Tech Report 2

Nikki Hazy
Structural Option
Advisor: Dr Hanagan

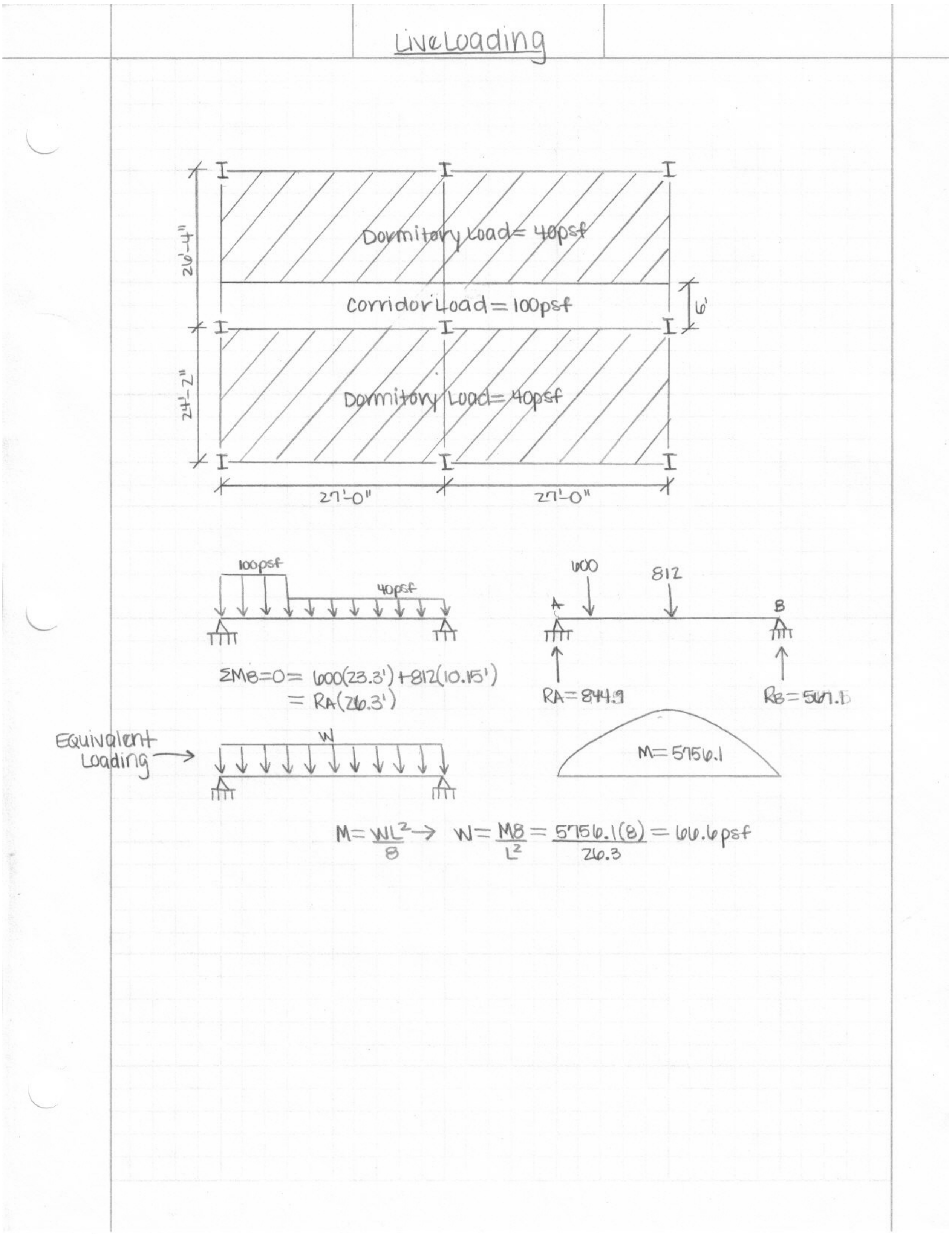
Upper Campus Housing Project

The following report is a study of optional structural systems that could be used on the Upper Campus Housing Project that is located in Pittsburgh, PA. The building will be used as a dormitory facility for The University of Pittsburgh students. The existing structure of the building is precast concrete hollow-core planks with concrete masonry bearing and shear walls. A typical floor plan is located in the section of this report containing a study of the existing structure (pg.3).

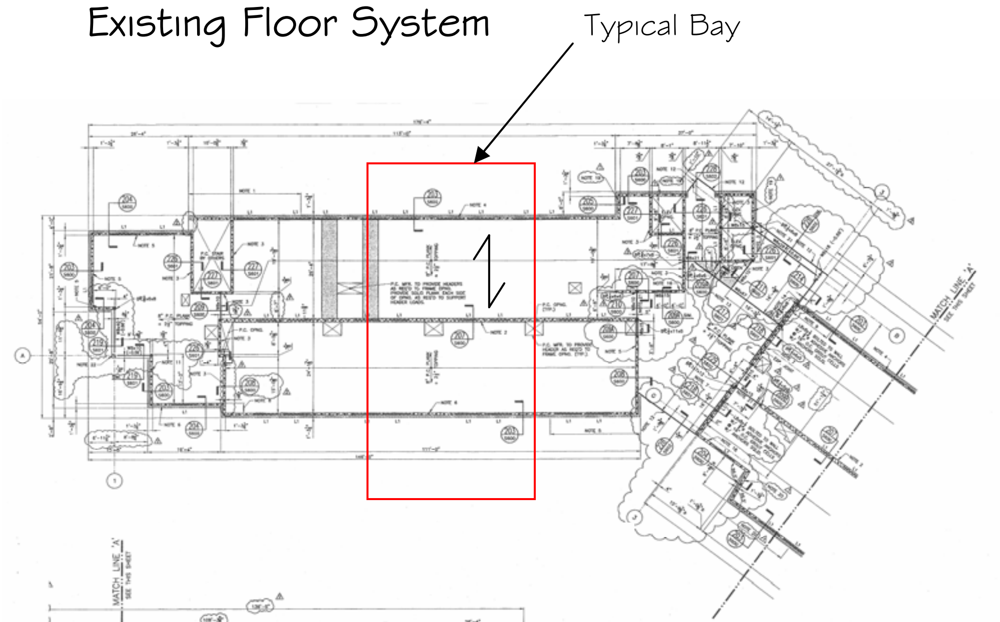
Included in this report are an analysis of the existing floor system and an analysis of four alternate systems for Upper Campus Housing Project. These systems include: Flat slab with drop panels, flat plate, waffle slab, and a composite steel system. Design aids were used in the analysis of the structure. Such aids included RAM and CRSI Design Handbook. Hand calculations were also done for three of these four systems. All charts from CRSI and all hand calculations are located in the Appendix. For the purposes of this assignment a typical bay was used to analyze each system. From examination of the architectural floor plans a typical bay consists of dormitory and corridor loads and an equivalent live load is shown on page 2.

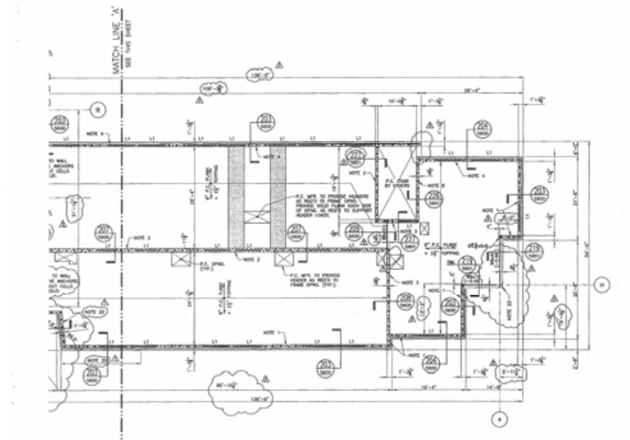
From the analysis and comparison of systems, the waffle slab and the flat plate systems will still be considered as options for the floor structure of the Upper Campus Housing Project. Other factors will still need to be considered to come to a definite alternative floor system. Such factors include: implications on the foundations, column design and shear at columns, and lateral system.

For simplification of analysis and design the following calculations were performed to obtain an approximate live load.

