CENTRE COURT APARTMENTS
STATE COLLEGE, PA

Anthony Dente

Thesis Tech Two
Advisor: Ali Memari
11/05/07

Executive Summary

This report was conducted with the intent of comparing the current as build structural system of the Centre Court Apartments to four other structural systems applied to the same building. Following design of the system they will be compared and contrasted for their varying qualities of weight, constructability, thickness of system, MEP compatibility, fireproofing, and vibration effects. The original system was made of 8" Precast Hollow Core Plates toped with a 3"-5.5" layer of concrete bearing mostly on CMU's. The four structures this was compared against were:

1. Two Way Post Tension Slab
2. Composite Lightweight Concrete Slab on Steel Frame
3. Two Way Flat Slab
4. Waffle Slab

Each structure had many benefits such as the ease of construction of the hollow core planks and the waffle slabs, or the thinnest slab offered by the post tension system. Although, following the technical evaluation of all the structures against the criteria listed about it was found that the two systems worth exploring further in detail where the composite lightweight concrete slab on steel frame and the two-way flat slab. Both systems a very familiar in the industry and also lend themselves well to the short spanning varying geometry of the spans in the Centre Court Apartments.

Contents

Existing Structural System

Listed below are the prominent structural elements contained in Centre Court Apartments:

- 8” CMU exterior above grade and 10” CMU exterior below grade
  - Load bearing units conforming to ASTM C90
  - Net Compressive Stress = 3000 PSI
  - Above grade CMU’s contain Dur-O-Wall every other course
  - Block cells with bars are grouted a minimum 2 courses below plank bearing

- 8” pre-cast hollow core planks
  - Conform to latest edition of ACI 318
  - Steel bearing will contain weld plates spaced 4’ O.C. max.
  - F’c=5000 PSI

- Steel beams and columns
  - Typical beam sizes: 12 X 26 and 14 X 43
  - Grade 50 or ASTM A992
  - Fabricated and erected in accordance to the latest edition of AISC specifications.

- Concrete columns, footings, and slabs
  - Mixed and placed in accordance with ACI 318 “Building Code Requirements for Concrete”
  - Footings and slabs f’c = 3000
  - Columns f’c =4000

The load-bearing CMU exterior walls dominate the structural design. This system also crosses north to south at particular portions of the interior building in order to be the primary lateral force resisting system. This structure has a number of benefits in the Centre Court Apartments. The added convenience of bearing the pre-cast hollow core slabs. Pre-cast hollow core concrete slabs make up at least 90% of all floor slabs in the building and the concrete to concrete block connection cuts down on the number of bearing plates that would be needed if the number of slab to steel connections were increased.

Another benefit of this system is the simplification of the beam to column connections throughout the building. Since no moment frames are required, all moment connections have been completely elevated from the building. There are also two non-structural benefits to the CMU design: the fire rating requirements for apartment buildings and the way it compliments the application of the aesthetic stucco applied to the exterior of the building.

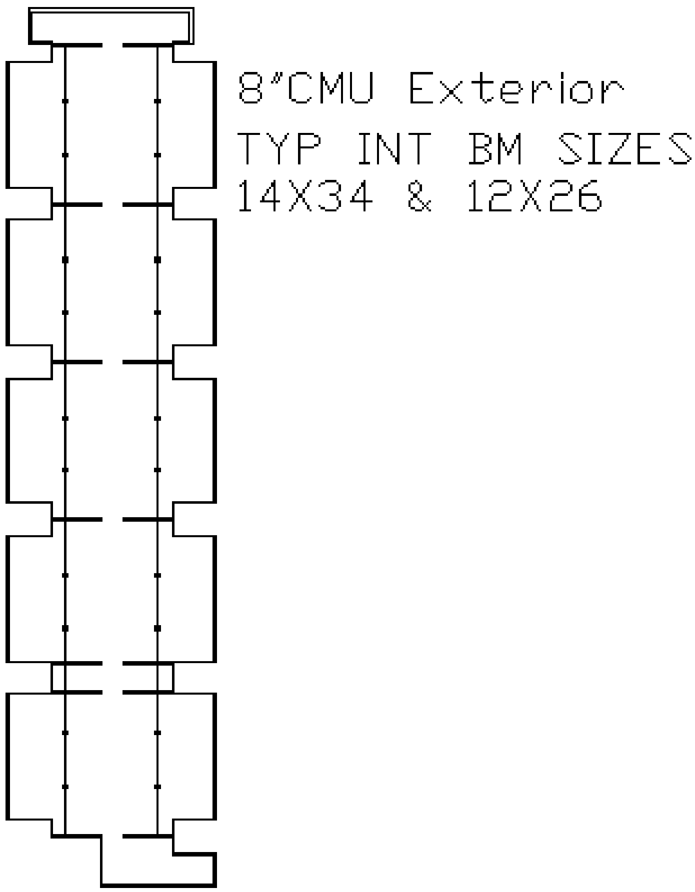
The remaining interior loads are carried by a series of wide flange beams, which distribute that load to steel columns in the top five floors. The bottom two levels of parking deck then convert to concrete columns, which at the end drop the load onto the 6' X 8' spread footings.

Advantages and disadvantages to this system:

Being that the structure is an apartment complex architectural freedom is very important. With the precast hollow core slab design that bears a great deal on the exterior walls the intrusion of columns is decreased greatly. The Hollow core slabs also decrease on site construction time by a great deal, although a longer lead-time is often a direct cost of this trait. Including the 3-5.5" concrete topping the floor structural system can be 13.5" thick at points, which is a moderately thick floor structure for this building.

The Hollow core slabs in conjunction with the CMU wall offer excellent fire protection benefits. This combination also aids well to noise dampening witch are both strong benefits to an apartment complex. Studies also show that insurance rates for buildings incorporating either of these technologies tend to be less than other structural options.

Existing Structural Plan



Codes and References

- The International Building Code 2003
- The American Concrete Institute
  - Section 530.1: Masonry
- The American Institute of Steel Construction
- CRSI 2002: Concrete Reinforcing Steel Institute
- United Steel Deck Design Manual 2002

Loads

Gravity Loads have been calculated in accordance with ASCE 7-05 with the Live Loads interpreted from section four. Assumptions were made for proper distribution of Gravity Loads.

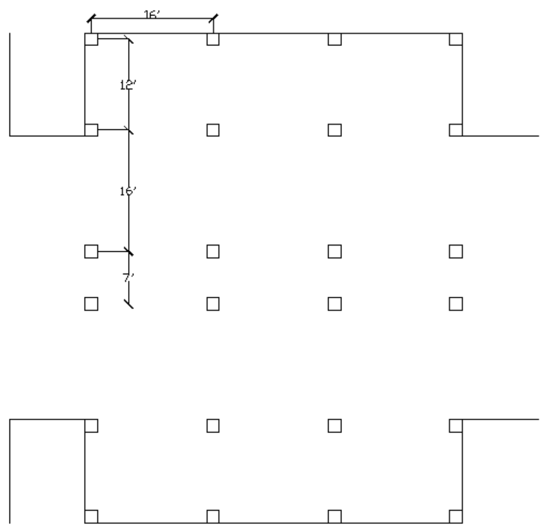
Dead Load		
Hollow Core Planks	60	psf
Concrete	150	pcf
Partitions	15	psf
MEP	10	psf
Misc.	5	psf
Brick	38	psf
8' CMU	60	psf
Windows	8	psf

