = 102.9$ kips

$V_c = 2\sqrt{f'_c}\,bd = 2\sqrt{6000}\cdot 156(8.5) = 187.5$ kips ok.

Appendix 3 – Two-Way Flat Plate with Drop Panels

Cost Analysis

Concrete	Square Feet	Cubic Yards	Material Cost Per Cubic Yard	Labor Cost Per Cubic Yard	Total Cost
	1953	31.6	$120.00	$25.50	$4,604.47

Reinforcing	Tons	Cost per Ton	Total Cost
Mild Steel, # 6 Bars	4.74	$1,875.00	$8,887.50

Forms	SF	Cost Per Square Foot	Total Cost
Metal	1953	$8.75	$17,088.75

Estimated Total Cost	$30,581
Cost Per Square Foot	$15.66
Total Cost	$34,448,326

Appendix 4 – Two-Way Filigree Flat Plate

Calculations

[redacted]

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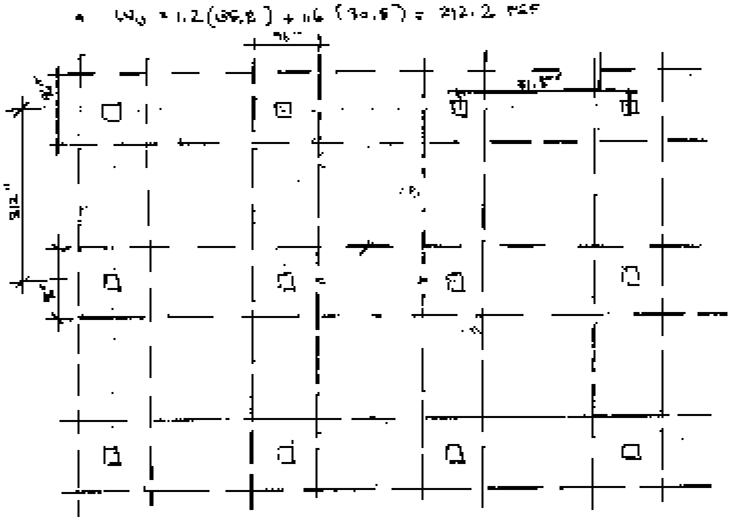
FILIGREE FLOOR SYSTEM

USE 10" SLAB

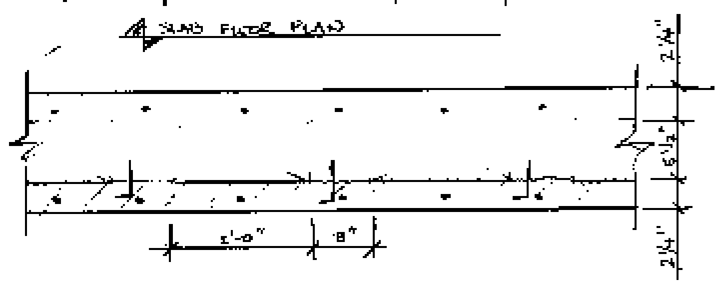
$w_D = 15 + \frac{10}{12} \cdot 145 = 135.8$

$w_{L_o} = 40\,PSF \qquad L = 40\left(0.25 + 15/\sqrt{31.5(26)}\right) \geq 0.77 L_o = 30.8\,PSF$

• $w_u = 1.2(135.8) + 1.6(30.8) = 212.2\,PSF$



SLAB FLOOR PLAN



TYPICAL SLAB SECTION

$w_u = 1.2(135.8) + 1.6(30.8) = 212.2\,PSF$

$M_{o\,short} = \frac{1}{8}(212.2)(31.5)(26 - \frac{30}{12})^2 = 462\,K\text{-}ft$

$M_{o\,long} = \frac{1}{8}(212.2)(26)(31.5 - \frac{30}{12})^2 = 580\,K\text{-}ft$

↳ LONG STEEL PLACED IN PRECAST
SHORT STEEL ON TOP

[redacted]

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FILIGREE FLOOR SYSTEM

LOAD DIRECTION

A_s, bottom is in precast panel

$M_u^- = 0.65(580) = 377$

$M_u^+ = 0.35(580) = 203$

t = 10"

