Biobehavioral Health Building

University Park, PA

Tech 2 Report: Pro-Con Structural Study of Alternate Floor Systems

2012-2013 AE Senior Thesis

Rendering provided by BCJ

Daniel Bodde

Structural Option

Advisor: Heather Sustersic

10/12/2012

Table of Contents

Executive Summary

The following technical report was written to compare various alternate floor systems for the Biobehavioral Health Building. Through the use of various tools and calculations, preliminary sizes were developed and summarized in the report. Such things as deflections, system depth, cost, constructability, etc. were calculated so to provide an easy comparison between the systems. All of the construction documents were provided by Massaro CMS Services.

In this report the follow floor systems were looked at:

1. Composite slab, beam, and girder system (existing)
2. Hollow core precast planks
3. One way concrete slab with interior beams
4. Two way concrete slab with drop panels

All of the systems led in at least one category that was used for comparison. For example the hollow core system is the easiest when it came to constructability but it also had the deepest system at 42". For this reason it is an unlikely candidate for a flooring system. As for the other systems they all seemed to be very plausible.

Building Introduction

Located on the campus of the Pennsylvania State University in University Park, Pennsylvania is the Biobehavior Health Building (Figure 1). It is currently under construction and is scheduled to be finish in November 2012. When completed, it will house faculty and graduate students from the College of Health and Human Development. The overall project cost is approximately $40,000,000 and is being funded by the Pennsylvania Department of General Services. The BBH Building is comprised of 5 stories above grade (including a penthouse) and has a full basement 100% below grade.

The BBH Building was designed to blend with that existing architecture that surrounds it. The majority of the façade was designed to mimic Henderson North's Georgian style architecture with its large amount of hand placed brick and limestone. On the northeast portion of the building the design is more modern to replicate HUB, which is a popular student hang out. Since a portion of the BBH building protruded into the HUB Lawn, which is a popular student hangout, a terrace has been provided (Figure 2). Not only does this offer a relaxing place for students to lounge but it will also be used as a stage for future concerts. A majority of the interior space is made up of offices and conference rooms that will house faculty and graduate students from the College of Health and Human Development. One of the key interior spaces is the lecture hall, which is located on the ground floor directly below the HUB lawn terrace. It is able to seat up to 200 people and has a ceiling designed to absorb any sounds or vibrations coming from the terrace above.

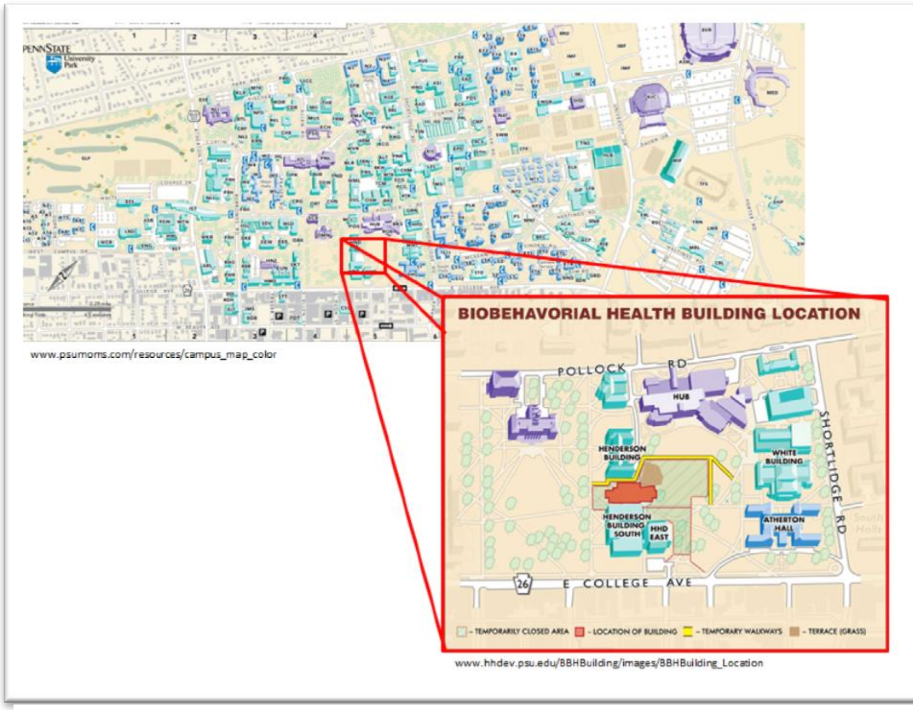


Figure 1: PSU Campus Map

Figure 2: Rendered View from HUB Lawn

Structural Overview

Foundation

CMT Laboratories, Inc. were the geotechnical engineers hired to investigate the soil conditions on which the BBH building was to be placed. In order to better understand the soil located on the site, CMT Laboratories took six test boring samples. With the information gathered from the test borings they were able develop recommendations for the structure below grade.

It was recommended that the foundations bear on sound dolomite bedrock. Accordiong the the geotechnical engineer, "the bedrock must be free of clay seams or voids near the surface to provide a stable surface to place the foundations." If bedrock is encountered before the required bearing elevations are met then over excavation is required and needed to be back filled with lean concrete. The bearing material must have a bearing capacity of 15 psf minimum.

The BBH Building uses a shallow strip and spread footing foundation system. The strip footings are placed under the foundation walls around the perimeter of the building. These footings are at an elevation of -15' and step down to -21' around the lecture hall. A typical strip footing is 30" and 18" deep as shown in Figure 3. Normal weight concrete is used for all footings and must have minimum compressive 28 day strength of 4 ksi.

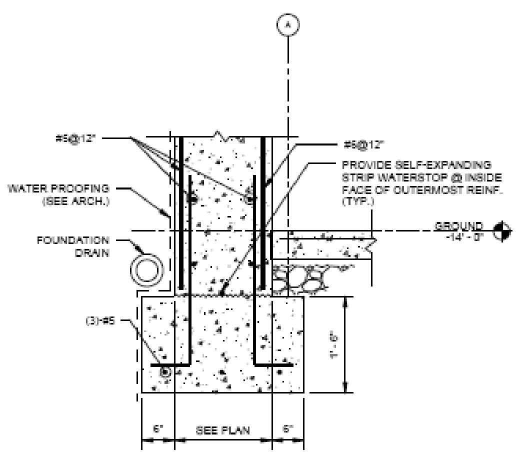


Figure 3: Typical Strip Footing

Floor/Framing System

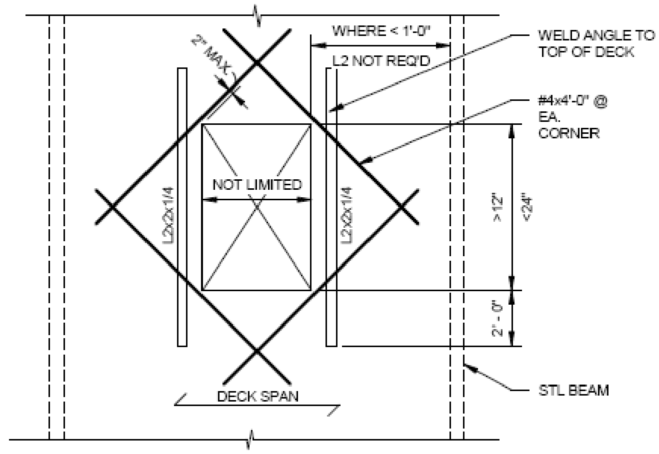


Figure 4: Openings in Slab on Steel Deck

The BBH Building floors are concrete slab on metal deck. The typical slab on deck consists of 3 ¼" light weight concrete on 3" 18 gage galvanized composite steel deck that is reinforced with 6"x6" W2.0xW2.0 welded wire fabric. Any deck opening that cuts through more than two deck webs needed to be reinforced. This was typically done with 4' long #4 rebar place at each corner as shown in Figure 4. This is typically done to keep the integrity of the slab and also prevents unwanted cracking in the concrete.

In order to decrease beam depth the BBH building was designed as a composite steel system. Figure 5 shows a typical section through this composite system. ¾" diameter shear studs are welded to the top flange of the beam/girder. The number of shear studs varies per beam/girder. The typical floor plan has beams spanning N-S and girder spanning E-W. See Figure 6 for a typical floor plan.

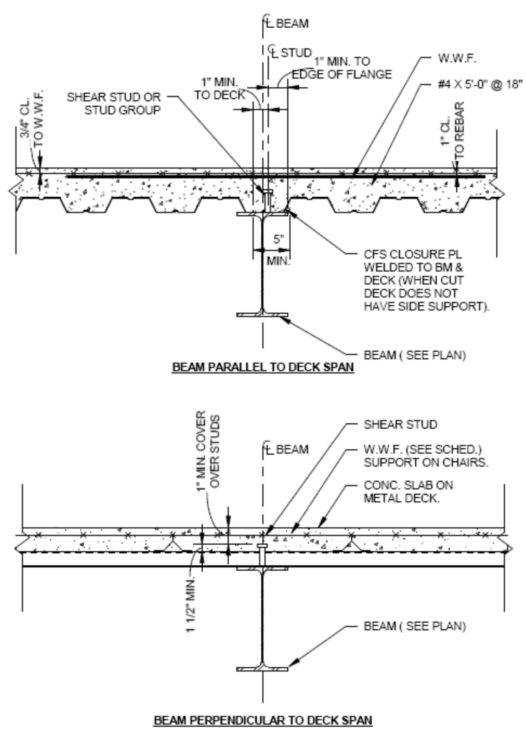


Figure 5: Typical Section Through Composite System

The composite slab supports gravity loads and transfers that load to the beams. The beams then transfer the load to the girders, which transfer the load to the columns. Finally the load is terminated at the foundations.

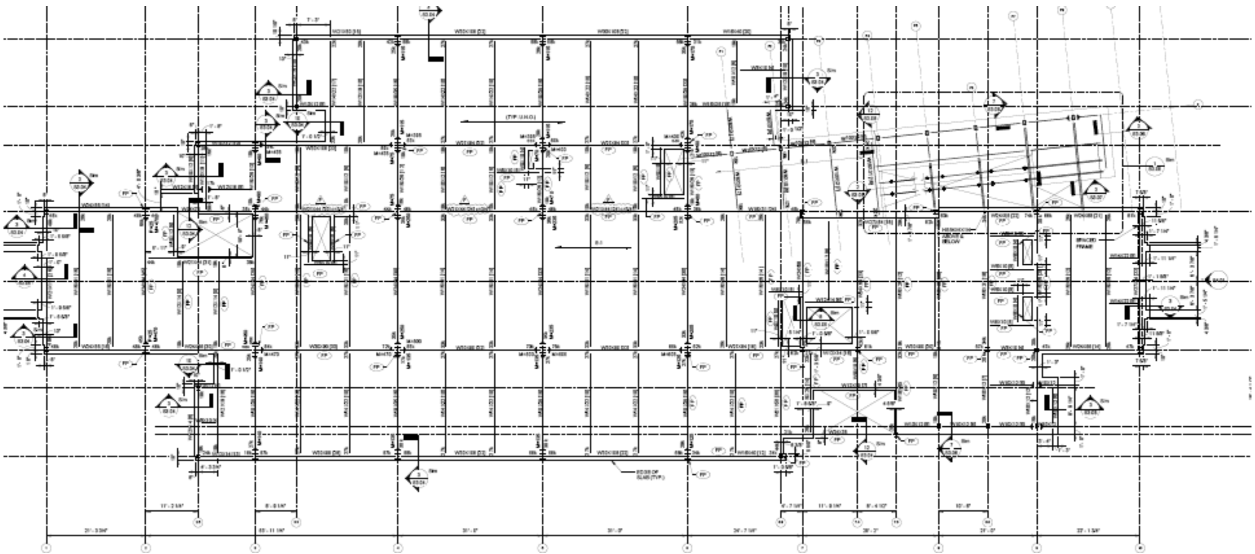


Figure 6: Typical Floor Framing Plan

Lateral System

The BBH Building uses two types of lateral force resisting systems, moment frames and an eccentric braced frame. These systems are used to resist lateral forces placed on the structure due to wind and seismic loads.

The moment frames are in both the N-S and E-W direction. Frames resisting N-S loads go from column line 2 to column line 6. Frames resisting E-W loads are only located along column lines B and D. This type of system is use on every level above grade. These moment frames are accomplished by designing a rigid connection between the beams and columns. A rigid connection is created by welding the top and bottom flange of the beam to the column as shown in Figure 7. Location of the moment connections are shown below in Figure 8. Because the east wing of the BBH Building is exposed to the HUB lawn, it will experience higher wind loads. This could be the reason for using a duel lateral system was used and why it is configured as such (Figure 8).

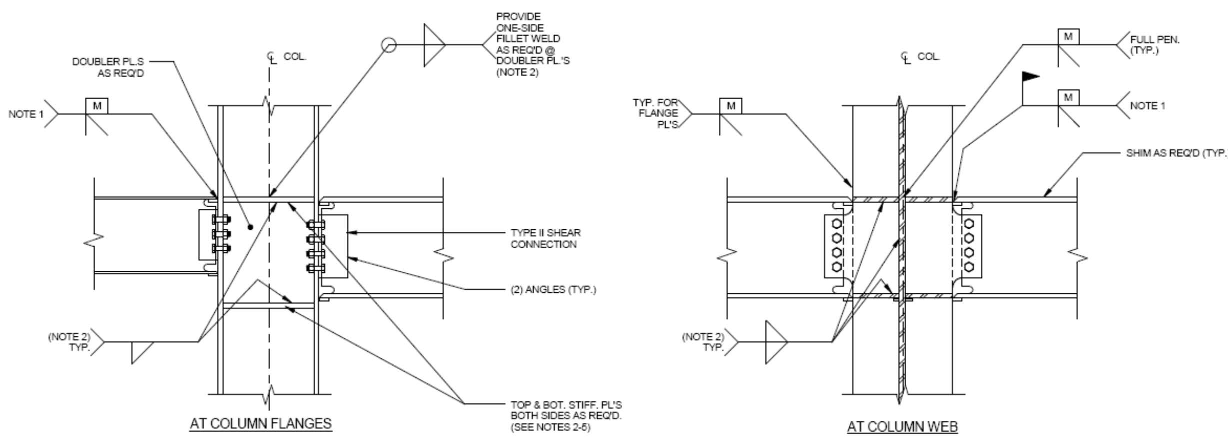


Figure 7: Typical Beam to Column Moment Connection

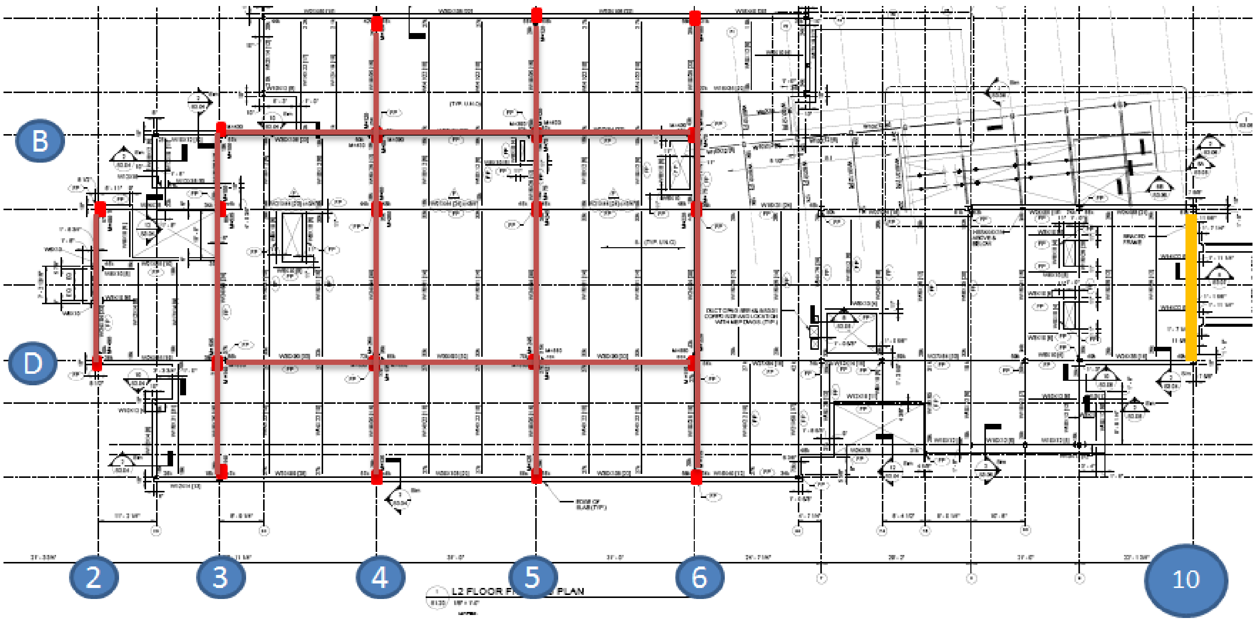


Figure 8: Location of Moment Connections (Red) and Braced Frame (Orange)

