Technical Assignment II
Structural Study of Alternate Floor Systems

Life Sciences Building
The Pennsylvania State University, University Park, Pennsylvania

Executive Summary|

This report is a study of alternative floor systems for the Life Sciences Building at The Pennsylvania State University – University Park Campus, University Park, Pennsylvania. The building was designed from 1999 and completed in 2004. The building is 'L' shaped, 6 floors (97') tall, and 154,000 GSF with a mechanical penthouse and has concrete floors with a steel frame using composite floor deck, composite beams and composite girders.

Five alternative systems with a reasonable chance of being considered as part of the final structural proposal were investigated in depth for the Life Sciences Building. They are Pre Cast Hollowcore Plank on Steel Beams, Concrete Flat Slab with Drop Panels, Post Tensioned Concrete Flat Plate, Concrete Waffle Slab, and Composite Steel Deck on Composite Steel Beams.

The conclusions reached through analysis, design, and research into the different floor systems are that only two of the five systems that were considered in detail are viable alternatives for the Life Sciences Building. The five systems were first designed for a typical bay using simplified methods because the purpose of this assignment was to be a schematic / preliminary design to help gather information for later decisions. After the five systems were designed they were compared using criteria such as self weight, depth, deflections, relative cost, fire resistance, vibration, how well moment frames can be integrated into the floor construction, and how easily they can accommodate irregularities in framing. The final conclusion of Technical Assignment II for the Life Sciences Building was that the post tension concrete flat plate and composite steel deck on composite structural steel framing were the only two options that should be studied further.

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Building Description|

The Life Sciences Building at The Pennsylvania State University, University Park Campus, University Park, Pennsylvania is a six story steel frame structure that is roughly shaped like an "L". The longer leg of the "L" runs in an east – west direction across the northern edge of the site. The shorter leg of the "L" runs north – south along the west central portion of the site. There is also an attached mechanical vault structure at the end of the long leg of the "L" and a two level above grade connection that ties into the knuckle of the "L".

The building can be conveniently broken down into three sections. The first section – referred to herein as "the long leg of the 'L'" – is the part of the building running east – west along the northern edge of the site occurring to the east of column line C. The long leg of the 'L' contains the bulk of the labs, offices and classrooms. The second section – referred to herein as "the knuckle" – is the part of the building that runs east – west along the northern edge of the site and occurs to the west of column line C. "The knuckle" is also the part of the building where the above grade connection to the Chemistry Building ties into the Life Sciences Building. The third and final section – referred to herein as "the short leg of the 'L'" – is the part of the building that runs north – south along the west central portion of the site and ties into the knuckle at its northern end.

Other notable features of the Life Sciences Building include the two story above grade connection to the adjacent Chemistry Building which occurs on the third and fourth floors. A one level mechanical vault was constructed along with the building at its lowest level and is located on the top of the long leg of the "L" (far east side of building). This mechanical vault is constructed entirely of reinforced concrete and its roof is used as a loading dock / truck parking area for the Life Sciences Building. A greenhouse is located on the top of the short leg of the "L". The greenhouse is located on the fourth floor which is also the rooftop of the short leg of the "L" (southernmost portion of building).

Floors of the Life Sciences Building will be referred to in this and all subsequent reports by using the following convention:

B	Basement	1150'-0"
V	Vault	1156'-6" **
G	Ground Floor	1166'-8"
1	First Floor	1180'-8"
2	Second Floor	1194'-8"
3	Third Floor	1208'-8"
4	Fourth Floor	1222'-8"
P	Penthouse	1236'-8"
R	Roof	1263'-0"

** mechanical vault area attached to and constructed with Life Sciences Building which is located adjacent to main structure with a roof used as a loading dock area.

Existing Structural System Summary|

Foundation|

The Life Sciences Building uses a combination of several foundation types to adapt to several different base slab elevations and varying subsurface conditions.

The vault area of the building is built on a continuous reinforced concrete mat foundation. Columns and walls of the vault will bear on thickened portions of the mat foundation. The mat foundation will have a thickness of 2'-0" and be reinforced with #6 and #7 bars at 12" o.c. The bearing capacity of the soil underneath the mat foundation is 2 ksf for exterior walls and 2.5 ksf for columns.

The foundation of the long leg of the "L" will consist primarily of reinforced concrete spread footings. The maximum allowed bearing pressure on the soil underneath the spread footings is 6 ksf. Underneath walls the foundation ranges from 1'-6" to 2'-3" thick and from 5'-6" to 10'-2" wide. To support columns the spread footings range from 1'-7" to 4'-0" thick and from 5'-6" to 17'-4" wide.

To support the rest of the building, including the knuckle and short leg of the "L", footings are supported on driven steel H – piles. The soil bearing capacity is considered to be 6 ksi on the gross section area of the steel H – pile (and the skin friction value is currently unknown). The piles used are HP10x57 and HP12x74 sections with allowable working loads of 100 k and 130 k respectively. Piles are driven in groups to an average depth of 25' and capped. Piles are driven vertically in the center of pile caps and battered outward on the perimeter of pile caps on a 1:6 (H:V) batter. The piles are arranged in groups of 2,3,4,5,6,8,11, and 16. The pile caps are reinforced concrete and range in thickness from 3'-0" to 5'-0" deep. Grade beams span between pile caps to support the exterior walls.

Floor Framing|

The typical basement slab on grade is 6" of 4000 psi concrete on 6" of PennDOT 2A aggregate reinforced with WWF6x6 – W4xW4. The typical ground level slab on grade is 5" of 4000 psi concrete reinforced with WWF6x6 – W2.9x2.9. The typical floor deck is composite 18 gage, 2" thick fluted with 4-1/2" of concrete cover for a total thickness of 6-1/2". The concrete is normal weight, 4000 psi with one layer of WWF4x4 – W5.5xW5.5. All beams and girders are composite steel wide flange sections using 5" long, ¾" diameter shear studs welded directly to the beam. The shear studs have a shear transfer capacity of 13.3 k/stud.

The basement level of the Life Sciences Building only occurs underneath the long leg of the "L". The basement level of the long leg of the "L" and ground floor level of the short leg of the "L" and knuckle are slabs on grade. Slabs on grade in the basement are typically 6" concrete reinforced with one layer of welded wire fabric. Slabs on grade at ground level are typically 5" thick.

Existing Structural System Summary (continued)|

Beginning with the ground floor level of the long leg of the “L” the floor framing system takes on a typical layout. This framing system is typical and occurs on the ground through fourth floors. The typical floor deck is composite 18 gage, 2” thick fluted with 4-1/2” of concrete cover for a total thickness of 6-1/2”. The concrete is normal weight, 4000 psi with one layer of WWF4x4 – W5.5xW5.5. Infill beams for the ground through fourth floors are typically composite W16x26 (spaced 8’-0” o.c.) and composite W16x31 (spaced 8’-8” o.c.) with a built in camber and span of 31’-0”. The girders supporting the W16x26 infill beams are composite W24x68 and span 31’-0”. The girders supporting the W16x26 infill beams are composite W30x99 and span 41’-0”.

The knuckle floor framing system starts with a typical slab on grade on the first floor. The framing for the second through fourth floors consists of the typical composite floor system bearing on W21x44 composite beams. Due to the knuckle not being square the span of the W21x44 beams ranges from roughly 34’ to 38’ and their spacing is between 8’ and 9’.

The framing of the short leg of the “L” is typical on the second through fourth floors, but becomes quite complex on the ground floor to accommodate an auditorium with a sloped floor. The floor framing system for the second through fourth floors of the short leg consists of the typical composite floor system bearing on composite W14x22 infill beams. The W14x22 infill beams are spaced at 8’-8” o.c. and span 20’-8”. They are supported by W21x57 composite girders which span 26’-0”. Each girder supports two infill beams at third points.

The mechanical penthouse level occurs at the top of the long leg of the “L”. The penthouse houses air handlers and various other pieces of mechanical and electrical equipment. The penthouse was designed for comparatively heavy live and dead loads so the beams and girders are much larger than the typical floor framing for the long leg of the “L”. The penthouse floor structure begins with the typical composite floor deck and slab that can be found throughout the rest of the building. This slab bears into various W18 infill beams ranging from composite W18x40 to W18x97 (used to frame around openings in the slab). The most typical infill beams are W18x46 and W18x50 but larger sizes are also common where slab openings exist or support structures for the mechanical equipment bear down on the infill beam. The typical span of the beams and girders is 31’. The girders are most typically composite steel W33x141 and W33x201.

Existing Structural System Summary (continued)|

Roof Framing|

The typical roof deck is 20 gage, 1-1/2" deep, wide rib steel roof decking. The roof consists of low roofs that are framed as part of the mechanical penthouse floor system. From the low roof, set back in from the building perimeter, a sharply angled roof / wall goes up to form the enclosure of the mechanical penthouse. On the top of the space created by the angled roof / walls there is another flat roof to completely enclose the mechanical penthouse. As stated previously the low roof is framed as part of the mechanical penthouse floor system. The sharply angled roof is framed by noncomposite W18x60 girders running at an angle that is more vertical than horizontal. These girders run from the low roof to the top of the mechanical penthouse enclosure and act as beams / columns by forming the walls and supporting the higher flat roof. The girders are spaced at 31'-0". W12x26 infill beams then span horizontally in between the W18x60 girders. The infill beams span the entire 31'-0" space between the girders and are spaced with three equal spaces measured from the low flat roof to the top of the high flat roof. Finally, the top of the mechanical penthouse covered by the high flat roof is framed by W16x40, W16x31, and W16x26 beams in various configurations that allow large openings for the vents that ventilate the laboratories. The flat roofs are both covered with the typical roof deck. The sloped roof / walls are covered with plywood and light gauge steel framing.

Lateral System|

The lateral force resisting system (and system of columns) is made up of a combination of braced and moment resisting frames. Due to the complex geometry of the footprint of the building; numerous lateral force resisting systems are located throughout the structure. The building is shaped roughly like an "L" with the long side of the "L" running east to west. A steel moment resisting frame runs along each of the long exterior walls of the building in the east – west direction. Additionally in the east – west direction are three combined moment / braced frames located internally in the short leg of the "L". One moment frame runs east –west on the end of the short leg of the "L". Two smaller moment frames also run east – west to support a section of the building that is isolated due to an expansion joint (isolated section not considered in this report). The total number of frames providing lateral support to the building in the east – west direction is eight.

In the north – south direction, three braced frames located inside the long leg of the "L" provide lateral support. Also, on the east end of the long leg of the "L" a braced frame provides north – south lateral support. In the short leg of the "L" one moment frame runs along each exterior wall. Additionally, in the north – south direction, a braced frame located at the outside corner where the long and short legs of the "L" meet provides additional lateral support. Finally, two braced frames provide north – south lateral load resistance to the portion of the building that is isolated due to an expansion joint. The total number of frames providing lateral support to the building in the north – south direction is nine.

Existing Structural System Summary (continued)|

Columns|

The system of columns and lateral force resisting system is designed so that very few columns aren't involved in a moment frame or braced frame. Most column loading depends on many more factors than gravity loads. The columns range in size from W10 up to W14. The weights generally vary from 33 lbs/ft to 311 lbs/ft. Estimated column loads vary from 60 k to 1100 k, with most column loads in the range of 200 k to 800 k.

Material Strength|

The following material strengths were assumed in the analysis of alternate floor systems for Technical Assignment II unless otherwise noted in individual calculations:

Reinforced Concrete|

- Compressive Strength
  - f'_c = 4000 psi
- Reinforcement Bars (ASTM A615 Grade 60)
  - f_y = 60000 psi
- Welded Wire Fabric (ASTM A185)
  - f_y = 70000 psi

Pre Cast Concrete|

- (given in appendix on data sheets)

Structural Steel|

- Beams, Columns, Other Framing Members = ASTM A572 Gr. 50
  - F_y = 50 ksi F_u = 65 ksi
- Plates, Bars, Angles = ASTM A36
  - F_y = 36 ksi F_u = 58 ksi
- Structural Tubing = ASTM A500 Gr. B
  - F_y = 42 ksi F_u = 58 ksi
- Structural Pipe = ASTM A501
  - F_y = 36 ksi F_u = 58 ksi
- All bolts will be ¾" ASTM A325N (threads included)
  - V_n = 15.9 k / bolt
- Shear Studs will be ¾" diameter 5" long
  - V_n = 13.3 k / stud

Steel Deck|

- Roof Deck
  - F_y = 33 ksi
- Composite Floor Deck
  - F_y = 40 ksi

Building Codes|

In the reanalysis of the floor systems for Technical Assignment II the most current building codes at this time will be used. Additionally information provided by manufacturers of products will be used in the analysis and design and incorporated into the appendix containing the calculations they were used for. The following codes will be used extensively in the reanalysis and design of the Life Sciences Building:

Building Code / Loading|
- International Code Council
  - IBC 2006
- American Society of Civil Engineers
  - ASCE 7 – 05

Reinforced / Precast / Postensioned Concrete|
- American Concrete Institute
  - ACI 318 – 05
  - ACI 216.1 – 97
- Concrete Reinforcing Steel Institute
  - CRSI Design Handbook 2002, 9th Edition
- Precast Concrete Institute
  - PCI Handbook, 6th Edition

Structural Steel|
- American Institute of Steel Construction
  - AISC – 13th Edition Steel Manual

Cold Formed Steel Decking|
- Steel Deck Institute
  - SDI – Steel Deck Institute Design Manual for Composite, Form, and Roof Decks

Other Design Resources|

For the analysis of potential floor systems in Technical Assignment II the following design aids were used in addition to the building codes.

Reinforced Concrete|
- Nitterhouse Concrete Products www.nitterhouse.com

Post – Tensioned Concrete|
- Atlas Prestressing Corp. – Post – Tensioned Concrete Design Workbook

Live Load|

Live loads used were recommended values from IBC 2006 and ASCE 7 – 05. Loads from the original design that were higher than recommended values from IBC 2006 and ASCE 7 – 05 were left unchanged from the original design as a conservative assumption. Several loads were specified by the end user of the building and these were not modified. The following lists the live load assumptions that were used in the analysis and design of alternate floor systems:

Assembly Areas|	
Fixed Seats	60 PSF
Lobbies / Moveable Seats	100 PSF
Corridors|	
All Floors	100 PSF
Classrooms, Labs, Offices|	
Reducible Live Load	80 PSF
Partition Load	20 PSF **
Electrical / Mechanical Rooms|	
	200 PSF *
Stairs / Landings|	
	100 PSF
Storage Areas|	
Light Storage	125 PSF *
File Areas	User Defined
Special Storage	User Defined

* Indicates that load is non-reducible because it is a heavy live load according to IBC 2006 and ASCE 7 – 05 (S.4.8.2).
** Indicates that load is non-reducible because it is a partition load which will constantly be applied to the structure (typically applied as dead load for this report for simplification).

Dead Load|

Dead loads will be taken as the self weights of the building materials used in the construction of the floor system. The partition load allowance will be added to classroom, lab and office areas and will be considered as part of the dead load for this analysis. Additional superimposed dead loads will be added to the classroom, lab and office areas, as well as added to the structures that are directly above mechanical and electrical rooms. The values used for these superimposed dead loads follow:

Classrooms, Labs, Offices|	
Collateral Dead Load	10 PSF
Partition Dead Load	20 PSF
Electrical / Mechanical Rooms|	
Collateral Dead Load	30 PSF

IBC Requirements|

The occupancy of the Life Sciences Building is IBC Occupancy Group B (the standard occupancy group for college campus buildings). The construction of the Life Sciences Building is IBC 2006 Type II-A which requires the following:

Stories < 5 + 1 (sprinkler allowance) = 6 stories

Height < 65' + 20' (sprinkler allowance) = 85'
(roof structures and mechanical penthouses may exceed this height)

Floor Area < 37,500 ft^2 + (sprinkler allowance) + (frontage allowance)

The Life Sciences Building meets all of the above requirements.

Fire Resistance Ratings|

IBC Type II-A construction requires the following fire resistances for all of the structural elements of the Life Sciences Building:

Structural Frame	> 1 hour
Bearing Walls	
Exterior	> 1 hour
Interior	> 1 hour
Non-bearing Walls	0 hours
Exterior Walls	> 1 hour
Floor Construction	> 1 hour
Roof Construction	> 1 hour

Fire Resistance of Concrete

Adequate fire resistance for cast in place concrete floor designs was ensured by consulting ACI 216.1-97. The following table from ACI 216.1-97 was used to determine the concrete cover to provide a 1 hour fire rating for all of the cast in place concrete floor assemblies.

Table 2.3—Minimum cover for concrete floor and roof slabs

Aggregate type	Cover[A,B] for corresponding fire resistance, in.					
	Restrained	Unrestrained				
	4 or less	1 hr	1 1/2 hr	2 hr	3 hr	4 hr
Nonprestressed						
Siliceous	3/4	3/4	3/4	1	1 1/4	1 5/8
Carbonate	3/4	3/4	3/4	3/4	1 1/4	1 1/4
Semi-lightweight	3/4	3/4	3/4	3/4	1 1/4	1 1/4
Lightweight	3/4	3/4	3/4	3/4	1 1/4	1 1/4
Prestressed						
Siliceous	3/4	1 1/8	1 1/2	1 3/4	2 3/8	2 3/4
Carbonate	3/4	1	1 3/8	1 5/8	2 1/8	2 1/4
Semi-lightweight	3/4	1	1 3/8	1 1/2	2	2 1/4
Lightweight	3/4	1	1 3/8	1 1/2	2	2 1/4

A. Shall also meet minimum cover requirements of 2.3.1
B. Measured from concrete surface to surface of longitudinal reinforcement

Pre cast concrete fire resistances were determined with information provided by the manufacturer. Information regarding the fire resistance of pre cast concrete units is listed in the appendix on the pre cast specification sheets.

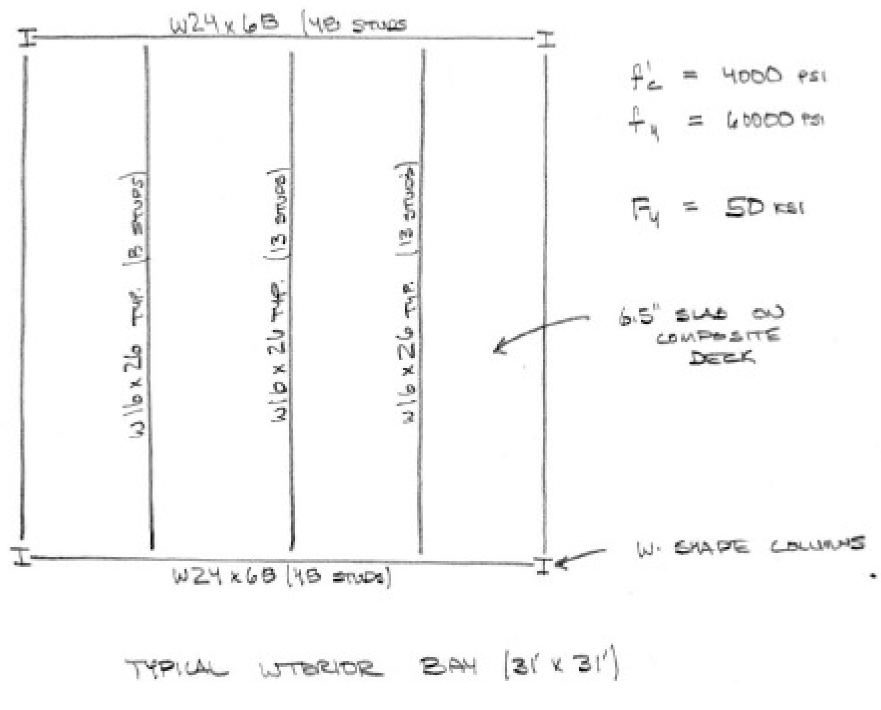
Fire Resistance of Steel

Fire resistance of steel should be provided for each individual floor assembly by choosing an assembly from the Underwriters Laboratories catalog and designing to meet the requirements of Underwriters Laboratories. For most rolled structural steel shapes this will require fireproofing the beams, girders and columns somehow (encasing in gypsum board, spraying on cementitious fire proofing, or painting with intumescent paint). For reinforced concrete on composite steel deck additional fireproofing may or may not be needed depending on the slab thickness, fire rating required and UL assembly chosen. In the basic designs contained in Technical Assignment II additional fire proofing required to be applied to steel beams, deck and other structural elements was recognized but the actual loads were unknown and not considered in the analysis of floor systems.