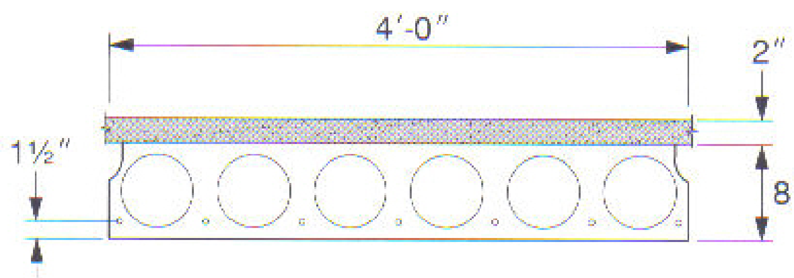


Existing Floor System



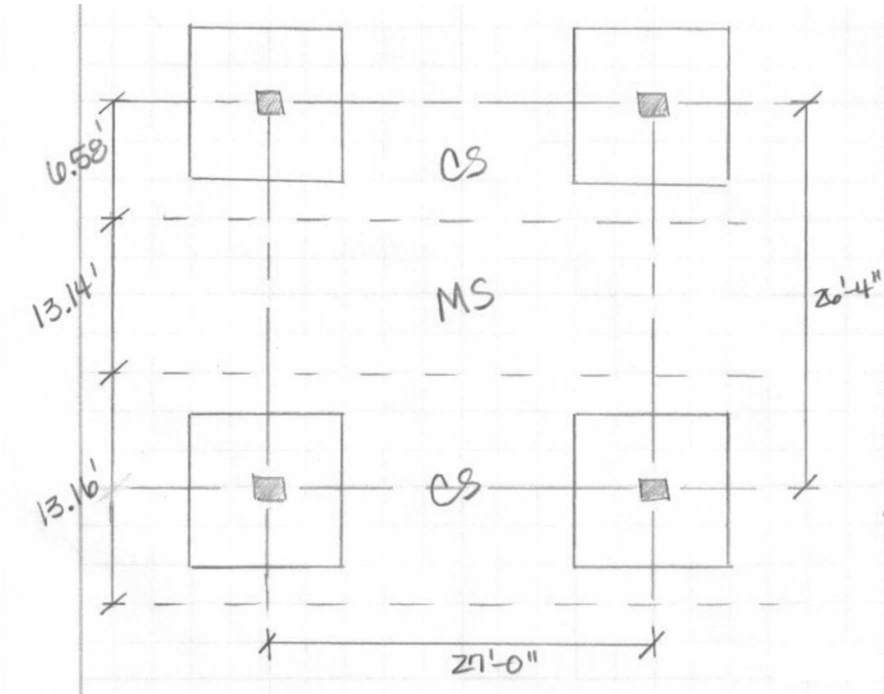


As stated, the existing floor system for Upper Campus Housing Project is 8" precast hollow-core planks with a 2 ½" topping. All walls are concrete masonry bearing and shear walls of varying thicknesses and reinforcement. The maximum span used for the plank is 27' (rounded up from 26'-4").



For design of the hollow-core deck, the load is calculated in pounds per square foot. This load includes a 15psf load for topped members plus a 25psf superimposed deal load and any live load. Using a load of 1.2(15psf+25psf) + 1.6(67psf) = 156psf and a span of 27ft the PCI Design Handbook recommends the use of a 78-S. The precast plant engineer will do any further design, including the design of the reinforcement and he also has the ability to make the plank solid where needed. In this system this occurs on the roof level where the plank is 10".

Two-Way Flat Slab w/ Drop Panels

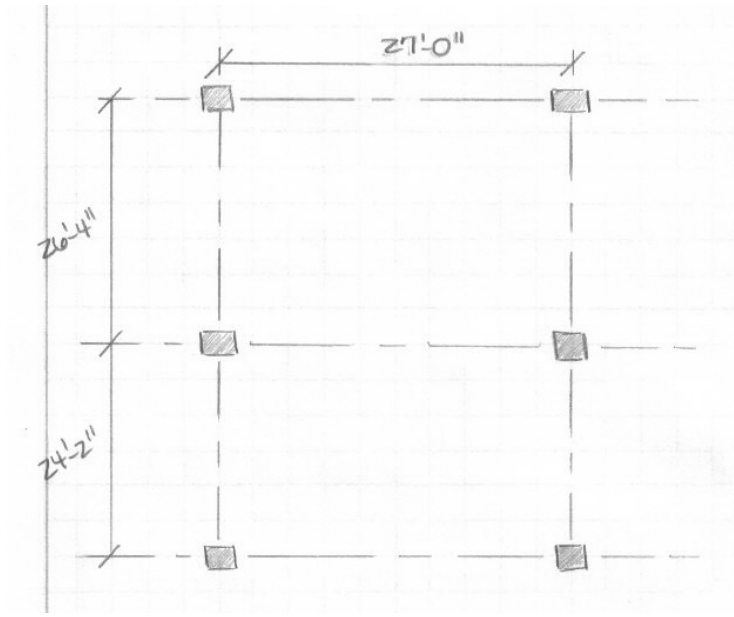


The framing layout shown to the left is the one used to design a two-way flat slab system. Hand calculations were done and are located in Appendix B-1.1/B-1.2. Also, the CRSI Handbook was used for an easy, quick, and efficient design. The hand calculations shown have similar results to those given by the CRSI Handbook. For the purposes of analysis a 24" x 24" column was assumed.

The total depth of this system is 9" with an 8 ½" drop panel and they will be 9ft x 9ft. In the column strips the reinforcement is broken down into top external (15 #4), bottom (11 #8), and top interior (14 #6). The middle strip is broken into bottom (9 #7) and top interior (10 #6). Also, a minimum column size is given as 15". The total load that this system can carry is 200psf. Some advantages of this system include heavier loads, longer spans, less concrete, and less reinforcement than a flat plate system.

Two-Way Flat Plate System

Another system alternative is a two-way flat plate system. For each two-way system a square or nearly square bay is needed. We can use the longer span to design this system. The system shown to the right is the framing layout for a flat plate. Hand calculations for this system are located in Appendix B-2.1/B-2.2.



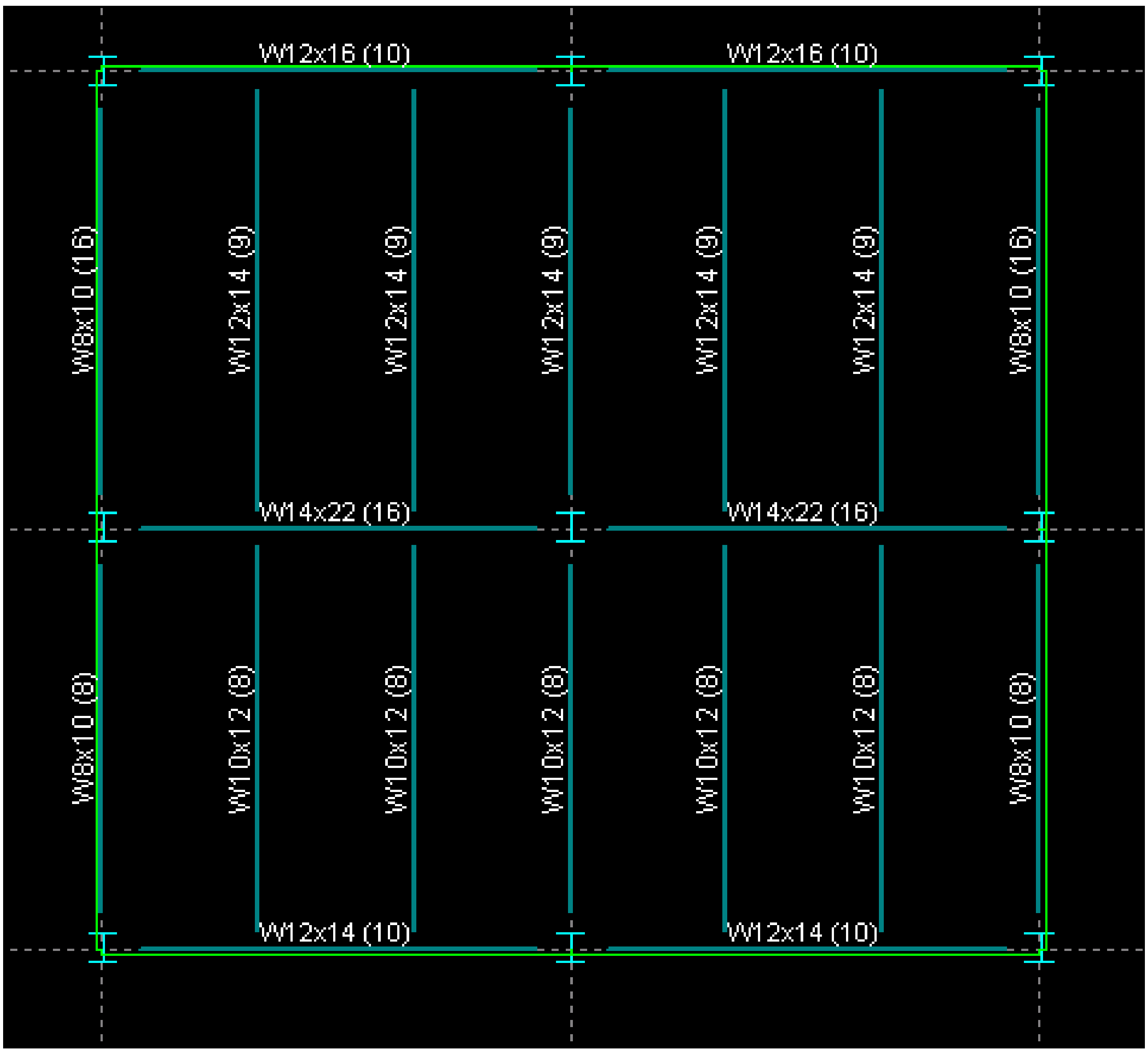
The design for this system according to CRSI is a slab thickness of 9 ½" with a minimum square column of 32". The reinforcement for this system is as follows for the column strip: top exterior (16 #5), bottom (10 #7), and top interior (14 #8). For the middle strip, the reinforcement should be designed with 9 #6 in the bottom and 11 #5 in the top. This system can hold a load of 150psf. One advantage of this system is easy formwork framing.