There is only a single eccentric braced frame in the BBH Building. It is located on the east side of the building along column line 10 (See Figure 8 above). Figure 9 shows the chevron bracing system used. Lateral movement in the frame is resisted through tension and compression in the HSS braces.

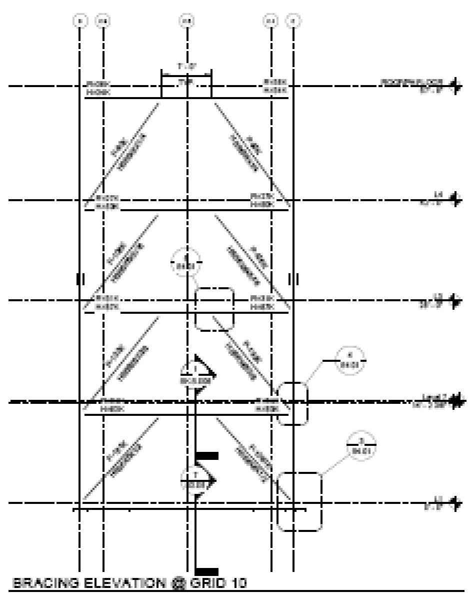


Figure 9: Eccentric Braced Frame

Design Codes

The BBH Building was designed using the following codes:

- IBC 2006 (as amended by Pennsylvania UCC administration)
- ASCE 7-05
- ACI 318-05
- ACI530/ASCE 5
- AISC, 13th Edition

For this thesis the following codes were used in the analysis for the BBH Building:

- AISC, 14th Edition
- ASCE 7-05
- ACI 318-11

Material Properties

Steel	
Wide flange shapes	A992 or A572, fy=50ksi
Square and round steel tubing	ASTM A500, Grade B
Miscellaneous shapes, channels and angles	A36, or A572, fy=50ksi
Round pipes	A53, Grade B, fy=35ksi
Plates	A36, fy=36ksi
Anchor Rods	ASTM F1554, Grade 55
Bolted connections for beams and girders	A325 or F1852, 3/4" diameter
Welded headed shear studs	A108 3/4" diameter
Stainless steel hanger rods	ASTM A564 Type 17-PH fy=50ksi

Concrete	
Type	28 day compressive strength
Foundations	4000 psi
Slabs and beams	4000 psi

Reinforcement	
Deformed Bars	ASTM A615, Grade 60
Welded Reinforcing Steel	ASTMA706 Grade 60
Welded Wire Fabric	ASTM A185

Design Loads

The following design loads given by the designer.

Dead

Dead Loads * (psf)	
Slate roof assembly	32
Green roof assembly	60
Floor, typical	60
Floor, stone tile	85
Plaza (above auditorium)	212
* self-weight of steel framing members not included	

Live

Live Load	Uniform (psf)	Concentrated (lbs)
Offices/Classrooms	80(1)	-
Lobbies/Assembly	100	2000(5)
Corridors, Stair	100	2000(5)
Mechanical Rooms	150(3)	-
Roof	30(2)	-
Plaza	125(4)	-
Assembly (fixed seats)	60	-
Heavy storage	250	2000(5)

1. Includes 20 psf partition load
2. Or Snow Load whichever is greater
3. Used in absence of actual weight of mechanical equipment
4. Used for roof over lecture Hall
5. Concentrated load shall be uniformly distributed over a 2.5 sq ft area and shall be located so as to produce maximum load effects in the structural members

Snow

The calculations for the design snow load can be found in Appendix A. The drift load was designed for the penthouse green roof as that is where the most drift would accumulate.

Snow Load Type	Uniform (psf)
Flat Roof Load	21
Sloped Roof Load	24
Drift Load	89.5

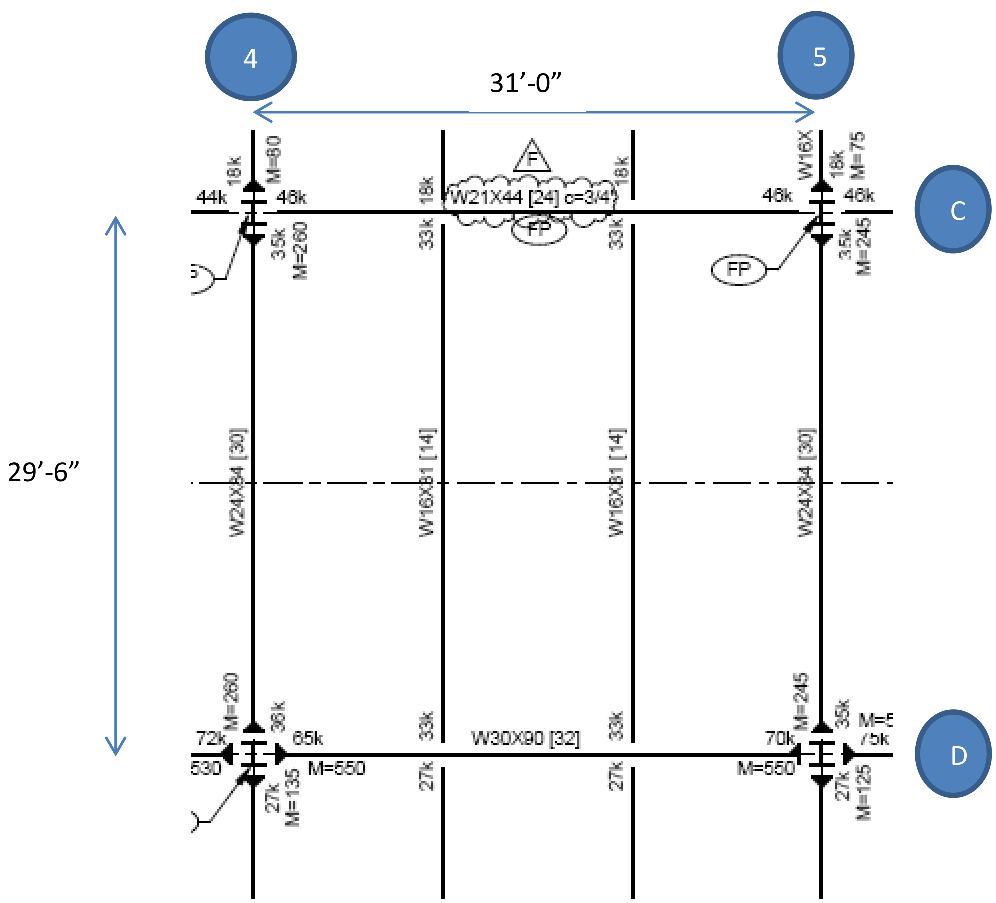
Alternative Floor Systems

In the text to follow, this tech report will provide a brief description of four different types of floor systems. These systems will be analyzed and designed for a typical by in the BBH building. From this a list of pros and cons can be established for each system which will allow for an adequate comparison between the different types of systems.

The following floor systems chosen to be analyzed for the BBH building:

1. Existing System: Composite slab, beam, and girder
2. Alternate System: Hollow core precast planks on steel
3. Alternate System: One way concrete slab with interior beams
4. Alternate System: Two way concrete slab with drop panels

Below is the typical bay used for this tech report:



Existing Composite Slab, Beam, and Girder System

Description

The BBH building is designed with one of the more common floor systems. The existing system is comprised of 3.25" light weight concrete on 3" 18 gage galvanized composite steel deck. This decking is able to achieve composite action with the beams and girders supporting it through the use of A108 ¾" diameter shear studs that are welded to the steel.

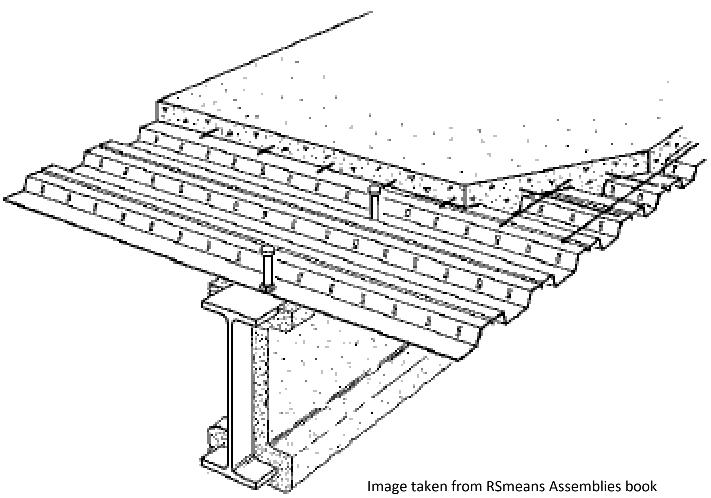


Image taken from RSmeans Assemblies book

A series of spot checks were done to verify that the existing flooring components had adequate strength to support the dead and live loads applied to it. Overall the system came to have a total depth of 27.25" and weighed approximately 53 psf. A rough estimate was done with the use of RSmeans Assembly Components to find an average cost of $22.01 per square foot.

Pros

One of the advantages of this system is that it is very light weight per square foot. This allows for the use of long spans, which are favorable among most architects. Composite action allows the total system depth to decrease by using the strengths of concrete and steel (concrete being good in compression and steel being good in tension). Overall this system is fairly easy a far as constructability goes.

Cons

A composite system can become expensive due to the large amount of welding of the shear studs that has to take place. Also, having a light weight system can cause the floor to be sensitive to vibrations. Fire proofing will need to be applied to the steel members to meet the fire rating of the BBH building.

Hollow Core Precast Planks on Steel

Description

The first alternate system evaluated for the BBH building was the use of hollow core precast planks that sit on steel wide flange girders. These precast planks span N-S across the whole bay. Nitterhouse Concrete precast charts were used in the sizing of the planks. It was found that a 10" x 4' hollow core plank with 2" topping and 7.5" diameter strand pattern would be able to support the loads applied.

The girders had to be designed to support this new flooring system. Assuming the girder was simply supported, a W30 x 116 was found fit to support the planks. Even though a shallower wide flange girder could have been used, it was determined that the W30 was a more economical choice. Overall the system came to have a total depth of 42" and weighed approximately 96.9 psf. A rough estimate was done with the use of RSmeans Assembly Components to find an average cost of $25.64 per square foot.

Pros

The biggest advantage to using this system is that the planks are made of site and shipped ready to be place on the structure. This eliminates curing time that usually comes with cast in place concrete. As far as constructability goes it is determined to be the easiest of the four systems.

Cons

With the increase in weight it is possible that the foundations might have to be resized, which can drive the already high square footage cost up. Also, this system is shown to be significantly deeper than that of the existing. This would cause either an increase in building height or a smaller above ceiling area for MEP piping/duct work. For these reasons this is an unlikely candidate for an alternate floor system.

Prestressed Concrete
10"x4'-0" Hollow Core Plank

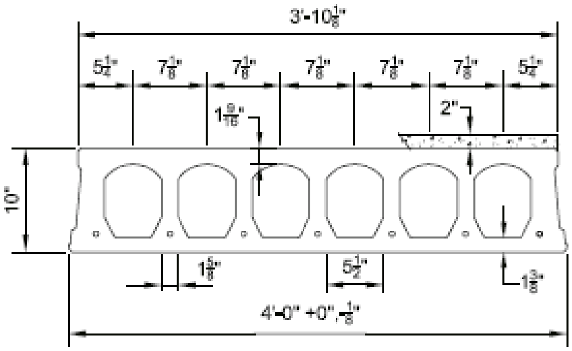
2 Hour Fire Resistance Rating With 2" Topping

PHYSICAL PROPERTIES
Composite Section

A_c = 327 in.^{2}	Precast b_w = 13.13 in.
I_c = 5102 in.^{4}	Precast S_{bcp} = 824 in.^{3}
Y_{bcp} = 6.19 in.	Topping S_{tct} = 1242 in.^{3}
Y_{tcp} = 3.81 in.	Precast S_{tcp} = 1340 in.^{3}
Y_{tcp} = 5.81 in.	Precast Wt. = 272 PLF
	Precast Wt. = 68.00 PSF

DESIGN DATA

1. Precast Strength @ 28 days = 6000 PSI
2. Precast Strength @ release = 3500 PSI
3. Precast Density = 150 PCF
4. Strand = 1/2"Ø and 0.6"Ø 270K Lo-Relaxation.
5. Strand Height = 1.75 in.
6. Ultimate moment capacity (when fully developed)...
   6-1/2"Ø, 270K = 168.1 k-ft at 60% jacking force
   7-1/2"Ø, 270K = 191.7 k-ft at 60% jacking force



7. Maximum bottom tensile stress is $10\sqrt{f'c}$ = 775 PSI
8. All superimposed load is treated as live load in the strength analysis of flexure and shear.
9. Flexural strength capacity is based on stress/strain strand relationships.
10. Deflection limits were not considered when determining allowable loads in this table.
11. Topping Strength @ 28 days = 3000 PSI. Topping Weight = 25 PSF.
12. These tables are based upon the topping having a uniform 2" thickness over the entire span. A lesser thickness might occur if camber is not taken into account during design, thus reducing the load capacity.
13. Load values to the left of the solid line are controlled by ultimate shear strength.
14. Load values to the right are controlled by ultimate flexural strength or fire endurance limits.
15. Load values may be different for IBC 2000 & ACI 318-99. Load tables are available upon request.
16. Camber is inherent in all prestressed hollow core slabs and is a function of the amount of eccentric prestressing force needed to carry the superimposed design loads along with a number of other variables. Because prediction of camber is based on empirical formulas it is at best an estimate, with the actual camber usually higher than calculated values.