Typical Floor Framing Bay

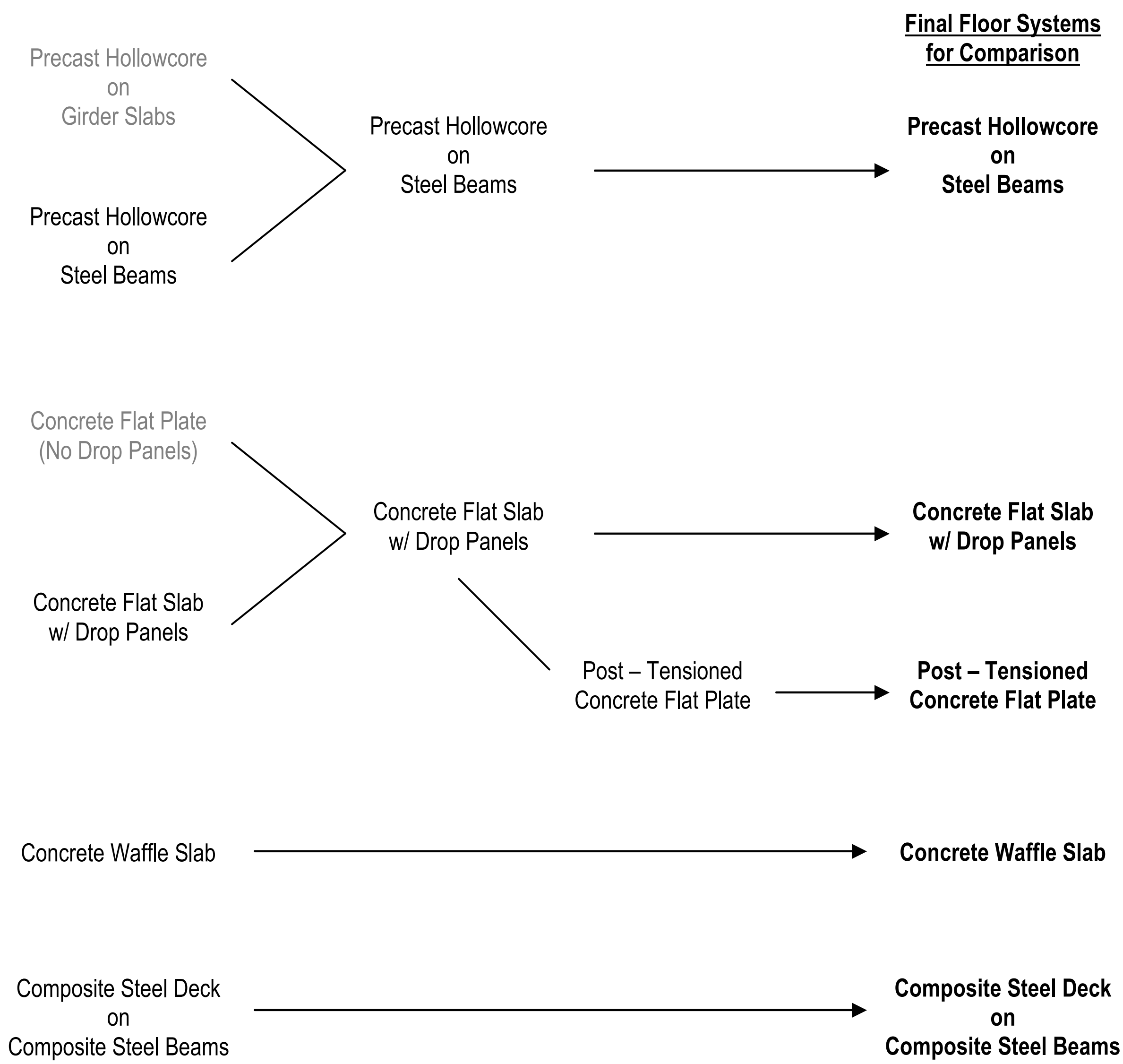
The existing typical floor framing bay used in the majority of the Life Sciences Building is a square of 31' on each side bounded on two parallel sides by girders and infilled orthogonally to those girders with beams. Each of the four corners of the square contains a steel column.

The typical bay dimensions of 31' by 31' will be used for Technical Assignment II when considering and designing alternative floor systems for the Life Sciences Building. The locations of columns will not be changed in Technical Assignment II and interior columns will be assumed to be located at the four corners of the typical 31' x 31' interior bay being analyzed. The structure of an interior bay will be analyzed, designed, and compared for several different floor framing systems. A diagram of a typical bay and its existing framing of composite steel deck, beams and columns supporting a concrete slab is shown below:



Floor Systems Considered|

Below is a flow chart diagramming all of the alternative floor systems that were considered. Calculations were performed for every floor system listed. Some floor systems were not a part of the final considerations because the initial analysis and design showed that they were not physically possible for the layout of the Life Sciences Building. The floor systems that were not considered as one of the final alternatives for this report are listed in **gray**. The floor systems that merited further analysis and comparison in my final recommendations of the report are listed in **black**. Even if a floor system listed was not part of the final comparison the calculations leading to its rejection can be found in the appendix.



Pre Cast Hollowcore Plank on Steel Beams|

System Design|

10” x 4’-0” Pre Cast Hollowcore Plank (untopped)
Span = 31’
w18x119 ASTM A572, Gr. 50 Beams
Span = 31’
Steel Columns

System Statistics|

w	=	68.7 PSF
d_{avg}	=	10”
d_{max}	=	29”
$	=	$14.53 / ft^2

Design Notes|

Pre cast hollowcore plank on steel girders was chosen as the first alternative structural system. The 10” hollowcore plank was pushed almost nearly to its limits to span 31’ from beam to beam. The hollowcore plank was sized using information available from Nitterhouse Concrete Products. Either topped or untopped plank could be used, I chose untopped to reduce floor thickness and cut down on the dead load of the floor system. However, using untopped pre cast could cause problems with the floor system being used as a lateral load diaphragm if not installed properly. PCI guidelines for rigid diaphragms will have to be closely followed if pre cast hollowcore plank are used in the untopped configuration. Steel beams were chosen because they offer greater strength, less weight, and a more compact shape than pre-cast beams. The steel beams were sized for deflection using the AISC 13th Edition Steel Manual. Additionally, attempts were made to use the Girder – Slab system of steel beams to support the pre cast plank. However, Girder – Slab is limited to 8” topped or untopped pre cast planks and no 8” plank could carry the loading and span 31’.

Advantages / Disadvantages|

+ Able to clear span between girders with 10” depth.
+ No additional fireproofing on plank.
+ Fast and simple construction in any conditions.
+ Controlled fabrication conditions lead to higher quality members.
+ Plank produced within 100 miles of site.
+ Most economical pre cast member for medium spans.
+ Low cost system.
+ Steel girders can still be part of moment frame.
- Small amount of fireproofing on beams, not cost effective.
- Lateral load diaphragm issues.
- Any floor penetrations need to be engineered ahead of construction.
- Long lead time, special plank may need special ordered.

Concrete Flat Slab with Drop Panels|

System Design|

10.5" Slab spanning 31' in both directions reinforced w/

Column Strip – Bottom|	(23) - #5
Column Strip – Top|	(26) - #5
Middle Strip – Bottom|	(15) - #5
Middle Strip – Top|	(13) - #6
Drop Panel|	9" x 10'-4" (square)

19" x 19" Columns

System Statistics|

w	=	143.7 PSF
d_{avg}	=	10.5"
d_{max}	=	19.5"
$	=	$17.10 / ft^2

Design Notes|

Design began as a concrete flat plate using CRSI 2002. The shear forces required that the flat plat have columns that were 52" x 52" – so concrete flat plate was immediately removed from consideration. The design then shifted toward a concrete flat slab with drop panels. Drop panels were chosen over column capitals to handle the shear because the column capitals do nothing to help increase the moment capacity of the span. Increased moment capacity is important because the span lengths are relatively large and the loading relatively high. The CRSI 2002 tables were entered using a span of 31' and a factored superimposed load of 200 PSF. Four different slab thicknesses and drop panels were considered and the 10.5" slab with 9" thick by 10'-4" square drop panels was considered to be the most suitable and economical for the Life Sciences Building.

Advantages / Disadvantages|

+ Thin floor profile.
+ Satisfies required fire rating.
+ Capable of handling relatively large superimposed loading.
+ Thick slab has increased stiffness – decreased vibrations.
+ More floor to ceiling height possible.
+ Formwork can be reused.
+ With alterations can combine with concrete moment frame.
- Dead load of system is very high and will require foundation redesign.
- Columns are relatively large.
- Much casting in place – ideal conditions desired.
- Formwork required for slab.
- Drop panels require extra formwork.
- Shoring must be left in place for some period.

Post Tensioned Concrete Flat Plate|

System Design|

8" Slab spanning 31' in both directions reinforced w/

Column|	Top |	(6) - #9 in both directions
Mid-Span|	Bot |	(in compression, no reinforcement needed)

(25) – 26.6k tendons in both directions (one direction banded, other distributed)
26" x 26" Columns (smaller columns possible with capitals)

System Statistics|

w	=	100 PSF
d_{avg}	=	8"
d_{max}	=	8"
$	=	$15.78 / ft^2

Design Notes|

The post – tensioned 8" slab was calculated following an example based on PTI and ACI guidelines provided by Dr. Ali Memari. Because the bays are square (31' x 31') the design of reinforcement and number of tendons determined from analysis is valid for both directions. The post – tensioning puts the interior bay in a fairly large amount of compression – balancing 90% of the slab load – so tension reinforcement is not needed at mid span of the slab. However, minimum reinforcement according to ACI guidelines should be everywhere. The post – tensioning compression is accomplished by (25) 26.6k tendons running in both directions. In one direction they should be banded over the columns, and in the other direction they should be evenly distributed. Negative moment reinforcement is provided by (6) #9 bars distributed over the columns in both directions. Shear where the slab meets the column is controlled by the area of slab intersecting with the columns so the column size of 26' x 26" was used. The column size could be greatly reduced by using column capitals which can be designed in later analyses.

Advantages / Disadvantages|

+ Thin floor profile.
+ Satisfies required fire rating.
+ Capable of handling very large superimposed loading.
+ Thick and post - tensioned slab has increased stiffness – decreased vibrations.
+ More floor to ceiling height possible.
+ Formwork can be reused.
+ With alterations can combine with concrete moment frame.
+ Dead load reduced over reinforced slab with drop panels.
- Columns are relatively large – but can be reduced in size with shear capitals.
- Much casting in place – ideal conditions desired.
- Formwork required for slab.
- Shoring must be left in place for some period.
- Post – tensioning is a long and involved process.

Concrete Waffle Slab|

System Design|

3" Slab + 16" Ribs - spanning 31' in both directions reinforced w/

Column Strip – Rib Bottom|	(1) - #5 & (1) - #6
Column Strip – Slab|	(30) - #5
Middle Strip – Rib Bottom|	(1) - #4 long bar & (1) - #4 short bar
Middle Strip – Slab|	(10) - #5
Solid Head|	12'-5" (square)

16" x 16" Columns

System Statistics|

w	=	165.25 PSF
d_{avg}	=	19"
d_{max}	=	19"
$	=	$22.35 / ft^2

Design Notes|

The CRSI Design Handbook 2002, 9th Edition was used to design the concrete waffle slab. The load factors differ from the current ACI code so the load combinations that were used in developing the tables were used to find the superimposed load that needs to be used to enter the tables. Deflections were kept within acceptable ranges by using the minimum effective slab thicknesses as suggested by the ACI. It is assumed that any design found in the CRSI manual will result in deflections being within the acceptable ranges. Because waffle slabs are modular in nature (24" and 36" modules) and the span of the bay was 31' in both directions some modifications had to be made so that the tables could be entered. I chose to use 24" modules – 19" dome width – because the smaller modules would allow greater flexibility in the design of my building. First, the bay will be designed with the same number of domes in the waffle slab as there would be if the span was only 30' in both directions (15 domes across the span). To compensate for the extra 1' difference in the domes and the actual span each dome will be spaced slightly farther apart – creating larger ribs. Because the rib size increased the dead load will also increase accordingly. The dead load of the slab assembly is figured in to the superimposed loads in the table – to compensate for the larger ribs the added dead load due to increased concrete was calculated and distributed across the area. This additional dead load in PSF was multiplied by the 1.4 dead load factor and added to the superimposed loads that the tables are entered with. The tables were entered with a larger 32' span (to be conservative) and a factored superimposed load of 200 PSF. After numerous trials a design that requires no stirrups in the ribs and no additional shear reinforcement was found – CRSI recommendations.

Concrete Waffle Slab (continued)|

Advantages / Disadvantages|

+ Thin floor profile throughout span.
+ Space in voids for mechanical and electrical equipment.
+ Satisfies required fire rating.
+ Capable of handling very large superimposed loading.
+ Waffle slab has increased stiffness – decreased vibrations.
+ More floor to ceiling height possible.
+ Formwork can be reused.
+ More efficient use of reinforcing steel.
+ With alterations can combine with concrete moment frame.
- Increased dead load.
- Columns are relatively large.
- Much casting in place – ideal conditions desired.
- Formwork required for slab and drop panels
- Shoring must be left in place for some period.
- Not very adaptable to variations in design – modular units.

Composite Steel Deck on Composite Steel Beams|

System Design|

Composite Floor Deck| 18 gage, 2" thick fluted with 4-1/2" of concrete cover for a total thickness of 6-1/2".

Concrete Floors|	150 PCF, 4000 psi w/ WWF4x4 – W5.5xW5.5.
Infill Beams|	w16x26 w/ (13) – 13.3k studs
Girders|	w24x68 w/ (48) – 13.3k studs
Columns|	Standard Steel W Shapes

System Statistics|

w	=	74.2 PSF
d_{avg}	=	6.5"
d_{max}	=	30.2"
$	=	$26.45 / ft^2

Design Notes|

This is the existing structural system of the building. The design was verified using LRFD with the AISC 13th Edition Steel Manual in Technical Assignment I. The calculations can be found in the appendix.

Advantages / Disadvantages|

+ No foundation redesign needed.
+ Steel deflections are known and easily calculated.
+ Shoring not usually required.
+ Erection is fast and can be performed in most conditions.
+ Best suited to moment and braced frames.
+ Best suited to irregular column layout and varying spans.
- Long lead time for production and fabrication.
- Requires the use of skilled labor in field.
- Requires spray on fireproofing.

Table: Comparison of Alternate Floor Systems|

System	Pre Cast Hollowcore Plank on Steel Beams	Concrete Flat Slab with Drop Panels	Post – Tensioned Concrete Flat Plate	Concrete Waffle Slab	Composite Steel Deck on Composite Steel Beams
Self Weight	68.7 PSF	143.7 PSF	100 PSF	165.3 PSF	74.2 PSF
d_{avg}	10"	10.5"	8"	19"	6.5"
d_{max}	29"	19.5"	8"	19"	30.2"
Deflections	OK	OK	OK	OK	OK
Cost	$14.53 / ft^2	$17.10 / ft^2	$15.78 / ft^2	$22.35 / ft^2	$26.45 / ft^2
Fire Resistance	> 1 hour	> 1 hour	> 1 hour	> 1 hour	> 1 hour
Vibration	Average	Above Avg.	Above Avg.	Best	Average
Moment Frame Integration	Complicated	Possible	Possible	Possible	Possible
Foundation Impact	Low	High	Low	High	None
Easily Accommodate Irregularities	No	Yes	Yes	No	Yes
Further Consideration Necessary	No	No	Yes	No	Yes

Final Recommendations|

From the infinite number of floor systems that could be created by combining different structural geometries, structural systems, and materials within systems – only two potential systems stand out. I feel that the two systems that should be advanced for further study are the existing composite steel deck, beam, and girder construction and the post tensioned concrete flat plate. I will compare all five of the systems that were studied in detail for Technical Assignment II and hopefully provide insight into why I feel only two systems should be given further consideration.

Self Weight|

The self weights of the alternatives considered ranged from 165.3 PSF for waffle slab construction down to 68.7 PSF for pre cast concrete on steel beam construction. It was important to keep the self weights as close as possible to or less than the original composite steel system so that the column and foundation system of the building doesn't need to be redesigned very much. For this reason I disqualified the waffle slab and concrete flat slab with drop panel systems from further consideration.

Average System Depth|

The average system depth (d_{avg}) is the depth of the system over the majority of the area. For example, the depth of beams and girders that only occur in certain locations was not considered in the calculation of this depth. The average system depth is basically the depth of the slab at some point in the bay away from the columns. The average depth of the original composite steel system was the thinnest profile of all the alternatives at 6.5". The waffle slab was by far the deepest – measured from the top of the slab to the bottom of the ribs – at 19" across the entire bay. Of all the concrete systems – precast, post tensioned or reinforced – the post tensioned slab was the thinnest at 8" which should make it a preferred alternative.

Maximum System Depth|

This was the depth of the flooring system alternative at its deepest point – it usually occurred at a girder, drop panel, or other significant structural member. The waffle slab and post tensioned concrete slab performed the best in this category, having maximum depths that are equal to the average depths they have over the entire system. The greatest depth was from the top of the slab to the bottom of a steel composite girder. The smallest maximum depth of all alternatives considered was the post tensioned concrete slab – at only 8" which makes it stand out once again.

Final Recommendations (continued)|

Deflections|

The deflections of structural members were prescribed by the IBC 2006. All of the concrete structural systems deflections were limited by using the minimum thickness guidelines provided by the CRSI and ACI. The pre cast deflections were confirmed using technical data sheets provided by the manufacturer. Steel beams were designed for live load and dead load deflections according to AISC methods and deflections were sometimes compensated for with a built in camber.