Two-Way Waffle Slab

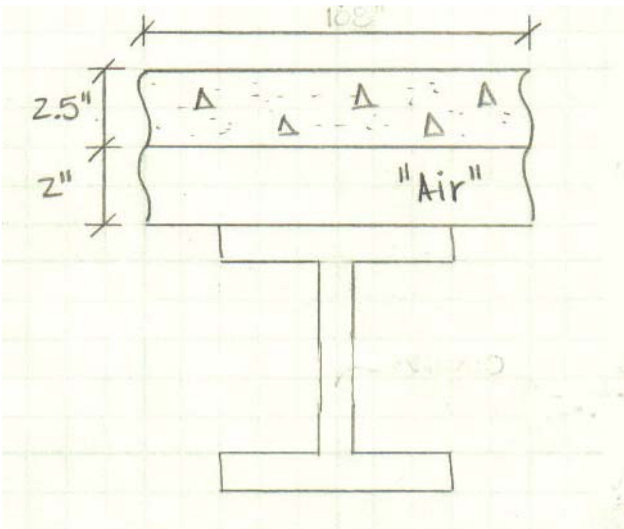
Waffle slab construction shares the same framing layout as shown above. However, this system allows for less dead load because it only has concrete in the moment region needed. Another advantage to a waffle slab is the geometric shape formed by the ribs. This shape is often desired by architects. This system also works well with MEP accommodations.

The CRSI Design Handbook was also used for this design. 30" x 30" with 6" voids would be used to make a total system of 36". The total load that this system can carry is 150psf. The reinforcement for the column strip is 20 #5 at the top edge, 1 #7 and 1 #8 at the bottom, and 24 #5 at the top interior. At the middle strip the bottom long bars should be #5 and the bottom short bars should be #6. At the top interior middle strip 8 #5 should be used. In column strip regions the waffles will be filled in solid.

Composite Steel System



The above composite deck system is another alternative design for the Upper Campus Housing Project. This system allows for an alternative to concrete design. The above member sizes are from RAM modeling and design software. Hand calculations were also done and are located in Appendix B-3.1/B-3.2.



The deepest member in the design above is a W14, which is approximately 14". This system is 4 inches deeper than the existing system. However, this system is considerably thinner than the flat slab because of the drop panels. Steel systems also have another major advantage. Even with steel prices, steel systems save money during construction. They can be built very quickly in comparison to poured concrete systems. However, the existing system is also very good in constructability because it is precast in a plant.

System Comparison and Summary

System	Depth	Constructability	Cost/ft2
Hollow-Core Plank	10 1/2"	Best	$10.33
Flat Slab w/ Drop Panels	17 1/2"	Good	$16.05
Flat Plate	9 1/2"	Moderate	$13.20
Waffle Slab	11"	Poor	$20.45
Composite Steel	18 1/2"	Moderate	$30.70

The above chart displays a comparison between all systems depth, constructability, and cost per square foot. From examination of this chart the original design is most likely the best system for the Upper Campus Housing Project. However, two of the other systems still can be examined further as alternatives. Although the waffle slab is not as good for constructability as the others, a waffle slab system is very advantageous when longer spans and heavier loads are desired without increasing the depth of the system. The flat plate system is also worth looking into further because it offers the smallest depth, decent constructability, and a low cost.

The two other system analyzed can be ruled out for the design of this building. The steel system proposed will not be a good solution to the structural system for the Upper Campus Housing Project. It comes in at the highest cost per square foot and at the deepest depth. Another consideration is that the cost for fire-proofing this system is not included. However, one advantage to this system is the decrease in structure weight. The flat slab system with drop panels is also very deep compared to the original system. Even though it has a relatively low cost, this system can also be ruled out.

The existing lateral system consists of reinforced concrete masonry shear walls. For each of the two alternative systems, the lateral system may change. Because concrete systems form a natural moment frame, these moment frames are capable of handling the lateral loads, and hence the system will be fine. However, if moment frames are not adequate, some shear walls may be needed.

The existing foundations system consists of concrete grade beams and caissons. Foundation systems for the two alternative systems have a possibility of changing to square or mat footings. This will be possible if moment frames are a possible solution for the lateral system. However, if shear walls are needed, the foundation system could remain similar to what exists currently.

Appendix A
References

References

CRSI Design Handbook, 2002

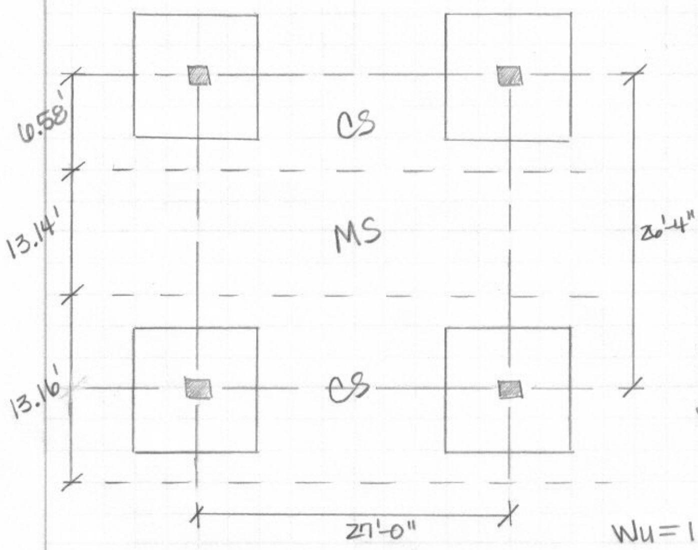
PCI Design Handbook 5th Edition

RS Means Assemblies Cost Data 25th Edition, 2005

RAM Structural System

Appendix B
Hand Calculations

Flat slab w/ Drop Panels



$0.25 l_2 = 0.25(26.3') = 6.58'$

Assume 24" Columns

9ft x 9ft x 8.5" Drop Panels

$t_{min} = l_n/33 = 24.3ft(12)/33$
$= 8.8" \rightarrow 9"$

SDL = 25psf
LL = 67psf
$self = (9.5"/12)150 + \frac{9'(9')(8.5"/12)(150)}{27'(26'-4')}$
$= 131 psf$

$W_u = 1.2(25psf + 131psf) + 1.6(67psf)$
$= 295psf$

$M_o = \frac{W_u l_2 l_n^2}{8} = \frac{295psf(26.3ft)(25ft)^2}{8}$
$= 606^{1K}$

$I_B = 1/12(13.16')(12in/ft)(9.5")^3 = 11283.1$
$I_S = 1/12(13.14')(12in/ft)(9.5")^3 = 11265.9$
$\alpha \approx 1.0$