SAFE SUPERIMPOSED SERVICE LOADS — IBC 2006 & ACI 318-05 (1.2 D + 1.6 L)

Strand Pattern		SPAN (FEET)																		
		26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
6 - 1/2"ø	LOAD (PSF)	202	181	161	144	128	114	101	90	79	69	60	52	45	38					
7 - 1/2"ø	LOAD (PSF)	246	222	200	180	162	146	131	118	105	94	84	74	66	58					

NITTERHOUSE
CONCRETE PRODUCTS

2655 Molly Pitcher Hwy. South, Box N
Chambersburg, PA 17202-9203
717-267-4505 Fax 717-267-4518

This table is for simple spans and uniform loads. Design data for any of these span-load conditions is available on request. Individual designs may be furnished to satisfy unusual conditions of heavy loads, concentrated loads, cantilevers, flange or stem openings and narrow widths. The allowable loads shown in this table reflect a 2 Hour & 0 Minute fire resistance rating.

11/03/08

10F2.0T

One Way Concrete Slab with Interior Beams

Description

The second alternate system evaluated for the BBH building is a one way concrete slab with interior beams. The concrete slab spans east to west and is supported by beams that span north to south. In the design of this system, provisions from ACI 318-11 were used. Overall the system came to have a total depth of 26.5" and weighed approximately 136.4 psf. A rough estimate was done with the use of RSmeans Assembly Components to find an average cost of $20.31 per square foot. For simplicity in design, the beam was assumed to be simply supported on both sides. Max moments for the girder were found using STAAD. See Appendix C for calculations.

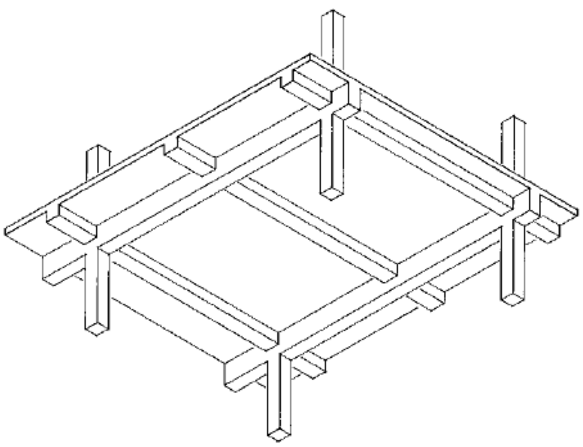


Image taken from RSmeans Assemblies book

Pros

This system proved to be the best out of the four when it came to total deflection. Because of the large mass of the system the vibration sensitivity is very low and should not be a concern. Due to the inherent fire resistive properties of concrete, there is no need for fire proofing as it has an adequate fire rating.

Cons

Like in most cast in place concrete systems, there is going to be a long lead time due to the concrete needing to cure to reach full strength. Shoring needs to be used in the construction of the one way system. Also this system is considerably heavier than the existing and will most likely cause the foundations to be increased, which will also drive up the cost.

Two Way Concrete Slab with Drop Panels

Description

The last alternate system evaluated for the BBH building is a two way concrete slab with drop panels. In order to avoid tedious calculations, the CRSI 2008 Design Handbook was use to find a preliminary size of the slab and drop panel along with reinforcement for the column and middle strip. Then spSlab was used to come up with a more precise design of the system. See Appendix D for calculations and results.

Overall the system came to have a total depth of 19.75" and weighed approximately 155 psf. A rough estimate was done with the use of RSmeans Assembly Components to find an average cost of $18.36 per square foot

Pros

The two way system is the cheapest per square foot and also has the least total system depth. Because of the large mass of the system the vibration sensitivity is very low and should not be a concern. Like in the one way slab, the two way slab has inherent fire resistive properties therefore there is no need for fire proofing.

Cons

Also this system is considerably heavier than the existing and will most likely cause the foundations to be increased.

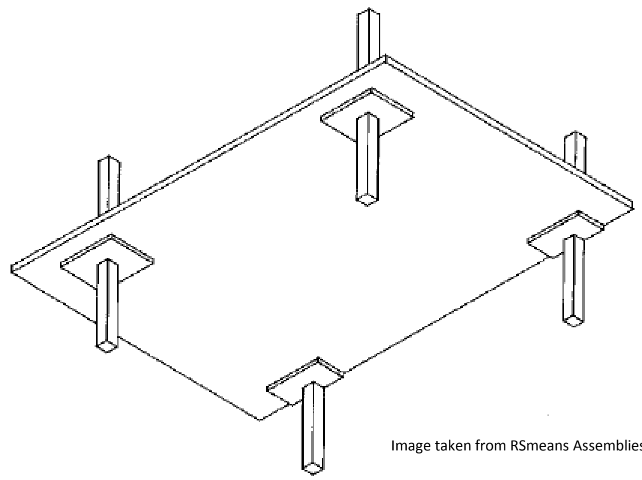


Image taken from RSmeans Assemblies book

Comparison Chart

	Existing Composite Slab, Beam, and Girder	Hollow Core Precast Planks on Steel	One Way Concrete Slab with Interior Beams	Two Way Slab with Drop Panels
Weight	53 psf	96.9 psf	136.4 psf	155 psf
Foundation Impact	n/a	Foundation system needs increased to support larger self weight.	Foundation system needs increased to support larger self weight.	Foundation system needs increased to support larger self weight.
Total System Depth	27.25"	42"	26.5"	19.75"
Cost	$22.01 per sq. ft.	$25.64 per sq. ft.	$20.31 per sq. ft.	$18.36 per sq. ft.
Total Deflection	1.25"	1.12"	0.26"	0.87"
Vibration Sensitivity	Medium	Medium	Low	Low
Constructability	Moderate	Easy	Difficult	Difficult
Viable Option	Yes	Unlikely	Yes	Yes

Conclusion

The process taken in this report gives great insight to how certain systems are considered and then finally chosen for the design of a building. Over the use of several tools and calculations, initial sizes were established and summarized. Such things as deflections, system depth, cost, constructability, etc. were calculated so to provide an easy comparison between the systems.

In this report the follow floor systems were looked at:

1. Composite slab, beam, and girder system (existing)
2. Hollow core precast planks
3. One way concrete slab with interior beams
4. Two way concrete slab with drop panels

All of the systems led in at least one category that was used for comparison. For example the hollow core system is the easiest when it came to constructability but it also had the deepest system at 42”. For this reason it is an unlikely candidate for a flooring system. As for the other systems they all seemed to be very plausible. The two concrete systems could possibly be used in the thesis proposal for a concrete redesign next semester.

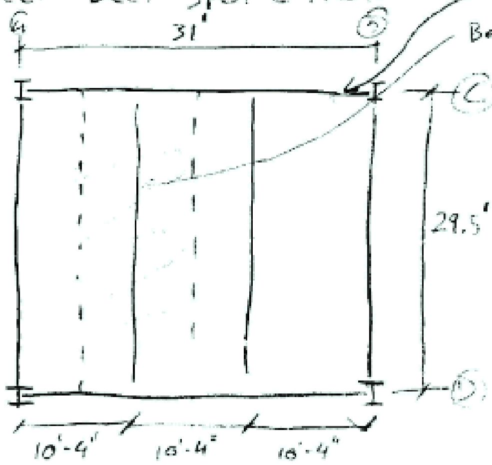
Appendix A: Calculations for Composite System

Daniel Bodde	tech 2	existing	1

Steel Deck spot check

Girder: W21x44 [24] C=3/4

Beam: W14x31 [14]



LW Concrete

Slab: 3 1/4" topping

3 spans (10'-4" Span)

unshored

3" 18GA composite deck

Loads:

LL = 80 psf

SDL = 15 psf

95 psf

2008 Vulcraft

3VLI 18

SDI Max Unshored Clr Span

3 span = 15' > 10'-4" OK

Superimposed LL at 10'-6" < 10'-4" clr span

= 218 psf > 95 psf OK

Existing Steel composite deck works

Daniel Bodde	Tech 2	Existing	2

Beam Spot Check (existing: W 16x31 [14])

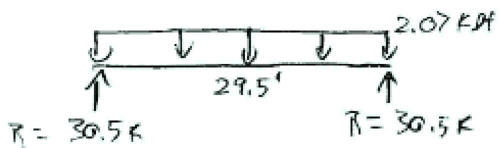
Dead load:

- typical floor DL = 60 psf

Live load:

- office/classrooms LL = 80 psf

$w_u = 1.2(60) + 1.6(80) = 200\text{psf} \times 10.33'/\text{floor} = 2.07 \text{ K/f}$



$M_u = \frac{wl^2}{8} = 225.2 \text{ K-ft}$

$b_{eff} = \min \begin{cases} \frac{(29.5)(12)}{8} = 44.25 \times 2 = 88.5'' \\ \frac{1}{2}(10.33)(12) = 62 \end{cases}$

Q_n (from table 3-21)

- Deck is ⊥ to bm
- assume studs in weak position
- one stud per rib
- 3/4" dia studs
- LW conc w/ f'c = 4 ksi

} $Q_n = 17.2\text{K}$

$Q_n = \min \begin{cases} 17.2\text{K} \\ R_g R_p (28.7) = (1.0)(0.6)(28.7) = 17.2 \end{cases} \quad \therefore Q_n = 17.2\text{K}$

Daniel Bodde | Tech 2 | Existing | 3

Check to see if existing has adequate moment capacity

Say $a = 1.5''$ then $Y2 = 6.25 - \frac{1.5}{2} = 5.5''$

From table 3-19

$\Sigma Q_n = 114$ K & $\phi M_n = 300$ k-ft $> M_u = 225$ k-ft OK

$a = \frac{\Sigma Q_n}{0.85 f'_c b_{eff}} = \frac{114}{(0.85)(4)(88.5)} = 0.38'' < 1.5''$ ∴ OK

# of studs $= \frac{114}{17.2} = 6.63$ round to $7 \times 2 = 14$ studs ✓ OK

Check unshored strength

W16x31 $\phi M_p = 203$ k-ft

$w_u = 1.2\,[60(10.33) + 31] + 1.6(20)(10.33) = 1.11$ klf
(781) (330)

$M_u = \frac{(1.11)(29.5)^2}{8} = 121$ k-ft < 203 k-ft ✓

Check wet conc deflection

$w_{wc} = (48)(10.33) + 31 = .506$ klf $I = 375\text{ in}^4$

$\Delta_{wc} = \frac{(5)(0.506)(29.5)^4(1728)}{384\,(29000)\,(375)} = 0.79$ in

max $\Delta_{wc} = \frac{l}{240} = \frac{(29.5)(12)}{240}$ 1.48'' > 0.79 in ✓

check LL deflection $I_{LB} = 705$ @ $Y = 5.5$ & $Y1 = 3.8''$

$w_{LL} = (80)(10.33) = 0.826$ klf

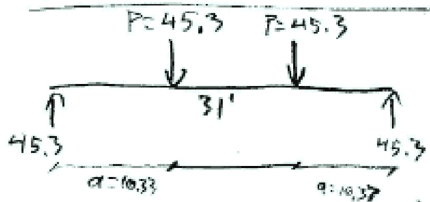
$\Delta_{LL} = \frac{(5)(0.826)(29.5)^4(1728)}{(384)(705)(29000)} = 0.688''$

max $\Delta_{LL} = \frac{l}{360} = \frac{(29.5)(12)}{360} = 0.98'' > 0.688''$ ✓

W16x31 [14] works

Daniel Bodde | Tech 2 | Existing | 4

Spot check Girder: ($W21 \times 44$ [24] c=3/4")



$M_u = P \cdot a = (45.3)(10.33) = 468$ k-ft

$b_{eff} = \min\left\{\frac{(31)(12)}{8} = 46.5,\ \frac{1}{2}(29.5)(12) = 177\right\} + \min\left\{\frac{(31)(12)}{8} = 46.5,\ \frac{1}{2}(14.33)(12) = 86"\right\} = 93"$

Same stud size & location as beam

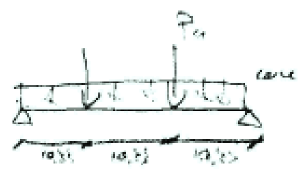
Say a = 2.5 then $Y2 = 6.25 - \frac{2.5}{2} = 5"$

$a = \frac{\Sigma Q_n}{0.85 f'_c b_{eff}} = \frac{163}{(0.85)(4)(93)} = 0.52" < 2.5"$ OK

$\phi M_n = 518$ k-ft $> M_u = 468$ k-ft OK

check unshored strength

$P_u = 16.1$ K (from beam)



$w_u = 1.2(44) = 0.053$ klf

$M_u = \frac{wl^2}{8} + Pa = \frac{(0.053)(31)^2}{8} + (16.1)(10.33)$

$= 173$ k-ft $< \phi M_p = 358$ k-ft ✓

Check LL defl

$I_{LB} = 1460$ in⁴

$\Delta_L = \frac{(8.14)(31)^3(1728)}{28(29000)(1460)} = 0.33$

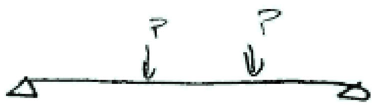
$\max \Delta_{LL} = \frac{31 \times 12}{360} = 1.03" > 0.33"$ ok

Daniel Bodde	Tech 2	Existing	5

Check wet conc def!

$$\Delta_{max} = \frac{l}{240} = \frac{31 \times 12}{240} = 1.55''$$

$$I_x = 843 \text{ in}^4$$

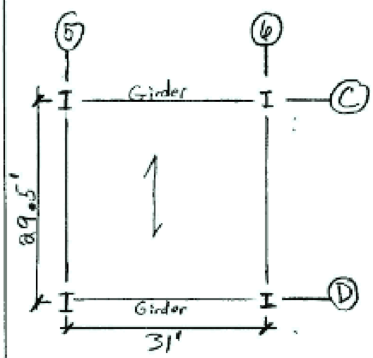


$$P = 7.12 \text{ K}$$

$$\Delta_{wc} = \frac{Pl^3}{28EI} = \frac{(7.12)(31)^3(1728)}{(28)(29000)(843)} = 0.54'' < 1.55'' \text{ OK}$$