Relative Costs|

The relative costs of the different floor system alternatives were calculated for a comparison by using *R.S. Means Assembly Cost Data, 32nd Annual Edition* and *R.S. Means Building Construction Cost Data, 66th Annual Edition*. The numbers calculated aren't an accurate idea of how much the actual floor system would cost to construct in State College, Pennsylvania. However, they are valid when used to make comparisons between the different types of construction. The existing system of composite steel deck on composite beams and girders was the most expensive overall, costing $26.45 per square foot. The cheapest system was pre cast concrete on steel beams at $14.53 per square foot; followed closely by the post tensioned concrete flat slab at $15.78 per square foot. Because the post tensioned concrete flat slab system costs considerably less money than the concrete slab with drop panels it was the preferred alternative between the two.

Fire Resistance|

The fire resistance of all of the systems met the minimum one hour requirement. However, only the cast in place concrete systems had all of their necessary fire protection built in. Additional fire protection would be required for the steel composite deck, beam, and girder construction and also the pre cast concrete on steel beam construction. This gives the cast in place concrete systems an edge.

Vibration|

The vibrations of all of the systems should be satisfactory. The concrete waffle slab stands out as the most rigid of all of the considered floor assemblies due to its large depth and high self weight. The vibration reducing effects of the post tensioning in the concrete slab should be investigated further and compared the vibration of the existing composite steel construction.

Final Recommendations (continued)|

Moment Frame Integration|

Looking ahead to Technical Assignment III, observations of how well a moment frame could be integrated into the proposed floor assembly were noted. The only system that would make it extremely hard to integrate lateral force resisting systems with the floor system would be the pre cast concrete plank. Due to their separate nature it may be impossible to use them efficiently as a floor system and lateral load distribution diaphragm. The composite steel construction and all three cast in place concrete constructions lend themselves to easily integrating lateral force resisting systems with the proposed floor systems.

Irregularities in Framing|

The Life Sciences Building has a very irregular framing plan and the ability of the floor system to adapt to changing column lines, floor penetrations, and other conditions is very important. For this reason the highly regular pre cast hollowcore concrete plank and cast in place concrete waffle slab systems were removed from consideration. The ability of the existing composite steel construction and a post tensioned concrete flat plate to adjust warrants their further study.

Schedule / Construction Considerations|

The Life Sciences Building did not have to meet a strict construction schedule and was designed using design – bid – build. Therefore, lead times for steel and pre cast concrete members were not big factors in the final recommendations for structural systems. Also, the fact that concrete should be poured in ideal conditions and needs to be shored for a period of time were not very heavily weighted in the decisions.

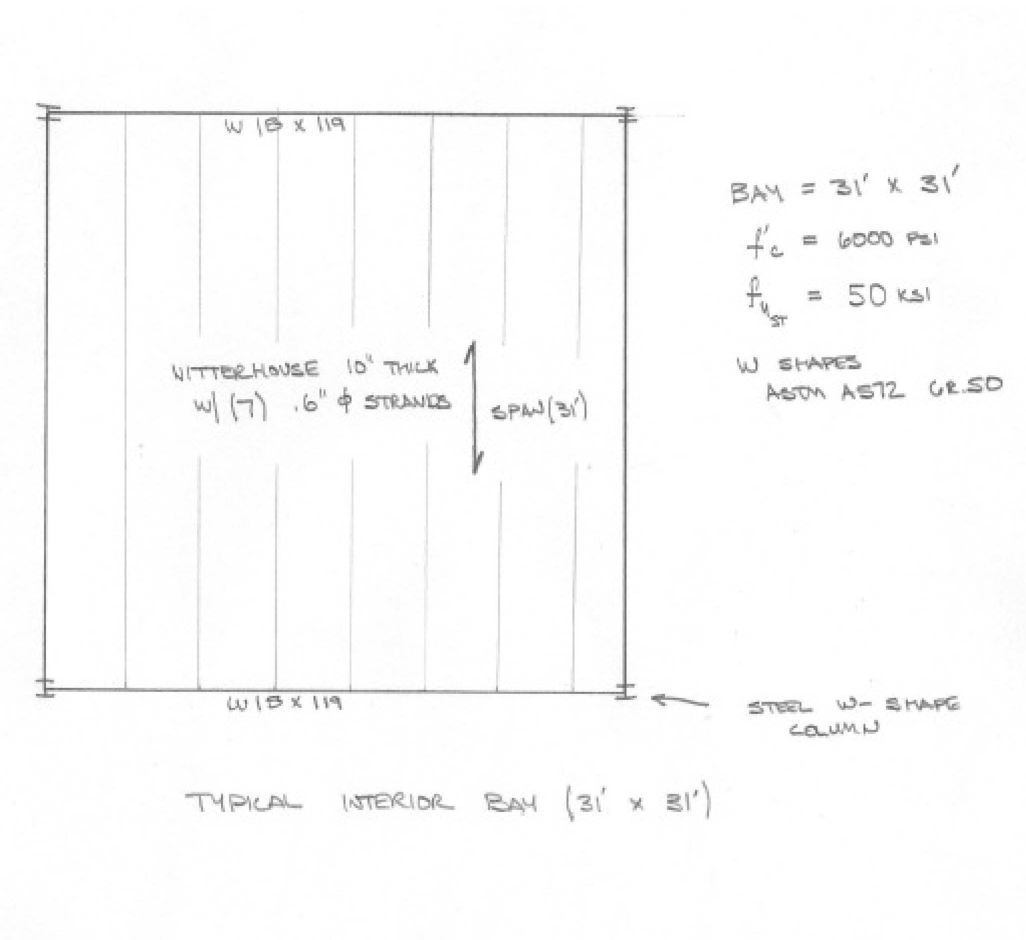
Lateral System Effects|

Effects on the lateral force resisting system by changes in self weights would be negligible because my building is in a very low seismic activity region. Wind design is almost guaranteed to control over seismic loads no matter what the building dead load is. For this reason the effects of different floor systems on the lateral force resisting system were not considered – other than how easily moment frames could be integrated.

Conclusion|

In conclusion, I feel that of all the cast in place concrete systems, the post tensioned flat plate is the most desirable for a number of reasons. I also feel that the original designer of the structure chose composite steel deck, beams and girders as a result of experience and research and that it should remain a system for consideration. The pre cast system is cheap and light, but I feel that my building is too irregular to achieve the economies of pre cast plank. **It is my recommendation to advance the post tensioned concrete flat plate and the composite steel deck, beam, and girder construction for further analysis.**

Appendix A – Pre Cast Hollowcore Plank on Steel Beams



Appendix A – Pre Cast Hollowcore Plank on Steel Beams

TYPICAL BAY = 31' x 31'

LOADS: DL = 10 + 20 + SELF WEIGHT
LL = 80
↑ REDUCIBLE

→ DESIGN PLANK

- PRECAST HOLLOWCORE CONCRETE PLANK (NITTERHOUSE)

SPAN = 31'
WIDTH = 4'

$(31)(4) = A_T = 124\ ft^2 (K_{LL}) = 248 < 400$ (K_{LL} = 2)

(NO LIVE LOAD REDUCTION FOR INDIVIDUAL PLANK.)

$TL_{PLANK} = 1.2(30) + 1.6(80) = 164$ PSF

→ TRY NITTERHOUSE 10" x 4'-0" HOLLOW CORE UNTOPPED PLANK

- FIRE RATING 1 HOUR
- SELF WEIGHT = 68 PSF

164 PSF REQUIRED < 186 PSF PROVIDED

NITTERHOUSE 10" x 4'-0" w/ (7) .6" φ STRANDS SPANNING 31 FEET WORKS

→ TRY NITTERHOUSE 10" x 4'-0" HOLLOWCORE TOPPED PLANK

- FIRE RATING 1 HOUR
- SELF WEIGHT = 68 PSF

164 PSF REQUIRED <
+ (1.2) 25 PSF TOPPING
194 PSF REQUIRED < 223 PSF PROVIDED

NITTERHOUSE 10" x 4'-0" w/ (7) .6" φ STRANDS TOPPED w/ 2" OF CONCRETE SPANNING 31' WORKS

✓ DEFLECTIONS:

ASSUMING CONCRETE PLANK DEFLECTIONS ARE WITHIN DEFLECTION LIMITS OF CONCRETE.

Appendix A – Pre Cast Hollowcore Plank on Steel Beams|

→ DESIGN SUPPORTING BEAMS|

BEAMS SPAN 31' (E-W ↔)
PLANK SPAN 31' (N-S ↕)

- TRY NON COMPOSITE STEEL BEAMS
- USE UNTOPPED PLANK (LESS D.L.)

→ TYPICAL INTERIOR BEAM:

SPAN = 31' $A_T = 31'/\text{FT}$ $K_{LL} A_T = (2)(961) = 1922$

$DL = (10 + 20 + 68) + SW_{BEAM} = 3238$ PLF
(SUPER., PARTITION, PLANK, 200 LB/FT)

$LL = 80 \rightarrow 80\left(.25 + \frac{15}{\sqrt{(1922)}}\right) = 47.3719$ PSF (31)
$= 1468.5$ PLF

$1.2(3238) + 1.6(1468.5) = 6.235$ K/FT

$M = \frac{6.235(31)^2}{8} = 749$ K·FT (TRY TO KEEP IN W16-18 RANGE THEY WERE USED IN ORIGINAL)

USE W18×97 DL = 3135 PLF LL = 1468.5 PLF $TL = 1.2(3135) + 1.6(1468.5) =$
$\phi M_p = 791$ K·FT

$M = \frac{6.111(31)^2}{8} = 734$ K·FT

STRENGTH:
W18×97 IS MOST ECONOMICAL SHAPE MEETING DEPTH LESS THAN W18 (ORIGINAL DESIGN)

** TOTAL DEPTH = 10" + 18.6" = 28.6"

✓ DEFLECTIONS;
(ASSUME PINNED-PINNED = WORST CASE)

$\Delta_{TL} = \frac{5wl^4}{384EI} = \frac{5(4.71)(1728)(31)^4}{384(29000)I} = \frac{31(12)}{240}$

$I_{TL} \geq 2175.71$ IN^4

$\Delta_{LL} = \frac{5(1.468)(1728)(31)^4}{384(29000)I} = \frac{31(12)}{360}$

$I_{LL} \geq 1018.29$ IN^4

Appendix A – Pre Cast Hollowcore Plank on Steel Beams

SIZE INTERIOR BEAM (CONTINUED):

$$I \geq 2175.7 \text{ IN}^4$$

$$M_n \geq 749 \text{ K·FT}$$

TRY W18 x 119 BEAMS

$$\Delta_{ACTUAL\ TL} = \frac{5(4.625)(31)^4(1728)}{384(29000)(2190)} = 1.513'' \downarrow \quad \checkmark OK$$

$$\Delta_{ALLOW\ TL} = \frac{(31)(12)}{240} = 1.55'' \downarrow$$

$$\Delta_{ACTUAL\ LL} = \frac{5(1.47)(31)^4(1728)}{384(29000)(2190)} = .480'' \downarrow \quad \checkmark OK$$

$$\Delta_{ALLOW\ LL} = \frac{(31)(12)}{360} = 1.033'' \downarrow$$

$$M_{u\ ACT} = 749 \text{ K·FT} \quad \checkmark OK$$

$$\phi M_p = 983 \text{ K·FT}$$

USE NONCOMPOSITE W18 x 119 TO SPAN 31' SUPPORTING UNTOPPED 10" HOLLOW CORE

$$d_{MAX} = 19'' + 10'' = 29''$$

$$d_{AVG} = 10'' = 10''$$

$$WT = \frac{31(119)(2) + 68(31)(31)}{(31)(31)} = 68.74 \text{ PSF}$$

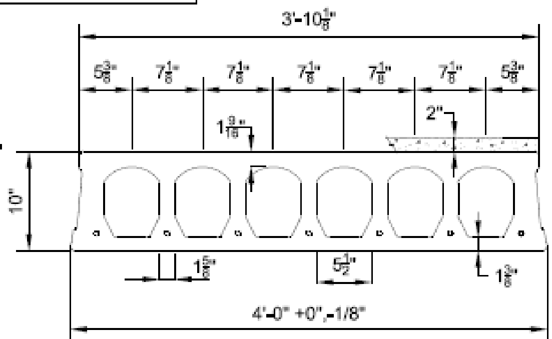
Appendix A – Pre Cast Hollowcore Plank on Steel Beams|

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

1 Hour Fire Resistance Rating With 2" Topping

PHYSICAL PROPERTIES
Composite Section

A_c = 327 in.^{2} Precast S_{bc} = 824 in.^{3}
I_c = 5102 in.^{4} Topping S_{tc} = 1242 in.^{3}
Y_{bc} = 6.19 in. Precast S_{tc} = 1340 in.^{3}
Y_{tc} = 3.81 in. Wt.= 272 PLF
Wt.= 68.00 PSF



DESIGN DATA

1. Precast Strength @ 28 days = 6000 PSI
2. Precast Strength @ release = 3500 PSI or 4000 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)...
   7-1/2"Ø, 270K = 192.2 k-ft
   7-0.6"Ø, 270K = 256.4 k-ft
7. Maximum bottom tensile stress is $7.5\sqrt{f'c}$ = 580 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 allowable service stresses.
15. Load values will 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 2003 & ACI 318-02 (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
7 - 1/2"ø	LOAD (PSF)	281	259	236	215	197	180	164	150	138	126	113	101	90	79					
7 - 0.6"ø	LOAD (PSF)			256	244	233	223	214	205	195	182	170	159	148	134	122	111	110	91	81

NITTERHOUSE
CONCRETE PRODUCTS
2655 Molly Pitcher Hwy. South, Box N
Chambersburg, PA 17201-0813
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 1 Hour & 0 Minute fire resistance rating.

05/14/07

10F1.0T

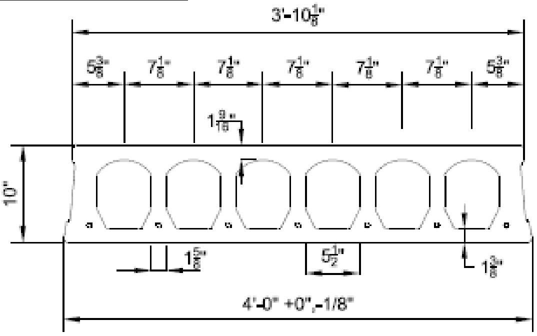
Appendix A – Pre Cast Hollowcore Plank on Steel Beams

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

1 Hour Fire Resistance Rating (Untopped)

PHYSICAL PROPERTIES
Precast

$A = 262\ in.^2$	$S_b = 640\ in.^3$
$I = 3196\ in.^4$	$S_t = 638\ in.^3$
$Y_b = 4.99\ in.$	Wt = 272 PLF
$Y_t = 5.01\ in.$	Wt = 68.00 PSF
$e = 3.24\ in.$	



DESIGN DATA

1. Precast Strength @ 28 days = 6000 PSI
2. Precast Strength @ release = 3500 PSI or 4000 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)...
   7-1/2"Ø, 270K = 163.8 k-ft
   7-0.6"Ø, 270K = 221.2 k-ft
7. Maximum bottom tensile stress is $7.5\sqrt{f'c} = 580$ 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. Load values to the left of the solid line are controlled by ultimate shear strength.
12. Load values to the right are controlled by ultimate flexural strength or allowable service stresses.
13. Load values will be different for IBC 2000 & ACI 318-99. Load tables are available upon request.
14. 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 2003 & ACI 318-02 (1.2 D + 1.6 L)

Strand Pattern		SPAN (FEET)																		
		28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
7 - 1/2"ø	LOAD (PSF)	202	188	175	161	148	136	125	116	106	98	90	83	76	70	64	59	53	X	X
7 - 0.6"ø	LOAD (PSF)	212	202	194	186	178	171	164	155	146	137	129	122	116	109	101	94	87	80	74

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05/14/07

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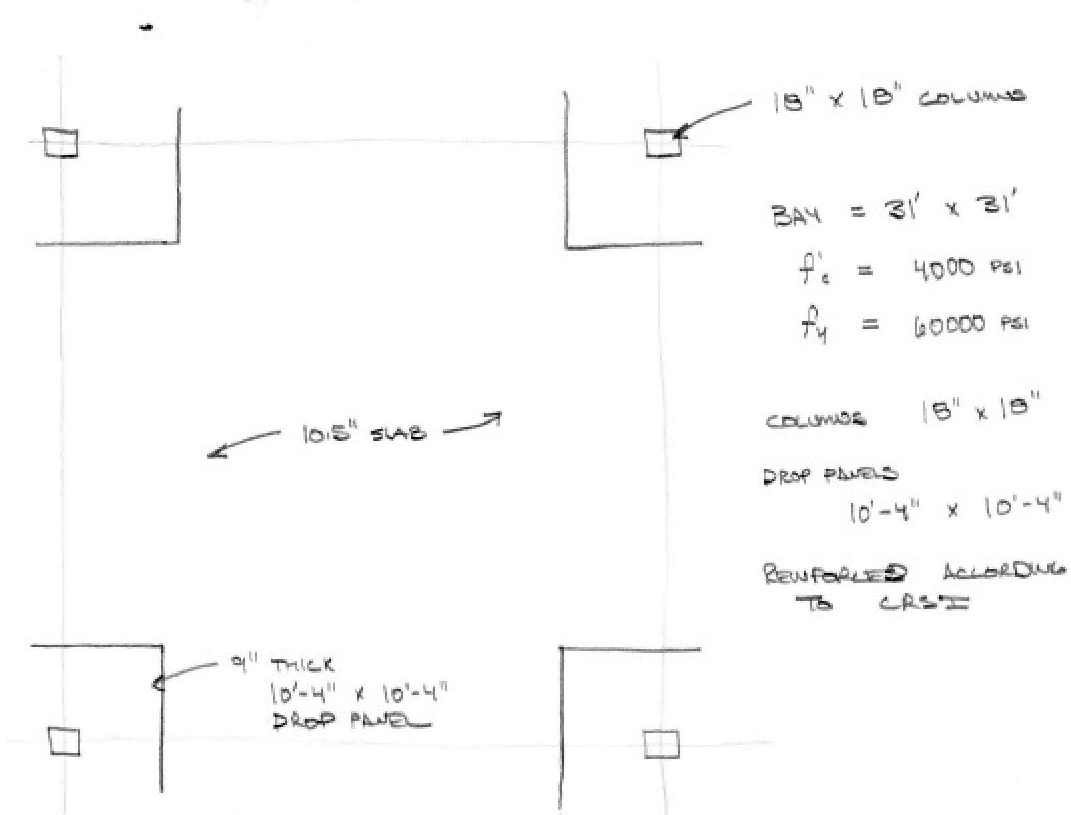
Appendix B – Concrete Flat Slab with Drop Panels



TYPICAL INTERIOR BAY (31' x 31')

Appendix B – Concrete Flat Slab with Drop Panels|

BAY = 31' x 31' f'_c = 4000 PSI f_y = 60000 PSI

DL = 30 PSF

LL = 80 PSF $\xrightarrow{\text{RED.}}$ 58.7 PSF

TL_{FACT} = 141.79 PSF

DEFLECTIONS|

(ASSUMED TO BE ACCEPTABLE USING CRSI)

USING TL = 150 PSF

$t_{MIN} = 5"$

$t_{REQ} = \frac{l_n}{33} = \frac{334}{33} = \boxed{10.12"}$

$l_n = 31(12) - 38 =$

CRSI $\boxed{t = 10"}$

DESIGN SLAB|

SPAN = 31'   TL = 150 PSF

38" x 38" COLUMNS ARE UNACCEPTABLE
TRY FLAT SLAB w/ DROP PANELS

Appendix B – Concrete Flat Slab with Drop Panels|

BAY = 31' x 31' f'_c = 4000 PSI f_y = 60000 PSI

TL = 178 PSF ⟶ USE 200 PSF (CONSERVATIVE)

⟶ USING CRSI 2002 TO TRY FLAT SLAB W/ DROPS

+ W/ DROPS SHEAR IS NOT AS SIGNIFICANT
+ MORE EFFICIENT USE OF CONC. & STEEL.