Int. Neg. Mom. $0.70M_o$	CS = 0.70(0.75)Mo = 318.2[1K]	→ 318.2[1K]/13.16' = 24.2[1K]
	MS = 0.70(0.25)Mo = 106.1[1K]	→ 106.1[1K]/13.14' = 8.1[1K]
Posit. Mom. $0.52M_o$	CS = 0.52(0.6)Mo = 189.1[1K]	→ 189.1/6.58' = 28.7[1K]
	MS = 0.52(0.4)Mo = 126.1[1K]	→ 126.1/13.14 = 9.6[1K]
Ext. Neg. Mom. $0.26M_o$	CS = 0.26(1.0)Mo = 157.6[1K]	→ 157.6/6.58 = 23.95[1K]
	MS = 0	

$d = 18" - 0.75" - 1" = 16.26"$
Assume $a = 1.5"$

At Supports

$M_n = M_u/\phi = 24.2^{1K}/0.9 = 26.9^{1K} = A_s f_y(d - a/2)$

$A_s = \frac{26.9^{1K}(12in/ft)}{60ksi(16.25" - 1.5"/2)} = 0.35in^2 \rightarrow$ 2#4 at 12" ($A_s = 0.40in^2$)

$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{0.40in^2(60ksi)}{0.85(4ksi)(12")} = 0.59"$

$M_n = A_s f_y(d - a/2) = 0.40in^2(60ksi)(16.26" - 0.59"/2) = 31.9^{1K}$

$\phi M_n = 28.72^{1K} > 24.2^{1K}$ OK

$c = 0.59"/0.85 = 0.694" \le 0.375(16.25") = 6.1"$ OK

Flat slab w/ Drop Panels con't

<u>Column Strip Midspan</u>

$d = 9.5'' - 0.75'' - 1'' = 7.75''$
Assume $a = 1''$

$M_n = \frac{M_u}{\phi} = \frac{28.7^{'k}}{0.9} = 31.9^{'k}$

$A_s = \frac{31.9^{'k}(12in/ft)}{60ksi(7.75'' - 1''/2)} = 0.88in^2 \rightarrow 4\#5$ at 4'' ($A_s = 1.24in^2$)

$a = \frac{1.24in^2(60ksi)}{0.85(4ksi)(12'')} = 1.82''$

$\phi M_n = 1.24in^2(60ksi)(7.75'' - 1.82''/2)0.9 = 38.17^{'k} > 31.9^{'k}$ OK

$c = 1.82''/0.85 = 2.14'' \leq 0.375(7.75'') = 2.91''$ OK

<u>Middle strip (+/- Moment)</u>

$M_n = \frac{M_u}{\phi} = \frac{9.6^{'k}}{0.9} = 10.7^{'k}$

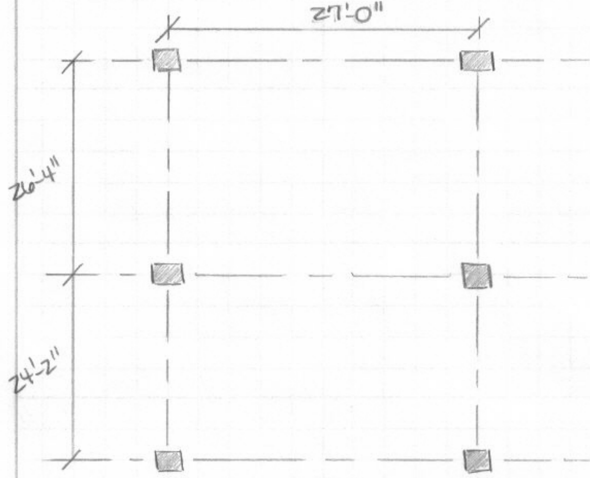
$A_s = \frac{10.7^{'k}(12in/ft)}{60ksi(7.75 - 1''/2)} = 0.30in^2 \rightarrow 2\#4$ ($A_s = 0.40in^2$)

$a = \frac{0.40in^2(60ksi)}{0.85(4ksi)(12'')} = 0.59''$

$\phi M_n = 0.40in^2(60ksi)(7.75'' - 0.59''/2)0.9 = 13.42^{'k} > 10.7^{'k}$ OK

$c = 0.59''/0.85 = 0.694'' \leq 2.91''$ OK

9½" Flate Plate Sys.



SDL = 25psf
LL = 67psf
self = $(9.5''/12)150\ \text{lb/ft}^3 = 118.8\text{psf}$

$Wu = 1.2(25\text{psf} + 119\text{psf}) + 1.6(67\text{psf})$
$= 280\text{psf}$

$Mu = \dfrac{280\text{psf}(26.3\text{ft})(25\text{ft})^2}{8}$
$= 575.3^{\text{IK}}$

Int. Neg Mom 0.70Mo	$CS = 0.70(0.75)Mo = 302.4^{\text{IK}} \rightarrow 302.4/13.16 = 23^{\text{IK}}$
	$MS = 0.70(0.25)Mo = 100.8^{\text{IK}} \rightarrow 100.8/13.14 = 8^{\text{IK}}$
Posit. Mom 0.52Mo	$CS = 0.52(0.6)Mo = 179.7^{\text{IK}} \rightarrow 179.7/6.58 = 28^{\text{IK}}$
	$MS = 0.52(0.4)Mo = 119.8^{\text{IK}} \rightarrow 120/13.14 = 10^{\text{IK}}$
Ext. Neg. Mom 0.26Mo	$CS = 0.26(1.0)Mo = 149.8^{\text{IK}} \rightarrow 149.8/6.58 = 23^{\text{IK}}$
	$MS = 0$

<u>At supports</u>

$d = 9.5'' - 0.75'' - 1'' = 7.75''$

$Mn = \dfrac{Mu}{\phi} = \dfrac{23^{\text{IK}}}{0.9} = 25.6^{\text{IK}}$

$As = \dfrac{25.6^{\text{IK}}(12\text{in/ft})}{60\text{Ksi}(7.75'' - 1''/2)} = 0.71\text{in}^2 \rightarrow 4\#4 \text{ at } 12'' \ (As = 0.80\text{in}^2)$

$a = \dfrac{Asfy}{0.85f'c\,b} = \dfrac{0.80\text{in}^2(60\text{Ksi})}{0.85(4\text{Ksi})12''} = 1.18''$

$Mn = 0.80\text{in}^2(60\text{Ksi})(7.75'' - 1.18''/2) = 28.64^{\text{IK}}$

$\phi Mn = 25.8^{\text{IK}} > 23^{\text{IK}}$ OK

$c = 1.18''/0.85 = 1.39'' \leq 0.375(7.75) = 2.91''$ OK

Flat Plate System con't

Column Strip Midspan

$Mn = \frac{Mu}{\phi} = \frac{28^{1K}}{0.9} = 32^{1K}$

$As = \frac{32^{1K}(12in/ft)}{60Ksi(7.75 - 1''/2)} = 0.88in^2 \rightarrow$ 4#5 at 4" ($As = 1.24in^2$)

$a = \frac{Asfy}{0.85f'_c b} = \frac{1.24in^2(60Ksi)}{0.85(4Ksi)(12'')} = 1.83''$

$Mn = Asfy(d - a/2) = 1.24in^2(60Ksi)(7.75'' - 1.83''/2) = 42.4^{1K}$

$\phi Mn = 38.2^{1K} > 28^{1K}$

$c = 1.83''/0.85 = 2.15'' \leq 2.91''$ OK

Middle Strip

$Mn = \frac{Mu}{\phi} = \frac{10^{1K}}{0.9} = 11.1^{1K}$

$As = \frac{11.1^{1K}(12in/ft)}{60Ksi(7.75'' - 1''/2)} = 0.31in^2 \rightarrow$ 2#4 ($As = 0.40in^2$)

$a = \frac{0.40in^2(60Ksi)}{0.85(4Ksi)(12'')} = 0.59''$

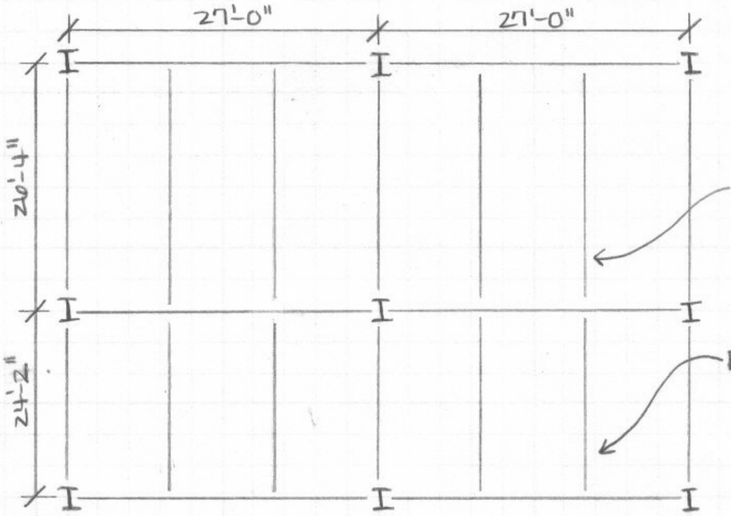
$Mn = 0.40in^2(60Ksi)(7.75'' - 0.59''/2) = 14.91^{1K}$