Appendix B: Calculations for Hollow Core Precast Planks

Daniel Bodde	Tech 2	Hollow Core Plank	1



SDL: 15 psf

LL: 80 psf

Slf wt: Already included in Nitterhouse precast charts

$w_u = 1.4D + 1.6L$

$= (1.4)(15) + (1.6)(80) = 149\text{ psf}$

@ 30' span

referencing Nitterhouse hollowcore load tables

Use 10" x 4' hollow core plank w/ 2" topping & 7.5" ϕ strand pattern

⇒ allowable load @ 30' is 162 psf > 149 psf ∴ OK

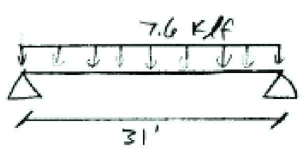
<u>Design girder</u>

Trib width = 29.5'

Precast 10" x4' w/topping slf wt: 68 + 25 = 93 psf (plank, topping)

$w_u = 1.2D + 1.6L$

$= [1.2(15+93) + 1.6(80)] \times 29.5' = 7.6\text{ klf}$



$M_u = \frac{wl^2}{8} = \frac{(7.6)(31)^2}{8} = 913\text{ k-ft}$

use W30 x 114 ⇒ $\phi M_n = 1420\text{ k-ft} > 913\text{ k-ft}$ ✓

(more economic size even though shallower beams can be used)

Daniel Bodde	Tech 2	Hollow Core Plank	2

check deflections: $I = 4930 \text{ in}^4$

Live Load

$$\Delta_{LL} \le \frac{L}{360} = \frac{31 \times 12}{360} = 1.03''$$

$$\Delta_{LL} = \frac{5 w l^4}{384 EI} = \frac{5(.08 \times 29.5)(31)^4(1728)}{(384)(29{,}000)(4930)} = 0.34'' < \frac{L}{360} \checkmark$$

Total Load

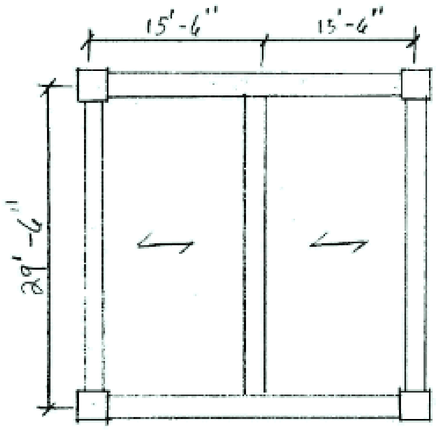
$$\Delta_{tot} \le \frac{L}{240} = \frac{31 \times 12}{240} = 1.55''$$

$$\Delta_{tot} = \frac{5 w l^4}{384 EI} = \frac{5(7.6)(31)^4(1728)}{(384)(29000)(4930)} = 1.10'' < \frac{L}{240} \checkmark$$

Use W30 x 116 for girder

Appendix C: Calculations for One Way Concrete Slab with Interior Beams

Daniel Bodde | Tech 2 | One-way w/ beams | 1



SDL = 15 psf

LL = 80 psf

Slf wt = ?

Min. Slab thickness (ACI 318-11)

Table 9.5 (a)

$h_{min} = \frac{l}{28} = \frac{15.5 \times 12}{28} = 6.64 \approx 7"$ Try 7" slab

Slab slf wt = $(150)\left(\frac{7}{12}\right) = 87.5$ psf

assume #5 bars

$d = h - cc - \frac{d_b}{2} = 7" - .75" - \frac{.625}{2} = 5.94"$

Estimate Col size

Based on h_{min} & the loads above estimate a col size (Per ch3 in the CRSI 2008 handbook)

- $P_u = 9.18$ K (from excel)
- using 50% fy

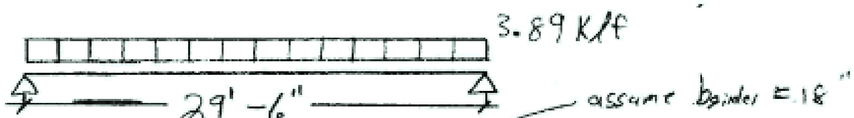
24" x 24" column is a good estimated column size

Daniel Bodde	Tech 2	One-way w/ beams	2

Beam Design (assume simply supported → conservative)

$DL = 15 + 87.5 = 102.5$ psf
$LL = 80$ psf

$w_u = 1.2D + 1.6L$
$= 1.2(102.5) + 1.6(80) = 251$ psf $\times 15.5' / 1000 = 3.89$ Klf



$M_u = \frac{w_u l_n^2}{8} = \frac{(3.89)(29.5 - \frac{18"}{12})^2}{8} \times 1.1 = 419$ K-ft
(1.1: est. eff. of self wt)

Estimate Size:

$bd^2 = 20 M_u$ try $b = \frac{4}{5} d$

$d^3 = (20)(419)\frac{5}{4} \rightarrow d = 21.88"$

$h = d + 2.5$ use $h = 25"$ & $b = 18"$
$bd^2 = 18 \times 22.5^2 = 9112.5$

Self wt effects:

$w_{sw} = \frac{25 \times 18}{144} \times 150 = 469$ plf

$w_u = 3.89 + 1.2 \times .469 = 4.45$ Klf

$M_u = \frac{4.45 \times 28^2}{8} = 436$ K-ft

$20(436) = 8720 < 9112$ ✓

Required Steel:

$As_{req} = \frac{M_u}{4d} = \frac{419}{(4)(22.5)} = 4.66$ in^2

try (5) #9 $5(1 \text{ in}^2) = 5 \text{ in}^2 = A_s$

$d = 25 - 1.5 - \frac{1.128}{2} = 22.9"$

Daniel Bodde	Tech 2	One-way w/ beams	3

Nominal Moment:

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(5)(60)}{(0.85)(4)(18)} = 4.90''$$

$$c = \frac{a}{\beta_1} = \frac{4.9}{0.85} = 5.76$$

$$\varepsilon_s = \varepsilon_u \left(\frac{d-c}{c}\right) = .003 \left(\frac{22.9 - 5.74}{5.74}\right) = 0.0089 \tfrac{in}{in} > \varepsilon_y$$

$$\therefore \phi = 0.9$$

$$\phi M_n = \phi A_s f_y \left(d - \frac{a}{2}\right) = (0.9)(5)(60)\left(22.9 - \frac{4.90}{2}\right)$$

$$= 5521.5 \text{ k-in}$$

$$= 460 \text{ k-ft} > M_u \quad \underline{\text{OK}}$$

Check $A_{s\,min}$ & $A_{s\,max}$:

$$A_{s\,min} \geq \begin{cases} \dfrac{3\sqrt{f'_c}}{f_y} bd = \dfrac{3\sqrt{4000}}{6000} \times 18 \times 22.9 = 1.3 \text{ in}^2 \\[2ex] \dfrac{200\,bd}{f_y} = \dfrac{(200)(18 \times 22.9)}{60{,}000} = 1.37 \text{ in}^2 \end{cases}$$

$A_s > A_{s\,min}$ OK

$$\rho_{max} = 0.85 \beta_1 \frac{f'_c}{f_y} \frac{\varepsilon_u}{\varepsilon_u + 0.004} = 0.85(0.85)\frac{4}{60}\frac{0.003}{0.003 + 0.004} = .0206$$

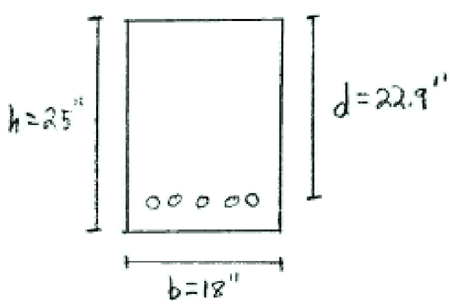
$$A_{s\,max} = 0.0206 \times 18 \times 22.9 = 8.5 \text{ in}^2$$

$A_s < A_{s\,max}$ OK

Table A.8 min # of bars for $b_w = 18''$ & #9 bars is 6

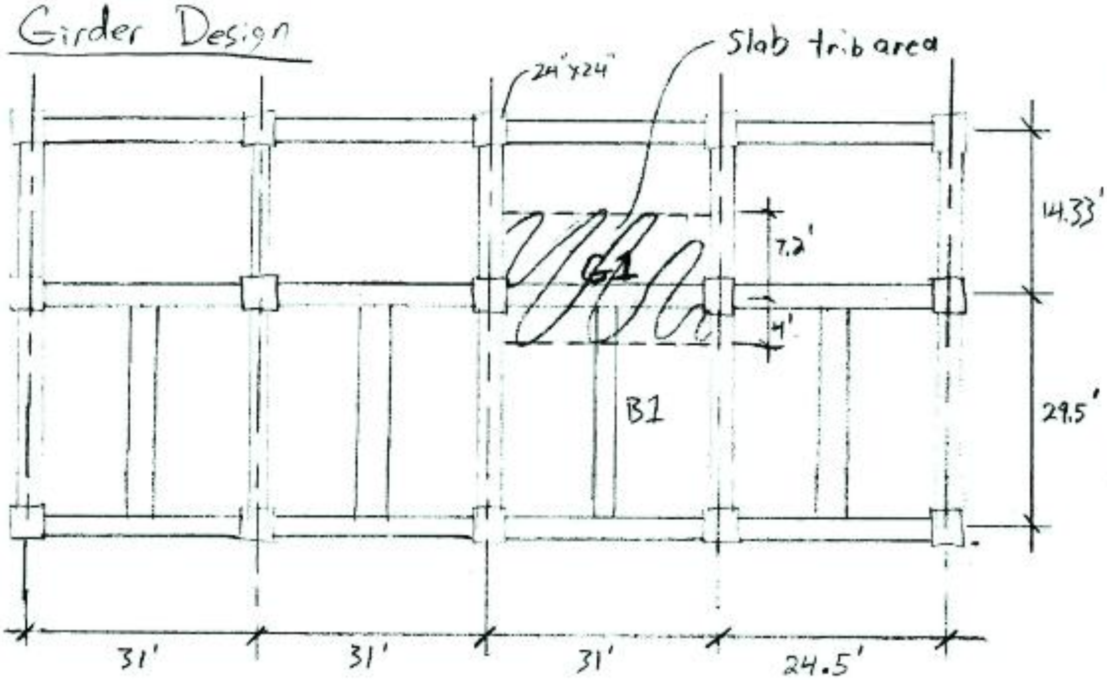
5 #9 < 6 #9 ∴ bars fit <u>OK</u>

Use 18" x 25" beam w/ (5) #9



Daniel Bodde | Tech 2 | one way w/ beams | 4

Girder Design



Distributed Load on girder from slab:

Slb wt = 150 pcf × $\frac{7''}{12''/ft}$ = 87.5 psf

$w_u = [1.2(87.5 + 15) + 1.6(80)] \times (7.2' + 4') = 2811$ plf

= 2.81 klf

Concentrated load from beam

use loads from beam design

$P = \frac{w_u l}{2} = \frac{(4.44)(29.5)}{2} = 65.5$ K

From STAAD output:

- positive moments at face of supports will control girder depth.

$M_u = 478.8$ k-ft × 1.1 = 526.7 k-ft ≈ 527 k-ft

Daniel Bodde	Tech 2	One way w/ beams	5

Estimate Size:

$bd^2 = 20\ M_u$ try $b = \frac{4}{5} d$

$d^3 = (20)(527)\frac{5}{4} \rightarrow d = 23.62''$

$h = d + 2.5$ use $h = 26.5''$ & $b = 20''$

Required Steel:

$A_{s,req} = \frac{M_u}{4d} = \frac{527}{(4)(24)} = 5.5\ in^2$

try (6) #9 $A_s = (6)(1\ in^2) = 6\ in^2 = A_s$

$d = 26.5 - 1.5 - \frac{1.128}{2} = 23.87''$

Nominal moment:

$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(6)(60)}{(0.85)(4)(20)} = 5.29''$

$c = \frac{a}{\beta_1} = \frac{5.29}{0.85} = 6.22''$

$\varepsilon_s = \varepsilon_u\left(\frac{d-c}{c}\right) = 0.003\left(\frac{23.87-6.22}{6.22}\right) = 0.0085\ \frac{in}{in} > \varepsilon_y \therefore \phi = 0.9$

$\phi M_n = \phi A_s f_y\left(d - \frac{a}{2}\right) = (0.9)(6)(60)\left(23.87 - \frac{5.29}{2}\right) = 6878\ k\text{-}in$

$= 573\ k\text{-}ft > M_u$ OK

Check $A_{s,min}$ & $A_{s,max}$

$A_{s,min} \geq \frac{3\sqrt{f'_c}\, bd}{f_y} = \frac{3\sqrt{4000}(20)(23.87)}{60{,}000} = 1.51\ in^2$

$\frac{200\, bd}{f_y} = \frac{200(20)(23.87)}{60{,}000} = 1.59\ in^2$

$A_s > A_{s,min}$ OK

Daniel Bodde	Tech 2	one way w/beams	6

$\rho_{max} = 0.85\beta_1 \frac{f'_c}{f_y} \frac{\varepsilon_u}{\varepsilon_u + 0.004} = 0.85(0.85)\frac{4}{60} \frac{0.003}{0.003+0.004}$

$= 0.0206$

$A_{s\,max} = 0.0206 \times 20 \times 23.57 = 9.83\,in^2 > A_s$ OK

Table A.8 min # of bars for $b_w = 20''$ & #9 bars is 7

6#9 < 7#9 ∴ bars fit OK

Use 20" × 26.5" girder

Daniel Bodde | Tech 2 | one-way w/ beams | 7

slab thickness = 7" assumed # 5 bars

Look at 1' wide strip

$A_{s\,min} = 0.002\,bh = 0.002(12")(7") = 0.168\ in^2/ft$

try # 5 @ 10" o.c.

$A_s = 0.31 \times \frac{12"}{10"} = 0.372\ in^2/ft$

$d = 5.94"$

<u>Nominal moment :</u>

$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(0.372)(60)}{(0.85)(4)(12)} = 0.55\ in$

$c = \frac{a}{\beta_1} = \frac{0.55}{0.85} = 0.64"$

$\varepsilon_s = \varepsilon_{cu}\left(\frac{d-c}{c}\right) = 0.003\left(\frac{5.94 - 0.64}{0.64}\right) = 0.0248 > \varepsilon_y \quad \therefore \phi = 0.9$

$\phi M_n = \phi A_s f_y \left(d - \frac{a}{2}\right) = (0.9)(0.372)\left(5.94 - \frac{0.55}{2}\right)(60)/12"/ft = 9.48\ k\text{-}ft$

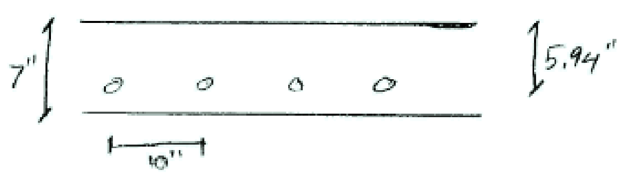
$w_u = 1.2D + 1.6L$

$= 1.2(15 + 87.5) + 1.6(80) = 251\ psf \times 1\ ft$

$= 0.251\ klf/ft$

$M_u = \frac{w_u l^2}{8} = \frac{(0.251)(15.5)^2}{8} = 7.54\ k\text{-}ft < \phi M_n$ <u>OK</u>

use 7" slab w/ # 5 bars @ 10" o.c.