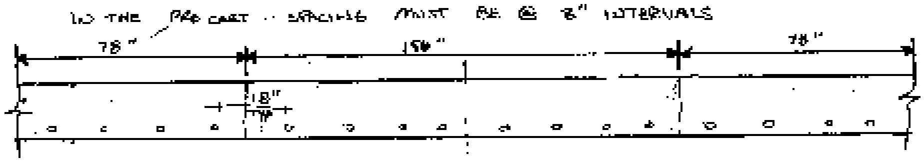
d = 10" − 0.75 −

Column strip gets 0.75 middle strip gets 25% (neg. mom.)

C.S. gets 60% MS gets 40% (pos. mom)

ITEM	DESCRIPTION	$M_{u\,cs}^-$	$M_{u\,cs}^+$	$M_{u\,ms}^-$	$M_{u\,ms}^+$
1	MOMENT	283	122	95	82
2	WIDTH	156	156	156	156
3	DEPTH	8.875	8.875	8.875	8.875
4	M_n	315	136	106	92
5	$R_n = M_n/bd^2$	308	133	104	90
6	ρ	0.0058	0.0023	0.0018	0.0015
7	$A = \rho bd$	8.03	3.18	2.49	2.08
8	$A_{s\,min}$ = 0.0018bt	3.12	3.12	3.12	3.12
9	$N = A_s/A_{bar}$	19	8	8	8
10	N_{max} = w/2t	8	8	8	8

In the precast spacing must be @ 3" intervals



Bottom steel must be spaced @ factor of 3 spacing per manufacturer specs.

CS: 8 bars − $\frac{156}{8} = 19.5"$ space at 18"

MS: 8 bars − $\frac{156}{8}$ → use 18" spacing

Top stl not governed by 3" increment − spaced @ req'd

CS gets 19 #6

MS gets 8 #6

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FILIGREE FLOOR SYSTEM

SHORT DIRECTION

BOTTOM STEEL IS NOT IN PRECAST PLANK, MUST ON ON TOP

$d_{bottom} = 10 - 2\frac{1}{4} - \frac{6}{16} = 7.375''$

$* d_{top} = 10 - 0.75 - \frac{4}{8} - \frac{6}{16} = 8.125''$

$M_o = 365$ k-ft

$M^- = 238$ k-ft — CS - 226 k-ft; MS - 75 k-ft

$M^+ = 128$ k-ft — CS - 97 k-ft; MS - 65 k-ft

ITEM	DESCRIPTION	M^-_{CS}	M^+_{CS}	M^-_{MS}	M^+_{MS}
1	MOMENT	226	97	75	65
2	WIDTH	189	189	189	189
3	DEPTH	8.125	7.375	8.125	7.375
4	M_u	252	108	84	75
5	$R_n = M_u/bd^2$	243	126	81	86
6	ρ	0.0043	0.0023	0.0015	0.0015
7	$A = \rho bd$	6.60	3.21	2.30	2.09
8	$A_{s,min} = 0.0018bh$	3.78	3.78	3.78	3.78
9	$N = A_s/A_{bar}$	12	9	9	9
10	$N_{min} = W/2t$	10	10	10	10

M^- CS – USE (12) #6; MS USE (10) #6

M^+ CS – USE (10) #6; MS – USE (10) #6

Appendix 4 – Two-Way Filigree Flat Plate

Cost Analysis

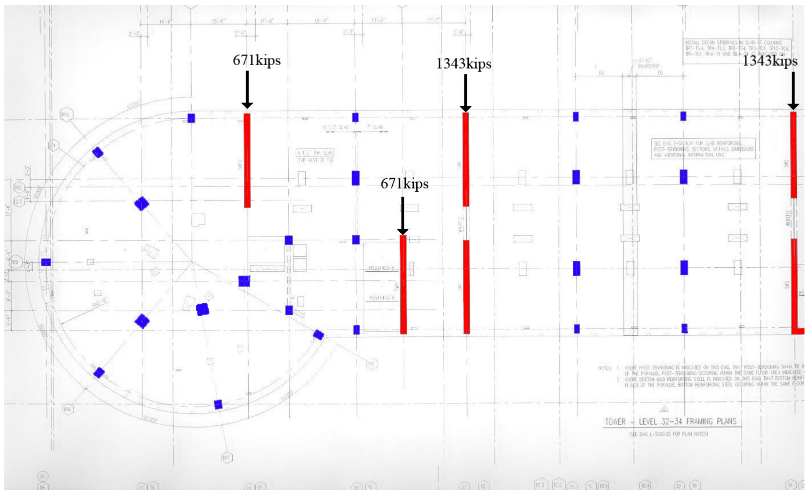
Precast Planks	SF	Cost/SF	Total Cost
	1953	$7.09	$13846.77