$\phi Mn = 13.42^{1K} > 10^{1K}$ OK

$c = 0.59''/0.85 = 0.69'' < 2.91''$ OK

Appendix B-3.1

Composite System



DL = Beam + slab + floor + ceiling

Beam B

$b_{eff} = L/4 = 26'\text{-}4"/4 = 78.9" = s = 108"$

Beam A

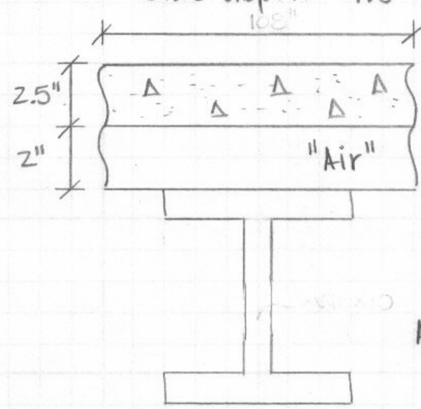
$b_{eff} = L/4 = 24'\text{-}2"/4 = 72.5" = s = 9' = 108"$

United Steel Deck Manual → try 2x12", 20gage

Max unshored span = 10.03 ft > 9ft OK

slab depth = 4.5" → Load = 225psf

Beam A



$f_y = 50ksi,\ f'_c = 4000ksi$

$W_{DL} = 150\,lb/ft^3(4.5/12)(9ft) + 25\,lb/ft^2(9ft) = 731.3\,lb/ft$

$W_{LL} = 40\,lb/ft^2(9ft) + 20\,lb/ft(9ft) = 540\,lb/ft$

$W_u = 1.2(732\,lb/ft) + 1.6(540\,lb/ft) = 1742.4\,lb/ft$

$M_u = \frac{W_u L^2}{8} = \frac{1742.4\,lb/ft(24.2ft)^2}{8} = 127.6^{1K}$

Assume $a = 1" \rightarrow Y_2 = 4.5" - 1"/2 = 4"$

Table 5-14 → W12x19

$\phi M_p = 92.6^{1K},\ \phi M_n = 146^{1K},\ \Sigma Q_n = 104K$

$W_c = 31.3psf$
$W_d = 1.8psf$
$W_B = 19plf$

$Y_1@6 = 1.68"$

$a = 104K/0.85(4ksi)(72.5") = 0.422" < 1"$ OK $\quad Y_2 = 4.5" - 0.422"/2 = 4.29"$

#of studs $= 104K/21K = 4.95 \rightarrow$ 5 studs → 10 whole beam

Check Construction Strength + Deflection

$W_{DL} = (31.3psf + 1.8psf)9ft + 19plf = 317plf$

$W_{LL} = 40psf(9ft) = 360$

$\Big\}\ W_u = 956.4plf$

$Mu_{const} = 0.957klf(24.3ft)^2/8 = 70.64^{1K} < 92.6^{1K}$ OK

$\Delta_{DL} = (5/384)(0.317(24.3^4)(12^3)/29000(130)) = 0.66" < 1" + 24.3(12)/360 = 0.81"$ OK

Table 5-15 → $I_{LB} = 284 in^4$

$\Delta_{LL} = (5/384)(0.36(24.3^4)(12^3)/29000(284)) = 0.34" < 1" + 0.81"$ OK

Check Shear

$\phi V_n = 77.4K$ (Table 5-3)

$V_u = 1742.4\,lb/ft(24.3ft)/2 = 21.2K < 77.4K$ OK

Beam B

$W_{DL} = 150\,lb/ft^3(4.5''/12)(9ft) + 25\,lb/ft^2(9ft) = 731.3\,lb/ft$
$W_{LL} = 67\,lb/ft^2(9ft) + 20\,lb/ft(9ft) = 783\,lb/ft$
$W_u = 1.2(731.3\,lb/ft) + 1.6(783\,lb/ft) = 2130.4\,lb/ft$
$M_u = \frac{W_u L^2}{8} = \frac{2130.4\,lb/ft(26.3ft)^2}{8} = 184.2^{1K}$

Assume $a = 1'' \rightarrow y_2 = 4.5'' - 1''/2 = 4''$
Table 5-14 $\rightarrow$ W12X26
$\phi M_p = 140^{1K}$, $\phi M_n = 194^{1K}$, $\Sigma Q_n = 116K$

$y_{1ee} = 1.07''$
$a = \frac{116K}{0.85(4KSI)(78.9'')} = 0.432'' < 1''$ OK
$y_2 = 4.5'' - 0.432''/2 = 4.284''$

# of studs $= 116K/21K = 5.52 \rightarrow$ 6 studs, 12 whole beam

Check Construction Strength & Deflection
$W_{DL} = (31.3psf + 1.8psf)9ft + 26plf = 323.9\,plf$
$W_{LL} = 67psf(9ft) = 603plf$
} $W_u = 1353.5\,plf$
$M_{u\,const} = 1.353\,klf(26.3ft)^2/8 = 117.02^{1K} < 140^{1K}$ OK

$\Delta_{DL} = (5/384)(0.323(26.3^4)(12^3)/29000(204in^4)) = 0.588'' < 1'' \;\&\; 26.3(12)/360 = 0.88''$
Table 5-15 $\rightarrow I_{LB} = 386in^4$
$\Delta_{LL} = (5/384)(0.603(26.3^4)(12^3)/29000(386)) = 0.579'' < 1'' \;\&\; 0.88''$

Check Shear
$\phi V_n = 75.8K$ (Table 5-3)
$V_u = 2130.4\,lb/ft(26.3ft/2) = 28K < 75.8K$ OK