→ DEFLECTION:

USE ACI 318-05, 8.9.5.3, T.9.5(c)

$t_{MIN} = 4''$ $t_{REQ} = \frac{l_n}{33}$ =

l_n =

→ REINFORCEMENT / DROP PANELS:

SPAN = 31' x 31' SUPERIMPOSED LOAD = 200 PSF

USE CRSI CHAPTER 10 TABLES

COMPARE ALTERNATIVES:

SLAB	COLUMN	DROP DIMENSIONS	EDGE STEEL	INT. STEEL
10.5"	18" x 18"	9" x 10.33' x 10.33'	4.29 PSF	3.60 PSF
11"	16" x 16"	11" x 10.33' x 10.33'	4.08 PSF	3.46 PSF
11.5"	16" x 16"	9" x 10.33' x 10.33'	4.17 PSF	3.56 PSF
12"	16" x 16"	9" x 10.33' x 10.33'	3.96 PSF	3.41 PSF

- CHOOSE 10.5" SLAB (SMALLEST DIMENSIONS) (SMALL STEEL INCREASE)

- FROM 10.5" SLAB TO 11" SLAB
  Δ CONC DL = ↑ 6.25 PSF
  Δ STEEL DL = ↓ .175 PSF (AVG)

⟶ 18" x 18" COLUMN REQUIRED FOR SHEAR

⟶ REINFORCEMENT TABLE ON NEXT PAGE.

Appendix B – Concrete Flat Slab with Drop Panels|

FLAT PLATE SYSTEM (WITHOUT SHEARHEADS) — f'_c = 4,000 psi, Grade 60 Bars

SQUARE EDGE PANEL — 10 in. = TOTAL THICKNESS OF SLAB — 0.833 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
26	50	20	0.762	115	230	309	12-#5	4	12-#5	15-#6	10-#5	10-#5	2.72	2.74	2.74
26	100	24	0.724	136	272	367	12-#5	5	14-#5	13-#7	10-#5	10-#5	2.96	2.98	2.96
26	150	28	0.685	157	313	421	14-#5	4	9-#7	12-#8	11-#5	10-#5	3.33	3.37	3.42
26	200	32	0.677	175	350	471	16-#5	5	10-#7	13-#8	12-#5	10-#5	3.70	3.73	3.83
26	250	36	0.612	192	384	517	12-#6	2	20-#5	15-#8	10-#6	11-#5	4.11	4.14	4.29
26	300	41	0.613	205	411	553	13-#6	3	9-#8	16-#8	11-#6	12-#5	4.47	4.52	4.71
26	350	47	0.610	216	431	580	19-#5	3	10-#8	17-#8	11-#6	9-#6	4.72	4.77	4.96
27	50	22	0.741	128	256	345	12-#5	5	10-#6	12-#7	10-#5	10-#5	2.80	2.80	2.74
27	100	26	0.708	151	303	407	13-#5	5	16-#5	12-#8	11-#5	10-#5	3.11	3.16	3.17
27	150	31	0.675	173	346	466	15-#5	6	10-#7	13-#8	12-#5	10-#5	3.50	3.54	3.66
27	200	35	0.652	194	387	521	12-#6	4	11-#7	15-#8	10-#6	12-#5	4.02	4.05	4.20
27	250	40	0.611	211	422	568	19-#5	3	12-#7	16-#8	11-#6	9-#6	4.41	4.42	4.65
27	300	46	0.610	224	447	602	14-#6	3	10-#8	17-#8	11-#6	13-#5	4.61	4.67	4.95
27	350	53	0.609	233	466	628	15-#6	2	9-#9	18-#8	9-#7	10-#6	5.13	5.18	5.32
28	50	24	0.706	142	283	381	13-#5	4	11-#6	14-#7	10-#5	10-#5	2.86	2.89	2.95
28	100	28	0.722	168	335	451	15-#5	6	10-#7	13-#8	12-#5	10-#5	3.33	3.36	3.50
28	150	33	0.665	192	383	516	17-#5	5	20-#5	15-#8	10-#6	11-#5	3.80	3.81	3.94
28	200	37	0.668	214	428	576	19-#5	6	12-#7	16-#8	11-#6	13-#5	4.24	4.26	4.50
28	250	44	0.616	230	460	619	20-#5	5	10-#8	18-#8	16-#5	10-#6	4.49	4.56	4.82
28	300	52	0.609	241	483	650	15-#6	3	11-#8	19-#8	12-#6	10-#6	4.90	4.97	5.18
28	350	59	0.608	252	504	678	16-#6	2	11-#8	20-#8	10-#7	11-#6	5.25	5.32	5.46
29	50	26	0.730	156	312	420	14-#5	7	12-#6	15-#7	11-#5	11-#5	3.03	3.05	3.07
29	100	31	0.665	184	369	496	16-#5	5	14-#6	14-#8	13-#5	11-#5	3.49	3.53	3.69
29	150	36	0.644	210	421	566	13-#6	4	12-#7	16-#8	11-#6	13-#5	4.03	4.08	4.14
29	200	42	0.611	233	466	627	15-#6	2	10-#8	18-#8	16-#5	10-#6	4.39	4.45	4.69
29	250	50	0.609	248	496	667	16-#6	2	11-#8	19-#8	10-#7	11-#6	4.91	4.97	5.11
29	300	57	0.608	261	521	702	23-#5	4	10-#9	20-#8	10-#7	11-#6	5.22	5.29	5.59
29	350	65	0.607	270	541	728	17-#6	2	10-#9	21-#8	10-#7	16-#5	5.43	5.50	5.88
30	50	28	0.699	171	343	462	15-#5	6	10-#7	17-#7	12-#5	11-#5	3.21	3.23	3.26
30	100	33	0.692	203	406	546	18-#5	7	12-#7	15-#8	10-#6	12-#5	3.77	3.78	3.86
30	150	39	0.642	231	462	622	20-#5	6	10-#8	18-#8	16-#5	10-#6	4.21	4.26	4.41
30	200	47	0.616	251	502	676	16-#6	4	11-#8	19-#8	10-#7	11-#6	4.74	4.79	4.95
30	250	55	0.608	267	534	718	17-#6	2	10-#9	21-#8	10-#7	11-#6	5.14	5.20	5.46
30	300	63	0.607	280	560	754	18-#6	1	10-#9	22-#8	14-#6	12-#6	5.35	5.42	5.77
30	350	71	0.607	290	579	780	19-#6	0	13-#8	23-#8	20-#5	12-#6	5.58	5.68	6.00
31	50	30	0.707	188	376	506	17-#5	7	14-#6	14-#8	13-#5	11-#5	3.28	3.33	3.46
31	100	35	0.705	222	444	597	14-#6	6	13-#7	17-#8	11-#6	13-#5	3.92	3.97	4.16
31	150	43	0.655	250	500	673	16-#6	5	11-#8	19-#8	13-#6	11-#6	4.53	4.58	4.75
31	200	52	0.609	270	541	728	17-#6	4	12-#8	21-#8	14-#6	16-#5	4.93	4.99	5.14
31	250	61	0.608	287	573	772	18-#6	3	13-#8	22-#8	20-#5	12-#6	5.19	5.26	5.62
31	300	69	0.607	300	600	808	19-#6	1	17-#7	23-#8	15-#6	13-#6	5.50	5.58	5.88
31	350	78	0.606	310	620	835	20-#6	0	11-#9	24-#8	12-#7	13-#6	5.89	5.95	6.34

SQUARE INTERIOR PANEL — 10 in. = TOTAL THICKNESS OF SLAB — 0.833 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
26	50	14	14-#6	10-#5	10-#5	10-#5	2.76	2.77	2.79
26	100	19	13-#7	10-#5	10-#5	10-#5	3.04	3.04	3.04
26	150	23	14-#7	11-#5	10-#5	10-#5	3.23	3.27	3.31
26	200	28	13-#8	9-#6	10-#5	10-#5	3.69	3.69	3.69
26	250	33	14-#8	10-#6	11-#5	10-#5	3.98	4.01	4.04
26	300	40	15-#8	11-#6	11-#5	10-#5	4.26	4.30	4.35
26	350	48	15-#8	11-#6	12-#5	10-#5	4.35	4.43	4.50
27	50	15	12-#7	10-#5	10-#5	10-#5	2.82	2.81	2.81
27	100	21	14-#7	11-#5	10-#5	10-#5	3.10	3.14	3.18
27	150	26	12-#8	9-#6	10-#5	10-#5	3.42	3.45	3.48
27	200	31	14-#8	10-#6	11-#5	10-#5	3.81	3.85	3.89
27	250	37	15-#8	11-#6	12-#5	10-#5	4.12	4.16	4.20
27	300	46	16-#8	16-#5	12-#5	11-#5	4.37	4.42	4.46
27	350	55	17-#8	9-#7	9-#6	11-#5	4.72	4.77	4.82
28	50	17	13-#7	10-#5	10-#5	10-#5	2.81	2.83	2.85
28	100	23	15-#7	12-#5	10-#5	10-#5	3.14	3.19	3.23
28	150	28	14-#8	10-#6	11-#5	10-#5	3.66	3.69	3.72
28	200	34	15-#8	11-#6	12-#5	10-#5	3.95	3.99	4.03
28	250	43	16-#8	16-#5	13-#5	11-#5	4.23	4.31	4.38
28	300	53	17-#8	12-#6	13-#5	11-#5	4.49	4.57	4.65
28	350	62	18-#8	10-#7	10-#6	12-#5	4.93	5.01	5.09
29	50	19	14-#7	11-#5	11-#5	11-#5	2.98	3.00	3.02
29	100	25	13-#8	13-#5	11-#5	11-#5	3.39	3.42	3.45
29	150	31	15-#8	11-#6	12-#5	11-#5	3.87	3.90	3.94
29	200	38	17-#8	12-#6	13-#5	11-#5	4.25	4.29	4.33
29	250	49	18-#8	10-#7	10-#6	12-#5	4.68	4.72	4.76
29	300	60	18-#8	10-#7	10-#6	12-#5	4.74	4.81	4.89
29	350	70	19-#8	10-#7	11-#6	13-#5	5.06	5.11	5.18
30	50	21	16-#7	13-#5	11-#5	11-#5	3.18	3.20	3.22
30	100	27	15-#8	11-#6	11-#5	11-#5	3.68	3.69	3.70
30	150	33	17-#8	12-#6	13-#5	11-#5	4.08	4.12	4.16
30	200	44	18-#8	10-#7	10-#6	12-#5	4.49	4.53	4.57
30	250	56	19-#8	10-#7	11-#6	13-#5	4.79	4.85	4.91
30	300	67	20-#8	14-#6	11-#6	13-#5	5.00	5.08	5.15
30	350	78	20-#8	20-#5	11-#6	13-#5	5.06	5.16	5.27
31	50	23	17-#7	14-#5	11-#5	11-#5	3.21	3.24	3.26
31	100	30	16-#8	16-#5	12-#5	11-#5	3.71	3.75	3.78
31	150	38	18-#8	13-#6	14-#5	12-#5	4.25	4.29	4.33
31	200	50	19-#8	14-#6	11-#6	13-#5	4.63	4.68	4.74
31	250	62	20-#8	20-#5	11-#6	14-#5	4.84	4.91	4.98
31	300	74	21-#8	11-#7	16-#5	14-#5	5.13	5.22	5.31
31	350	85	22-#8	12-#7	12-#6	14-#5	5.46	5.54	5.61

(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).

9-30 CONCRETE REINFORCING STEEL INSTITUTE

Appendix B – Concrete Flat Slab with Drop Panels|

f'_c = 4,000 psi
Grade 60 Bars

FLAT SLAB SYSTEM
SQUARE EDGE PANEL With Drop Panels
No Beams

SPAN c.-c. $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	Square Drop Panel Depth (in.)	Square Drop Panel Width (ft)	Square Column[(3)] Size (in.)	Square Column γ_f	Reinforcing Bars (E. W.) 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)
h = 10.5 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS															
26	100	6.00	8.67	12	0.760	12-#5	2	15-#5	15-#5	10-#5	10-#5	2.46	151.6	303.2	408.1
26	200	6.00	8.67	15	0.798	12-#5	4	11-#7	14-#6	13-#5	11-#5	3.08	198.2	396.4	533.6
26	300	7.50	8.67	18	0.679	12-#5	2	18-#6	12-#7	9-#7	10-#6	3.83	244.7	489.4	658.8
26	400	9.00	8.67	20	0.632	12-#5	2	16-#7	13-#7	14-#6	9-#7	4.39	291.2	582.3	783.9
26	500	9.00	10.40	22	0.707	14-#5	2	12-#9	12-#8	12-#7	10-#7	5.17	336.6	673.1	906.1
26	600	9.00	10.40	26	0.701	16-#5	3	17-#8	13-#8	9-#9	9-#8	6.00	379.8	772.7	1022.5
27	100	6.00	9.00	12	0.797	12-#5	3	9-#7	12-#6	12-#5	10-#5	2.66	170.3	340.6	458.5
27	200	7.50	9.00	16	0.651	12-#5	1	12-#7	20-#5	15-#5	9-#6	3.25	222.6	445.2	599.3
27	300	9.00	9.00	18	0.634	12-#5	2	15-#7	12-#7	10-#7	11-#6	3.96	274.9	549.8	740.1
27	400	9.00	9.00	20	0.741	14-#5	4	14-#8	12-#8	9-#8	10-#7	4.88	327.9	655.8	882.8
27	500	9.00	10.80	25	0.694	16-#5	3	13-#9	13-#8	9-#9	15-#6	5.70	375.4	750.8	1010.7
28	100	7.50	9.33	12	0.750	13-#5	2	19-#5	18-#5	13-#5	11-#5	2.74	191.0	382.0	514.2
28	200	7.50	9.33	16	0.767	13-#5	4	18-#6	16-#6	12-#6	10-#6	3.50	249.3	498.5	671.1
28	300	9.00	9.33	18	0.745	13-#5	5	13-#8	26-#5	11-#7	17-#5	4.32	308.1	616.1	829.4
28	400	9.00	11.20	23	0.722	15-#5	4	13-#9	16-#7	10-#8	11-#7	5.20	365.1	730.3	983.1
28	500	9.00	11.20	28	0.644	17-#5	2	18-#8	14-#8	12-#8	10-#8	5.95	415.8	831.6	1119.4
29	100	7.50	9.67	12	0.787	13-#5	3	22-#5	14-#6	10-#6	12-#5	2.88	212.8	425.5	572.8
29	200	9.00	9.67	16	0.702	13-#5	3	15-#7	23-#5	10-#7	11-#6	3.67	277.7	555.4	747.6
29	300	9.00	9.67	19	0.763	14-#5	5	12-#9	15-#7	10-#8	19-#5	4.75	342.7	685.5	922.7
29	400	9.00	11.60	25	0.702	17-#5	3	14-#9	14-#8	12-#8	10-#8	5.68	405.3	810.5	1091.1
30	100	9.00	10.00	12	0.722	14-#5	1	17-#6	14-#6	16-#5	13-#5	3.00	236.8	473.6	637.6
30	200	9.00	10.00	16	0.763	14-#5	4	13-#8	18-#6	11-#7	17-#5	3.99	308.5	617.1	830.7
30	300	9.00	10.00	22	0.691	16-#5	3	13-#9	17-#7	18-#6	15-#6	5.07	377.6	755.2	1016.6
30	400	9.00	12.00	28	0.700	18-#5	5	16-#9	15-#8	10-#9	18-#6	5.96	444.1	888.3	1195.7
31	100	9.00	10.33	12	0.777	14-#5	3	11-#8	16-#6	13-#6	15-#5	3.29	261.9	523.8	705.1
31	200	9.00	10.33	18	0.749	14-#5	5	12-#9	15-#7	12-#7	19-#5	4.29	339.6	679.2	914.3
31	300	9.00	10.33	24	0.731	17-#5	6	18-#8	14-#8	12-#8	13-#7	5.38	416.0	832.0	1120.0
31	400	9.00	12.40	31	0.697	14-#6	4	17-#9	14-#9	11-#9	12-#8	6.43	483.9	967.9	1302.9

SQUARE INTERIOR PANEL
With Drop Panels[(2)]
No Beams

SPAN c.-c. $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	Square Column[(3)] Size (in.)	Reinforcing Bars (E. W.) Column Strip Top	Column Strip Bottom	Middle Strip Top	Middle Strip Bottom	Total Steel (psf)	Concrete (cu. ft / sq. ft)
h = 10.5 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS								
26	100	12	14-#5	10-#5	10-#5	10-#5	2.29	0.931
26	200	18	18-#5	13-#5	10-#5	10-#5	2.67	0.931
26	300	21	15-#6	9-#7	9-#6	11-#5	3.39	0.944
26	400	23	12-#7	14-#6	15-#5	13-#5	3.82	0.958
26	500	26	26-#5	12-#7	10-#7	15-#5	4.41	0.995
26	600	26	12-#8	11-#8	11-#7	18-#5	5.19	0.995
27	100	12	16-#5	12-#5	10-#5	10-#5	2.40	0.931
27	200	18	14-#6	15-#5	12-#5	10-#5	2.85	0.944
27	300	22	15-#6	13-#6	10-#6	12-#5	3.40	0.958
27	400	23	18-#6	9-#8	9-#7	15-#5	4.24	0.958
27	500	26	12-#8	11-#8	14-#6	9-#7	4.93	0.995
28	100	12	16-#5	13-#5	11-#5	11-#5	2.48	0.944
28	200	18	15-#6	12-#6	13-#5	11-#5	3.07	0.944
28	300	22	13-#7	21-#5	16-#5	10-#6	3.75	0.958
28	400	24	15-#7	18-#6	10-#7	12-#6	4.51	0.995
28	500	27	13-#8	12-#8	12-#7	10-#7	5.25	0.995
29	100	12	18-#5	14-#5	11-#5	11-#5	2.52	0.944
29	200	19	15-#6	19-#5	10-#6	12-#5	3.13	0.958
29	300	22	26-#5	17-#6	10-#7	15-#5	4.01	0.958
29	400	24	13-#8	12-#8	12-#7	18-#5	4.95	0.995
30	100	12	18-#5	16-#5	12-#5	11-#5	2.57	0.958
30	200	19	17-#6	21-#5	16-#5	10-#6	3.43	0.958
30	300	22	16-#7	11-#8	14-#6	12-#6	4.48	0.958
30	400	26	14-#8	10-#9	10-#8	20-#5	5.16	0.995
31	100	12	20-#5	18-#5	14-#5	12-#5	2.77	0.958
31	200	19	26-#5	23-#5	13-#6	15-#5	3.60	0.958
31	300	22	17-#7	21-#6	12-#7	19-#5	4.68	0.958
31	400	29	16-#8	11-#9	11-#8	12-#7	5.65	0.995

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.