Live Loads		
Corridors	100	psf
Garages	40	psf
Private Rooms	40	psf
Public Rooms	100	psf
Roof	20	psf
Snow	21	psf

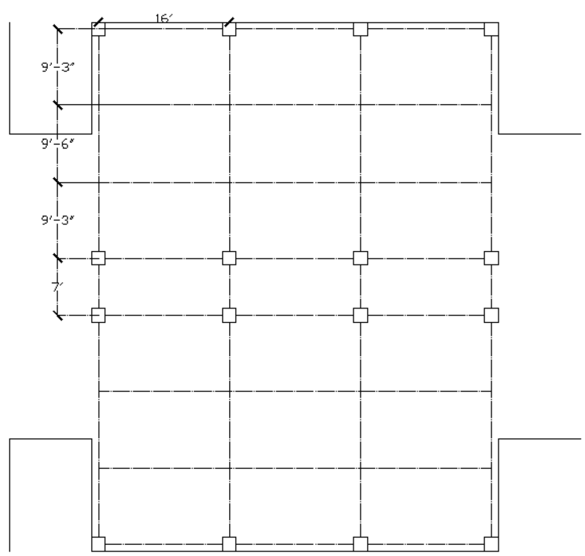
Alternative Designs

There where four alternative deign methods tested for this technical assignment, post tensioned two way flat plate, composite light weight concrete slab on steel frame, two way flat slab, and a waffle slab deign. The strict architectural layout minimizes the diversity of column arrangement strategies. The plans bellow show the most functional column layout applicable to a redesign of the system. All Concrete columns in the bellow plans are taken as 20"X 20" to keep uniformity with the parking deck bellow.

Concrete Design:

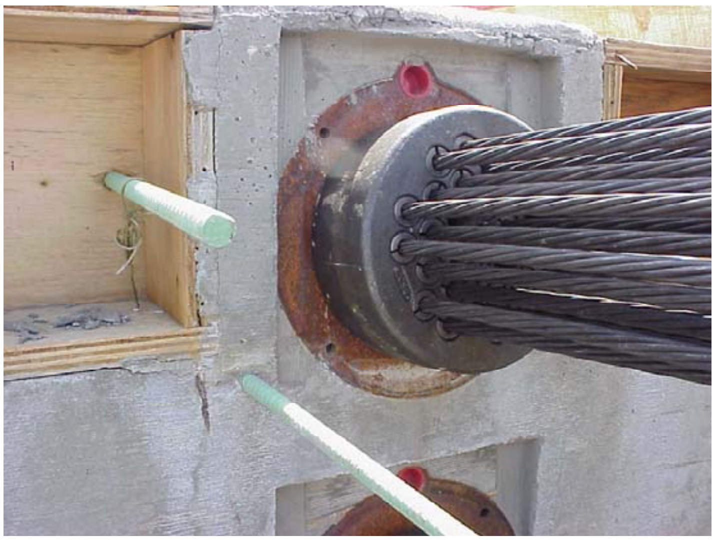


Steel Design:



Post Tensioned 2 Way Flat Plate

Post Tension concrete is traditionally used to span long distances with minimal thickness increases and also to minimize visual cracking in such spans. Although, due to the architectural layout of the Centre Court Apartments discussed above this system was tested over moderately sized spans with an attempt to see if the decreases in thickness would be worth the costs of this system even with the shorter span lengths.

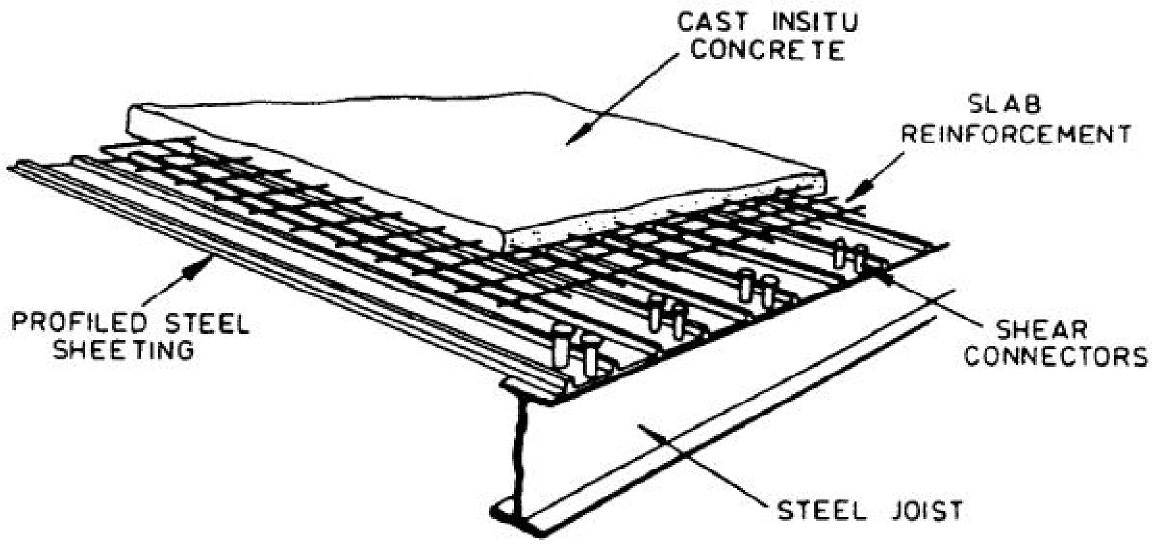


Advantages and Disadvantages to this system.

The slab analysis resulted in a 5 in slab. This is severely less that the current system although due to this extreme decrease in depth the punching shear surrounding the columns requires extra shear reinforcement which will certainly counteract some of the savings due to deceased amount of concrete. From a construction standpoint not all contractors work well and are comfortable with post tension slabs. If not installed correctly the extreme force applied to this system shortly after construction can result in very dangerous situations. Although as long as an expedited crew is obtained it should be a very viable solution.

Composite Light Weight Concrete Slab on Steel Frame

The composite lightweight slab on steel frame system is a standard system in the industry. The system can adapt to all kinds of floor framing layouts with ease, which obviously benefits the Centre Court Apartments architectural plan. This system was analyzed with an attempt to use the moderately thin slab it affords in conjunction with lightweight concrete to not only minimize floor to floor height but more importantly the dead load of the building as a whole.

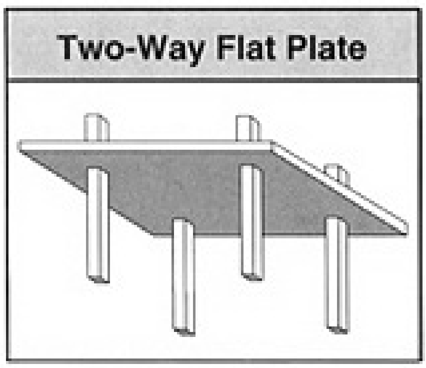


Advantages and disadvantages to this system:

Many contractors work well with the slab on steel frame system because it is very commonplace in the industry. The slab depth came out to be 5.25" being only .25" thicker than the post tension design. This along with the 115pcf lightweight concrete does a lot in decreasing the load of the slab bearing on the structure. Vibration can be a concern with the steel system and should b given optimal attention due to its high level of impotence in an apartment complex such as this and additional fireproofing with certainly be needed to cover the steel. Those disadvantages aside the concrete slab on steel frame appears to be a viable alternative.