Appendix C

Design Charts

Appendix C-1

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

f'_c = 4,000 psi
Grade 60 Bars

Span c-c Columns $\ell_1 = \ell_2$ (ft)	Factored Super-imposed Load (psf)	SQUARE EDGE PANELS: Square Edge Column (1) Steel (psf)	$c_1 = c_2$ (in.)	γ_f	(2) Stirrups	Reinforcing Bars—Each Direction: Column Strip Top Edge No.-size +	Column Strip Bottom No. Ribs	Column Strip Bottom Bars per Rib	Column Strip Top Interior No.-size	Middle Strip Bottom No. Ribs	Middle Strip Bottom Long Bars	Middle Strip Bottom Short Bars	Middle Strip Top Interior No.-size	Moments −M Edge (ft-k)	+M Bot. (ft-k)	−M Int. (ft-k)	SQUARE INTERIOR PANELS: (1) Steel (psf)	Square Interior Column $c_1 = c_2$ (in.)	(2) Stirrups	Reinforcing Bars—Each Direction: Column Strip Bottom No. Ribs	Column Strip Bottom Bars per Rib	Column Strip Top Interior No.-size	Middle Strip Bottom No. Ribs	Middle Strip Bottom Long Bars	Middle Strip Bottom Short Bars	Middle Strip Top Interior No.-size
Total Depth = 11 in.		Rib Depth = 8 in.			Total Slab Depth = 3 in.												Total Depth = 11 in.			Rib Depth = 8 in.			Total Slab Depth = 3 in.			
15'-0" D=8.500 RIB ON COLUMN LINE 0.515 CF SF	50	1.88	12	0.654		11-#5+ 0	3	2-#4	11-#5	2	#4	#4	4-#5	15	29	40	1.85	12		3	2-#4	11-#5	2	#4	#4	4-#5
	100	1.88	12	0.675		11-#5+ 0	3	2-#4	11-#5	2	#4	#4	4-#5	20	42	53	1.85	12		3	2-#4	11-#5	2	#4	#4	4-#5
	150	1.88	12	0.696		11-#5+ 0	3	2-#4	11-#5	2	#4	#4	4-#5	24	57	65	1.85	12		3	2-#4	11-#5	2	#4	#4	4-#5
	200	1.88	12	0.717		11-#5+ 0	3	2-#4	11-#5	2	#4	#4	4-#5	29	72	78	1.85	12		3	2-#4	11-#5	2	#4	#4	4-#5
	300	1.99	12	0.760		11-#5+ 0	3	1-#4 and 1-#5	11-#5	2	#4	#5	4-#5	39	102	104	1.85	12		3	2-#4	11-#5	2	#4	#4	4-#5
	400	2.34	12	0.803		11-#5+ 0	3	1-#5 and 1-#6	11-#5	2	#5	#6	4-#5	48	130	130	2.03	12	3 S 4 1	3	1-#4 and 1-#5	11-#5	2	#4	#5	4-#5
18'-0" D=8.500 RIB ON COLUMN LINE 0.523 CF SF	50	1.86	12	0.728		13-#5+ 0	3	2-#4	13-#5	3	#4	#4	5-#5	26	51	69	1.84	12		3	2-#4	13-#5	3	#4	#4	5-#5
	100	1.86	12	0.755		13-#5+ 0	3	2-#4	13-#5	3	#4	#4	5-#5	34	73	92	1.84	12		3	2-#4	13-#5	3	#4	#4	5-#5
	150	1.92	12	0.781		13-#5+ 0	3	1-#4 and 1-#5	13-#5	3	#4	#4	5-#5	43	100	115	1.84	12		3	2-#4	13-#5	3	#4	#4	5-#5
	200	2.05	12	0.807		13-#5+ 0	3	2-#5	13-#5	3	#4	#4	5-#5	51	127	138	1.95	12		3	1-#4 and 1-#5	13-#5	3	#4	#4	5-#5
	300	2.34	12	0.859		13-#5+ 0	3	2-#6	13-#5	3	#5	#5	5-#5	68	179	183	2.05	12	3 S 4 1	3	2-#5	13-#5	3	#4	#4	5-#5
	400	2.75	12 *	0.912	3 S 4 1	13-#5+ 0	3	2-#7	13-#5	3	#5	#6	5-#5	85	229	229	2.40	12 *	3 S 4 1	3	2-#6	13-#5	3	#4	#5	5-#5
21'-0" D=9.500 RIB NOT ON COLUMN LINE 0.555 CF SF	50	1.84	12	0.792		15-#5+ 0	4	2-#4	15-#5	3	#4	#4	6-#5	43	85	115	1.82	12		4	2-#4	15-#5	3	#4	#4	6-#5
	100	1.90	12	0.822		15-#5+ 0	4	1-#4 and 1-#5	15-#5	3	#4	#4	6-#5	56	121	151	1.82	12		4	2-#4	15-#5	3	#4	#4	6-#5
	150	2.06	12	0.853		15-#5+ 0	4	2-#5	15-#5	3	#5	#5	6-#5	70	165	188	1.82	12		4	2-#4	15-#5	3	#4	#4	6-#5
	200	2.36	12 *	0.890		15-#5+ 1	4	2-#6	15-#5	3	#5	#6	6-#5	84	208	225	2.01	12		4	1-#4 and 1-#5	15-#5	3	#4	#5	6-#5
	300	2.94	12 *	0.630		15-#5+ 1	4	2-#7	17-#5	3	#6	#7	6-#5	111	292	298	2.49	12 *	3 S 4 1	4	1-#5 and 1-#6	16-#5	3	#5	#6	6-#5
	400	3.73	16 *	0.625		15-#5+ 0	4	2-#8	15-#6	3	#7	#8	7-#5	135	362	364	3.19	13 *	3 S 4 1	4	1-#6 and 1-#7	14-#6	3	#6	#6	7-#5
24'-0" D=9.500 RIB NOT ON COLUMN LINE 0.532 CF SF	50	1.92	12	0.848		18-#5+ 0	4	1-#4 and 1-#5	18-#5	4	#4	#4	7-#5	63	127	171	1.86	12		4	2-#4	18-#5	4	#4	#4	7-#5
	100	2.14	12 *	0.882		18-#5+ 0	4	1-#5 and 1-#6	18-#5	4	#4	#5	7-#5	84	180	226	1.95	12		4	1-#4 and 1-#5	18-#5	4	#4	#4	7-#5
	150	2.40	12 *	0.915		18-#5+ 0	4	1-#6 and 1-#7	18-#5	4	#5	#5	7-#5	105	247	282	2.05	12 *	3 S 4 1	4	2-#5	18-#5	4	#4	#4	7-#5
	200	2.80	13 *	0.629		18-#5+ 0	4	2-#7	20-#5	4	#6	#6	7-#5	125	310	336	2.36	12 *	3 S 4 1	4	2-#6	18-#5	4	#4	#5	7-#5
	300	3.72	18 *	0.623		18-#5+ 1	4	1-#8 and 1-#9	26-#5	4	#6	#7	9-#5	162	412	435	3.24	14 *	3 S 4 1	4	2-#7	17-#6	4	#5	#6	8-#5
27'-0" D=9.500 RIB NOT ON COLUMN LINE 0.523 CF SF	50	2.06	13	0.870		20-#5+ 0	4	1-#5 and 1-#6	20-#5	5	#4	#4	8-#5	90	180	242	1.94	13		4	1-#4 and 1-#5	20-#5	5	#4	#4	8-#5
	100	2.29	13 *	0.914		20-#5+ 1	4	1-#6 and 1-#7	20-#5	5	#4	#5	8-#5	119	246	321	2.02	13	3 S 4 1	4	2-#5	20-#5	5	#4	#4	8-#5
	150	2.83	15 *	0.930		20-#5+ 4	4	1-#7 and 1-#8	24-#5	5	#5	#6	8-#5	148	339	398	2.42	13 *	3 S 4 1	4	2-#6	22-#5	5	#4	#5	8-#5
	200	3.51	18 *	0.623		20-#5+ 1	4	1-#8 and 1-#9	20-#6	5	#6	#6	9-#5	175	426	472	3.10	13 *	3 S 4 1	4	2-#7	19-#6	5	#5	#5	9-#5
30'-0" D=12.500 RIB ON COLUMN LINE 0.545 CF SF	50	2.12	15 *	0.879		22-#5+ 1	5	1-#5 and 1-#6	22-#5	5	#4	#5	9-#5	125	249	336	1.94	15		5	1-#4 and 1-#5	22-#5	5	#4	#4	9-#5
	100	2.62	18 *	0.923		22-#5+ 5	5	1-#6 and 1-#7	26-#5	5	#5	#6	9-#5	164	329	443	2.31	15 *	3 S 4 1	5	1-#5 and 1-#6	24-#5	5	#4	#5	9-#5
	150	3.30	22 *	0.921		22-#5+ 8	5	1-#7 and 1-#8	23-#6	5	#6	#6	11-#5	201	437	541	3.02	15 *	3 S 4 1	5	1-#6 and 1-#7	22-#6	5	#5	#5	10-#5

NOTES: * Factored shear stress for the column size so designated is greater than $4\sqrt{f'_c}$ but less than $6\sqrt{f'_c}$. Shear reinforcement, structural steel shearheads, or shear caps must be provided with columns indicated.

(1) Average reinforcing steel weight (psf) includes twice the flexural reinforcement tabulated (tabulated reinforcement placed in each direction). Shrinkage and temperature reinforcement, integrity reinforcement, and shear reinforcement are not included.

(2) The notation "3 S 4 1" for the stirrups: the first character "3" is the bar size, i.e., #3; the "S" stands for "stirrup"; and the "4" is the spacing of the stirrups in inches. The last character indicates the length over which stirrups are required in each joist rib; the "1" denotes the length from the face of the solid head to the first cross rib, i.e., a length of one module; a "2" indicates stirrups are required to the second cross rib from the face of the solid head, i.e., a length of two modules.