CONCRETE REINFORCING STEEL INSTITUTE

SQUARE TIED COLUMNS 22" x 22"

Short columns – no sidesway
Bars symmetrical in 4 faces

f'_c = 4,000 psi, f_y = 60,000 psi
ϕM_n in inch-kips, ϕP_n in kips

BARS	RHO	Max Cap ϕM_n	Max Cap ϕP_n	0% f_y ϕM_n	0% f_y ϕP_n	25% f_y ϕM_n	25% f_y ϕP_n	50% f_y ϕM_n	50% f_y ϕP_n	100% f_y ϕM_n	100% f_y ϕP_n	ε_t = 0.005 ϕM_n	ε_t = 0.005 ϕP_n	Zero Axial Load ϕM_n
4-#10	1.05	2261	1005	2982	899	3707	756	4113	643	4541	471	5508	404	2535
4-#11	1.29	2321	1039	3185	912	3929	765	4364	647	4862	465	5868	389	3038
4-#14	1.86	2480	1121	3614	957	4447	797	4977	666	5677	459	6870	367	4235
4-#18	3.31	2627	1327	4641	1074	5697	882	6465	718	7659	444	9195	298	7112
8-#8	1.31	2204	1042	2909	934	3640	783	4044	663	4460	479	5440	350	3131
8-#9	1.65	2279	1091	3117	964	3891	805	4342	676	4855	477	5959	327	3886
8-#10	2.10	2373	1155	3378	1003	4209	833	4720	694	5358	475	6612	296	4836
8-#11	2.58	2452	1223	3661	1039	4531	858	5092	708	5843	468	7162	249	5772
8-#14	3.72	2674	1385	4288	1138	5300	931	6010	753	7067	461	8671	158	8018
8-#18	6.61	3191	1798	5799	1392	7163	1115	8238	867	10045	442	12175	-103	11941
12-#10	3.15	2599	1304	3893	1106	4849	910	5470	750	6359	473	8037	229	6833
12-#11	3.87	2728	1407	4277	1165	5297	952	5989	776	7041	464	8828	162	7998
12-#14	5.58	3062	1650	5160	1319	6384	1065	7279	850	8762	454	10987	26	10859
16-#10	4.20	2832	[illegible]	[illegible]	1210	5500	993	6267	[illegible]	[illegible]	477	9465	160	8756
16-#11	5.16	[illegible]	1590	4927	1291	6076	1053	6943	838	8307	[illegible]	10502	69	10231

SQUARE TIED COLUMNS 24" x 24"

BARS	RHO	Max Cap ϕM_n	Max Cap ϕP_n	0% f_y ϕM_n	0% f_y ϕP_n	25% f_y ϕM_n	25% f_y ϕP_n	50% f_y ϕM_n	50% f_y ϕP_n	100% f_y ϕM_n	100% f_y ϕP_n	ε_t = 0.005 ϕM_n	ε_t = 0.005 ϕP_n	Zero Axial Load ϕM_n
4-#11	1.08	2953	1202	3899	1075	4855	903	5395	768	5973	561	7269	482	3395
4-#14	1.56	3140	1283	4386	1119	5441	935	6088	787	6892	554	8439	464	4746
4-#18	2.78	3555	1489	5556	1235	6862	1019	7776	838	9138	539	11189	408	8010
8-#8	1.10	2815	1204	3578	1098	4522	923	5029	785	5514	577	6724	440	3491
8-#9	1.39	2902	1254	3813	1128	4804	945	5363	799	5957	575	7332	420	4341
8-#10	1.76	3011	1317	4108	1167	5162	973	5788	816	6522	573	8105	394	5412
8-#11	2.17	3105	1386	4432	1202	5530	998	6211	831	7072	566	8758	351	6481
8-#14	3.13	3366	1548	5143	1302	6399	1071	7247	876	8453	560	10522	268	9039
8-#18	5.56	3962	1960	6861	1557	8513	1257	9774	992	11828	543	14664	34	14554
12-#10	2.65	3270	1467	4685	1271	5879	1052	6628	874	7643	573	9742	331	7804
12-#11	3.25	3411	1569	5125	1330	6391	1094	7220	900	8418	564	10683	269	9143
12-#14	4.69	3807	1813	6125	1485	7620	1207	8677	975	10362	556	13209	145	12407
16-#10	3.53	3525	1616	5295	1376	6610	1136	7523	926	8831	578	11377	268	9907
16-#11	4.33	3723	1753	5857	1457	7267	1196	8293	963	9842	569	12610	185	11733
16-#14	6.25	4219	2078	7163	1668	8862	1353	10198	1065	12381	561	15904	17	15833
20-#10	4.41	3760	1766	5906	1478	7377	1214	8428	984	10033	578	13044	190	12009
20-#11	5.42	3990	1937	6597	1583	8187	1291	9379	1033	11285	568	14570	84	14122

SQUARE TIED COLUMNS 26" x 26"

BARS	RHO	Max Cap ϕM_n	Max Cap ϕP_n	0% f_y ϕM_n	0% f_y ϕP_n	25% f_y ϕM_n	25% f_y ϕP_n	50% f_y ϕM_n	50% f_y ϕP_n	100% f_y ϕM_n	100% f_y ϕP_n	ε_t = 0.005 ϕM_n	ε_t = 0.005 ϕP_n	Zero Axial Load ϕM_n
4-#14	1.33	3904	1460	[illegible]	1296	6570	1086	7351	919	8266	[illegible]	10199	567	5256
4-#18	2.37	4392	1666	6569	1411	[illegible]	[illegible]	[illegible]	[illegible]	10777	643	13377	521	8908
8-#9	1.18	3629	1431	4602	1307	5851	1098	6536	932	7219	682	8849	515	4795
8-#10	1.50	3754	1494	4931	1346	6249	1126	7007	950	7844	680	9708	489	5987
8-#11	1.85	3863	1562	5299	1381	6663	1151	7482	964	8460	673	10543	457	7188
8-#14	2.66	4150	1725	6095	1481	7633	1224	8637	1010	9997	667	12565	382	10057
8-#18	4.73	4845	2137	8022	1736	10000	1411	11462	1127	13769	653	17352	169	16742
12-#10	2.25	4046	1644	5571	1451	7044	1206	7938	1009	9087	681	11531	427	8730
12-#11	2.77	4209	1746	6068	1509	7620	1247	8602	1035	9955	673	12726	380	10326
12-#14	3.99	4661	1990	7187	1665	8992	1362	10227	1111	12120	666	15625	266	14002
12-#18	7.10	5724	2608	9903	2061	12340	1652	14203	1303	17427	644	22477	-52	22269

(1) "0% f_y" indicates zero tension in bars on the tension side, "50% f_y" indicates 50% f_y stress in bars on the tension side, and "100% f_y" indicates 100% f_y stress (i.e., balance point) in bars on the tension side.

3-13

SQUARE TIED COLUMNS [illegible]

Short columns – no sidesway
Bars symmetrical in 4 faces

f'_c = 4,000 psi, f_y = 60,000 psi
ϕM_n in inch-kips, ϕP_n in kips

BARS	RHO	Max Cap ϕM_n	Max Cap ϕP_n	0% f_y ϕM_n	0% f_y ϕP_n	25% f_y ϕM_n	25% f_y ϕP_n	50% f_y ϕM_n	50% f_y ϕP_n	100% f_y ϕM_n	100% f_y ϕP_n	ε_t = 0.005 ϕM_n	ε_t = 0.005 ϕP_n	Zero Axial Load ϕM_n
16-#10	3.01	4332	1793	6248	1556	7854	1290	8930	1062	10403	687	13348	368	11080
16-#11	3.69	4547	1930	6882	1638	8593	1351	9794	1099	11537	679	14908	304	13141
16-#14	5.33	5121	2255	8342	1850	10373	1510	11920	1202	14367	674	18687	150	17993
20-#10	3.76	4581	1943	6918	1658	8705	1370	9934	1121	11736	688	15204	291	13524
20-#11	4.62	4861	2113	7695	1763	9616	1447	11001	1170	13140	679	17131	207	15913

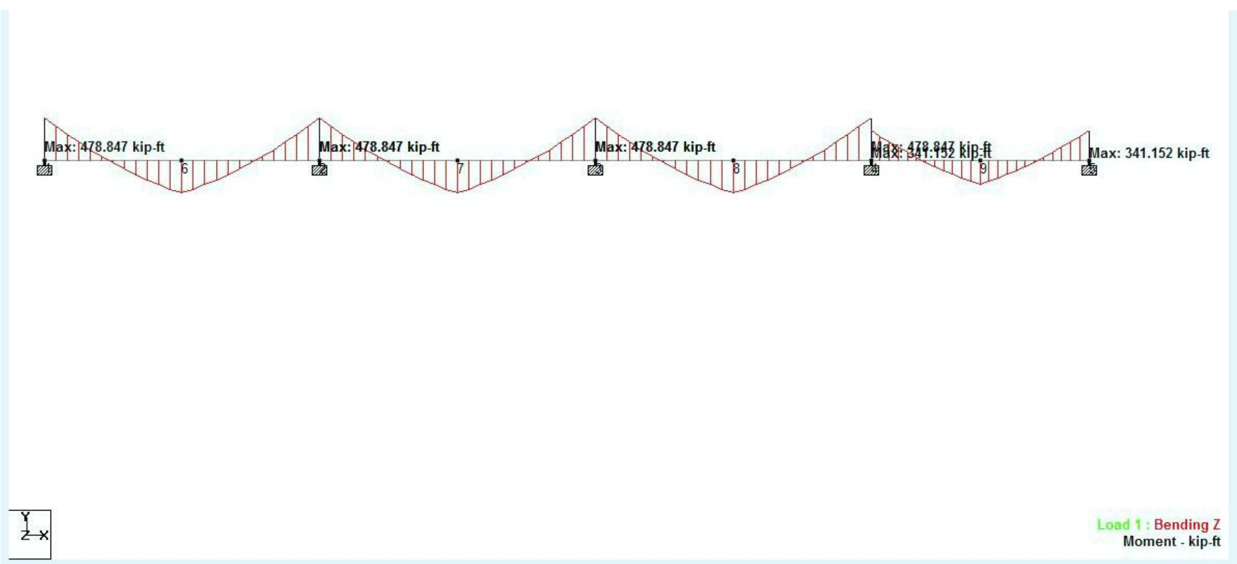
SQUARE TIED COLUMNS 28" x 28"

BARS	RHO	Max Cap ϕM_n	Max Cap ϕP_n	0% f_y ϕM_n	0% f_y ϕP_n	25% f_y ϕM_n	25% f_y ϕP_n	50% f_y ϕM_n	50% f_y ϕP_n	100% f_y ϕM_n	100% f_y ϕP_n	ε_t = 0.005 ϕM_n	ε_t = 0.005 ϕP_n	Zero Axial Load ϕM_n
4-#14	1.15	4781	1651	6225	1489	7845	1250	8778	1062	9812	773	12130	673	5765
4-#18	2.04	5340	1857	7686	1603	9609	1332	10868	1111	12587	757	15773	639	9805
8-#9	1.02	4467	1622	5493	1502	7043	1264	7873	1077	8653	798	10569	617	5247
8-#10	1.30	4608	1685	5856	1540	7481	1292	8391	1095	9339	795	11512	592	6560
8-#11	1.59	4733	1753	6268	1575	7942	1316	8918	1108	10020	789	12434	560	7894
8-#14	2.30	5059	1916	7149	1674	9013	1389	10191	1155	11714	783	14764	496	11073
8-#18	4.08	5846	2328	9286	1930	11633	1576	13316	1272	15883	770	20251	305	18709
12-#10	1.94	4935	1835	6558	1646	8354	1372	9413	1154	10703	797	13520	531	9594
12-#11	2.39	5121	1937	7114	1704	8994	1414	10149	1181	11664	790	14844	484	11505
12-#14	3.44	5607	2181	8352	1860	10509	1529	11942	1257	14052	783	18183	385	15643
12-#18	6.12	6819	2799	11364	2257	14217	1621	16342	1452	19922	765	26039	96	25430
16-#10	2.59	5253	1984	7302	1752	9243	1457	10501	1208	12147	805	15518	474	12275
16-#11	3.18	5496	2121	8010	1833	10065	1518	11461	1246	13404	798	17248	411	14573
16-#14	4.59	6141	2446	9624	2046	12031	1678	13807	1350	16526	794	21596	277	20121
20-#10	[illegible]	5530	2134	8031	1853	10177	1537	11604	1268	13611	807	17562	397	15028
20-#11	[illegible]	5826	2304	8895	1958	11190	1615	12788	1318	15167	799	19702	316	17757
20-#14	[illegible]	6621	2711	10892	2226	13630	1817	15694	1453	19033	794	25077	138	24263
24-#10	[illegible]	5845	2283	8762	1955	11103	1615	12723	1322	15095	814	19618	349	17588
24-#11	[illegible]	6230	2488	9726	2089	12315	1710	14137	1383	16955	807	22173	253	20858

SQUARE TIED COLUMNS 30" x 30"

BARS	RHO	Max Cap ϕM_n	Max Cap ϕP_n	0% f_y ϕM_n	0% f_y ϕP_n	25% f_y ϕM_n	25% f_y ϕP_n	50% f_y ϕM_n	50% f_y ϕP_n	100% f_y ϕM_n	100% f_y ϕP_n	ε_t = 0.005 ϕM_n	ε_t = 0.005 ϕP_n	Zero Axial Load ϕM_n
4-#14	[illegible]	5779	1856	7306	1696	9276	1427	10382	1216	11544	896	14219	781	6273
4-#18	1.78	6411	2062	8915	1809	11213	1508	12674	1264	14584	879	18392	762	10702
8-#10	1.13	5582	1890	6689	1749	8868	1471	9950	1250	11020	920	13535	702	7133
8-#11	1.39	5724	1959	7346	1783	9376	1494	10530	1264	11766	913	14544	671	8598
8-#14	2.00	6089	2121	8312	1883	10549	1567	11922	1310	13617	908	17089	607	12086
8-#18	3.56	6974	2533	10662	2138	13423	1755	15347	1429	18183	895	23375	443	20510
12-#10	1.69	5946	2040	7654	1855	9818	1551	11064	1311	12505	922	15729	642	10455
12-#11	2.08	6154	2142	8269	1913	10524	1592	11873	1337	13559	915	17162	595	12566
12-#14	3.00	6695	2386	9626	2069	12182	1708	13834	1414	16169	910	20835	497	17331
12-#18	5.33	8044	3004	12936	2467	16251	2002	18659	1611	22603	895	29830	245	28145
16-#10	2.26	6296	2189	8464	1962	10787	1637	12249	1365	14078	931	17860	579	13491
16-#11	2.77	6569	2326	9246	2043	11692	1697	13304	1403	15457	924	19808	526	16029
16-#14	4.00	7263	2651	11017	2256	13845	1858	15870	1509	18871	922	24569	394	22135
16-#18	7.11	8967	3475	15342	2797	19129	2266	22184	1775	27280	911	36279	50	36023
20-#10	2.82	6603	2339	9252	2063	11805	1718	13450	1425	15672	934	20141	511	16462
20-#11	3.47	6933	2509	10204	2167	12920	1795	14752	1476	17380	926	22494	431	19652
20-#14	5.00	7815	2916	12389	2436	15592	1999	17932	1613	21609	924	28383	257	26829
24-#10	3.39	6950	2488	10048	2165	12805	1794	14670	1480	17289	942	22384	465	19355
24-#11	4.16	7348	2693	11166	2292	14137	1890	16224	1542	19331	935	25195	371	22969

3



Appendix D: Calculations and spSlab Output for Two Way Concrete Slab with Drop Panels

Daniel Bodde	Tech 2	2-way w/ drop panels	1

CRSI 2008 Design Hand book:

assume $l_1 = l_2 = 31'$

Find superimposed load (factored)

$w = 1.2D + 1.6L$

$= 1.2(15) + 1.6(80) = 146 \text{ psf}$

Preliminary size of 2-way slab w/ drop panels:

Slab thickness = 11.5"

Square drop panel:
depth = 8.25"
width = 10.33'

Sq Column Size = 20"

Input prelim size into spSlab.