2 Way Flat Plate Slab

The two way flat plate design is most likely the most convent and feasible for the short span lengths of the Centre Court Apartments. The design hopes to only increase the slab thickness slightly from the post tension design and steel deck slab design while taking advantage of the short spans by alleviating the need for drop panels or additional shear reinforcement. The Equivalent frame method was used in analyzing the system and although the slab could have shortened it's thickness in the interior spans, the change was not that drastic and the design was kept constant for ease of construction.



Advantages and disadvantages of this system:

Although assembly and disassembly of formwork for a job of this size can be very timely and costly to a contractor and owner will once again rarely find a contractor who's team doesn't have the ability or is not familiar with this system. No additional fireproofing is needed and the vibration effects are also much better than that of the slab on steel decking system. The 6.5" depth is by no means in a situation to cause building height issues and because the punching shear design does not require drop panels the MEP system can scale along the system with ease.

Waffle Flat Slab

Waffle slab systems are often incorporated because although they often add a lot of thickness compared to their alternatives they, more times than not will decrease the weight of the structure dramatically. The system is also most applicable over large spans, which, as discussed above, is definitely not the case with the Centre Court Apartments. The system was selected through design tables out of the Concrete Reinforcing Steel Institute Design Guide of 2002. The slabs have 19" x 19" voids with 5" ribs at 24" O.C.. The rib depth also came out to be 8" with a slab depth of 3".

Advantages and disadvantages to this system:

Waffle slabs have very similar characteristics to the existing structure of hollow core floor planks in the area of construction and lead-time. That being, simpler and faster construction methods as compared to other systems although a longer setting-on-site time due to the nature of the product. Waffle slabs often compliments MEP systems well and the vibration effects that are mitigated by such an assembly are very good as well. On the other hand waffle slab construction is not typically designed for a building whose bays are constantly alternating in size. I designed the slab for the maximum span although when all is said and done, if preferred, many sizes and shapes of waffle slabs could technically be incorporated in this design. At least to alternative sizes would be practical from a construction standpoint. I also found that the weight saved by the system was not significant enough to justify the increase in thickness.

Comparison

	Hollow Core Planks	Comp. Slab on Steel Deck	2 Way Flat Plate	Post T.	Waffle Slab
Weight	96 psf	62 psf	81 psf	62.5 psf	95.7 psf
Thickness	13.5 "	5.25 "	6.5 "	5 "	11 "
Vibration	no	yes	no	no	no
Additional Fire Proofing	no	yes	no	no	no
Const. Difficulties	no	no	no	yes	ye
Lead Time	yes	a little	no	no	yes
Amount of Form Work	none	good amount	a lot	a lot	none
Acceptable Alternative		yes	yes	no	no

Conclusion

Following analysis of the 5 methods, four alternatives and one existing I found that each of them have many individual advantages but also drawbacks as compared to the other methods. The thinnest slab was obtained with Post tension, although the savings in the end where not that significant compared to the other methods and the technical experience needed on such a project most likely is not necessary for this building with it's smaller spans. The Waffle slab did not end up saving weight in the long run and as well as the existing structure it's thickness and lead time were not completely justified in the end. The ease of construction and adaptability to the span geometry of the slab on steel decking gave positive results and is worth continuing research on in the future. Although the final conclusion stands with the two way flat plate slab. This system is relatively thin, light, easy to construct, and won't be terribly expensive. It can take economic benefit from the varying slab size changes and at this point will be the top selection for further review.

Appendix

Post Tension Two Way Flat Plate

Composite Lightweight Concrete Slab on Steel Frame

Two Way Flat Plate

Waffle Slab

1

POST TENSIONED 2 WAY FLAT PLATE

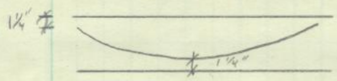
20 x 20 col's
$f'_c = 3{,}000$ PSI
$f_y = 60$ KSI
$f_{pu} = 270$ KSI ½" DIAMETER TENDONS
$A_T = 0.53$ M²

16' MAX SPAN

SPAN/DEPTH RATIO = 45

$\frac{16\,(12")}{45} = 4.26 \Rightarrow$ TRY 5" SLAB

$d = 5 - .75 - 0.5 =$



1" CLR AT TOP & BOTTOM FOR 2 HR FIRE RATING

$a = 5 - 2(1.25) = 2.50"$

LOADS

DL: SLAB - 5(1/12)150 = 62.5 PSF
MEP 10 PSF
PARTITIONS 15 PSF
MISC 5 PSF
92.5 PSF

LL: 40 PSF

BANDED TENDONS IN THE EAST-WEST DIR.
UNIFORM TENDONS IN THE NORTH-SOUTH

$W_{PRE} = 0.9(62.5) = 56.25$ PSF
$W_{NET} = 132.5 - 56.25 = 76.25$ PSF

$M_{PRE} = \frac{56.25\,(16)^2}{8} = 1800$ 'K

$F = \frac{M_{PRE}}{a} = \frac{1800(12)}{2.5} = 8.46$ K

$F/A = \frac{8.46(1000)}{60} = 141$ PSI

$A = 5"(12"\text{ strip}) = 60$ IN²

BUNDLES AT STRIP IN E-W DIRECTION

$M_o = \frac{(0.07625)(16')^2}{8} = 2.4$ 'K

$M^- = .65(2.4) = 1.56$ 'K

$M^+ = .35(2.4) = 0.84$ 'K

2

AVG STRESSES

$S = 2(5^2) = 50\ in^3$

STRESS LIMITS

SPAN ENDS: $f_t = 6\sqrt{f'_c} = 328.63$
MID SPANS: $f_t = 3\sqrt{f'_c} = 124.3$
$f_c = 0.45 f'_c = 1350$

$f = \frac{F}{A} \pm \frac{M_D}{S}$

M_u^-:

$f = -141\ PSI \pm \frac{1.56(12)(1000)}{50} =$ 233.4 < 328.63 ✓
-515.4 < 1350 ✓

M_u^+:

$f = -141\ PSI \pm \frac{0.84(12)(1000)}{50} =$ 60 < 124 ✓
= -342.6 < 1350 ✓

BUNDLES @ STRIPS IN E-W
$F = 8.46\ ^{k}/_{FT}(16') = 135.36$

$N_T = \frac{135.36}{(270)(0.153)} = 3.28$ ⟹ USE 4 TENDONS EACH WAY

NORMAL REINFORCEMENT DESIGN

DL: SLAB $0.1(62.5) = 6.25$ PSF
MEP, PART, MISC = 30 PSF
36.25 PSF

LL: 40 PSF

$W_u = 1.2(36.25) + 1.6(40) = 107.5$

$M_o = \frac{W_u l_2 l_n^2}{8} = \frac{107.5(16')(16 - \frac{20}{12})^2}{8} = 44.17'^k$

$M_u^- = .65(44.17) = 28.7'^k$
$M_u^+ = .35(44.17) = 15.5'^k$

CS M_u^- = .75 (28.7) = 21.53
MS M_u^- = .25 (28.7) = 7.18

CS M_u^+ = .63 (15.5) = 9.77
MS M_u^+ = .37 (15.5) = 5.74

3

ASSUMING #4 BARS EACH WAY

①

	M_u^-		M_u^+		
	CS	MS	CS	MS	
M_u	21.53	7.18	9.77	5.74	$b = \frac{16(12)}{2} = 96$
DEPTH	3.75"	3.75"	3.75"	3.75"	
$M_n = M_u/\phi$	23.9 'k	7.98 'k	10.86 'k	6.38 'k	
FLEXURAL RESIST. FACTOR $R = \frac{M_n(12000)}{bd^2}$	212.5 PSI	70.93 PSI	96.53 PSI	56.71 PSI	
REIN. RATIO TABLE A.5	0.00375	0.00125	0.00175	0.0012	
$A_s = \rho bd$	1.35	0.45	0.63	0.432	
$A_{s,min} = 0.002bT$	0.96 in²	0.96 in²	0.96 in²	0.96 in²	
NUMBER OF BARS $N = A_s / A_{s(\#4)}$	6.75→7	2.25→3	3.15→4	2.16→3	
MIN BARS b/2t	9.6→10	10	10	10	→ GOVERNS
SPACING s = b/N	9.5"	9.5"	9.5"	9.5"	
REINFORCEMENT	#4 @ 9.5" OC	→	→	→	