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

FLAT SLAB SYSTEM

SQUARE EDGE PANEL — With Drop Panels — No Beams

SPAN c.-c. $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	Square Drop Panel Depth (in.)	Square Drop Panel Width (ft)	(3) Square Column Size (in.)	(3) Square Column γ_f	Reinforcing Bars (E. W.) Column Strip (1) Top Ext. +	Column Strip (1) Bottom	Column Strip (1) Top Int.	Middle Strip Bottom	Middle Strip Top Int.	Total Steel (psf)	Moments Edge (–) (ft-k)	Moments Bot. (+) (ft-k)	Moments Int. (–) (ft-k)
h = 9 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS														
23	100	4.00	7.67	12	0.771	12-#4 4	17-#4	19-#4	8-#5	8-#5	2.16	93.9	187.9	252.9
23	200	5.50	7.67	15	0.631	12-#4 1	11-#6	22-#4	10-#5	13-#4	2.61	125.9	251.8	339.0
23	300	7.00	7.67	17	0.631	13-#4 1	8-#8	25-#4	9-#6	16-#4	3.19	158.6	317.2	427.0
23	400	7.00	7.67	19	0.664	15-#4 3	17-#6	14-#6	11-#6	13-#5	3.89	190.0	380.0	511.5
23	500	8.50	9.20	21	0.629	16-#4 2	16-#7	11-#7	19-#5	8-#7	4.59	222.6	467.3	599.3
24	100	5.50	8.00	12	0.689	13-#4 2	13-#5	19-#4	13-#4	8-#5	2.20	107.5	215.0	289.4
24	200	5.50	8.00	15	0.746	13-#4 5	18-#5	12-#6	12-#5	10-#5	2.86	143.8	287.7	387.3
24	300	7.00	8.00	17	0.684	14-#4 4	12-#7	14-#6	8-#7	12-#5	3.58	181.3	362.6	488.2
24	400	8.50	8.00	19	0.631	16-#4 2	15-#7	11-#7	8-#8	8-#7	4.39	217.6	435.2	585.9
24	500	8.50	9.60	21	0.684	18-#4 3	14-#8	13-#7	11-#7	8-#8	5.08	253.8	507.6	683.4
25	100	5.50	8.33	12	0.735	13-#4 3	15-#5	14-#5	10-#5	13-#4	2.36	121.9	243.8	328.2
25	200	7.00	8.33	15	0.666	13-#4 4	20-#5	12-#6	13-#5	11-#5	2.95	163.7	327.5	440.8
25	300	8.50	8.33	17	0.633	15-#4 3	11-#8	14-#6	9-#7	10-#6	3.92	205.7	411.3	553.7
25	400	8.50	10.00	20	0.702	18-#4 5	13-#8	13-#7	20-#5	9-#7	4.55	247.2	494.5	665.6
25	500	8.50	10.00	24	0.669	13-#5 2	20-#7	19-#6	10-#8	14-#6	5.49	285.7	571.4	769.2
26	100	7.00	8.67	12	0.646	13-#4 2	9-#7	14-#5	11-#5	9-#5	2.47	138.0	276.0	371.6
26	200	7.00	8.67	15	0.720	15-#4 4	23-#5	14-#6	15-#5	19-#4	3.27	185.0	370.0	498.1
26	300	8.50	8.67	17	0.715	17-#4 5	12-#8	12-#7	10-#7	16-#5	4.13	232.6	465.2	626.2
26	400	8.50	10.40	22	0.687	13-#5 2	15-#8	26-#5	23-#5	10-#7	5.02	277.8	555.7	748.0
27	100	7.00	9.00	12	0.716	14-#4 3	19-#5	16-#5	19-#4	16-#4	2.61	155.0	310.1	417.4
27	200	8.50	9.00	15	0.658	15-#4 3	11-#8	14-#6	9-#7	10-#6	3.62	208.5	417.0	561.4
27	300	8.50	9.00	19	0.701	12-#5 3	14-#8	13-#7	15-#6	10-#7	4.52	260.0	520.0	700.0
27	400	8.50	10.80	24	0.717	22-#4 6	17-#8	12-#8	11-#8	9-#8	5.62	310.9	621.7	836.9

SQUARE INTERIOR PANEL — With Drop Panels(2) — No Beams

SPAN (ft)	Factored Superimposed Load (psf)	(3) Square Column Size (in.)	Reinforcing Bars (E. W.) Column Strip Top	Column Strip Bottom	Middle Strip Top	Middle Strip Bottom	Total Steel (psf)	Concrete (cu. ft / sq. ft)
h = 9 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS								
23	100	12	12-#5	12-#4	8-#5	8-#5	2.09	0.787
23	200	18	14-#5	15-#4	8-#5	8-#5	2.34	0.801
23	300	20	15-#5	19-#4	10-#5	13-#4	2.71	0.815
23	400	22	18-#5	11-#6	12-#5	10-#5	3.38	0.815
23	500	23	14-#6	19-#5	10-#6	19-#4	3.93	0.863
24	100	12	12-#5	13-#4	8-#5	8-#5	2.04	0.801
24	200	18	11-#6	18-#4	9-#5	8-#5	2.51	0.801
24	300	20	17-#5	15-#5	8-#6	10-#5	3.07	0.815
24	400	22	14-#6	18-#5	10-#6	12-#5	3.70	0.829
24	500	24	12-#7	11-#7	16-#5	10-#6	4.32	0.863
25	100	12	13-#5	15-#4	13-#4	13-#4	2.13	0.801
25	200	18	16-#5	13-#5	10-#5	13-#4	2.58	0.815
25	300	21	18-#5	9-#7	19-#4	11-#5	3.32	0.829
25	400	23	15-#6	20-#5	11-#6	13-#5	3.87	0.863
25	500	24	13-#7	10-#8	10-#7	11-#6	4.80	0.863
26	100	12	13-#5	11-#5	13-#4	13-#4	2.15	0.815
26	200	18	18-#5	15-#5	12-#5	10-#5	2.87	0.815
26	300	21	14-#6	19-#5	22-#4	19-#4	3.46	0.829
26	400	23	13-#7	23-#5	10-#7	15-#5	4.36	0.863
27	100	12	15-#5	19-#4	10-#5	9-#5	2.31	0.815
27	200	18	18-#5	9-#7	13-#5	11-#5	3.07	0.829
27	300	21	12-#7	21-#5	16-#5	10-#6	3.79	0.829
27	400	23	12-#8	11-#8	14-#6	9-#7	4.91	0.863

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

FLAT PLATE SYSTEM (WITHOUT SHEARHEADS)

f'_c = 4,000 psi
Grade 60 Bars

SQUARE EDGE PANEL

9.5 in. = TOTAL THICKNESS OF SLAB — 0.792 c.f./s.f.