See spSlab output for slab design

Daniel Bodde

Advisor: Heather Sustersic

10-34

CONCRETE REINFORCING STEEL INSTITUTE

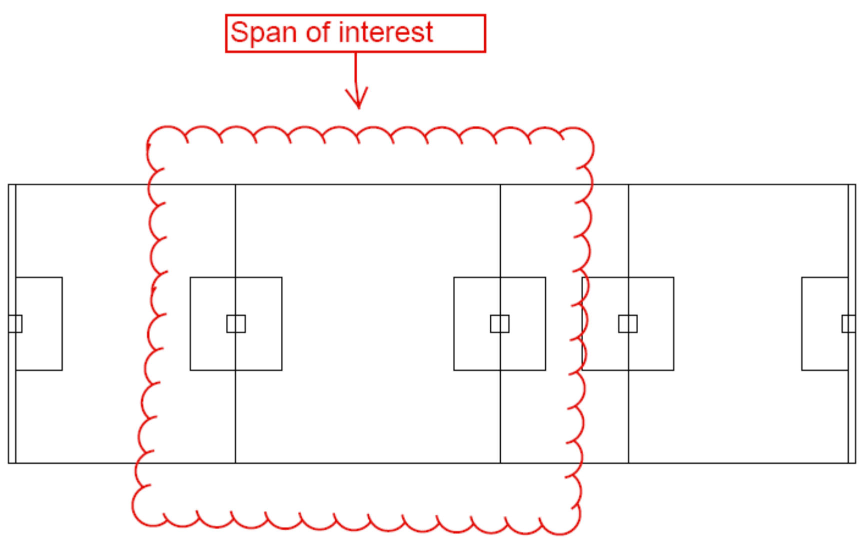
f'_c = 4,000 psi
Grade 60 Bars

FLAT SLAB SYSTEM — SQUARE EDGE PANEL, With Drop Panels, No Beams | SQUARE INTERIOR PANEL, With Drop Panels(2), No Beams

h = 11.5 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS

SPAN c.-c. $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	Square Drop Panel Depth (in.)	Square Drop Panel Width (ft)	(3) Square Column Size (in.)	γ_f	Column Strip (1) Top Ext. +	Column Strip Bottom	Column Strip Top Int.	Middle Strip Bottom	Middle Strip Top Int.	Total Steel (psf)	Moments Edge (–) (ft-k)	Moments Bot. (+) (ft-k)	Moments Int. (–) (ft-k)	Interior: Factored Superimposed Load (psf)	(3) Square Column Size (in.)	Column Strip Top	Column Strip Bottom	Middle Strip Top	Middle Strip Bottom	Total Steel (psf)	Concrete (cu. ft / sq. ft)
27	100	4.25	9.00	12	0.815	12-#5 3	15-#5	12-#6	11-#5	11-#5	2.56	162.8	325.7	438.4	100	12	16-#5	11-#5	11-#5	11-#5	2.46	0.998
27	200	6.25	9.00	16	0.648	12-#5 1	10-#7	14-#6	9-#6	11-#5	2.96	214.8	429.6	578.3	200	19	18-#5	9-#6	11-#5	11-#5	2.70	1.016
27	300	6.25	9.00	19	0.702	12-#5 3	17-#6	13-#7	16-#5	13-#5	3.54	265.8	531.6	715.6	300	23	12-#7	11-#6	12-#5	11-#5	3.16	1.016
27	400	8.25	9.00	21	0.631	13-#5 2	12-#8	26-#5	10-#7	16-#5	4.25	317.9	635.8	855.9	400	25	13-#7	10-#7	15-#5	9-#6	3.78	1.035
27	500	8.25	9.00	23	0.720	15-#5 4	11-#9	12-#8	9-#8	10-#7	5.02	368.1	736.2	991.0	500	27	12-#8	9-#8	9-#7	15-#5	4.47	1.035
27	600	10.25	10.80	25	0.630	16-#5 2	14-#9	22-#6	9-#9	15-#6	5.85	422.1	915.3	1136.3	600	27	12-#8	9-#9	14-#6	18-#5	5.04	1.095
27	700	10.25	10.80	25	0.737	17-#5 4	17-#9	14-#8	17-#7	10-#8	6.85	476.2	1070.2	1282.0	700	27	13-#8	11-#9	9-#8	15-#6	5.93	1.095
28	100	6.25	9.33	12	0.728	13-#5 1	16-#5	17-#5	12-#5	12-#5	2.62	182.7	365.5	492.0	100	12	16-#5	12-#5	12-#5	12-#5	2.51	1.016
28	200	6.25	9.33	16	0.762	13-#5 4	12-#7	16-#6	10-#6	12-#5	3.18	240.6	481.1	647.7	200	19	20-#5	14-#5	12-#5	12-#5	2.81	1.016
28	300	6.25	9.33	20	0.773	14-#5 5	11-#8	27-#5	10-#7	15-#5	3.89	297.0	593.9	799.5	300	23	13-#7	18-#5	10-#6	12-#5	3.38	1.016
28	400	8.25	9.33	21	0.731	15-#5 4	17-#7	16-#7	15-#6	10-#7	4.48	356.5	713.0	959.8	400	25	14-#7	15-#6	16-#5	10-#6	3.90	1.035
28	500	10.25	11.20	24	0.631	15-#5 3	13-#9	16-#7	10-#8	11-#7	5.16	413.0	826.0	1111.9	500	28	15-#7	10-#8	10-#7	16-#5	4.43	1.095
28	600	10.25	11.20	25	0.689	17-#5 3	15-#9	14-#8	12-#8	10-#8	6.09	472.2	981.8	1271.2	600	28	13-#8	12-#8	12-#7	14-#6	5.29	1.095
29	100	6.25	9.67	12	0.783	13-#5 3	18-#5	14-#6	12-#5	12-#5	2.65	203.6	407.1	548.1	100	12	17-#5	12-#5	12-#5	12-#5	2.46	1.016
29	200	6.25	9.67	17	0.774	13-#5 5	17-#6	13-#7	16-#5	13-#5	3.30	266.6	533.3	717.9	200	20	16-#6	16-#5	12-#5	12-#5	2.94	1.016
29	300	8.25	9.67	20	0.665	14-#5 3	16-#7	19-#6	14-#6	12-#6	4.00	332.1	664.2	894.1	300	23	13-#7	14-#6	15-#5	13-#5	3.49	1.035
29	400	10.25	9.67	22	0.632	15-#5 2	12-#9	16-#7	10-#8	14-#6	4.85	396.2	792.4	1066.7	400	26	14-#7	17-#6	10-#7	11-#6	4.15	1.053
29	500	10.25	11.60	24	0.658	17-#5 2	14-#9	14-#8	12-#8	10-#8	5.63	461.5	923.1	1242.6	500	28	22-#6	12-#8	15-#6	18-#5	4.82	1.095
29	600	12.25	11.60	25	0.632	18-#5 1	20-#8	14-#8	13-#8	11-#8	6.22	527.0	1064.6	1419.0	600	29	13-#8	13-#8	10-#8	11-#7	5.43	1.122
30	100	6.25	10.00	12	0.813	14-#5 3	20-#5	15-#6	10-#6	13-#5	2.88	225.9	451.8	608.2	100	12	14-#6	14-#5	13-#5	13-#5	2.70	1.016
30	200	8.25	10.00	17	0.665	14-#5 2	11-#8	17-#6	10-#7	15-#5	3.56	297.0	594.0	799.7	200	20	16-#6	18-#5	10-#6	13-#5	3.09	1.035
30	300	8.25	10.00	20	0.734	15-#5 4	11-#9	16-#7	12-#7	10-#7	4.47	369.3	738.6	994.2	300	23	15-#7	12-#7	12-#6	15-#5	3.92	1.035
30	400	10.25	10.00	22	0.645	16-#5 3	17-#8	17-#7	11-#8	12-#7	5.22	440.8	881.6	1186.8	400	26	16-#7	11-#8	20-#5	18-#5	4.54	1.053
30	500	12.25	12.00	24	0.633	17-#5 2	16-#9	14-#8	10-#9	11-#8	5.89	513.3	1026.6	1382.0	500	29	22-#6	10-#9	10-#8	20-#5	5.01	1.122
30	600	12.25	12.00	25	0.700	19-#5 3	18-#9	16-#8	12-#9	12-#8	6.91	585.0	1170.0	1575.0	600	30	15-#8	12-#9	11-#8	10-#8	6.06	1.122
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	200	8.25	10.33	17	0.731	14-#5 4	12-#8	14-#7	14-#6	12-#6	3.71	328.9	657.8	885.5	200	20	18-#6	14-#6	15-#5	13-#5	3.24	1.035
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	400	10.25	10.33	22	0.760	18-#5 6	15-#9	15-#8	12-#8	13-#7	5.58	488.7	977.3	1315.7	400	26	14-#8	21-#6	12-#7	19-#5	4.78	1.053
31	500	12.25	12.40	24	0.712	19-#5 5	18-#9	16-#8	14-#8	12-#8	6.38	569.4	1138.7	1532.9	500	29	14-#8	14-#8	11-#8	12-#7	5.45	1.122

(Continued on next Page)



```
                     oooooo     o                  o
                    oo    oo   oo                 oo
 ooooo    oooooo    oo         oo       ooooo     oo
oo    o   oo   oo    oo        oo      o     oo   oo
oo        oo   oo     ooo      oo       oooooo    oooooo
 ooooo    oo   oo       ooo    oo      oo    oo   oo   oo
     oo   oooooo          oo   oo      oo    oo   oo   oo
o    oo   oo        oo    oo   oo  o   oo    oo   oo   oo
 ooooo    oo         oooooo     ooo     ooooo o    ooooo   (TM)
```

===

spSlab v3.18 (TM)
A Computer Program for Analysis, Design, and Investigation of
Reinforced Concrete Beams, One-way and Two-way Slab Systems
Copyright © 2003-2011, STRUCTUREPOINT, LLC
All rights reserved

===

Licensee stated above acknowledges that STRUCTUREPOINT (SP) is not and cannot be responsible for either the accuracy or adequacy of the material supplied as input for processing by the spSlab computer program. Furthermore, STRUCTUREPOINT neither makes any warranty expressed nor implied with respect to the correctness of the output prepared by the spSlab program. Although STRUCTUREPOINT has endeavored to produce spSlab error free the program is not and cannot be certified infallible. The final and only responsibility for analysis, design and engineering documents is the licensee's. Accordingly, STRUCTUREPOINT disclaims all responsibility in contract, negligence or other tort for any analysis, design or engineering documents prepared in connection with the use of the spSlab program.

===

[2] DESIGN RESULTS*

===

*Unless otherwise noted, all results are in the direction of analysis only. Another analysis in the perpendicular direction has to be carried out for two-way slab systems.

Strip Widths and Distribution Factors

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

Units: Width (ft).

Span	Strip	Width Left**	Width Right**	Width Bottom*	Moment Factor Left**	Moment Factor Right**	Moment Factor Bottom*
1	Column	12.34	12.34	12.34	1.000	1.000	0.600
	Middle	18.66	18.66	18.66	0.000	0.000	0.400
2	Column	12.34	12.34	12.34	1.000	0.750	0.600
	Middle	18.66	18.66	18.66	0.000	0.250	0.400
3	Column	12.34	7.17	14.75	0.750	0.750	0.600
	Middle	18.66	23.84	16.25	0.250	0.250	0.400
4	Column	7.17	7.17	7.17	0.750	0.750	0.600
	Middle	23.84	23.84	23.84	0.250	0.250	0.400
5	Column	7.17	12.34	12.34	0.750	1.000	0.600
	Middle	23.84	18.66	18.66	0.250	0.000	0.400
6	Column	12.34	12.34	12.34	1.000	1.000	0.600
	Middle	18.66	18.66	18.66	0.000	0.000	0.400

*Used for bottom reinforcement. **Used for top reinforcement.