4

DESIGN SHEAR REIN. FOR PUNCHING SHEAR

SHEAR PERIMETER:

$\frac{d}{2} = 1.875 \quad b_o = 23.75 \times 4 = 95 in$

FACTORED LOAD INT. COL: $1.2(92.5) + 1.6(100) = 271$ PSF

$V_u = 271(16^2 - 2^2) = 68{,}292$ lbs

NO SHEAR REIN.:

$V_c = 0.75(4)\sqrt{3000} \times 95 \times 3.75 = 58{,}537 < 68{,}292$ — NO GOOD

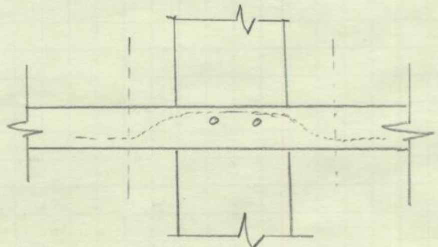
W/ 45° SHEAR BARS CONC. CONTRIBUTION:

$\phi V_c = 0.75(2)\sqrt{3000} \times 95 \times 3.75 = 29268.9$

$V_s = \frac{68292 - 29268.9}{.75} = 52030.8$

$A_v = \frac{52030.8}{60{,}000 \sin(45)} = 1.35''$

2 BARS EACH DIRECTION #4 BARS
AREA PER BAR = 1.35/8 = 0.17



NEW SHEAR PERIMETER
CRITICAL SEC: 3.75"
$= 27.5 \times 4 = 110$

$V_u = 271(16^2 - 2.75^2) = 67{,}326.6$

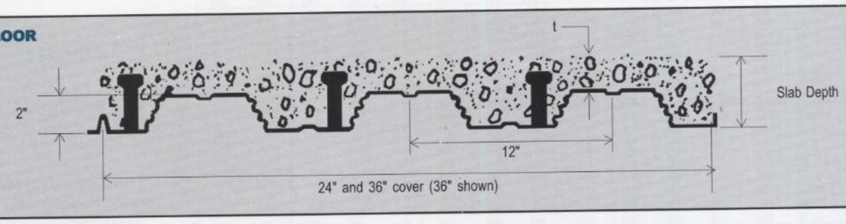
$\phi V_c = 0.75(4)\sqrt{3000}(110) \times (3.75) = 67786$ ✓

2 x 12" DECK F_y = 33ksi f'_c = 3 ksi   115 pcf concrete

USD United Steel Deck, Inc.

LRFD

2" LOK-FLOOR



The **Deck Section Properties** are per foot of width. The **I** value is for positive bending (in.[4]); **t** is the gage thickness in inches; **w** is the weight in pounds per square foot; S_p and S_n are the section moduli for positive and negative bending (in.[3]); R_b and ϕV_n are the interior reaction and the shear in pounds (per foot of width); studs is the number of studs required per foot in order to obtain the full resisting moment, ϕM_{nf}.

The **Composite Properties** are a list of values for the composite slab. The **slab depth** is the distance from the bottom of the steel deck to the top of the slab in inches as shown on the sketch. U.L. ratings generally refer to the cover over the top of the deck so it is important to be aware of the difference in names. ϕM_{nf} is the factored resisting moment provided by the composite slab when the "full" number of studs as shown in the upper table are in place; inch kips (per foot of width). A_c is the area of concrete available to resist shear, in.[2] per foot of width. **Vol.** is the volume of concrete in ft.[3] per ft.[2] needed to make up the slab; no allowance for frame or deck deflection is included. **W** is the concrete weight in pounds per ft.[2]. S_c is the section modulus of the "cracked" concrete composite slab; in.[3] per foot of width. I_{av} is the average of the "cracked" and "uncracked" moments of inertia of the transformed composite slab; in.[4] per foot of width. The I_{av} transformed section analysis is based on steel; therefore, to calculate deflections the appropriate modulus of elasticity to use is 29.5 x 10^6 psi. ϕM_{no} is the factored resisting moment of the composite slab if there are no studs on the beams (the deck is attached to the beams or walls on which it is resting) inch kips (per foot of width). ϕV_{nt} is the factored vertical shear resistance of the composite system; it is the sum of the shear resistances of the steel deck and the concrete but is not allowed to exceed $\phi 4(f'_c)^{1/2} A_c$; pounds (per foot of width). The next three columns list the **maximum unshored spans** in feet; these values are obtained by using the construction loading requirements of the SDI; combined bending and shear, deflection, and interior reactions are considered in calculating these values. A_{wwf} is the minimum area of welded wire fabric recommended for temperature reinforcing in the composite slab; square inches per foot.

DECK PROPERTIES

Gage	t	w	As	I	S_p	S_n	R_b	ϕV_n	studs
22	0.0295	1.5	0.440	0.338	0.284	0.302	714	1990	0.43
20	0.0358	1.8	0.540	0.420	0.367	0.387	1010	2410	0.52
19	0.0418	2.1	0.630	0.490	0.445	0.458	1330	2810	0.61
18	0.0474	2.4	0.710	0.560	0.523	0.529	1680	3180	0.69
16	0.0598	3.1	0.900	0.700	0.654	0.654	2470	3990	0.87