SPAN c.-c. Cols. $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	(1) Min. Square Column (in.)	γ_f	Total Panel Moments −M Ext. (ft-kip)	+M Int. (ft-kip)	−M 1st. int. (ft-kip)	Reinforcing Bars, Each Column Strip: Top Ext.	+	Bottom	Top Int.	Each Middle Strip: Bottom	Top Int.	End Panel Steel (psf), Location of Panel: E	EC	C
24	50	17	0.806	88	176	237	11-#5	4	10-#5	12-#6	8-#5	8-#5	2.40	2.42	2.36
24	100	21	0.763	105	209	282	11-#5	5	12-#5	20-#5	8-#5	8-#5	2.64	2.65	2.63
24	150	25	0.660	121	242	325	11-#5	3	10-#6	13-#7	9-#5	8-#5	2.94	2.98	3.12
24	200	28	0.687	136	272	367	13-#5	4	8-#7	11-#8	10-#5	9-#5	3.29	3.32	3.41
24	250	32	0.619	149	299	402	14-#5	3	9-#7	12-#8	8-#6	10-#5	3.64	3.65	3.78
24	300	35	0.612	163	326	439	15-#5	3	8-#8	13-#8	12-#5	10-#5	4.01	4.07	4.21
24	350	40	0.610	171	343	461	16-#5	2	8-#8	14-#8	9-#6	8-#6	4.30	4.33	4.48
25	50	19	0.784	98	197	265	12-#5	4	11-#5	14-#6	9-#5	9-#5	2.61	2.64	2.62
25	100	23	0.746	117	235	316	12-#5	5	13-#5	12-#7	9-#5	9-#5	2.84	2.86	2.88
25	150	27	0.689	135	271	365	13-#5	4	11-#6	14-#7	10-#5	9-#5	3.22	3.24	3.25
25	200	31	0.648	152	304	409	14-#5	4	9-#7	12-#8	11-#5	10-#5	3.58	3.60	3.66
25	250	35	0.628	167	334	449	16-#5	4	10-#7	14-#8	9-#6	11-#5	3.98	4.03	4.24
25	300	40	0.610	179	357	481	12-#6	2	20-#5	15-#8	13-#5	11-#5	4.22	4.25	4.40
25	350	46	0.609	186	373	502	13-#6	1	9-#8	15-#8	10-#6	12-#5	4.50	4.55	4.66
26	50	21	0.750	110	219	295	12-#5	4	12-#5	15-#6	9-#5	9-#5	2.61	2.63	2.70
26	100	25	0.714	131	262	353	12-#5	5	11-#6	14-#7	10-#5	9-#5	3.06	3.07	3.10
26	150	29	0.680	151	301	406	14-#5	4	9-#7	12-#8	11-#5	10-#5	3.40	3.41	3.43
26	200	34	0.645	168	337	454	16-#5	5	10-#7	14-#8	9-#6	11-#5	3.81	3.87	4.08
26	250	39	0.613	183	367	494	17-#5	4	11-#7	15-#8	10-#6	12-#5	4.17	4.19	4.35
26	300	45	0.609	194	389	523	13-#6	1	9-#8	16-#8	11-#6	12-#5	4.49	4.55	4.79
26	350	52	0.608	202	405	545	19-#5	3	10-#8	17-#8	11-#6	9-#6	4.74	4.81	5.10
27	50	23	0.729	122	244	329	12-#5	5	10-#6	13-#7	9-#5	9-#5	2.76	2.77	2.72
27	100	27	0.740	146	291	392	14-#5	7	16-#5	12-#8	11-#5	9-#5	3.11	3.15	3.23
27	150	32	0.671	167	334	450	16-#5	5	10-#7	14-#8	9-#6	11-#5	3.63	3.70	3.82
27	200	37	0.668	186	373	502	13-#6	4	9-#8	15-#8	10-#6	12-#5	4.10	4.12	4.27
27	250	44	0.610	200	399	537	19-#5	3	12-#7	16-#8	11-#6	9-#6	4.42	4.44	4.64
27	300	51	0.608	210	420	566	14-#6	3	10-#8	17-#8	11-#6	13-#5	4.62	4.68	4.95
27	350	58	0.607	219	439	590	15-#6	0	11-#8	18-#8	9-#7	10-#6	5.07	5.13	5.33
28	50	25	0.693	135	270	364	13-#5	4	11-#6	14-#7	10-#5	10-#5	2.88	2.91	2.94
28	100	30	0.685	161	321	433	15-#5	6	10-#7	13-#8	12-#5	10-#5	3.37	3.40	3.53
28	150	35	0.619	184	368	496	17-#5	4	11-#7	15-#8	10-#6	12-#5	3.87	3.89	4.05
28	200	42	0.615	203	406	546	19-#5	5	10-#8	17-#8	11-#6	13-#5	4.31	4.36	4.57
28	250	49	0.609	217	433	583	20-#5	3	10-#8	18-#8	16-#5	10-#6	4.63	4.67	4.81
28	300	57	0.608	227	454	611	15-#6	3	11-#8	19-#8	12-#6	10-#6	4.90	4.97	5.15
28	350	64	0.607	236	472	636	16-#6	2	11-#8	20-#8	10-#7	11-#6	5.28	5.36	5.49
29	50	27	0.719	149	298	401	14-#5	7	12-#6	15-#7	11-#5	10-#5	2.99	3.00	3.05
29	100	32	0.699	177	355	477	17-#5	7	14-#6	14-#8	13-#5	11-#5	3.51	3.54	3.70
29	150	39	0.642	201	403	542	19-#5	6	12-#7	17-#8	11-#6	13-#5	4.09	4.14	4.36
29	200	47	0.609	219	439	591	15-#6	2	11-#8	18-#8	16-#5	10-#6	4.53	4.58	4.76
29	250	55	0.608	233	466	628	16-#6	2	11-#8	19-#8	10-#7	11-#6	4.92	4.97	5.10
29	300	63	0.607	244	489	658	23-#5	2	12-#8	20-#8	10-#7	11-#6	5.17	5.24	5.52
29	350	71	0.606	254	507	683	17-#6	2	12-#8	21-#8	10-#7	16-#5	5.38	5.45	5.80

SQUARE INTERIOR PANEL

9.5 in. = TOTAL THICKNESS OF SLAB — 0.792 c.f./s.f.

(2) Span c.-c. (ft)	(3) Load (psf)	(1) Min. Sq. Col. (in.)	Reinforcing Bars, Column Strip: Top	Bottom	Middle Strip: Top	Bottom	Steel (psf), Location of Panel: I	IE	IC
24	50	11	16-#5	8-#5	8-#5	8-#5	2.38	2.30	2.41
24	100	16	11-#7	8-#5	8-#5	8-#5	2.69	2.67	2.65
24	150	20	12-#7	9-#5	8-#5	8-#5	2.90	2.93	2.95
24	200	24	13-#7	8-#6	8-#5	8-#5	3.20	3.25	3.30
24	250	29	12-#8	8-#6	9-#5	8-#5	3.56	3.57	3.58
24	300	33	13-#8	9-#6	10-#5	8-#5	3.89	3.89	3.89
24	350	41	13-#8	9-#6	10-#5	9-#5	4.03	4.08	4.11
25	50	13	13-#6	9-#5	9-#5	9-#5	2.63	2.65	2.67
25	100	18	15-#6	9-#5	9-#5	9-#5	2.80	2.82	2.85
25	150	22	13-#7	11-#5	9-#5	9-#5	3.16	3.19	3.21
25	200	27	12-#8	12-#5	9-#5	9-#5	3.52	3.53	3.54
25	250	32	13-#8	9-#6	10-#5	9-#5	3.81	3.95	3.90
25	300	39	14-#8	10-#6	11-#5	9-#5	4.12	4.15	4.19
25	350	48	14-#8	10-#6	11-#5	9-#5	4.17	[illegible]	[illegible]
26	50	15	14-#6	9-#5	9-#5	9-#5	2.61	2.62	2.61
26	100	20	13-#7	10-#5	9-#5	9-#5	2.95	[illegible]	3.00
26	150	25	12-#8	12-#5	9-#5	9-#5	3.37	3.38	3.30
26	200	30	13-#8	9-#6	10-#5	9-#5	3.65	3.69	3.73
26	250	37	14-#8	10-#6	11-#5	9-#5	3.91	3.98	4.03
26	300	46	15-#8	11-#6	11-#5	10-#5	4.29	4.31	4.38
26	350	55	15-#8	11-#6	12-#5	10-#5	4.39	[illegible]	4.55
27	50	16	12-#7	10-#5	9-#6	9-#5	2.73	2.75	2.77
27	100	22	14-#7	11-#5	9-#5	9-#5	3.02	3.05	3.09
27	150	27	13-#8	9-#6	10-#5	9-#5	3.49	3.53	3.57
27	200	33	14-#8	10-#6	11-#5	10-#5	3.82	3.86	3.90
27	250	43	15-#8	11-#6	12-#5	10-#5	4.15	4.19	4.23
27	300	53	16-#8	16-#5	12-#5	11-#5	4.41	4.46	4.50
27	350	62	17-#8	16-#5	9-#6	11-#5	4.61	4.69	4.71
28	50	18	13-#7	11-#5	10-#5	10-#5	2.89	2.91	2.93
28	100	24	13-#8	12-#5	10-#5	10-#5	3.33	3.33	3.33
28	150	30	14-#8	10-#6	11-#5	10-#5	3.67	3.71	3.74
28	200	38	16-#8	11-#6	12-#5	10-#5	4.09	4.13	4.17
28	250	49	17-#8	16-#5	13-#5	11-#5	4.39	4.43	4.48
28	300	60	17-#8	12-#6	13-#5	11-#5	4.53	4.61	4.69
28	350	70	18-#8	10-#7	10-#6	12-#5	4.98	5.06	5.11
29	50	20	15-#7	12-#5	10-#5	10-#5	3.02	3.02	3.02
29	100	26	14-#8	10-#6	11-#5	10-#5	3.52	3.52	3.52
29	150	33	16-#8	11-#6	12-#5	10-#5	3.92	3.96	3.99
29	200	44	17-#8	12-#6	13-#5	11-#5	4.28	4.32	4.36
29	250	56	18-#8	10-#7	10-#6	12-#5	4.71	4.76	4.80
29	300	67	18-#8	10-#7	10-#6	12-#5	4.77	4.85	4.93
29	350	77	19-#8	10-#7	11-#6	13-#5	5.09	5.16	5.22

(1) Columns same above and below plate.

(2) Center-to-center of columns; $\ell_1 = \ell_2$.

(3) Superimposed factored load (factored dead load has been deducted).