CONCRETE REINFORCING STEEL INSTITUTE

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Appendix B – Concrete Flat Slab with Drop Panels|

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

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	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)	Interior: Factored Superimposed Load (psf)	Interior: (3) Square Column Size (in.)	Interior: Column Strip Top	Interior: Column Strip Bottom	Interior: Middle Strip Top	Interior: Middle Strip Bottom	Interior: Total Steel (psf)	Interior: Concrete (cu. ft / sq. ft)
h = 11 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS																h = 11 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS							
28	100	7.00	9.33	12	0.761	13-#5	2	19-#5	18-#5	13-#5	11-#5	2.77	196.6	393.2	529.4	100	12	17-#5	13-#5	11-#5	11-#5	2.53	0.981
28	200	7.00	9.33	16	0.777	13-#5	4	10-#8	23-#5	16-#5	10-#6	3.42	253.9	507.8	683.6	200	19	15-#6	16-#5	13-#5	11-#5	2.98	0.981
28	300	9.00	9.33	18	0.643	13-#5	1	16-#7	18-#6	14-#6	12-#6	4.07	313.6	627.2	844.3	300	22	23-#5	14-#6	15-#5	13-#5	3.51	1.000
28	400	11.00	9.33	20	0.634	14-#5	1	12-#9	27-#5	10-#8	14-#6	4.94	372.5	744.9	1002.8	400	24	13-#7	17-#6	10-#7	11-#6	4.23	1.019
28	500	11.00	11.20	22	0.696	16-#5	3	14-#9	13-#8	12-#8	10-#8	5.76	430.5	861.0	1159.1	500	27	15-#7	12-#8	11-#7	18-#5	4.91	1.063
29	100	7.00	9.67	12	0.797	13-#5	3	11-#7	14-#6	10-#6	12-#5	2.94	219.0	438.0	589.7	100	12	13-#6	14-#5	12-#5	12-#5	2.64	0.981
29	200	9.00	9.67	16	0.688	13-#5	3	15-#7	23-#5	10-#7	15-#5	3.64	283.9	567.9	764.5	200	19	15-#6	18-#5	10-#6	12-#5	3.08	1.000
29	300	9.00	9.67	18	0.778	14-#5	5	14-#8	15-#7	12-#7	10-#7	4.52	350.0	699.9	942.2	300	22	26-#5	12-#7	12-#6	15-#5	3.91	1.000
29	400	11.00	11.60	21	0.698	15-#5	4	17-#8	16-#7	11-#8	12-#7	5.28	416.4	832.8	1121.1	400	25	15-#7	11-#8	11-#7	18-#5	4.58	1.063
29	500	11.00	11.60	23	0.740	17-#5	4	16-#9	14-#8	13-#8	11-#8	6.17	479.4	958.9	1290.8	500	27	13-#8	10-#9	10-#8	20-#5	5.28	1.063
30	100	9.00	10.00	12	0.710	14-#5	1	17-#6	14-#6	11-#6	13-#5	3.03	244.0	488.0	656.9	100	12	18-#5	11-#6	12-#5	12-#5	2.63	1.000
30	200	9.00	10.00	16	0.751	14-#5	4	16-#7	18-#6	20-#5	12-#6	3.81	315.5	631.0	849.4	200	19	17-#6	20-#5	11-#6	13-#5	3.30	1.000
30	300	11.00	10.00	19	0.638	14-#5	3	13-#9	15-#7	10-#8	11-#7	4.79	388.7	777.3	1046.4	300	22	26-#5	10-#8	10-#7	16-#5	4.04	1.019
30	400	11.00	12.00	21	0.747	17-#5	4	19-#8	14-#8	10-#9	18-#6	5.72	463.2	926.5	1247.2	400	25	22-#6	10-#9	12-#7	14-#6	4.93	1.063
30	500	11.00	12.00	26	0.735	19-#5	5	18-#9	16-#8	14-#8	12-#8	6.64	528.7	1057.4	1423.4	500	27	15-#8	14-#8	11-#8	12-#7	5.75	1.063
31	100	9.00	10.33	12	0.767	14-#5	3	11-#8	16-#6	12-#6	14-#5	3.20	269.8	539.7	726.5	100	12	20-#5	17-#5	13-#5	12-#5	2.69	1.000
31	200	11.00	10.33	16	0.639	14-#5	2	14-#8	18-#6	12-#7	19-#5	4.08	350.2	700.4	942.8	200	19	17-#6	22-#5	12-#6	15-#5	3.46	1.019
31	300	11.00	10.33	19	0.693	16-#5	3	14-#9	17-#7	12-#8	13-#7	5.21	430.5	861.1	1159.2	300	22	15-#7	15-#7	15-#6	18-#5	4.39	1.019
31	400	11.00	12.40	24	0.739	18-#5	6	17-#9	15-#8	11-#9	12-#8	6.20	508.9	1017.8	1370.1	400	25	14-#8	11-#9	18-#6	12-#7	5.35	1.063
31	500	11.00	12.40	29	0.737	15-#6	4	20-#9	14-#9	13-#9	13-#8	7.23	577.8	1155.5	1555.5	500	29	16-#8	13-#9	12-#8	13-#7	6.19	1.063
32	100	9.00	10.67	12	0.811	15-#5	5	15-#7	17-#6	19-#5	11-#6	3.38	297.4	594.9	800.8	100	12	16-#6	19-#5	15-#5	13-#5	2.93	1.000
32	200	11.00	10.67	16	0.688	15-#5	3	20-#7	15-#7	13-#7	11-#7	4.34	386.4	772.9	1040.4	200	19	26-#5	13-#7	19-#5	16-#5	3.70	1.019
32	300	11.00	10.67	20	0.758	17-#5	6	16-#9	18-#7	16-#7	18-#6	5.51	474.0	948.0	1276.2	300	22	17-#7	22-#6	13-#7	20-#5	4.70	1.019
32	400	11.00	12.80	27	0.694	20-#5	4	23-#8	17-#8	12-#9	16-#7	6.57	557.5	1115.0	1500.9	400	25	16-#8	12-#9	12-#8	13-#7	5.81	1.063
33	100	11.00	11.00	12	0.753	15-#5	4	13-#8	17-#6	11-#7	13-#6	3.61	328.1	656.2	883.4	100	12	16-#6	11-#7	16-#5	14-#5	3.07	1.019
33	200	11.00	11.00	16	0.765	15-#5	5	17-#8	22-#6	11-#8	12-#7	4.68	425.1	850.1	1144.4	200	19	15-#7	11-#8	11-#7	18-#5	4.06	1.019
33	300	11.00	11.00	23	0.721	19-#5	5	17-#9	16-#8	11-#9	12-#8	6.04	517.4	1034.9	1393.1	300	22	15-#8	11-#9	11-#8	12-#7	5.30	1.019
33	400	11.00	13.20	30	0.689	22-#5	5	21-#9	18-#8	13-#9	11-#9	7.02	604.0	1207.9	1626.1	400	28	17-#8	13-#9	16-#7	11-#8	6.08	1.063

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.

CONCRETE REINFORCING STEEL INSTITUTE

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Appendix B – Concrete Flat Slab with Drop Panels|

f'_c = 4,000 psi
Grade 60 Bars

FLAT SLAB SYSTEM
SQUARE EDGE PANEL — With Drop Panels — 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.)	(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)
29	100	7.00	9.67	12	0.786	13-#5 3	11-#7	14-#6	10-#6	12-#5	2.94	225.5	451.0	607.1
29	200	9.00	9.67	16	0.673	13-#5 3	11-#8	16-#6	10-#7	15-#5	3.61	290.2	580.4	781.3
29	300	9.00	9.67	19	0.717	14-#5 4	11-#9	15-#7	12-#7	10-#7	4.50	355.0	710.0	955.8
29	400	11.00	9.67	21	0.640	15-#5 3	13-#9	16-#7	18-#6	15-#6	5.11	420.6	841.2	1132.4
29	500	11.00	11.60	23	0.707	17-#5 3	15-#9	14-#8	12-#8	10-#8	5.87	485.4	970.8	1306.9
30	100	9.00	10.00	12	0.698	14-#5 1	12-#7	14-#6	15-#5	13-#5	2.99	251.2	502.3	676.2
30	200	9.00	10.00	16	0.721	14-#5 3	12-#8	18-#6	14-#6	16-#5	3.79	322.4	644.9	868.1
30	300	11.00	10.00	19	0.636	14-#5 3	12-#9	15-#7	10-#8	20-#5	4.61	395.5	791.0	1064.8
30	400	11.00	10.00	21	0.698	17-#5 3	18-#8	14-#8	12-#8	10-#8	5.55	467.8	935.7	1259.6
30	500	11.00	12.00	25	0.757	19-#5 6	17-#9	16-#8	11-#9	12-#8	6.52	536.9	1073.9	1445.6
31	100	9.00	10.33	12	0.740	14-#5 2	18-#6	16-#6	12-#6	14-#5	3.16	277.8	555.5	747.8
31	200	9.00	10.33	16	0.777	14-#5 5	11-#9	15-#7	12-#7	13-#6	4.17	357.0	713.9	961.1
31	300	11.00	10.33	19	0.678	16-#5 3	17-#8	22-#6	11-#8	12-#7	5.01	438.1	876.2	1179.5
31	400	11.00	12.40	23	0.749	18-#5 6	16-#9	15-#8	13-#8	11-#8	5.89	517.8	1035.7	1394.2
31	500	11.00	12.40	28	0.746	15-#6 4	19-#9	14-#9	12-#9	16-#7	6.92	588.5	1176.9	1584.3
32	100	9.00	10.67	12	0.803	15-#5 5	15-#7	17-#6	13-#6	11-#6	3.36	306.2	612.4	824.3
32	200	11.00	10.67	16	0.651	15-#5 2	12-#9	15-#7	13-#7	14-#6	4.31	394.9	789.8	1063.2
32	300	11.00	10.67	19	0.781	17-#5 7	15-#9	18-#7	12-#8	13-#7	5.30	483.7	967.4	1302.3
32	400	11.00	12.80	26	0.718	20-#5 5	18-#9	17-#8	12-#9	12-#8	6.49	567.2	1134.4	1527.1
32	500	11.00	12.80	31	0.692	16-#6 3	21-#9	15-#9	13-#9	11-#9	7.31	639.5	1278.9	1721.6
33	100	11.00	11.00	12	0.710	15-#5 2	22-#6	17-#6	20-#5	12-#6	3.48	337.7	675.5	909.3
33	200	11.00	11.00	16	0.754	15-#5 5	17-#8	16-#7	11-#8	12-#7	4.63	434.4	868.8	1169.5
33	300	11.00	11.00	22	0.734	19-#5 5	17-#9	15-#8	13-#8	11-#8	5.84	528.0	1056.0	1421.5
33	400	11.00	13.20	29	0.711	22-#5 6	20-#9	18-#8	13-#9	13-#8	6.83	616.2	1232.4	1659.0
34	100	11.00	11.33	12	0.762	16-#5 4	14-#8	26-#5	12-#7	19-#5	3.77	370.1	740.2	996.4
34	200	11.00	11.33	18	0.752	17-#5 6	18-#8	18-#7	12-#8	13-#7	4.84	473.9	947.8	1275.9
34	300	11.00	11.33	24	0.757	20-#5 8	18-#9	17-#8	12-#9	12-#8	6.19	576.4	1152.8	1551.9
34	400	11.00	13.60	31	0.689	17-#6 3	21-#9	16-#9	14-#9	14-#8	7.18	667.9	1335.8	1798.2

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

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

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)
29	100	12	13-#6	14-#5	12-#5	12-#5	2.64	1.023
29	200	19	15-#6	18-#5	10-#6	12-#5	3.08	1.042
29	300	22	26-#5	12-#7	12-#6	10-#6	3.86	1.042
29	400	24	15-#7	18-#6	14-#6	12-#6	4.40	1.060
29	500	27	13-#8	12-#8	12-#7	14-#6	5.10	1.105
30	100	12	18-#5	15-#5	13-#5	13-#5	2.67	1.042
30	200	19	17-#6	14-#6	15-#5	13-#5	3.31	1.042
30	300	22	26-#5	17-#6	10-#7	16-#5	3.92	1.060
30	400	24	16-#7	15-#7	12-#7	10-#7	4.78	1.060
30	500	27	15-#8	11-#9	18-#6	12-#7	5.67	1.105
31	100	12	20-#5	12-#6	13-#5	13-#5	2.78	1.042
31	200	19	26-#5	12-#7	12-#6	14-#5	3.56	1.042
31	300	22	15-#7	11-#8	11-#7	18-#5	4.35	1.060
31	400	25	14-#8	13-#8	13-#7	11-#7	5.12	1.105
31	500	28	16-#8	12-#9	12-#8	13-#7	6.02	1.105
32	100	12	16-#6	13-#6	14-#5	13-#5	2.90	1.042
32	200	19	26-#5	17-#6	13-#6	11-#6	3.62	1.060
32	300	22	17-#7	21-#6	12-#7	19-#5	4.52	1.060
32	400	25	15-#8	12-#9	11-#8	13-#7	5.66	1.105
32	500	31	17-#8	13-#9	16-#7	11-#8	6.30	1.105
33	100	12	16-#6	11-#7	11-#6	14-#5	3.06	1.060
33	200	19	15-#7	11-#8	20-#5	17-#5	3.97	1.060
33	300	22	15-#8	11-#9	13-#7	15-#6	5.13	1.060
33	400	27	17-#8	13-#9	12-#8	18-#6	5.91	1.105
34	100	12	18-#6	12-#7	17-#5	15-#5	3.25	1.060
34	200	19	22-#6	21-#6	12-#7	19-#5	4.15	1.060
34	300	22	16-#8	19-#7	12-#8	13-#7	5.40	1.060
34	400	30	18-#8	14-#9	13-#8	12-#8	6.29	1.105

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

CONCRETE REINFORCING STEEL INSTITUTE

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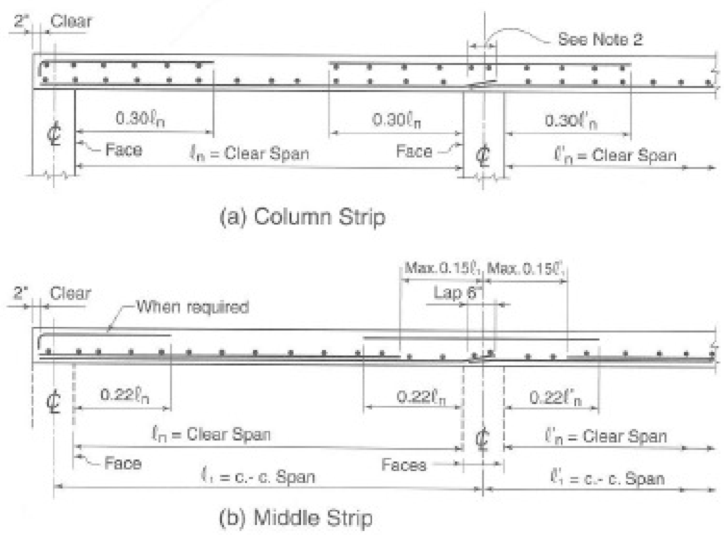
Appendix B – Concrete Flat Slab with Drop Panels|

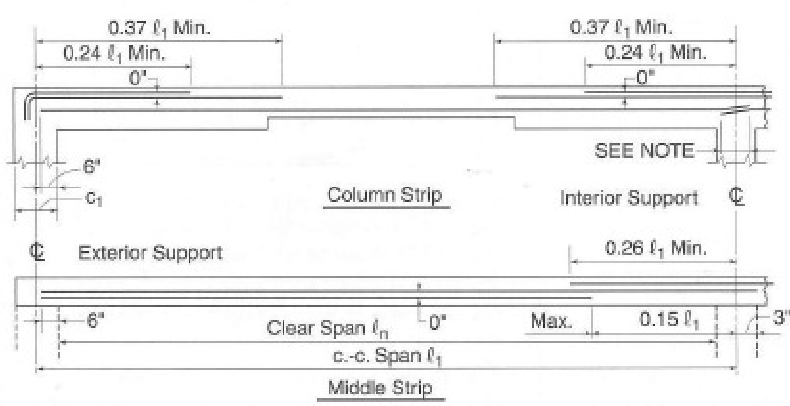


Notes:

1. Top bars must be concentrated within width of the column plus 1.5h on each side of the column (ACI 13.5.3.2 and 13.5.3.4).
2. Integrity reinforcement is required (ACI 13.3.8.5). All bottom bars in the column strip must be continuous or spliced over the support with Class A tension lap splices. At least two of the column strip bottom bars in each direction must pass within the column core and be anchored at exterior supports.

Figure 9-2 Typical Bar Length Details

9-2 CONCRETE REINFORCING STEEL INSTITUTE

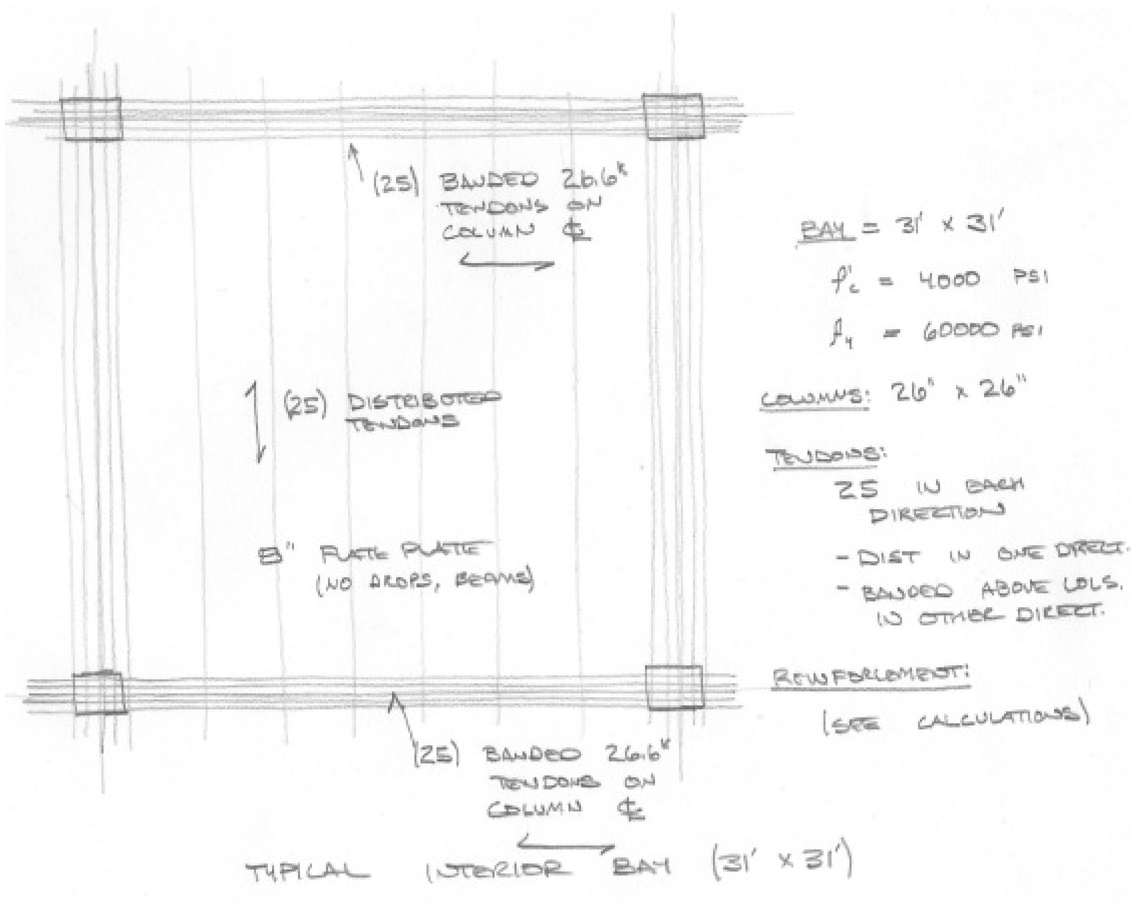


NOTE: Integrity reinforcement is required (ACI 13.3.8.5). All bottom bars in the column strip must be continuous or spliced over the support with Class A tension lap splices. At least two of the column strip bottom bars in each direction must pass within the column core and be anchored at exterior supports.