COMPOSITE PROPERTIES

	Slab Depth	ϕM_{nf} in.k	A_c in²	Vol. ft³/ft²	W psf	S_c in³	I_{av} in⁴	ϕM_{no} in.k	ϕV_{nt} lbs.	Max. unshored spans, ft. 1span	2span	3span	A_{wwf}
22 gage	4.50	40.27	32.6	0.292	34	1.00	4.4	28.13	4270	6.32	8.46	8.56	0.023
	5.00	46.44	37.5	0.333	38	1.18	6.0	33.12	4610	6.03	8.09	8.19	0.027
	5.25	49.53	40.0	0.354	41	1.27	6.9	35.69	4790	5.90	7.93	8.02	0.029
	5.50	52.61	42.6	0.375	43	1.36	7.9	38.29	4970	5.77	7.77	7.86	0.032
	6.00	58.78	48.0	0.417	48	1.55	10.1	43.58	5340	5.55	7.49	7.58	0.036
	6.25	61.87	50.8	0.438	50	1.65	11.3	46.26	5540	5.45	7.36	7.45	0.038
	6.50	64.95	53.6	0.458	53	1.75	12.7	48.97	5730	5.36	7.24	7.32	0.041
	7.00	71.12	59.5	0.500	58	1.94	15.7	54.44	6150	5.18	7.01	7.10	0.045
	7.25	74.21	61.9	0.521	60	2.04	17.4	57.20	6310	5.10	6.91	6.99	0.047
	7.50	77.29	64.3	0.542	62	2.14	19.2	59.97	6480	5.05	6.81	6.89	0.050
20 gage	4.50	48.60	32.6	0.292	34	1.20	4.8	33.77	4560	7.42	9.71	10.03	0.023
	5.00	56.18	37.5	0.333	38	1.42	6.5	39.80	5030	7.07	9.28	9.59	0.027
	5.25	59.96	40.0	0.354	41	1.53	7.4	42.91	5210	6.91	9.09	9.39	0.029
	5.50	63.75	42.6	0.375	43	1.64	8.5	46.05	5390	6.76	8.91	9.20	0.032
	6.00	71.32	48.0	0.417	48	1.87	10.9	52.47	5760	6.49	8.57	8.86	0.036
	6.25	75.11	50.8	0.438	50	1.99	12.2	55.73	5960	6.37	8.42	8.70	0.038
	6.50	78.90	53.6	0.458	53	2.10	13.7	59.02	6150	6.26	8.27	8.55	0.041
	7.00	86.47	59.5	0.500	58	2.34	16.9	65.67	6570	6.05	8.00	8.27	0.045
	7.25	90.26	61.9	0.521	60	2.46	18.7	69.03	6730	5.95	7.87	8.14	0.047
	7.50	94.05	64.3	0.542	62	2.58	20.6	72.41	6900	5.89	7.75	8.01	0.050
19 gage	4.50	55.85	32.6	0.292	34	1.38	5.1	38.67	4560	8.35	10.55	10.91	0.023
	5.00	64.68	37.5	0.333	38	1.63	6.9	45.61	5240	7.94	10.10	10.43	0.027
	5.25	69.10	40.0	0.354	41	1.75	7.9	49.19	5590	7.76	9.89	10.22	0.029
	5.50	73.52	42.6	0.375	43	1.88	9.0	52.83	5790	7.59	9.69	10.01	0.032
	6.00	82.35	48.0	0.417	48	2.15	11.6	60.25	6160	7.29	9.33	9.64	0.036
	6.25	86.77	50.8	0.438	50	2.28	13.0	64.02	6360	7.15	9.16	9.47	0.038
	6.50	91.19	53.6	0.458	53	2.42	14.5	67.83	6550	7.02	9.00	9.30	0.041
	7.00	100.03	59.5	0.500	58	2.69	17.9	75.53	6970	6.78	8.71	9.00	0.045
	7.25	104.44	61.9	0.521	60	2.83	19.8	79.42	7130	6.67	8.57	8.86	0.047
	7.50	108.86	64.3	0.542	62	2.97	21.8	83.33	7300	6.59	8.44	8.72	0.050
18 gage	4.50	62.08	32.6	0.292	34	1.53	5.4	42.99	4560	9.20	11.33	11.71	0.023
	5.00	72.04	37.5	0.333	38	1.81	7.3	50.72	5240	8.75	10.84	11.20	0.027
	5.25	77.02	40.0	0.354	41	1.95	8.3	54.72	5590	8.54	10.62	10.97	0.029
	5.50	82.00	42.6	0.375	43	2.10	9.5	58.78	5950	8.35	10.41	10.76	0.032
	6.00	91.95	48.0	0.417	48	2.39	12.1	67.07	6530	8.01	10.02	10.36	0.036
	6.25	96.93	50.8	0.438	50	2.54	13.6	71.29	6730	7.86	9.84	10.17	0.038
	6.50	101.91	53.6	0.458	53	2.69	15.2	75.55	6920	7.71	9.68	10.00	0.041
	7.00	111.87	59.5	0.500	58	3.00	18.8	84.17	7340	7.44	9.36	9.67	0.045
	7.25	116.85	61.9	0.521	60	3.16	20.7	88.52	7500	7.32	9.21	9.52	0.047
	7.50	121.83	64.3	0.542	62	3.31	22.8	92.91	7670	7.24	9.07	9.38	0.050
16 gage	4.50	62.08	32.6	0.292	34	1.88	6.0	42.99	4560	10.49	12.57	12.99	0.023
	5.00	72.04	37.5	0.333	38	2.22	8.0	50.72	5240	9.96	12.03	12.43	0.027
	5.25	77.02	40.0	0.354	41	2.40	9.2	54.72	5590	9.72	11.78	12.18	0.029
	5.50	82.00	42.6	0.375	43	2.58	10.5	58.78	5950	9.50	11.55	11.94	0.032
	6.00	91.95	48.0	0.417	48	2.94	13.4	67.07	6700	9.11	11.13	11.50	0.036
	6.25	96.93	50.8	0.438	50	3.13	15.0	71.29	7090	8.93	10.94	11.30	0.038
	6.50	101.91	53.6	0.458	53	3.32	16.8	75.55	7490	8.76	10.75	11.11	0.041
	7.00	111.87	59.5	0.500	58	3.71	20.6	84.17	8150	8.45	10.40	10.75	0.045
	7.25	116.85	61.9	0.521	60	3.90	22.8	88.52	8310	8.31	10.24	10.59	0.047
	7.50	121.83	64.3	0.542	62	4.10	25.1	92.91	8480	8.22	10.09	10.43	0.050