Top Reinforcement

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

Units: Width (ft), Mmax (k-ft), Xmax (ft), As (in^2), Sp (in)

Span	Strip	Zone	Width	Mmax	Xmax	AsMin	AsMax	SpReq	AsReq	Bars	
1	Column	Left	12.34	0.39	0.240	3.064	25.901	14.802	0.009	10-#5	*3
		Middle	12.34	1.15	0.445	3.064	25.901	14.802	0.026	10-#5	*3
		Right	12.34	2.61	0.685	3.064	25.901	14.802	0.060	10-#5	*3
	Middle	Left	18.66	0.00	0.000	4.636	39.192	14.932	0.000	15-#5	*3
		Middle	18.66	0.00	0.342	4.636	39.192	14.932	0.000	15-#5	*3
		Right	18.66	0.00	0.685	4.636	39.192	14.932	0.000	15-#5	*3
2	Column	Left	12.34	58.32	0.750	3.064	25.901	14.802	1.349	10-#5	*3
		Middle	12.34	0.00	12.210	0.000	25.901	0.000	0.000	---	
		Right	12.34	638.66	23.670	4.907	40.201	5.286	8.177	28-#5	
	Middle	Left	18.66	0.09	0.996	4.636	39.192	14.932	0.002	15-#5	*3
		Middle	18.66	0.00	12.210	0.000	39.192	0.000	0.000	---	
		Right	18.66	212.90	23.670	4.636	39.192	13.175	4.985	17-#5	
3	Column	Left	12.34	657.57	1.000	4.907	40.201	5.286	8.428	28-#5	
		Middle	14.75	0.00	14.750	0.000	30.972	0.000	0.000	---	

		Right	7.17	413.21	28.500	3.057	27.857	4.777	5.279	18-#5	
	Middle	Left	18.66	219.19	1.000	4.636	39.192	13.175	5.135	17-#5	
		Middle	16.25	0.00	14.750	0.000	34.121	0.000	0.000	---	
		Right	23.84	137.74	28.500	5.921	50.048	14.301	3.192	20-#5	*3
4	Column	Left	7.17	169.75	5.170	1.780	15.045	4.777	4.069	18-#5	
		Middle	7.17	179.54	9.015	1.780	15.045	6.141	4.316	14-#5	
		Right	7.17	182.19	9.160	1.780	15.045	4.525	4.383	19-#5	
	Middle	Left	23.84	100.88	1.000	5.921	50.048	14.301	2.331	20-#5	*3
		Middle	23.84	59.85	9.015	5.921	50.048	14.301	1.379	20-#5	*3
		Right	23.84	113.69	13.330	5.921	50.048	14.301	2.630	20-#5	*3
5	Column	Left	7.17	458.81	1.000	3.057	27.857	4.525	5.882	19-#5	
		Middle	12.34	0.00	12.460	0.000	25.901	0.000	0.000	---	
		Right	12.34	98.81	23.920	3.064	25.901	14.802	2.299	10-#5	*3
	Middle	Left	23.84	152.95	1.000	5.921	50.048	14.301	3.549	20-#5	*3
		Middle	18.66	0.00	12.460	0.000	39.192	0.000	0.000	---	
		Right	18.66	0.26	23.429	4.636	39.192	14.932	0.006	15-#5	*3
6	Column	Left	12.34	2.61	0.145	3.064	25.901	14.802	0.060	10-#5	*3
		Middle	12.34	1.15	0.385	3.064	25.901	14.802	0.026	10-#5	*3
		Right	12.34	0.39	0.590	3.064	25.901	14.802	0.009	10-#5	*3
	Middle	Left	18.66	0.00	0.145	4.636	39.192	14.932	0.000	15-#5	*3
		Middle	18.66	0.00	0.488	4.636	39.192	14.932	0.000	15-#5	*3
		Right	18.66	0.00	0.830	4.636	39.192	14.932	0.000	15-#5	*3

NOTES:
*3 - Design governed by minimum reinforcement.

Top Bar Details

Units: Length (ft)

		Left				Continuous		Right			
Span	Strip	Bars	Length	Bars	Length	Bars	Length	Bars	Length	Bars	Length
1	Column	---		---		10-#5	0.83	---		---	
	Middle	---		---		15-#5	0.83	---		---	
2	Column	10-#5	8.31	---		---		16-#5	9.57	12-#5	6.08
	Middle	15-#5	5.79	---		---		17-#5	9.57	---	
3	Column	16-#5	10.08	12-#5	6.50	---		10-#5	10.08	8-#5	6.50
	Middle	17-#5	9.87	---		---		20-#5	7.64	---	
4	Column	4-#5	5.31	---		14-#5	14.33	5-#5	6.07	---	
	Middle	---		---		20-#5	14.33	---		---	
5	Column	10-#5	8.56	9-#5	5.58	---		10-#5	8.31	---	
	Middle	20-#5	7.59	---		---		15-#5	5.79	---	
6	Column	---		---		10-#5	0.83	---		---	
	Middle	---		---		15-#5	0.83	---		---	

Bottom Reinforcement

Units: Width (ft), Mmax (k-ft), Xmax (ft), As (in^2), Sp (in)

Span	Strip	Width	Mmax	Xmax	AsMin	AsMax	SpReq	AsReq	Bars	
1	Column	12.34	0.00	0.342	0.000	25.901	0.000	0.000	---	
	Middle	18.66	0.00	0.342	0.000	39.192	0.000	0.000	---	
2	Column	12.34	192.21	8.876	3.064	25.901	9.868	4.536	15-#5	
	Middle	18.66	128.14	8.876	4.636	39.192	14.932	2.975	15-#5	*3
3	Column	14.75	193.62	15.870	3.664	30.972	11.800	4.548	15-#5	
	Middle	16.25	129.08	15.870	4.037	34.121	13.929	3.003	14-#5	*3
4	Column	7.17	0.00	7.165	0.000	15.045	0.000	0.000	---	
	Middle	23.84	0.00	7.165	0.000	50.048	0.000	0.000	---	
5	Column	12.34	232.61	14.559	3.064	25.901	8.223	5.523	18-#5	
	Middle	18.66	155.07	14.559	4.636	39.192	14.932	3.610	15-#5	*3
6	Column	12.34	0.00	0.488	0.000	25.901	0.000	0.000	---	
	Middle	18.66	0.00	0.488	0.000	39.192	0.000	0.000	---	

NOTES:
*3 - Design governed by minimum reinforcement.

Bottom Bar Details

Units: Start (ft), Length (ft)

		Long Bars			Short Bars		
Span	Strip	Bars	Start	Length	Bars	Start	Length

1	Column	---			---
	Middle	---			---
2	Column	15-#5	0.00	24.67	---
	Middle	15-#5	0.00	24.67	---
3	Column	15-#5	0.00	29.50	---
	Middle	14-#5	0.00	29.50	---
4	Column	---			---
	Middle	---			---
5	Column	18-#5	0.00	24.67	---
	Middle	15-#5	0.00	24.67	---
6	Column	---			---
	Middle	---			---

Flexural Capacity
=================

Units: x (ft), As (in^2), PhiMn (k-ft)

Span	Strip	x	AsTop	AsBot	PhiMn-	PhiMn+
1	Column	0.000	3.10	0.00	-132.56	0.00
		0.240	3.10	0.00	-132.56	0.00
		0.415	3.10	0.00	-132.56	0.00
		0.445	3.10	0.00	-132.56	0.00
		0.685	3.10	0.00	-132.56	0.00
		0.830	3.10	0.00	-132.56	0.00
	Middle	0.000	4.65	0.00	-198.88	0.00
		0.240	4.65	0.00	-198.88	0.00
		0.415	4.65	0.00	-198.88	0.00
		0.445	4.65	0.00	-198.88	0.00
		0.685	4.65	0.00	-198.88	0.00
		0.830	4.65	0.00	-198.88	0.00
2	Column	0.000	3.10	4.65	-132.56	196.91
		0.750	3.10	4.65	-132.56	196.91
		7.314	3.10	4.65	-132.56	196.91
		8.314	0.00	4.65	0.00	196.91
		8.772	0.00	4.65	0.00	196.91
		12.335	0.00	4.65	0.00	196.91
		15.103	0.00	4.65	0.00	196.91
		15.648	2.42	4.65	-103.95	196.91
		16.220	4.96	4.65	-209.63	196.91
		18.592	4.96	4.65	-209.63	196.91
		19.500	7.98	4.65	-330.96	196.91
		19.500	7.98	4.65	-624.12	196.91
		19.709	8.68	4.65	-676.53	196.91
		23.670	8.68	4.65	-676.53	196.91
		24.670	8.68	4.65	-676.53	196.91
	Middle	0.000	4.65	4.65	-198.88	198.88
		0.750	4.65	4.65	-198.88	198.88
		4.793	4.65	4.65	-198.88	198.88
		5.793	0.00	4.65	0.00	198.88
		8.772	0.00	4.65	0.00	198.88
		12.335	0.00	4.65	0.00	198.88
		15.103	0.00	4.65	0.00	198.88
		15.648	2.56	4.65	-110.51	198.88
		16.224	5.27	4.65	-224.82	198.88
		23.670	5.27	4.65	-224.82	198.88
		24.670	5.27	4.65	-224.82	198.88
3	Column	0.000	8.68	4.65	-676.53	197.86
		1.000	8.68	4.65	-676.53	197.86
		5.170	8.68	4.65	-676.53	197.86
		5.170	8.68	4.65	-358.18	197.86
		5.349	8.68	4.65	-358.18	197.86
		6.501	4.96	4.65	-209.63	197.86
		8.924	4.96	4.65	-209.63	197.86
		10.075	0.00	4.65	0.00	197.86
		10.625	0.00	4.65	0.00	197.86
		14.750	0.00	4.65	0.00	197.86
		18.875	0.00	4.65	0.00	197.86
		19.425	0.00	4.65	0.00	197.86
		20.546	3.10	4.65	-130.70	197.86
		22.999	3.10	4.65	-130.70	197.86
		24.121	5.58	4.65	-228.87	197.86
		24.330	5.58	4.65	-228.87	197.86
		24.330	5.58	4.65	-436.03	197.86
		28.500	5.58	4.65	-436.03	197.86
		29.500	5.58	4.65	-436.03	197.86
	Middle	0.000	5.27	4.34	-224.82	185.36
		1.000	5.27	4.34	-224.82	185.36
		8.719	5.27	4.34	-224.82	185.36
		9.875	0.00	4.34	0.00	185.36
		10.625	0.00	4.34	0.00	185.36

	14.750	0.00	4.34	0.00	185.36
	18.875	0.00	4.34	0.00	185.36
	21.865	0.00	4.34	0.00	185.36
	22.865	6.20	4.34	-264.94	185.36
	28.500	6.20	4.34	-264.94	185.36
	29.500	6.20	4.34	-264.94	185.36
4 Column	0.000	5.58	0.00	-436.03	0.00
	1.000	5.58	0.00	-436.03	0.00
	4.310	5.58	0.00	-436.03	0.00
	5.170	4.51	0.00	-354.93	0.00
	5.170	4.51	0.00	-187.35	0.00
	5.310	4.34	0.00	-180.50	0.00
	5.316	4.34	0.00	-180.50	0.00
	7.165	4.34	0.00	-180.50	0.00
	8.260	4.34	0.00	-180.50	0.00
	9.015	5.51	0.00	-226.17	0.00
	9.160	5.74	0.00	-234.82	0.00
	9.160	5.74	0.00	-447.76	0.00
	9.260	5.89	0.00	-459.41	0.00
	13.330	5.89	0.00	-459.41	0.00
	14.330	5.89	0.00	-459.41	0.00
Middle	0.000	6.20	0.00	-264.94	0.00
	1.000	6.20	0.00	-264.94	0.00
	5.316	6.20	0.00	-264.94	0.00
	7.165	6.20	0.00	-264.94	0.00
	9.015	6.20	0.00	-264.94	0.00
	13.330	6.20	0.00	-264.94	0.00
	14.330	6.20	0.00	-264.94	0.00
5 Column	0.000	5.89	5.58	-459.41	234.90
	1.000	5.89	5.58	-459.41	234.90
	4.400	5.89	5.58	-459.41	234.90
	5.170	4.08	5.58	-321.41	234.90
	5.170	4.08	5.58	-170.04	234.90
	5.585	3.10	5.58	-130.70	234.90
	7.380	3.10	5.58	-130.70	234.90
	8.564	0.00	5.58	0.00	234.90
	9.022	0.00	5.58	0.00	234.90
	12.335	0.00	5.58	0.00	234.90
	15.898	0.00	5.58	0.00	234.90
	16.356	0.00	5.58	0.00	234.90
	17.356	3.10	5.58	-132.56	234.90
	23.920	3.10	5.58	-132.56	234.90
	24.670	3.10	5.58	-132.56	234.90
Middle	0.000	6.20	4.65	-264.94	198.88
	1.000	6.20	4.65	-264.94	198.88
	6.591	6.20	4.65	-264.94	198.88
	7.591	0.00	4.65	0.00	198.88
	9.022	0.00	4.65	0.00	198.88
	12.335	0.00	4.65	0.00	198.88
	15.898	0.00	4.65	0.00	198.88
	18.877	0.00	4.65	0.00	198.88
	19.877	4.65	4.65	-198.88	198.88
	23.920	4.65	4.65	-198.88	198.88
	24.670	4.65	4.65	-198.88	198.88
6 Column	0.000	3.10	0.00	-132.56	0.00
	0.145	3.10	0.00	-132.56	0.00
	0.385	3.10	0.00	-132.56	0.00
	0.415	3.10	0.00	-132.56	0.00
	0.590	3.10	0.00	-132.56	0.00
	0.830	3.10	0.00	-132.56	0.00
Middle	0.000	4.65	0.00	-198.88	0.00
	0.145	4.65	0.00	-198.88	0.00
	0.385	4.65	0.00	-198.88	0.00
	0.415	4.65	0.00	-198.88	0.00
	0.590	4.65	0.00	-198.88	0.00
	0.830	4.65	0.00	-198.88	0.00

Slab Shear Capacity
===================

Units: b, d (in), Xu (ft), PhiVc, Vu(kip)

Span	b	d	Vratio	PhiVc	Vu	Xu
1	372.00	9.69	1.000	341.88	0.00	0.00
2	372.00	9.69	1.000	341.88	153.79	22.86
3	372.00	9.69	1.000	341.88	155.66	1.81
4	372.00	9.69	1.000	341.88	66.21	12.52
5	372.00	9.69	1.000	341.88	141.57	1.81
6	372.00	9.69	1.000	341.88	0.00	0.00

Flexural Transfer of Negative Unbalanced Moment at Supports
===

Units: Width (in), Munb (k-ft), As (in^2)

Supp	Width	Width-c	d	Munb	Comb	Pat	GammaF	AsReq	AsProv	Add Bars

1	--- Not checked ---									
2	83.25	83.25	17.94	27.07	U1	All	0.600	0.201	4.882	---
3	83.25	83.25	17.94	221.51	U1	All	0.600	1.663	5.403	---
4	83.25	83.25	17.94	232.34	U1	All	0.600	1.745	5.703	---
5	--- Not checked ---									

Punching Shear Around Columns

Critical Section Properties

Units: b1, b2, b0, CG, c(left), c(right) (in), Ac (in^2), Jc (in^4)

Supp	b1	b2	b0	CG	c(left)	c(right)	Ac	Jc
1	--- Not checked ------							
2	41.94	41.94	167.75	0.00	20.97	20.97	3009	9.2236e+005
3	41.94	41.94	167.75	0.00	20.97	20.97	3009	9.2236e+005
4	41.94	41.94	167.75	0.00	20.97	20.97	3009	9.2236e+005
5	--- Not checked ------							

Punching Shear Results

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

Supp	Vu	vu	Munb	Comb	Pat	GammaV	vu	Phi*vc
1	--- Not checked ---							
2	348.70	115.9	27.07	U1	All	0.400	118.8	189.7
3	229.10	76.1	-221.51	U1	All	0.400	100.3	189.7
4	247.02	82.1	232.34	U1	All	0.400	107.4	189.7
5	--- Not checked ---							

Punching Shear Around Drops

Critical Section Properties

Units: b1, b2, b0, CG, c(left), c(right) (in), Ac (in^2), Jc (in^4)

Supp	b1	b2	b0	CG	c(left)	c(right)	Ac	Jc
1	--- Not checked ------							
2	133.77	133.77	535.07	0.00	66.88	66.88	5183.5	1.5479e+007
3	133.77	133.77	535.07	0.00	66.88	66.88	5183.5	1.5479e+007
4	133.77	133.77	535.07	0.00	66.88	66.88	5183.5	1.5479e+007
5	--- Not checked ------							

Punching Shear Results

Units: Vu (kip), vu (psi), Phi*vc (psi)