Figure 10-1 Recommeded Bar Details

CONCRETE REINFORCING STEEL INSTITUTE 10-1

Appendix C – Post Tensioned Concrete Flat Plate



Appendix C – Post Tensioned Concrete Flat Plate

POST TENSIONED SLAB — TYP BAY = 31' × 31'

DETERMINE LOADS / SLAB THICKNESS:

CHECK SPAN/DEPTH RATIO LIMITS FOR DEFLECTIONS:

2-WAY POST TENSIONED $\frac{31(12)}{t} = 48$

$t_{min} = 7.75"$ $f_y = 60000$ PSI

USE 8" SLAB: $f'_c = 4000$ PSI

$LL = 80$ PSF $\xrightarrow{RED}$ 58.70 PSF | $DL = 10 + 20$ PSF $= 30$ PSF

S/P $TL_{UNF} = 88.7$ PSF S/P $TL_{FACT} = 1.2(30) + 1.6(58.7) = 129.92$ PSF

$\left(\frac{8}{12}\right)150 = 100$ PSF $= DL_{SLAB}$ (8") $\frac{LL}{DL} = \frac{80}{130} = .61 < .75$ ✓

SLAB PROPERTIES:

$A = 372(8) = 2976$ IN²

$S = \frac{372(8^2)}{6} = 3968$ IN²

ALLOWABLE STRESSES:

(ACI 18.4.1) TIME OF JACKING:

$f'_{ci} = 3000$ PSI

EXTREME FIBER COMP. $= .6(3000) = 1800$ PSI

EXTREME FIBER TENS. $= 3\sqrt{3000} = 164$ PSI

(ACI 18.4.2 & ACI 18.3.3) SERVICE LOADS:

$f'_c = 4000$ PSI

EXTREME FIBER COMP. $= .45(4000) = 1800$ PSI

EXTREME FIBER TENS. $= 6\sqrt{4000} = 379.5$ PSI

AVERAGE PRECOMPRESSION LIMITS:

$P/A = 125$ PSI MIN ↔ 300 PSI MAX

TARGET LOAD BALANCES:

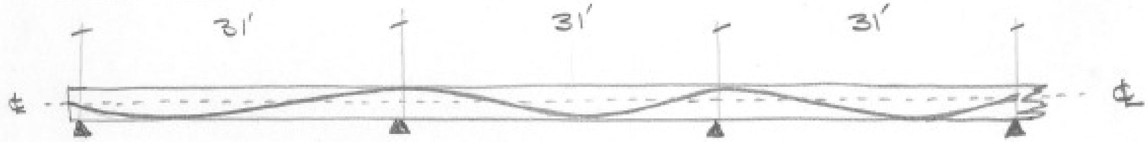
$(.75)\,DL = 75$ PSF

Appendix C – Post Tensioned Concrete Flat Plate

COVER REQUIREMENTS (FIRE):

3/4" COVER

TENDON PROFILE:



TENDON LOCATION (FROM SLAB BOTTOM)

EXTERIOR SUPPORT	4"
MIDSPAN	1"
INTERIOR SUPPORT	7"

$\alpha_{INT} = 6''$

$\alpha_{EXT} = 3.75''$

BALANCE 75% OF DL_{SLAB}:

$w_B = (100)(.75)(31) = 2.325$ KLF
(EXTERIOR BAY)

TENDON FORCE NEEDED TO COUNTERACT 75% DL:

$$P = \frac{(2.325)(31)^2}{(8(3.75/12))} = 893.73^K$$

DETERMINE # OF TENDONS:

– ASSUMING 26.6^K TENDONS

$$n = \frac{893.73^K}{26.6^K} = 33 \text{ TENDONS}$$

ACTUAL TENDON FORCE:

$$P = (33)(26.6) = 877.8^K$$

$$w_B = \left(\frac{877.8}{893.73}\right)(2.325) = 2.2836 \text{ KLF}$$

ACTUAL PRECOMPRESSION STRESS:

$$\sigma = \frac{877.8}{2976} = 295 \text{ PSI} \quad (\sqrt{OK})$$

Appendix C – Post Tensioned Concrete Flat Plate

(INTERIOR BAY)
TENDON FORCE NEEDED TO COUNTERACT DL:

$$P = \frac{(2.235)(31^2)}{(8(6/12))} = 537\text{ K}$$

CHECK EXTERIOR FORCE FOR INTERIOR FORCE:

$$w_B = (877.8)(8)(1/2) \,/\, (31^2) = 3.653\text{ KLF} \; (w_B) > 3.100\text{ KLF} \; (w_{DL})$$

FAILS

TRY LESS POST-TENSION FORCE:

DESIGN INTERIOR BAY FIRST:

- USE 85% DL AS GUIDELINE

$$w_B = 100(.85)(31) = 2.635\text{ KLF}$$

$$P = \frac{(2.635)(31)^2}{(8)(.5)} = 633.0\text{ K}$$

$$n = \frac{633}{26.6} = 24 \text{ CABLES (TENDONS)}$$

$$\sigma_{ACT} = \frac{24(26.6)}{2976} = 215\text{ PSI} \quad \checkmark\text{OK} \qquad P_{ACT} = 638.4^{k}$$

CHECK EXTERIOR BAY:

✓ INTERIOR POST TENSION FOR EXTERIOR DL:

$$w_B = (638.4)(8)(8.75/12) \,/\, (31)^2 = 1.63 \; (w_B) < 3.100 \; (w_{DL})$$

✓OK

Appendix C – Post Tensioned Concrete Flat Plate

DESIGN ULTIMATE POST TENSIONING CONFIGURATION:

INTERIOR BAY (BALANCE 90% DL):

$W_B = .9(100)(31) = 2.790$ KLF

$P = \frac{2.790(31)^2}{(8)(1.5)} = 670.298^K$

$n = \frac{670.298}{26.6} = 25$ $P_{ACT} = 665^K$

$\sigma = \frac{665000}{2976} = 223.5$ PSI √OK

EXTERIOR BAY (CHECK USING INT. POST TENS):

$W_{B_{EXT}} = 665(8)\left(\frac{3.75}{12}\right) \Big/ 31^2 = 1.729$ KLF < 3.1 KLF √OK

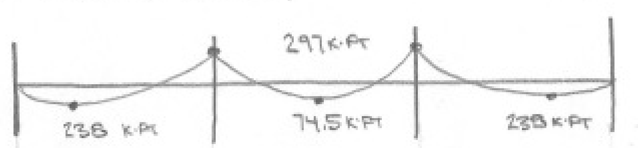
E-W:
N-S: USE 25 TENDONS (BANDED ACROSS COLUMNS)

$P_{EFF} = 665^K$

$W_{B_{EXT}} = 1.729$ KLF $W_{B_{INT}} = 2.768$ KLF

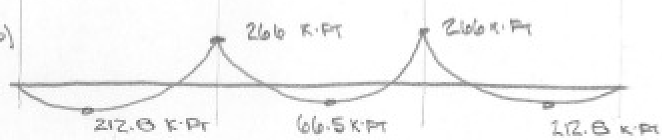
MOMENTS: (AISC 13TH EDITION, T. 3-23)

DEAD LOAD:
$W_{DL} = 3.1$ KLF



LIVE LOAD:
$W_{LL} = 1.82$ KLF

BALANCING: (FLIPPED)
$W_B = 2.768$ KLF
(USING INT. BAY TYPICAL BAY)



Appendix C – Post Tensioned Concrete Flat Plate

CHECK STRESSES UNDER LOADING: (INTERIOR BAY – TYP.)

MIDSPAN STRESSES:

$$f_{TOP} = (-M_{DL} - M_{LL} + M_{BAL})/S - P/A$$

$$f_{BOT} = (+M_{DL} + M_{LL} - M_{BAL})/S - P/A$$

$$f_{TOP} = \frac{(-74.5 - 43.7 + 66.5)12000}{3968} - \frac{665000}{2976} \quad \checkmark_{OK}$$

$$f_{TOP} = -156.351 - 223.454 = \boxed{-379.8 \text{ PSI (C)} < 1800 \text{ PSI}}$$

$$f_{BOT} = \frac{(74.5 + 43.7 - 66.5)(12000)}{3968} - \frac{665000}{2976} \quad \checkmark_{OK}$$

$$\checkmark f_{BOT} = 156.351 - 223.454 = \boxed{+67.1 \text{ PSI (C)} < 379.5 \text{ PSI}}$$

SUPPORT STRESSES:

$$f_{TOP} = (+M_{DL} + M_{LL} - M_{B})/S - P/A$$

$$f_{BOT} = (-M_{DL} - M_{LL} + M_{B})/S - P/A$$

$$f_{TOP} = \frac{(297 + 174.9 - 266)12000}{3968} - \frac{665000}{2976} \quad \checkmark_{OK}$$

$$f_{TOP} = 622.681 - 223.454 = \boxed{+399 \text{ PSI (T)} < 379.5 \text{ PSI}}$$

WITHIN 5%, CLOSE ENOUGH!

$$f_{BOT} = \frac{(-297 - 174.9 + 266)12000}{3968} - \frac{665000}{2976} \quad \checkmark_{OK}$$

$$f_{BOT} = -622.681 - 223.454 = \boxed{-846.1 \text{ PSI (C)} < 1800 \text{ PSI}}$$

Appendix C – Post Tensioned Concrete Flat Plate

POST TENSIONED 8" SLAB ULTIMATE STRENGTH:
(INTERIOR BAY)

PRIMARY POST TENSIONING MOMENTS:

EXT. SUPPORT
$e = 0$
$M_1 = 0$

INT. SUPPORT
$e = 3.0$
$M_1 = \frac{3(665)}{12} = 166.25$ FT·K

SECONDARY POST TENSIONING MOMENTS:

$M_2 = 0$ FT·K

$M_2 = 266.25 - 166.25 = 100$ FT·K

→ (LINEAR VARIATION BETWEEN SUPPORTS) →

APPLIED LOADING MOMENTS:

SUPPORT: $-1.2(297) + -1.6(174.9) + 100 = -536.2$ FT·K

MIDDLE: $1.2(74.5) + 1.6(43.7) + 100 = 379.8$ FT·K

MIDSPANS: $f_T = -67.1$ PSI (C) $< 2\sqrt{4000}$

NO REINFORCEMENT

SUPPORTS:

$A_{s\,MIN} = .00075(8)(31)(12) = 2.232$ in^2

MINIMUM REINFORCEMENT:
(6) - #6
- SPANNING 1/6 OF CLEAR SPAN ON EACH SIDE
- AT LEAST 4 BARS IN EACH DIRECTION
- BARS WITHIN 12" OF SUPPORT (COLUMN) FACE
- MAX. BAR SPACING IS 12"

CHECK MIN. REINF: $A_{ST} = 2.64$ in^2

$\phi M_n = (.9)[(6.0)(60) + (3.825)(195)][7 - .437174] = 544.3$ K·FT

$A_{PS} = 25(.153) = 3.825$

$a = \frac{6(60) + 3.825(195)}{.85(4000)(372)} = .874"$

→ TRY (6) #9 BARS $A_{ST} = 6$ in^2

Appendix C – Post Tensioned Concrete Flat Plate

CHECK SHEAR: $V_{APPLIED} = (31^2)\left(1.2(130) + 1.6(58.7)\right) = 240^K$

$V_c = (\beta_P \sqrt{f'_c} + .3 f_{PC}) b_o (d) + V_P$ (ACI EQ 11-36)

V_P: 0 = CONSERVATIVE

18" x 18" COLS

$\beta_P = 3.5$

$(40(8))/72 + 1.5 = 5.94$

$f_{PC} = 223.5$ psi

$b_o = 72"$

$V_c = 3.5\sqrt{4000} + .3(223.5)(72)(8) = 166.1^K < 240^K$ (FAILS)

24 x 24 COLS

$\beta_P = 3.5$

$f_{PC} = 223.5$

$b_o = 96"$

$V_c = (3.5\sqrt{4000} + .3(223.5))(96)(8) = 221.4^K < 240^K$ (FAILS)

25 x 25 COLS

$\beta_P = 3.5$

$f_{PC} = 223.5$

$b_o = 100"$

$V_c = (3.5\sqrt{4000} + .3(223.5))(100)(8) = 230.7^K < 240^K$ (FAILS)

26 x 26 COLS.

$\beta_P = 3.5$

$f_{PC} = 223.5$

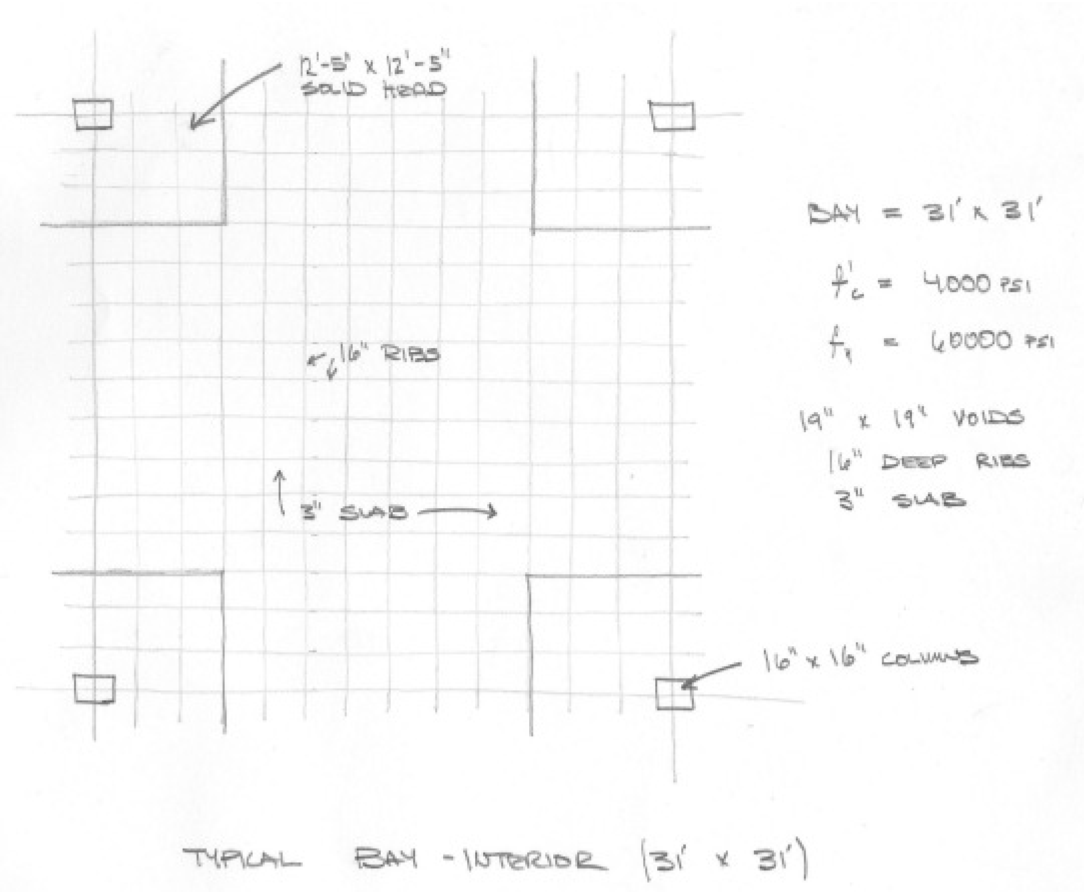
$b_o = 104"$

$V_c = (3.5\sqrt{4000} + .3(223.5))104(8) = 239.96^K \approx 240^K$

> USE 26" x 26" COLUMNS
> NO CAPITALS OR DROPS.

(COLUMN SIZE CAN BE REDUCED W/ CAPITALS OR DROP PANELS.)

Appendix D – Concrete Waffle Slab



Appendix D – Concrete Waffle Slab|

BAY = 31' x 31' f'_c = 4000 PSI f_y = 60000 PSI

DL = 10 + 20 = 30 PSF

LL = 80 $\xrightarrow[\text{RED.}]{}$ 58.70 PSF

$TL_{UNF.}$ = 88.7 PSF $TL_{FACT.}$ = 1.4(30) + 1.7(58.70) =

TL_{FACT} = 141.79 PSF

DEFLECTIONS|

(ASSUMED TO BE ACCEPTABLE WHEN USING CRSI)

$t_e = \frac{l_e}{33} = \frac{(31)(12)}{33} = 11.27"$

USING 19" x 19" DOMES|

CONSIDER → 10" DOMES + 4.5" SLAB MAX. SPAN = 32.33'

12" DOMES + 3" SLAB MAX. SPAN = 33.33'

USING 30" x 30" DOMES|

CONSIDER →

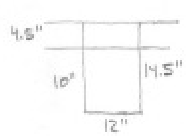
10" DOMES + 4.5" SLAB MAX. SPAN = 31.25'

12" DOMES + 3" SLAB MAX. SPAN = 33.25'

DESIGN 19" x 19" DOMES (TYPICAL INTERIOR BAY)|

10" + 4.5"| 31' BAY BUT 32' WAFFLE SLAB DIMENSIONS

- ASSUME THAT DOMES WILL BE SPACED TO CREATE LARGER RIBS MAKING UP THE 12"
- LARGER RIBS INCREASE DL OF SLAB BY:



$\left(\frac{14.5}{12}\right)\left(\frac{12}{12}\right)(150)(31) = 5618.75$ ↕ RIBS

$\left(\frac{14.5}{12}\right)\left(\frac{12}{12}\right)(150)(30) = 5437.5$ ↔ RIBS

FACTOR DL OF SLAB = 1.4(11056) = $\frac{15478.8 \text{ LBS}}{31^2}$

→ ADD 16 PSF TO SLAB DL

DL_{TOT} = 141.79 + 16.10 = 158 PSF

Appendix D – Concrete Waffle Slab

CONTINUE DESIGNING 19" x 19" DOMES FOR TYP. INT. BAY |

DL = 158 → 200 PSF (CONSERVATIVE)

GO INTO CRSI TABLE AND DESIGN REINFORCEMENT FOR 32' BAY
(OVER REINFORCED FOR USE IN 31' BAY – CONSERVATIVE)

COLS = 16" x 16" SOLID HEAD = 12' – 5" SQUARE
→ (ADDITIONAL SHEAR REINFORCEMENT NEEDED)
→ 3 S 4 1 STIRRUPS NEEDED

(TRY ALTERNATIVE SOLUTIONS USING LESS REINF.)