Light Weight

2" LOK-FLOOR

2 x 12" DECK F_y = 33ksi f'_c = 3 ksi 115 pcf concrete

LRFD

L, Uniform Live Service Loads, psf *

Gage	Slab Depth	φMn in.k	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00
22 gage	4.50	40.27	400	370	315	270	235	205	180	160	140	125	110	100	90
	5.00	46.44	400	400	365	315	270	240	210	185	165	145	130	115	105
	5.25	49.53	400	400	390	335	290	255	225	195	175	155	140	125	110
	5.50	52.61	400	400	400	355	310	270	235	210	185	165	150	130	120
	6.00	58.78	400	400	400	400	345	300	265	235	210	185	165	150	135
	6.25	61.87	400	400	400	400	365	320	280	245	220	195	175	155	140
	6.50	64.95	400	400	400	400	380	335	295	260	230	205	185	165	145
	7.00	71.12	400	400	400	400	400	365	320	285	250	225	200	180	160
20 gage	4.50	48.60	400	400	385	335	290	255	225	200	175	155	140	125	115
	5.00	56.18	400	400	400	385	335	295	260	230	205	180	165	145	130
	5.25	59.96	400	400	400	400	360	315	275	245	220	195	175	155	140
	5.50	63.75	400	400	400	400	380	335	295	260	230	205	185	165	150
	6.00	71.32	400	400	400	400	400	375	330	290	260	230	210	185	170
	6.25	75.11	400	400	400	400	400	395	345	310	275	245	220	200	180
	6.50	78.90	400	400	400	400	400	400	365	325	290	255	230	210	185
	7.00	86.47	400	400	400	400	400	400	400	355	315	280	255	230	205
19 gage	4.50	55.85	400	400	400	385	335	295	260	230	205	185	165	150	130
	5.00	64.68	400	400	400	400	390	345	300	270	240	215	190	175	155
	5.25	69.10	400	400	400	400	400	365	325	285	255	230	205	185	170
	5.50	73.52	400	400	400	400	400	390	345	305	270	245	220	200	180
	6.00	82.35	400	400	400	400	400	400	385	345	305	275	245	220	200
	6.25	86.77	400	400	400	400	400	400	400	360	320	290	260	235	210
	6.50	91.19	400	400	400	400	400	400	400	380	340	305	275	245	225
	7.00	100.03	400	400	400	400	400	400	400	400	370	335	300	270	245
18 gage	4.50	62.08	400	400	400	400	375	330	290	260	230	205	180	155	135
	5.00	72.04	400	400	400	400	400	385	340	300	270	240	220	195	180
	5.25	77.02	400	400	400	400	400	400	365	325	290	260	235	210	190
	5.50	82.00	400	400	400	400	400	400	390	345	305	275	250	225	205
	6.00	91.95	400	400	400	400	400	400	400	385	345	310	280	250	230
	6.25	96.93	400	400	400	400	400	400	400	400	365	325	295	265	240
	6.50	101.91	400	400	400	400	400	400	400	400	385	345	310	280	255
	7.00	111.87	400	400	400	400	400	400	400	400	400	380	340	310	280
16 gage	4.50	62.08	400	400	400	400	375	330	290	260	230	205	180	155	135
	5.00	72.04	400	400	400	400	400	385	340	300	270	240	220	195	180
	5.25	77.02	400	400	400	400	400	400	365	325	290	260	235	210	190
	5.50	82.00	400	400	400	400	400	400	390	345	305	275	250	225	205
	6.00	91.95	400	400	400	400	400	400	400	385	345	310	280	250	230
	6.25	96.93	400	400	400	400	400	400	400	400	365	325	295	265	240
	6.50	101.91	400	400	400	400	400	400	400	400	385	345	310	280	255
	7.00	111.87	400	400	400	400	400	400	400	400	400	380	340	310	280
22 gage	4.50	28.13	300	250	215	180	155	135	120	105	90	80	70	60	55
	5.00	33.12	355	295	250	215	185	160	140	125	110	95	85	75	65
	5.25	35.69	380	320	270	235	200	175	150	135	115	105	90	80	70
	5.50	38.29	400	345	290	250	215	185	165	145	125	110	100	85	75
	6.00	43.58	400	395	335	285	245	215	185	165	145	130	115	100	90
	6.25	46.26	400	400	355	305	260	230	200	175	155	135	120	105	95
	6.50	48.97	400	400	375	320	280	240	210	185	165	145	130	115	100
	7.00	54.44	400	400	400	360	310	270	235	205	185	160	145	125	115
20 gage	4.50	33.77	365	305	260	225	195	170	145	130	115	100	90	80	70
	5.00	39.80	400	360	310	265	230	200	175	155	135	120	105	95	85
	5.25	42.91	400	390	335	285	245	215	190	165	145	130	115	105	90
	5.50	46.05	400	400	360	305	265	230	205	180	160	140	125	110	100
	6.00	52.47	400	400	400	350	305	265	235	205	180	160	145	130	115
	6.25	55.73	400	400	400	375	325	280	250	220	195	170	155	135	120
	6.50	59.02	400	400	400	395	345	300	265	230	205	180	160	145	130
	7.00	65.67	400	400	400	400	385	335	295	260	230	205	180	160	145
19 gage	4.50	38.67	400	355	300	260	225	195	170	150	135	120	105	95	85
	5.00	45.61	400	400	360	310	265	235	205	180	160	140	125	115	100
	5.25	49.19	400	400	385	330	290	250	220	195	175	155	135	125	110
	5.50	52.83	400	400	400	355	310	270	240	210	185	165	150	130	120
	6.00	60.25	400	400	400	400	355	310	270	240	215	190	170	150	135
	6.25	64.02	400	400	400	400	375	330	290	255	225	205	180	160	145
	6.50	67.83	400	400	400	400	400	350	310	270	240	215	190	175	155
	7.00	75.53	400	400	400	400	400	390	345	305	270	240	215	195	175
18 gage	4.50	42.99	400	395	340	290	255	220	195	170	150	135	120	110	95
	5.00	50.72	400	400	400	345	300	260	230	205	180	160	145	130	115
	5.25	54.72	400	400	400	375	325	285	250	220	195	175	155	140	125
	5.50	58.78	400	400	400	400	350	305	270	235	210	190	170	150	135
	6.00	67.07	400	400	400	400	400	350	305	270	240	215	195	175	155
	6.25	71.29	400	400	400	400	400	370	325	290	255	230	205	185	165
	6.50	75.55	400	400	400	400	400	395	345	305	275	245	220	195	175
	7.00	84.17	400	400	400	400	400	400	390	345	305	275	245	220	200
16 gage	4.50	42.99	400	400	395	340	290	255	220	195	170	150	135	120	110	95
	5.00	50.72	400	400	400	345	300	260	230	205	180	160	145	130	115
	5.25	54.72	400	400	400	375	325	285	250	220	195	175	155	140	125
	5.50	58.78	400	400	400	400	350	305	270	235	210	190	170	150	135
	6.00	67.07	400	400	400	400	400	350	305	270	240	215	195	175	155
	6.25	71.29	400	400	400	400	400	370	325	290	255	230	205	185	165
	6.50	75.55	400	400	400	400	400	395	345	305	275	245	220	195	175
	7.00	84.17	400	400	400	400	400	400	390	345	305	275	245	220	200

Light Weight

1 STUD/FT.

NO STUDS

* The **Uniform Live Loads** are based on the LRFD equation $\phi M_n = (1.6L + 1.2D)\ell^2/8$. Although there are other load combinations that may require investigation, this will control most of the time. The equation assumes there is no negative bending reinforcement over the beams and therefore each composite slab is a single span. Two sets of values are shown; ϕM_{nf} is used to calculate the uniform load when the full required number of studs is present; ϕM_{no} is used to calculate the load when no studs are present. A straight line interpolation can be done if the average number of studs is between zero and the required number needed to develop the "full" factored moment. The tabulated loads are checked for shear controlling (it seldom does), and also limited to a live load deflection of 1/360 of the span.

An upper limit of 400 psf has been applied to the tabulated loads. This has been done to guard against equating large concentrated to uniform loads. Concentrated loads may require special analysis and design to take care of servicibility requirements not covered by simply using a uniform load value. On the other hand, for any load combination the values provided by the composite properties can be used in the calculations.

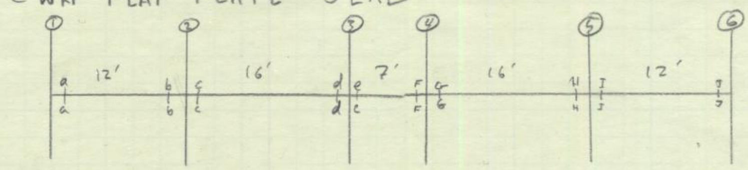
Welded wire fabric in the required amount is assumed for the table values. If welded wire fabric is not present, deduct 10% from the listed loads.

Refer to the example problems for the use of the tables.