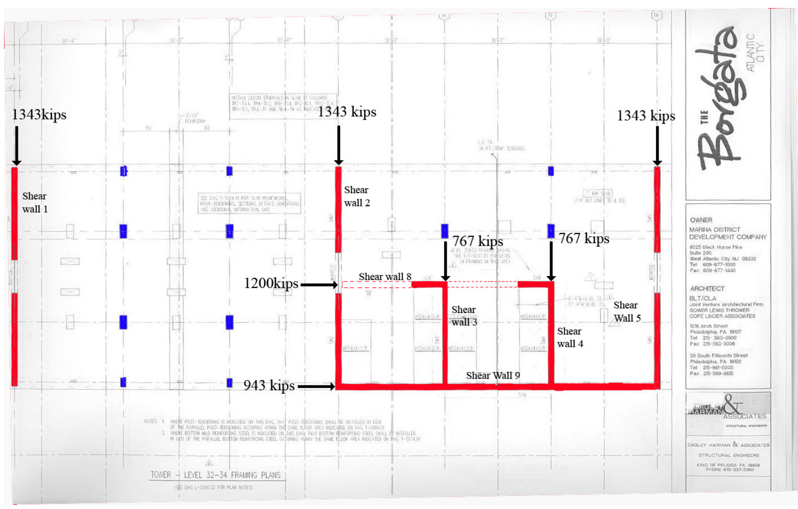
Concrete Topping	CY	Material Cost (PCY)	Labor Cost(PCY)	Total Cost
	48.222	$120.00	$25.50	$7016.30

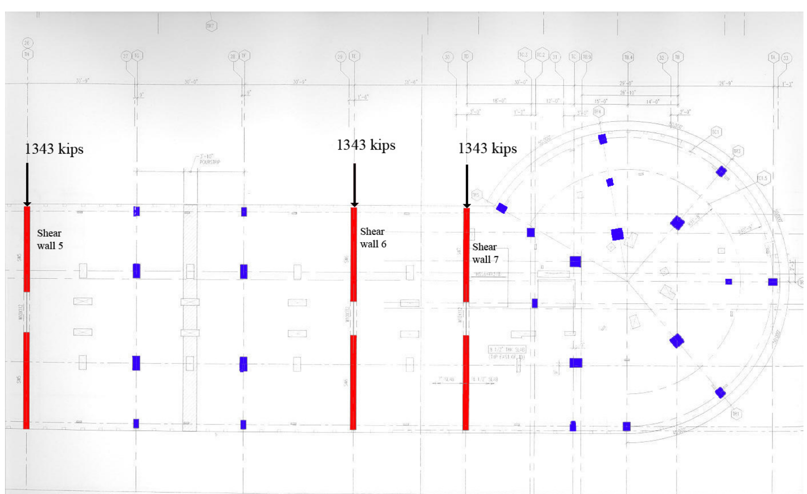
Reinforcing	Tons	Cost/Ton	Total Cost
	5.08	$1875.00	$9525.00

Estimated Cost	$30,388
Cost Per Square Foot	$15.56
Total Cost	$34,231,314

Appendix 5 – Building Floor Plan







Appendix 6 – References and Design Aides

Girder-Slab System Design Guide V1.3, Girder-Slab Technologies, LLC. www.Girder-Slab.com

RAM Structural System, Bentley Systems, Inc.

ACI 318-05, American Concrete Institute

AISC Manual of Steel Construction, Thirteenth Edition American Institute of Steel Construction