12" + 3" |

31' BAY BUT 32' SLAB DIMENSIONS
– ASSUME DOMES WILL HAVE LARGER SPACING TO CREATE LARGER RIBS TO MAKE UP 12"
– SLAB DL INCREASES BY:

$\left(\frac{15}{12}\right)\left(\frac{12}{12}\right)(31)\ 150 = 5812.5$ LBS ↕ RIBS

$\left(\frac{15}{12}\right)\left(\frac{12}{12}\right)(30)\ 150 = 5625$ LBS ↔ RIBS

– FACTOR SLAB DL = $1.4(11437.5) = \frac{16012.5}{31^2}$

– ADD 16.66 PSF TO SLAB DL

$DL_{TOT} = 16.66 + 141.79 = \boxed{158.5\ PSF}$

DL = 200 PSF (CONSERVATIVE)

USE CRSI TABLE TO DESIGN REINF. FOR 32' BAY:
(OVERREINFORCED FOR 31' BAY – CONSERVATIVE)

COLS = 16" x 16" SOLID HEAD = 12' – 5" (SQUARE)
→ (ADDITIONAL SHEAR REINF. NEEDED)
→ 4 S 6 1 STIRRUPS NEEDED

COMPARISON OF 19" x 19" SYSTEMS:

	10" + 4.5" |	12" + 3" |	
STEEL	3.55 PSF	3.29 PSF	MORE EFFICIENT & ECONOMICAL
CONC	119.7 PSF	114.9 PSF	

Appendix D – Concrete Waffle Slab

HOWEVER CRSI SUGGESTS AVOIDING COLUMN CAPITALS, DROP PANELS, REINFORCEMENT FOR SHEAR & STIRRUPS.

SO FINDING THE MOST ECONOMICAL DESIGNS THAT ALLOW SHEAR TO NOT CONTROL:

THE FOLLOWING WILL BE THE MOST ECONOMICAL WAFFLE SLABS FOR CONSTRUCTION TIME, REINFORCING $ COST...

16" + 3" (19" x 19" MODULES)

- ADJUST DL TO COMPENSATE FOR WIDE RIBS MAKING UP FOR 31' BAY W 32' MODULES.

$+DL = (19/12)(150)(31+30) = 14487.5$ LBS

FACTOR $+DL = 1.4(14487.5) = \frac{20282.5 \text{ LBS}}{31^2}$

$+DL = 21.10$ PSF

$DL_{TOT} = 141.79 + 21.10 = 163$ PSF

→ USE 200 PSF (CONSERVATIVE)

COL = 16" x 16" SOLID HEAD = 12'-5" (SQUARE)

→ NO ADDITIONAL SHEAR OR STIRRUP REINF.

16" DEEP X 19" X 19" DOMES W/ 3" SLAB IS MOST EFFECTIVE WAFFLE SLAB

Appendix D – Concrete Waffle Slab

Table 11-3 Waffle Flat Slabs (19″ x 19″ Voids at 2′-0″)—Equivalent Thickness and Maximum Load Based on *L*/360 Deflection

Rib+ Slab Depths (in.)	Equiv. Thickness t_e* (in.)	Max. Span in Tables (ft)	Maximum Span Limited by *L*/360 Deflection for Load Shown Below						
			L/t_e=30	L/t_e=31	L/t_e=32	L/t_e=33	L/t_e=34	L/t_e=35	L/t_e=36
8 + 3	8.89	30	22′-3″	23′-0″	23′-8″	24′-5″	25′-2″	25′-11″	26′-8″
8 + 4½	10.11	34	25′-3″	26′-1″	27′-0″	27′-10″	28′-8″	29′-6″	30′-4″
10 + 3	10.51	36	26′-3″	27′-2″	28′-0″	28′-11″	29′-9″	30′-8″	31′-6″
10 + 4½	11.75	38	29′-5″	30′-4″	31′-4″	32′-4″	33′-4″	34′-3″	35′-3″
12 + 3	12.12	38	30′-4″	31′-4″	32′-4″	33′-4″	34′-4″	35′-4″	36′-4″
12 + 4½	13.38	38	33′-5″	34′-7″	35′-8″	36′-10″	37′-11″	39′-0″	40′-2″
14 + 3	13.72	38	34′-4″	35′-5″	36′-7″	37′-9″	38′-10″	40′-0″	41′-2″
14 + 4½	15.02	38	37′-7″	38′-10″	40′-1″	41′-4″	42′-7″	43′-10″	45′-1″
16 + 3	15.31	38	38′-3″	39′-7″	40′-10″	42′-1″	43′-5″	44′-8″	45′-11″
16 + 4½	16.64	38	41′-7″	43′-0″	44′-4″	45′-9″	47′-2″	48′-6″	49′-11″
Maximum Load (psf) for Immediate (Elastic) Deflection of *L*/360**			504	457	416	379	346	318	292

* Based on gross moment of inertia.
** For long-term (creep) deflection limited to *L*/360, multiply the long-term loads, including the waffle slab weight, times 2; deduct from loads shown above. Result is maximum superimposed service live load.

11-4 CONCRETE REINFORCING STEEL INSTITUTE

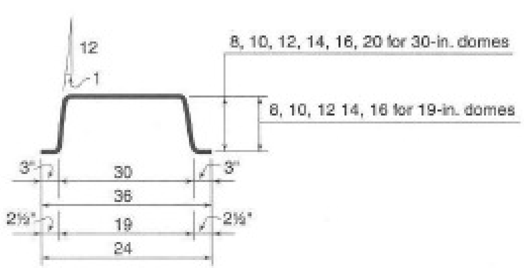
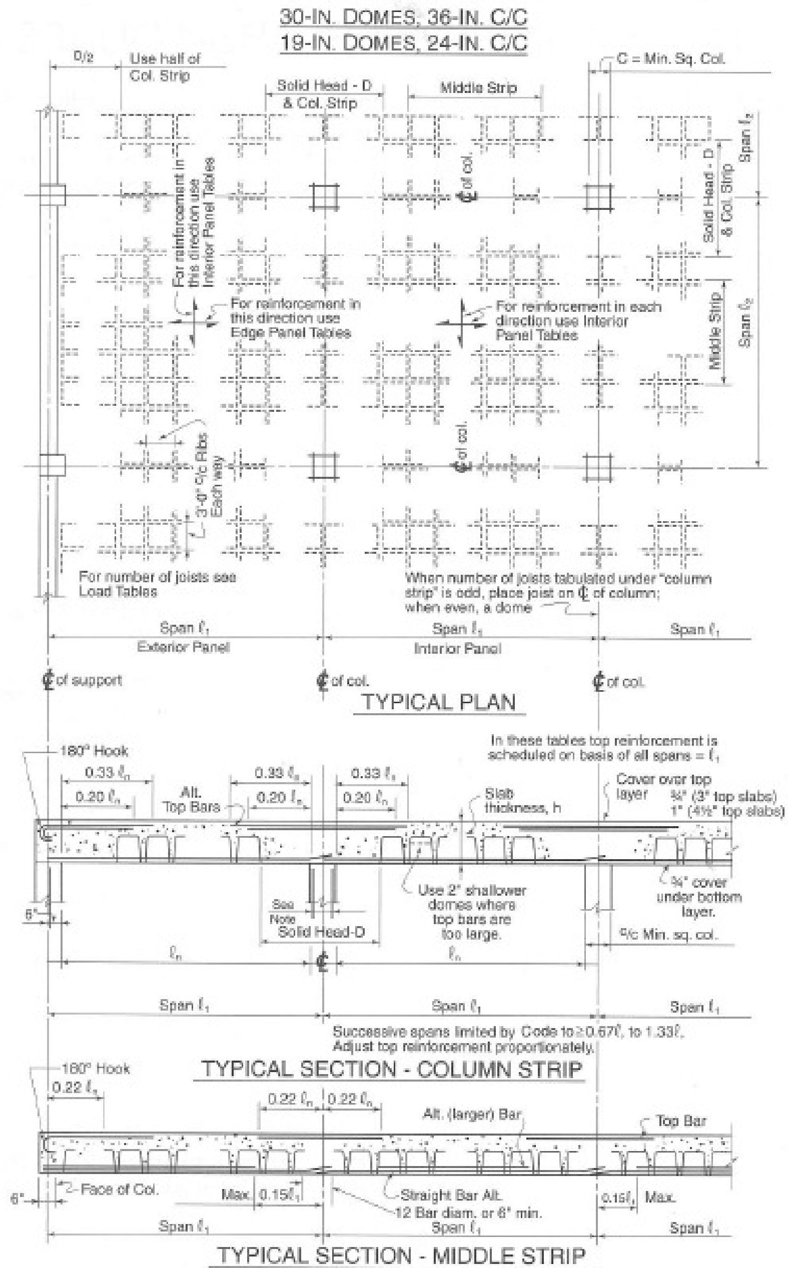


Table 11-1 Standard Dome Dimensions and Other Data

Dome Size	Dome Depth (in.)	Volume of Void (ft³)	Floor Dead Load (psf) per Slab Thickness	
			3 in.	4.5 in.
30-in.	8	3.98	71	90
	10	4.92	80	99
	12	5.84	90	109
	14	6.74	100	119
	16	7.61	111	129
	20	9.30	132	151
19-in.	8	1.56	79	98
	10	1.91	91	110
	12	2.25	103	122
	14	2.58	116	134
	16	2.90	129	148

Appendix D – Concrete Waffle Slab



NOTE: Integrity reinforcement is required (ACI 13.3.8.5*). All bottom bars in the column strip must be continuous or spliced over the support with Class A tension lap splices. At least two of the column strip bottom bars in each direction must pass within the column core and be anchored at exterior supports.

For other end support conditions; see Figs. 11-2 and 11-3.

Figure 11-1 Reinforcing Bar Details and Layout

*All references to ACI 318-99 are given as "ACI" followed by the appropriate section number.

Appendix D – Concrete Waffle Slab

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

f'_c = 4,000 psi
Grade 60 Bars

SQUARE EDGE PANELS

Total Depth = 15 in. Rib Depth = 12 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)
30'- 0" D=10.417 RIB NOT ON COLUMN LINE 0.749 CF/SF	50	2.37	15	0.795		22-#5+ 0	6	2-#5	22-#5	9	#4	#4	9-#5	159	319	429
	100	2.50	15	0.835		22-#5+ 0	6	1-#5 and 1-#6	22-#5	9	#4	#4	9-#5	200	400	538
	150	2.85	15*	0.885		22-#5+ 2	6	1-#6 and 1-#7	27-#5	9	#4	#4	9-#5	240	518	646
	200	3.27	15*	0.633		22-#5+ 0	6	2-#7	22-#6	9	#4	#5	10-#5	280	650	755
	300	4.38	19*	0.628		22-#5+ 1	6	2-#8	29-#6	9	#5	#6	9-#6	357	892	960
32'- 0" D=12.417 RIB ON COLUMN LINE 0.766 CF/SF	50	2.40	16	0.813		24-#5+ 0	7	2-#5	24-#5	9	#4	#4	10-#5	195	390	526
	100	2.60	16*	0.866		24-#5+ 2	7	1-#5 and 1-#6	27-#5	9	#4	#4	10-#5	244	488	657
	150	3.09	16*	0.917		24-#5+ 6	7	1-#6 and 1-#7	23-#6	9	#4	#5	11-#5	293	620	789
	200	3.65	17*	0.630		24-#5+ 3	7	2-#7	27-#6	9	#5	#5	12-#5	341	779	918
	300	4.67	23*	0.625		24-#5+ 6	7	2-#8	35-#6	9	#6	#6	11-#6	428	996	1151
34'- 0" D=12.417 RIB ON COLUMN LINE 0.757 CF/SF	50	2.52	17	0.822		25-#5+ 0	7	1-#5 and 1-#6	26-#5	10	#4	#4	10-#5	233	466	627
	100	2.81	17*	0.887		25-#5+ 4	7	2-#6	24-#6	10	#4	#4	10-#5	292	583	785
	150	3.39	17*	0.630		25-#5+ 2	7	2-#7	28-#6	10	#4	#5	13-#5	350	720	943
	200	4.08	21*	0.626		25-#5+ 4	7	1-#7 and 1-#8	33-#6	10	#5	#5	10-#6	405	903	1080
36'- 0" D=12.417 RIB ON COLUMN LINE 0.749 CF/SF	50	2.70	18*	0.853		27-#5+ 3	7	2-#6	31-#5	11	#4	#4	11-#5	276	551	742
	100	3.20	18*	0.913		27-#5+ 8	7	1-#6 and 1-#7	28-#6	11	#4	#5	12-#5	345	690	929
	150	3.71	20*	0.627		27-#5+ 4	7	1-#7 and 1-#8	34-#6	11	#4	#5	15-#5	413	826	1111
	200	4.53	24*	0.624	4 S 6 1	27-#5+ 4	7	2-#8	38-#6	11	#5	#6	12-#6	477	1033	1285
38'- 0" D=14.417 RIB NOT ON COLUMN LINE 0.763 CF/SF	50	2.83	19*	0.878		28-#5+ 7	8	2-#6	26-#6	11	#4	#4	12-#5	326	653	879
	100	3.45	20*	0.921		28-#5+12	8	2-#7	33-#6	11	#4	#5	15-#5	407	815	1097
	150	4.11	24*	0.624		28-#5+ 6	8	1-#7 and 1-#8	39-#6	11	#5	#5	13-#6	484	969	1304

SQUARE INTERIOR PANELS

Total Depth = 15 in. Rib Depth = 12 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
30'- 0" D=10.417 RIB NOT ON COLUMN LINE 0.749 CF/SF	50	2.22	15		6	2-#4	22-#5	9	#4	#4	9-#5
	100	2.33	15		6	1-#4 and 1-#5	22-#5	9	#4	#4	9-#5
	150	2.57	15	4 S 6 1	6	2-#5	25-#5	9	#4	#4	9-#5
	200	2.91	15*	4 S 6 1	6	1-#5 and 1-#6	21-#6	9	#4	#4	9-#5
	300	3.99	15*	4 S 6 2	6	2-#7	27-#6	9	#4	#5	12-#5
32'- 0" D=12.417 RIB ON COLUMN LINE 0.766 CF/SF	50	2.24	16		7	2-#4	24-#5	9	#4	#4	10-#5
	100	2.41	16		7	1-#4 and 1-#5	25-#5	9	#4	#4	10-#5
	150	2.71	16*	4 S 6 1	7	2-#5	30-#5	9	#4	#4	10-#5
	200	3.29	16*	4 S 6 1	7	2-#6	25-#6	9	#4	#4	12-#5
	300	4.12	19*	4 S 6 2	7	1-#6 and 1-#7	33-#6	9	#4	#5	10-#6
34'- 0" D=12.417 RIB ON COLUMN LINE 0.757 CF/SF	50	2.34	17		7	1-#4 and 1-#5	25-#5	10	#4	#4	10-#5
	100	2.61	17		7	2-#5	30-#5	10	#4	#4	10-#5
	150	3.06	17*	4 S 6 1	7	1-#5 and 1-#6	26-#6	10	#4	#4	12-#5
	200	3.85	17*	4 S 6 2	7	1-#6 and 1-#7	31-#6	10	#4	#5	10-#6
36'- 0" D=12.417 RIB ON COLUMN LINE 0.749 CF/SF	50	2.50	18		7	2-#5	29-#5	11	#4	#4	11-#5
	100	2.96	18*	4 S 6 1	7	1-#5 and 1-#6	26-#6	11	#4	#4	12-#5
	150	3.39	18*	4 S 6 1	7	2-#6	31-#6	11	#4	#4	10-#6
	200	4.23	18*	4 S 6 2	7	2-#7	37-#6	11	#4	#5	12-#6
38'- 0" D=14.417 RIB NOT ON COLUMN LINE 0.763 CF/SF	50	2.65	19		8	2-#5	34-#5	11	#4	#4	12-#5
	100	3.13	19*	4 S 6 1	8	1-#5 and 1-#6	30-#6	11	#4	#4	14-#5
	150	3.82	19*	4 S 6 1	8	2-#6	37-#6	11	#4	#5	12-#6

See the notes on Page 11-19.