2" LOK-FLOOR

①

2 WAY FLAT PLATE SLAB



SLAB THICKNESS

$EX = \frac{\ell_n}{30} = \frac{(16(12) - 20/2)}{30} = 6.34 = 6.5''$

$INT = \frac{\ell_n}{33} = 5.76 \Rightarrow$ USE 6.5" TO KEEP UNIFORMITY

DL: $6.5/12\,(150) = 81.25$
SI $= 30.00$
111.25

$1.2(111.25) + 1.6(100) = 293.5$ PSF

$I_s = 16(12)(6.5^3)/12 = 4394\ in^4$

$K_{s(12')} = \frac{4E_cI_c}{\ell_n - c/2} = \frac{4E_c(4394)}{12(12) - 20/2} = 131.2E_c$ IN lb/RAD

$K_{s(16')} = \frac{4E_c(4394)}{16(12) - 20/2} = 96.6E_c$

$K_{s(7')} = \frac{4E_c(4394)}{7(12) - 20/2} = 237.5E_c$

20x20 col $\quad K_c = \frac{4E_cI_c}{L - 2t} = \frac{4E_c(20^4/12)}{(12)9.6 - 2(6.5)} = 521.9E_c$

FLR Ht = 9.66 FT

$C = \left(1 + .63\left(\frac{6.5}{20}\right)\right)\frac{6.5^3(20)}{3} = 2205.7$

$K_t = \frac{9E_cC}{\ell_2(1 - c/\ell_2)} = \frac{9E_c(2205.7)}{16(12)(1 - 20/16(12))} = 115.4E_c$

$\frac{1}{K_{ec}} = \frac{1}{2 \cdot 521.9E_c} + \frac{1}{2 \times 115.4E_c} \Rightarrow K_{ec} = 189E_c$

DISTRIBUTION FACTORS

$DF_{A-A,\,J-J} = \frac{131.2E_c}{131.2 + 189} = 0.410$

$DF_{B-B,\,I-I} = \frac{131.2}{131.2 + 96.6 + 189} = 0.315$

$DF_{C-C,\,H-H} = \frac{96.6}{131.2 + 96.6 + 189} = 0.232$

$DF_{D-D,\,G-G} = \frac{96.6}{96.6 + 237.5 + 189} = 0.185$

$DF_{E-E,\,F-F} = \frac{237.5}{96.6 + 237.5 + 189} = 0.454$

(2)

FEM

12' : $W_u = 293.5(12) = 3.522^{KLF}$

$M_u^- = \frac{3.522(12)^2}{12} = 42.3^{'K}$

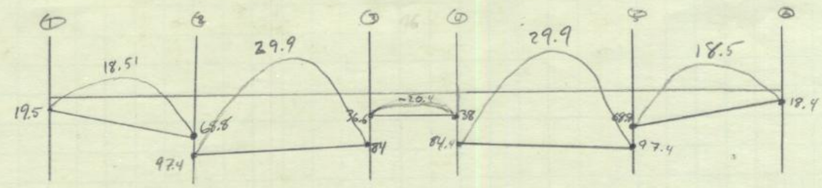
16' : $W_u = 4.696^{KLF}$ $M_u^- = \frac{4.696(16^2)}{12} = 100.2^{'K}$

7' : $W_u = 2.055^{KLF}$ $M_u^- = \frac{2.055(7^2)}{12} = 8.4^{'K}$

MOM DIST

COL LINE	(1)	(2)	(2)	(3)	(3)	(4)	(4)	(5)	(5)	(6)
DF	.41	.315	.232	.185	.454	.454	.185	.232	.315	.41
FEM	-42.3	+42.3	-100.2	+100.2	-8.4	+8.4	-100.2	+100.2	-42.3	+42.3
DIST	17.3									
		+8.65								
		+15.5	+11.4							
	+7.75			5.7						
				-18	-44.3					
			-9							
						-22.15				
						+51.73	21.1			
					+25.9					
								10.5		
								-15.9	-21.6	
							-7.9			
										-10.8
										-12.9
									-6.5	
								1.5	2	
										1
							.75			
						3.9	1.6			
								.8		
					2.0					
				-5.2	-12.6					
						-6.3				
			-2.6							
		3.7	2.7							
				1.3						
	1.8									
	-3.9									
		-2.0								
		.63	.464							
	.315									
				0.2						
				-0.28	-0.68					
						-.34				
			-.14							
						3.0	1.2			
					1.5					
								0.6		
								-.3	-.44	
							+.15			
										-.22
MOMENTS	-19.5	+68.78	-97.4	83.92	-36.54	38.26	-84.8	97.4	-68.8	18.4

(3)



$\frac{W\ell^2}{8} \Rightarrow$ 1-2, 5-6: $\frac{293.4(16)(12 - \frac{20}{12})^2}{8} = 62.66$ 'k

2-3, 4-5: $\frac{293.4(16)(16 - \frac{20}{12})^2}{8} = 120.6$ 'k

3-4: $\frac{293.4(16)(7 - \frac{20}{12})^2}{8} = 16.7$ 'k

MAX $M_u^- = 97.4$
MAX $M_u^+ = 29.9$

CS $M_u^- = 0.75(97.4) = 73.1$ 'k
MS $M_u^- = 0.25(97.4) = 24.4$ 'k

CS $M_u^+ = 0.6(29.9) = 17.94$ 'k
MS $M_u^+ = 0.4(29.9) = 11.96$ 'k

DESIGN REINFORCEMENT

$\frac{16(12)}{2} = 96$

	M_u^- CS	M_u^- MS	M_u^+ CS	M_u^+ MS
MOMENTS	73.1 'k	24.4 'k	17.94 'k	11.96 'k
EFF DEPTH (.75" CLR) ASSUME #5 BARS BOTH DIRECTION	5.4375"	5.4375"	5.4375"	5.4375"
$M_n = M_u / \phi$	81.2 'k	27.1 'k	19.9 'k	13.3 'k
$R = M_n / bd^2$	309	103.2	75.89	50.6
REIN. RATIO ρ (TABLE A.5)	0.0055	0.0053	0.00125	0.0007
STEEL AREA ρbd (in²)	2.87	2.77	0.65	0.37
MIN STEEL AREA $A_{s\,min} = 0.0018\,bt$ (in²)	1.13	1.13	1.13	1.13
# OF BARS $N = A_s / A_{s\,BAR}$	(#5) 9.26 => 10 BARS	(#5) 8.93 9 BARS	(#4 BAR) 3.25 4 BARS	(#4) 1.85 USE 4 BARS
MIN # OF BARS $N_{min} = b/2t$	7.38 = 8 BARS			
SPACING OF BARS $S = b/N$	9.6" → FOR UNIFORMITY		24"	24"
FINAL REINFORCEMENT	#5@9.5"	#5@9.5"	#4@24"	#4@24"

SHEAR REINF. CHECK

$\frac{d}{2} = 2.72 \quad b_o = 25.44 \times 4 = 102$

$V_u = 293.5\,PSF(16^2 - 2^2) = 73,962$ lbs

$V_c = 0.75(4)\sqrt{3000}(102)(5.4375) = 92181 > V_u$ → NO EXTRA SHEAR REIN. REQ'D