Supp	Vu	Comb	Pat	vu	Phi*vc
1	--- Not checked ------				
2	309.74	U1	All	59.8	129.2
3	190.14	U1	All	36.7	129.2
4	208.06	U1	All	40.1	129.2
5	--- Not checked ------				

Deflections

Section properties

Units: Ig, Icr, Ie (in^4), Mcr, Mmax (k-ft)

	Ie,avg						Load Level			
							Dead		Dead+Live	
Span	Dead	Dead+Live	Zone	Ig	Icr	Mcr	Mmax	Ie	Mmax	Ie
1	133502	133502	Right	133502	13976	689.22	-3.09	133502	-3.09	133502
2	65270	65270	Left	133502	13976	689.22	-110.50	133502	-110.50	133502
			Middle	47147	5096	324.11	266.95	47147	266.95	47147
			Right	133502	22781	689.22	-850.93	81613	-850.93	81613
3	64604	64604	Left	133502	22781	689.22	-873.49	77172	-873.49	77172
			Middle	47147	4947	324.11	268.92	47147	268.92	47147
			Right	133502	19851	689.22	-582.23	133502	-582.23	133502
4	73054	73054	Left	133502	19851	689.22	-397.63	133502	-397.63	133502
			Middle	47147	47147	324.11	0.00	47147	0.00	47147
			Right	133502	20279	689.22	-447.29	133502	-447.29	133502
5	73054	73054	Left	133502	20279	689.22	-640.91	133502	-640.91	133502
			Middle	47147	5537	324.11	323.06	47147	323.06	47147
			Right	133502	13976	689.22	-151.88	133502	-151.88	133502
6	133502	133502	Left	133502	13976	689.22	-3.09	133502	-3.09	133502

Maximum Instantaneous Deflections - Direction of Analysis

Units: D (in), Ig (in^4)

	Frame			Strips						
Span	Ddead	Dlive	Dtotal	Strip	Ig	LDF	Ratio	Ddead	Dlive	Dtotal
1	-0.011	0.000	-0.011	Column	18760	0.800	2.011	-0.022	0.000	-0.022
				Middle	28387.1	0.200	0.332	-0.004	0.000	-0.004
2	0.094	0.000	0.094	Column	18760	0.738	1.853	0.174	0.000	0.174
				Middle	28387.1	0.262	0.436	0.041	0.000	0.041

```
      3    0.143      0.000      0.143 Column        22432.9  0.675  1.419    0.202     0.000     0.202
                                       Middle        24714.2  0.325  0.620    0.088     0.000     0.088
      4   -0.024      0.000     -0.024 Column        10897.1  0.675  2.920   -0.069     0.000    -0.069
                                       Middle        36250.1  0.325  0.423   -0.010     0.000    -0.010
      5    0.122      0.000      0.122 Column          18760  0.738  1.853    0.226     0.000     0.226
                                       Middle        28387.1  0.262  0.436    0.053     0.000     0.053
      6   -0.013      0.000     -0.013 Column          18760  0.800  2.011   -0.026     0.000    -0.026
                                       Middle        28387.1  0.200  0.332   -0.004     0.000    -0.004

  Maximum Long-term Deflections - Direction of Analysis
  -----------------------------------------------------
  Time dependant factor for sustained loads = 2.000
  Units:  D (in)
       _______________________Column Strip_______________________ _______________________Middle Strip_______________________
  Span    Dsust Lambda      Dcs   Dcs+lu    Dcs+l   Dtotal    Dsust Lambda      Dcs   Dcs+lu    Dcs+l   Dtotal
  ---- -------- ------ -------- -------- -------- -------- -------- ------ -------- -------- -------- --------
     1   -0.022  2.000   -0.044   -0.044   -0.044   -0.067   -0.004  2.000   -0.007   -0.007   -0.007   -0.011
     2    0.174  2.000    0.347    0.347    0.347    0.521    0.041  2.000    0.082    0.082    0.082    0.123
     3    0.202  2.000    0.404    0.404    0.404    0.607    0.088  2.000    0.177    0.177    0.177    0.265
     4   -0.069  2.000   -0.138   -0.138   -0.138   -0.208   -0.010  2.000   -0.020   -0.020   -0.020   -0.030
     5    0.226  2.000    0.453    0.453    0.453    0.679    0.053  2.000    0.107    0.107    0.107    0.160
     6   -0.026  2.000   -0.053   -0.053   -0.053   -0.079   -0.004  2.000   -0.009   -0.009   -0.009   -0.013

Material Takeoff
================
  Reinforcement in the Direction of Analysis
  ------------------------------------------
  Top Bars:      2408.6 lb    <=>  25.40 lb/ft    <=>  0.819 lb/ft^2
  Bottom Bars:   2513.3 lb    <=>  26.50 lb/ft    <=>  0.855 lb/ft^2
  Stirrups:         0.0 lb    <=>   0.00 lb/ft    <=>  0.000 lb/ft^2
  Total Steel:   4921.9 lb    <=>  51.90 lb/ft    <=>  1.674 lb/ft^2
  Concrete:      3111.3 ft^3  <=>  32.81 ft^3/ft  <=>  1.058 ft^3/ft^2
```

Appendix E: Comparison Calculations

weights

Composite deck

slab/deck : 46 psf

Beam:

W14x31: 2x(31 plf x 29.5') = 1829 lb
W24x84: 84 plf x 29.5' = 2478 lb
4307 lb / (29.5' x 31') = 4.7 psf

Girder:
W21x44: ½ (44x31) = 682 lb
W30x90: ½ (90x31) = 1395 lb
2077 lb / 914.5 ft² = 2.3 psf

Total = 53 psf

Precast plank

plank + topping: 68 + 25 = 93 psf

Girder:
W30x116 : 116 plf / 29.5' = 3.9 psf

Total = 96.9 psf

One way slab w/ bm

Slab: (150 pcf)(7/12) = 87.5 psf
Beam: [(150 pcf)(25/12)(18/12)] / 31' = 15.1 psf x2 = 30.2 psf
girder: [(150 pcf)(29/12)(26.5/12)] / 29.5 = 18.7 psf

Total = 136.4 psf

2-way slab w/ drop panels

slab: (150)(11.5/12) = 143 psf
drop panel: (150)(8.25/12)(10.33)² / (29.5 x 31) = 12 psf
Total = 155 psf

Deflections

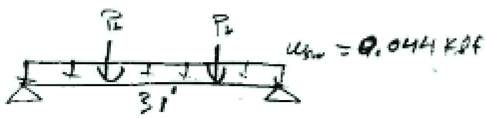
Composite deck system

$I_{LB} = 1460 \text{ in}^4$

Girder: W21 x 44 , 3/4" camber

DL = 40 psf
LL = 80 psf
SW = 44 plf

$P_L = 45.3 \text{ K}$



$$\Delta_{TL} = \frac{5 w_{sw} l^4}{384 E I_{LB}} + \frac{P_L l^3}{28 E I_{LB}}$$

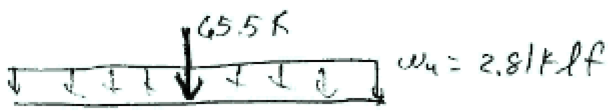
$$= 2'' - 3/4'' = 1.25'' < \frac{l}{240} \checkmark$$

One Way Slab

Girder:

$$I = \frac{1}{12} b h^3 = \frac{1}{12}(20)(26.5)^3 = 31{,}016 \text{ in}^4$$

$$E = 57000\sqrt{4000} = 3605 \text{ Ksi}$$



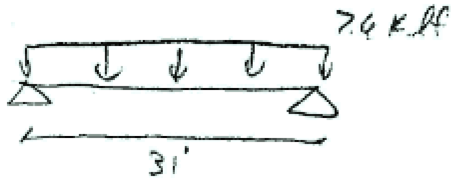
$$\Delta_{TL} = \frac{w l^4}{384 E I} + \frac{P l^3}{192 E I}$$

$$= 0.26'' < \frac{l}{240} \checkmark$$

Deflections

Precast planks

Girder: W30x116 $I = 4930 \text{ in}^4$



$w_u = 7.4 \text{ klf} + 1.2(116)/1000 = 7.74 \text{ klf}$

$\Delta_{max} = \frac{5 w_u l^4}{384 EI} = 1.12 \text{ in}$

Two way slab

deflections calculated in spSlab

Col strip: $\Delta = 0.607''$

middle strip: $\Delta = 0.265$

$\Delta_{max} = 0.607 + 0.265 = 0.872''$

Appendix F: RSmeans Cost Estimate Tables

- Tables are represent a rough estimate of the closest size to system used in this report

Assembly B10102414300 **Based on National Average Costs**

W beam and girder, 25'x20' bay, 40 PSF superimposed load, 18" deep, fireproofing .702 SF/SF, 90 PSF total load

Description	Quantity	Unit	Material	Installation	Total
Structural steel project, apartment, nursing home, etc, 100-ton project, 3 to 6 stories,...	6.00000	Lb.	8.40	2.58	10.98
Sprayed fireproofing, cementitious, normal density, beams, 1 hour rated, 1-3/8" thick...	0.70200	S.F.	0.41	0.69	1.10
Total			$8.80	$3.27	$12.07

Assembly B10102564500 **Based on National Average Costs**

Floor, composite metal deck, shear connectors, 5.5" slab, 30'x30' bay, 29.5" total depth, 125 PSF superimposed load, 168 PSF total load

Description	Quantity	Unit	Material	Installation	Total
Welded wire fabric, sheets, 6 x 6 - W1.4 x W1.4 (10 x 10) 121 lb. per C.S.F., A185, inc...	0.01000	C.S.F.	0.15	0.36	0.51
Structural concrete, placing, elevated slab, pumped, less than 6" thick, includes strike...	0.33300	C.F.	0.00	0.51	0.51
Structural concrete, ready mix, lightweight, 110 #/C.F., 3000 psi, includes local aggre...	0.33300	C.F.	2.41	0.00	2.41
Concrete finishing, floors, for specified Random Access Floors in ACI Classes 1, 2, 3 an...	1.00000	S.F.	0.00	0.86	0.86
Concrete surface treatment, curing, sprayed membrane compound	0.01000	C.S.F.	0.08	0.09	0.17
Weld shear connector, 3/4" dia x 4-7/8" L	0.16300	Ea.	0.12	0.33	0.45
Structural steel project, apartment, nursing home, etc, 100-ton project, 3 to 6 stories,...	6.80600	Lb.	9.53	2.93	12.45
Metal floor decking, steel, non-cellular, composite, galvanized, 3" D, 20 gauge	1.05000	S.F.	2.32	1.04	3.36
Metal decking, steel edge closure form, galvanized, with 2 bends, 12" wide, 18 gauge	0.03300	L.F.	0.13	0.08	0.21
Sprayed fireproofing, cementitious, normal density, beams, 1 hour rated, 1-3/8" thick...	0.66700	S.F.	0.39	0.66	1.05
Total			$15.15	$6.86	$22.01

Assembly B10102197300 **Based on National Average Costs**

Cast-in-place concrete beam and slab, 7.5" slab, one way, 20" column, 30'x30' bay, 125 PSF superimposed load, 245 PSF total load

Description	Quantity	Unit	Material	Installation	Total
C.I.P. concrete forms, beams and girders, exterior spandrel, plywood, 12" wide, 4 use...	0.15600	SFCA	0.14	1.60	1.74
C.I.P. concrete forms, beams and girders, interior, plywood, 12" wide, 4 use, includes...	0.32500	SFCA	0.35	2.73	3.08
C.I.P. concrete forms, elevated slab, flat plate, plywood, to 15' high, 4 use, includes s...	0.85500	S.F.	0.97	4.83	5.81
Reinforcing Steel, in place, elevated slabs, #4 to #7, A615, grade 60, incl labor for acc...	4.35000	Lb.	2.44	1.87	4.31
Structural concrete, ready mix, normal weight, 3000 psi, includes local aggregate, san...	0.79900	C.F.	3.32	0.00	3.32
Structural concrete, placing, elevated slab, pumped, 6" to 10" thick, includes strike of...	0.79900	C.F.	0.00	1.03	1.03
Concrete finishing, floors, for specified Random Access Floors in ACI Classes 1, 2, 3 an...	1.00000	S.F.	0.00	0.86	0.86
Concrete surface treatment, curing, sprayed membrane compound	0.01000	C.S.F.	0.08	0.09	0.17
Total			$7.30	$13.01	$20.31

Assembly B10102303600 **Based on National Average Costs**

Precast concrete plank, 2" topping, 10" total thickness, 30' span, 100 PSF superimposed load, 180 PSF total load

Description	Quantity	Unit	Material	Installation	Total
C.I.P. concrete forms, elevated slab, edge forms, to 6" high, 4 use, includes shoring, e...	0.10000	L.F.	0.02	0.41	0.43
Welded wire fabric, sheets, 6 x 6 - W1.4 x W1.4 (10 x 10) 121 lb. per C.S.F., A185, inc...	0.01000	C.S.F.	0.15	0.36	0.51
Structural concrete, ready mix, normal weight, 3000 psi, includes local aggregate, san...	0.17000	C.F.	0.71	0.00	0.71
Structural concrete, placing, elevated slab, pumped, less than 6" thick, includes strike...	0.17000	C.F.	0.00	0.26	0.26
Concrete finishing, floors, basic finishing for unspecified flatwork, bull float, manual fl...	1.00000	S.F.	0.00	1.13	1.13
Concrete surface treatment, curing, sprayed membrane compound	0.01000	C.S.F.	0.08	0.09	0.17
Precast slab, roof/floor members, grouted, hollow, 8" thick, prestressed	1.00000	S.F.	7.85	2.52	10.37
Total			$8.80	$4.77	$13.57

Assembly B10102226800 **Based on National Average Costs**

Flat slab, concrete, with drop panels, 10.5" slab/9" panel, 22" column, 30'x30' bay, 125 PSF superimposed load, 269 PSF total load

Description	Quantity	Unit	Material	Installation	Total
C.I.P. concrete forms, beams and girders, exterior spandrel, plywood, 12" wide, 4 use...	0.03600	SFCA	0.03	0.37	0.40
C.I.P. concrete forms, elevated slab, flat slab with drop panels, to 15' high, 4 use, incl...	0.99200	S.F.	1.27	5.80	7.07
Reinforcing Steel, in place, elevated slabs, #4 to #7, A615, grade 60, incl labor for acc...	4.66200	Lb.	2.61	2.00	4.62
Structural concrete, ready mix, normal weight, 3000 psi, includes local aggregate, san...	0.95800	C.F.	3.99	0.00	3.99
Structural concrete, placing, elevated slab, pumped, 6" to 10" thick, includes strike of...	0.95800	C.F.	0.00	1.24	1.24
Concrete finishing, floors, for specified Random Access Floors in ACI Classes 1, 2, 3 an...	1.00000	S.F.	0.00	0.86	0.86
Concrete surface treatment, curing, sprayed membrane compound	0.01000	C.S.F.	0.08	0.09	0.17
Total			$8.00	$10.36	$18.36