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

f'_c = 4,000 psi
Grade 60 Bars

SQUARE EDGE PANELS

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

Span c.-c. Columns $\ell_1 = \ell_2$ (ft)	Factored Super-imposed Load (psf)	(1) Steel (psf)	Square Edge Column $c_1 = c_2$ (in.)	Square Edge Column γ_f	Square Edge Column (2) Stirrups	Column Strip Top Edge No.-size +	Column Strip Bottom No. Ribs	Column Strip Bottom Bars per Rib	Column Strip Top Interior No.-size	Middle Strip Bottom No. Ribs	Middle Strip Bottom Long Bars	Middle Strip Bottom Short Bars	Middle Strip Top Interior No.-size	Moments −M Edge (ft-k)	Moments +M Bot. (ft-k)	Moments −M Int. (ft-k)
14'- 0"	50	2.25	12	0.629		10-#5+ 0	4	2-#4	10-#5	3	#4	#4	4-#5	13	26	34
D= 6.417	100	2.25	12	0.636		10-#5+ 0	4	2-#4	10-#5	3	#4	#4	4-#5	17	35	45
RIB NOT ON	150	2.25	12	0.656		10-#5+ 0	4	2-#4	10-#5	3	#4	#4	4-#5	20	48	55
COLUMN LINE	200	2.25	12	0.677		10-#5+ 0	4	2-#4	10-#5	3	#4	#4	4-#5	24	60	65
0.599 CF/SF	300	2.25	12	0.717		10-#5+ 0	4	2-#4	10-#5	3	#4	#4	4-#5	32	84	86
	400	2.25	12	0.758		10-#5+ 0	4	2-#4	10-#5	3	#4	#4	4-#5	40	107	107
16'- 0"	50	2.30	12	0.694		12-#5+ 0	4	2-#4	12-#5	4	#4	#4	5-#5	19	38	52
D= 6.417	100	2.30	12	0.716		12-#5+ 0	4	2-#4	12-#5	4	#4	#4	5-#5	25	52	67
RIB NOT ON	150	2.30	12	0.739		12-#5+ 0	4	2-#4	12-#5	4	#4	#4	5-#5	31	72	83
COLUMN LINE	200	2.30	12	0.761		12-#5+ 0	4	2-#4	12-#5	4	#4	#4	5-#5	37	90	99
0.582 CF/SF	300	2.39	12	0.806		12-#5+ 0	4	1-#4 and 1-#5	12-#5	4	#4	#4	5-#5	48	126	130
	400	2.47	12	0.850		12-#5+ 0	4	2-#5	12-#5	4	#4	#4	5-#5	60	162	162
18'- 0"	50	2.25	12	0.734		13-#5+ 0	4	2-#4	13-#5	5	#4	#4	5-#5	28	55	74
D= 6.417	100	2.25	12	0.760		13-#5+ 0	4	2-#4	13-#5	5	#4	#4	5-#5	36	75	97
RIB NOT ON	150	2.25	12	0.787		13-#5+ 0	4	2-#4	13-#5	5	#4	#4	5-#5	44	103	120
COLUMN LINE	200	2.33	12	0.813		13-#5+ 0	4	1-#4 and 1-#5	13-#5	5	#4	#4	5-#5	53	130	143
0.571 CF/SF	300	2.58	12 *	0.865		13-#5+ 0	4	1-#5 and 1-#6	13-#5	5	#4	#4	5-#5	70	182	188
	400	2.84	12 *	0.630		13-#5+ 0	4	2-#6	14-#5	5	#4	#5	5-#5	87	233	234
20'- 0"	50	2.28	12	0.788		15-#5+ 0	5	2-#4	15-#5	5	#4	#4	6-#5	39	78	104
D= 8.417	100	2.28	12	0.816		15-#5+ 0	5	2-#4	15-#5	5	#4	#4	6-#5	50	105	136
RIB ON	150	2.36	12	0.844		15-#5+ 0	5	1-#4 and 1-#5	15-#5	5	#4	#4	6-#5	62	145	168
COLUMN LINE	200	2.45	12	0.872		15-#5+ 0	5	2-#5	15-#5	5	#4	#4	6-#5	74	182	199
0.590 CF/SF	300	2.80	12 *	0.630		15-#5+ 0	5	2-#6	15-#5	5	#4	#5	6-#5	97	254	262
	400	3.48	14 *	0.627		15-#5+ 0	5	1-#6 and 1-#7	14-#6	5	#5	#6	6-#5	120	323	323
22'- 0"	50	2.25	12	0.818		16-#5+ 0	5	2-#4	16-#5	6	#4	#4	7-#5	52	103	139
D= 8.417	100	2.25	12	0.850		16-#5+ 0	5	2-#4	16-#5	6	#4	#4	7-#5	68	140	182
RIB ON	150	2.40	12 *	0.882		16-#5+ 0	5	2-#5	16-#5	6	#4	#4	7-#5	83	193	224
COLUMN LINE	200	2.56	12 *	0.914		16-#5+ 0	5	1-#5 and 1-#6	16-#5	6	#4	#4	7-#5	99	243	267
0.579 CF/SF	300	3.26	14 *	0.627		16-#5+ 0	5	1-#6 and 1-#7	15-#6	6	#5	#5	7-#5	130	337	349
	400	3.87	18 *	0.623	3 S 4 1	16-#5+ 0	5	2-#7	18-#6	6	#5	#6	8-#5	156	392	419

SQUARE INTERIOR PANELS

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

Span c.-c. Columns $\ell_1 = \ell_2$ (ft)	Factored Super-imposed Load (psf)	(1) Steel (psf)	Square Interior Column $c_1 = c_2$ (in.)	Square Interior Column (2) Stirrups	Column Strip Bottom No. Ribs	Column Strip Bottom Bars per Rib	Column Strip Top Interior No.-size	Middle Strip Bottom No. Ribs	Middle Strip Bottom Long Bars	Middle Strip Bottom Short Bars	Middle Strip Top Interior No.-size
14'- 0"	50	2.20	12		4	2-#4	10-#5	3	#4	#4	4-#5
	100	2.20	12		4	2-#4	10-#5	3	#4	#4	4-#5
	150	2.20	12		4	2-#4	10-#5	3	#4	#4	4-#5
	200	2.20	12		4	2-#4	10-#5	3	#4	#4	4-#5
	300	2.20	12		4	2-#4	10-#5	3	#4	#4	4-#5
	400	2.20	12		4	2-#4	10-#5	3	#4	#4	4-#5
16'- 0"	50	2.26	12		4	2-#4	12-#5	4	#4	#4	5-#5
	100	2.26	12		4	2-#4	12-#5	4	#4	#4	5-#5
	150	2.26	12		4	2-#4	12-#5	4	#4	#4	5-#5
	200	2.26	12		4	2-#4	12-#5	4	#4	#4	5-#5
	300	2.26	12		4	2-#4	12-#5	4	#4	#4	5-#5
	400	2.26	12	3 S 4 1	4	2-#4	12-#5	4	#4	#4	5-#5
18'- 0"	50	2.21	12		4	2-#4	13-#5	5	#4	#4	5-#5
	100	2.21	12		4	2-#4	13-#5	5	#4	#4	5-#5
	150	2.21	12		4	2-#4	13-#5	5	#4	#4	5-#5
	200	2.21	12		4	2-#4	13-#5	5	#4	#4	5-#5
	300	2.36	12	3 S 4 1	4	1-#4 and 1-#5	13-#5	5	#4	#4	5-#5
	400	2.49	12 *	3 S 4 1	4	2-#5	13-#5	5	#4	#4	5-#5
20'- 0"	50	2.25	12		5	2-#4	15-#5	5	#4	#4	6-#5
	100	2.25	12		5	2-#4	15-#5	5	#4	#4	6-#5
	150	2.25	12		5	2-#4	15-#5	5	#4	#4	6-#5
	200	2.25	12		5	2-#4	15-#5	5	#4	#4	6-#5
	300	2.39	12 *	3 S 4 1	5	1-#4 and 1-#5	15-#5	5	#4	#4	6-#5
	400	2.99	12 *	3 S 4 1	5	1-#5 and 1-#6	18-#5	5	#4	#5	6-#5
22'- 0"	50	2.23	12		5	2-#4	16-#5	6	#4	#4	7-#5
	100	2.23	12		5	2-#4	16-#5	6	#4	#4	7-#5
	150	2.23	12		5	2-#4	16-#5	6	#4	#4	7-#5
	200	2.36	12 *	3 S 4 1	5	1-#4 and 1-#5	16-#5	6	#4	#4	7-#5
	300	2.81	12 *	3 S 4 1	5	1-#5 and 1-#6	19-#5	6	#4	#4	7-#5
	400	3.47	16 *	3 S 4 2	5	2-#6	17-#6	6	#4	#5	8-#5

(Continued on next page)