Appendix D – Concrete Waffle Slab

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

f'_c = 4,000 psi
Grade 60 Bars

SQUARE EDGE PANELS

Total Depth = 19 in. Rib Depth = 16 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)
26'- 0" D=10.417 RIB NOT ON COLUMN LINE 0.967 CF/SF	50	2.25	13	0.662		19-#5+ 0	6	2-#4	19-#5	7	#4	#4	8-#5	125	250	336
	100	2.25	13	0.692		19-#5+ 0	6	2-#4	19-#5	7	#4	#4	8-#5	15'	302	407
	150	2.32	13	0.721		19-#5+ 0	6	1-#4 and 1-#5	19-#5	7	#4	#4	8-#5	177	380	477
	200	2.46	13	0.750		19-#5+ 0	6	2-#5	19-#5	7	#4	#4	8-#5	20'	470	548
	300	2.84	13	0.809		19-#5+ 0	6	2-#6	21-#5	7	#4	#5	8-#5	256	640	689
	400	3.38	13 *	0.875		19-#5+ 1	6	2-#7	18-#6	7	#5	#5	8-#5	308	804	830
	500	3.97	13 *	0.641		19-#5+ 0	6	1-#7 and 1-#8	22-#6	7	#5	#6	7-#6	36'	965	972
28'- 0" D=10.417 RIB NOT ON COLUMN LINE 0.952 CF/SF	50	2.25	14	0.688		21-#5+ 0	6	2-#4	21-#5	8	#4	#4	8-#5	155	310	417
	100	2.32	14	0.720		21-#5+ 0	6	1-#4 and 1-#5	21-#5	8	#4	#4	8-#5	188	375	505
	150	2.45	14	0.752		21-#5+ 0	6	2-#5	21-#5	8	#4	#4	8-#5	220	467	593
	200	2.63	14	0.783		21-#5+ 0	6	2-#6	21-#5	8	#4	#4	8-#5	253	580	682
	300	3.32	14 *	0.853		21-#5+ 1	6	2-#7	19-#6	8	#5	#5	9-#5	319	791	858
	400	3.93	14 *	0.639		21-#5+ 0	6	1-#7 and 1-#8	23-#6	8	#5	#6	8-#6	384	996	1034
30'- 0" D=10.417 RIB NOT ON COLUMN LINE 0.940 CF/SF	50	2.30	15	0.699		22-#5+ 0	6	1-#4 and 1-#5	22-#5	9	#4	#4	9-#5	190	379	510
	100	2.37	15	0.735		22-#5+ 0	6	2-#5	22-#5	9	#4	#4	9-#5	230	460	619
	150	2.52	15	0.770		22-#5+ 0	6	1-#5 and 1-#6	23-#5	9	#4	#4	9-#5	270	565	727
	200	2.91	15	0.806		22-#5+ 0	6	1-#6 and 1-#7	28-#5	9	#4	#5	9-#5	310	704	836
	300	3.64	15 *	0.891		22-#5+ 3	6	1-#7 and 1-#8	24-#6	9	#5	#5	11-#5	39'	964	1053
32'- 0" D=12.417 RIB ON COLUMN LINE 0.961 CF/SF	50	2.40	16	0.722		24-#5+ 0	7	2-#5	24-#5	9	#4	#4	10-#5	232	484	625
	100	2.56	16	0.760		24-#5+ 0	7	1-#5 and 1-#6	24-#5	9	#4	#4	10-#5	28'	562	757
	150	2.71	16	0.798		24-#5+ 0	7	2-#6	28-#5	9	#4	#4	10-#5	330	682	808
	200	3.16	16 *	0.848		24-#5+ 2	7	1-#6 and 1-#7	23-#6	9	#4	#5	10-#5	379	852	1020
	300	4.13	16 *	0.636		24-#5+ 1	7	1-#7 and 1-#8	29-#6	9	#5	#6	9-#6	477	1167	1283
34'- 0" D=12.417 RIB ON COLUMN LINE 0.950 CF/SF	50	2.43	17	0.733		25-#5+ 0	7	2-#5	25-#5	10	#4	#4	10-#5	277	554	746
	100	2.63	17	0.775		25-#5+ 0	7	2-#6	28-#5	10	#4	#4	10-#5	336	671	904
	150	3.03	17 *	0.824		25-#5+ 1	7	1-#6 and 1-#7	24-#6	10	#4	#5	11-#5	394	799	1062
	200	3.54	17 *	0.882		25-#5+ 5	7	2-#7	27-#6	10	#5	#5	12-#5	453	1004	1220
36'- 0" D=12.417 RIB ON COLUMN LINE 0.940 0CF/SF	50	2.53	18	0.754		27-#5+ 0	7	1-#5 and 1-#6	28-#5	11	#4	#4	11-#5	328	656	882
	100	2.96	18	0.805		27-#5+ 1	7	1-#6 and 1-#7	34-#5	11	#4	#4	11-#5	397	794	1069
	150	3.30	18 *	0.867		27-#5+ 5	7	2-#7	28-#6	11	#4	#5	13-#5	467	934	1257
	200	3.86	18 *	0.634		27-#5+ 2	7	1-#7 and 1-#8	33-#6	11	#5	#5	10-#6	536	1168	1444
38'- 0" D=14.417 RIB NOT ON COLUMN LINE 0.958 CF/SF	50	2.68	19	0.774		28-#5+ 1	8	2-#6	33-#5	11	#4	#4	12-#5	388	776	1045
	100	3.10	19 *	0.847		28-#5+ 6	8	1-#6 and 1-#7	28-#6	11	#4	#5	13-#5	470	940	1266
	150	3.60	19 *	0.899		28-#5+10	8	2-#7	34-#6	11	#5	#5	15-#5	552	1104	1486
	200	4.27	19 *	0.633		28-#5+ 6	8	1-#7 and 1-#8	39-#6	11	#5	#6	13-#6	634	1358	1706

SQUARE INTERIOR PANELS

Total Depth = 19 in. Rib Depth = 16 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
26'- 0"	50	2.23	13		6	2-#4	19-#5	7	#4	#4	8-#5
	100	2.23	13		6	2-#4	19-#5	7	#4	#4	8-#5
	150	2.23	13		6	2-#4	19-#5	7	#4	#4	8-#5
	200	2.38	13		6	1-#4 and 1-#5	19-#5	7	#4	#4	8-#5
	300	2.52	13		6	2-#5	20-#5	7	#4	#4	8-#5
	400	2.85	13 *	4 S 6 1	6	1-#5 and 1-#6	24-#5	7	#4	#4	8-#5
	500	3.40	13 *	4 S 6 1	6	2-#6	20-#6	7	#4	#5	9-#5
28'- 0"	50	2.23	14		6	2-#4	21-#5	8	#4	#4	8-#5
	100	2.23	14		6	2-#4	21-#5	8	#4	#4	8-#5
	150	2.35	14		6	1-#4 and 1-#5	21-#5	8	#4	#4	8-#5
	200	2.35	14		6	1-#4 and 1-#5	21-#5	8	#4	#4	8-#5
	300	2.78	14	4 S 6 1	6	1-#5 and 1-#6	25-#5	8	#4	#4	8-#5
	400	3.37	14 *	4 S 6 1	6	2-#6	21-#6	8	#4	#5	10-#5
30'- 0"	50	2.22	15		6	2-#4	22-#5	9	#4	#4	9-#5
	100	2.22	15		6	2-#4	22-#5	9	#4	#4	9-#5
	150	2.33	15		6	1-#4 and 1-#5	22-#5	9	#4	#4	9-#5
	200	2.52	15		6	2-#5	24-#5	9	#4	#4	9-#5
	300	3.13	15 *	4 S 6 1	6	2-#6	22-#6	9	#4	#4	10-#5
32'- 0"	50	2.24	16		7	2-#4	24-#5	9	#4	#4	10-#5
	100	2.37	16		7	1-#4 and 1-#5	24-#5	9	#4	#4	10-#5
	150	2.44	16		7	1-#4 and 1-#5	25-#5	9	#4	#4	10-#5
	200	2.86	16		7	1-#5 and 1-#6	30-#5	9	#4	#4	10-#5
	300	3.72	16 *	4 S 6 1	7	1-#6 and 1-#7	27-#6	9	#4	#5	12-#5
34'- 0"	50	2.34	17		7	1-#4 and 1-#5	25-#5	10	#4	#4	10-#5
	100	2.36	17		7	1-#4 and 1-#5	26-#5	10	#4	#4	10-#5
	150	2.66	17		7	2-#5	31-#5	10	#4	#4	10-#5
	200	3.17	17 *	4 S 6 1	7	2-#6	25-#6	10	#4	#4	12-#5
36'- 0"	50	2.36	18		7	1-#4 and 1-#5	27-#5	11	#4	#4	11-#5
	100	2.60	18		7	2-#5	31-#5	11	#4	#4	11-#5
	150	2.96	18	4 S 6 1	7	1-#5 and 1-#6	26-#6	11	#4	#4	12-#5
	200	3.50	18 *	4 S 6 1	7	1-#6 and 1-#7	30-#6	11	#4	#4	10-#6
38'- 0"	50	2.41	19		8	1-#4 and 1-#5	30-#5	11	#4	#4	12-#5
	100	2.76	19		8	2-#5	26-#6	11	#4	#4	12-#5
	150	3.18	19 *	4 S 6 1	8	1-#5 and 1-#6	31-#6	11	#4	#4	14-#5
	200	3.91	19 *	4 S 6 1	8	1-#6 and 1-#7	36-#6	11	#4	#5	16-#5

See the notes on Page 11-19.

11-46 CONCRETE REINFORCING STEEL INSTITUTE

Appendix D – Concrete Waffle Slab

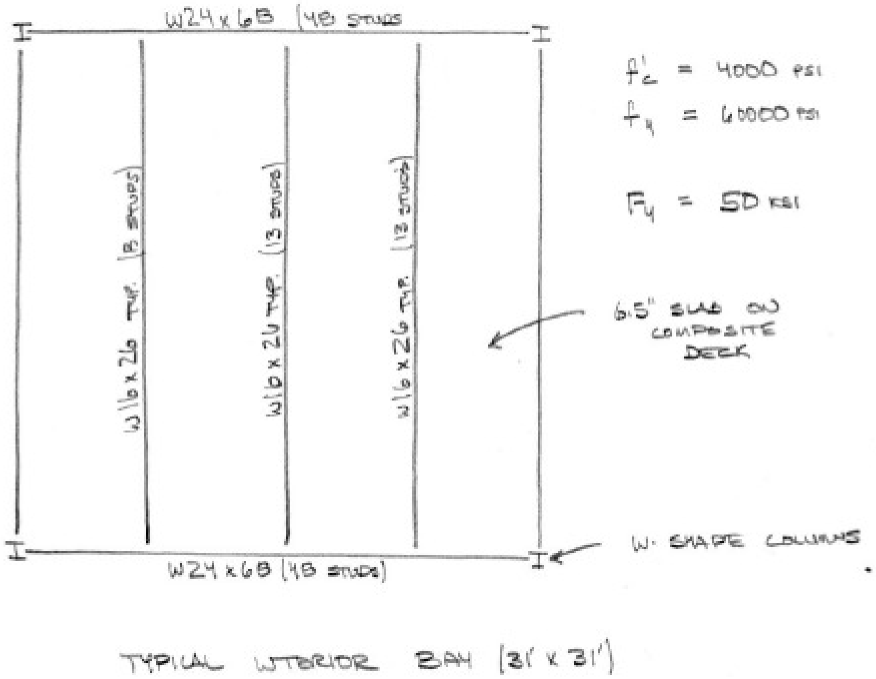
WAFFLE FLAT SLAB SYSTEM 19″ X 19″ Voids: 5″ Ribs @ 24″

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: (1) Steel (psf)	Square Edge Column: $c_1 = c_2$ (in.)	Square Edge Column: γ_f	Square Edge Column: (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)	Moments: +M Bot. (ft-k)	Moments: −M Int. (ft-k)	SQUARE INTERIOR PANELS: (1) Steel (psf)	Square Interior Column: $c_1 = c_2$ (in.)	Square Interior Column: (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 = 14½ in.		Rib Depth = 10 in.		Total Slab Depth = 4½ in.													Total Depth = 14½ in.		Rib Depth = 10 in.		Total Slab Depth = 4½ in.					
30'- 0" D=10.417 RIB NOT ON COLUMN LINE 0.784 CF/SF	50	2.37	15	0.817		22-#5+ 0	6	2-#5	22-#5	9	#4	#4	9-#5	166	333	448	2.22	15		6	2-#4	22-#5	9	#4	#4	9-#5
	100	2.52	15 *	0.864		22-#5+ 1	6	1-#5 and 1-#6	24-#5	9	#4	#4	9-#5	207	413	557	2.33	15		6	1-#4 and 1-#5	22-#5	9	#4	#4	9-#5
	150	3.02	15 *	0.914		22-#5+ 4	6	1-#6 and 1-#7	21-#6	9	#4	#5	9-#5	247	519	665	2.64	15 *	3 S 4 1	6	2-#5	27-#5	9	#4	#4	9-#5
	200	3.41	16 *	0.631		22-#5+ 1	6	2-#7	24-#6	9	#4	#5	11-#5	286	652	771	3.13	15 *	3 S 4 1	6	2-#6	22-#6	9	#4	#4	10-#5
	300	4.49	21 *	0.626		22-#5+ 2	6	2-#8	23-#7	9	#5	#6	10-#6	359	855	967	4.12	17 *	3 S 4 2	6	2-#7	21-#7	9	#4	#5	9-#6
32'- 0" D=12.417 RIB ON COLUMN LINE 0.798 CF/SF	50	2.46	16	0.836		24-#5+ 0	7	2-#5	24-#5	9	#4	#4	10-#5	203	407	548	2.37	16		7	1-#4 and 1-#5	24-#5	9	#4	#4	10-#5
	100	2.74	16 *	0.896		24-#5+ 4	7	2-#6	29-#5	9	#4	#4	10-#5	252	505	679	2.48	16		7	1-#4 and 1-#5	27-#5	9	#4	#4	10-#5
	150	3.25	16 *	0.631		24-#5+ 2	7	1-#6 and 1-#7	25-#6	9	#4	#5	11-#5	301	620	811	2.98	16 *	3 S 4 1	7	1-#5 and 1-#6	23-#6	9	#4	#4	10-#5
	200	3.92	19 *	0.628		24-#5+ 3	7	1-#7 and 1-#8	21-#7	9	#5	#5	9-#6	347	778	935	3.55	16 *	3 S 4 1	7	2-#6	27-#6	9	#4	#5	12-#5
	300	4.54	26 *	0.622	3 S 4 1	24-#5+ 4	7	1-#7 and 1-#8	20-#8	9	#5	#6	12-#6	427	854	1150	4.31	23 *	3 S 4 2	7	1-#6 and 1-#7	20-#8	9	#4	#5	11-#6
34'- 0" D=12.417 RIB ON COLUMN LINE 0.790 CF/SF	50	2.55	17 *	0.857		25-#5+ 2	7	1-#5 and 1-#6	28-#5	10	#4	#4	10-#5	243	486	654	2.36	17		7	1-#4 and 1-#5	26-#5	10	#4	#4	10-#5
	100	3.10	17 *	0.914		25-#5+ 6	7	1-#6 and 1-#7	25-#6	10	#4	#5	11-#5	302	603	812	2.77	17 *	3 S 4 1	7	2-#5	24-#6	10	#4	#4	10-#5
	150	3.49	19 *	0.626		25-#5+ 3	7	2-#7	22-#7	10	#4	#5	10-#6	358	717	965	3.19	17 *	3 S 4 1	7	1-#5 and 1-#6	28-#6	10	#4	#4	13-#5
	200	4.37	23 *	0.624		25-#5+ 5	7	2-#8	26-#7	10	#5	#6	11-#6	412	900	1110	3.92	17 *	3 S 4 2	7	1-#6 and 1-#7	24-#7	10	#4	#5	10-#6
36'- 0" D=12.417 RIB ON COLUMN LINE 0.784 CF/SF	50	2.77	18 *	0.883		27-#5+ 5	7	2-#6	34-#5	11	#4	#4	11-#5	288	575	774	2.60	18		7	2-#5	31-#5	11	#4	#4	11-#5
	100	3.37	18 *	0.629		27-#5+ 3	7	2-#7	30-#6	11	#4	#5	10-#6	357	714	962	3.05	18 *	3 S 4 1	7	1-#5 and 1-#6	28-#6	11	#4	#4	12-#5
	150	3.94	22 *	0.625		27-#5+ 5	7	1-#7 and 1-#8	27-#7	11	#5	#5	11-#6	423	845	1138	3.55	18 *	3 S 4 2	7	2-#6	25-#7	11	#4	#4	15-#5
	200	4.47	29 *	0.621	3 S 4 1	27-#5+ 5	7	2-#8	23-#8	11	#5	#5	13-#6	478	957	1288	4.27	22 *	3 S 4 2	7	1-#6 and 1-#7	23-#8	11	#4	#5	12-#6
38'- 0" D=14.417 RIB NOT ON COLUMN LINE 0.795 CF/SF	50	3.10	19 *	0.904		28-#5+ 9	8	1-#6 and 1-#7	28-#6	11	#4	#5	13-#5	340	680	916	2.76	19 *		8	2-#5	26-#6	11	#4	#4	12-#5
	100	3.77	22 *	0.921		28-#5+14	8	2-#7	26-#7	11	#5	#5	11-#6	419	838	1128	3.48	19 *	3 S 4 1	8	2-#6	25-#7	11	#4	#4	15-#5
	150	4.41	29 *	0.621		28-#5+ 7	8	1-#7 and 1-#8	24-#8	11	#5	#6	13-#6	491	982	1322	4.14	20 *	3 S 4 2	8	1-#6 and 1-#7	29-#7	11	#4	#5	13-#6

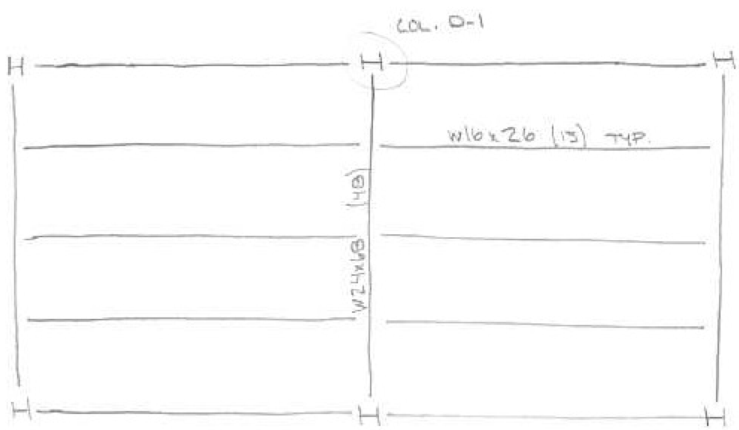
See the notes on Page 11-19.

Appendix E - Composite Steel Deck on Composite Steel Beams



Appendix E - Composite Steel Deck on Composite Steel Beams|

CHECKING BEAMS | GIRDERS TYING INTO COLUMN (D)-(1)



CHECK TYPICAL W16 x 26 BEAM:

SPAN = 31'

SPACING = 7'-9"

$A_T = 240.25\ ft^2$

LIVE LOAD:

80 PSF

LL = 80 PSF

DEAD LOAD:

10 PSF + 20 PSF + 71 PSF

DL = 101 PSF

REDUCE LL:

$$80\left(.25 + \frac{15}{\sqrt{(2)(240.25)}}\right) = 74.7438 \text{ PSF}$$

$$TL = 1.2(101) + 1.6(74.7438) = 240.79 \text{ LBS}(7.75') = 1866.12 \tfrac{\text{LBS}}{\text{FT}}$$

$$M = \frac{1866(31)^2}{8} = 224.168 \text{ K·FT} \qquad M_{+\text{SELF WEIGHT}} = \frac{1.8972(31)^2}{8} = 227.9$$

SHEAR STUD 3/4" φ

$$Q_n = 13.3^K \qquad \Sigma Q_n = (15)(13.3) = 199.5^K$$

$$b_{EFF} = .5(7.75)(12) = 46.5$$
$$.125(31)(12) = 46.5$$
$$46.5(2) = b_{EFF} = 93''$$

Appendix E - Composite Steel Deck on Composite Steel Beams

CHECK TYPICAL W16x26 BEAM:

COMPOSITE ACTION w/ 15 SHEAR STUDS

$\Sigma Q_n = 199.5^k$ $Y_2 = 6.5'' - \frac{199.5}{1.7(4)(93)} = 6.18''$

{AISC T.3-19} $\rightarrow a = .64''$

$\phi M_n = 311$ K·FT
AT LEAST

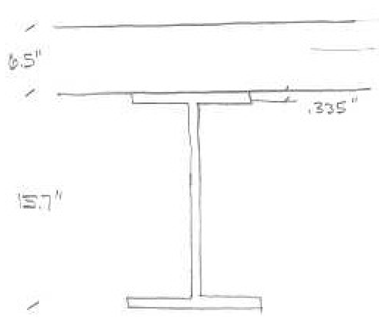
$a = \frac{199.5}{.85(4)(93)} = .63093''$ ✓

$C_c = .85(4)(93)(.63093) = 199.5^k$

$T_s = 7.68(50) = 384^k$

$T_s = 384 - 199.5 = \frac{184.5^k}{2} = 92.25^k$

$C_c = 199.5^k$ $T_s = 199.5^k$
$C_s = 92.25^k$ $T_s = 92.25^k$



a = .63093"

$t_f = .345''$
$b_f = 5.50''$
$d = 15.7''$
$t_w = .250''$

$M_n = 199.5(.315465) + 92.125(6.675) - 2.624(6.83977) - 187.625(14.35) - 94.875(22.0275)$

$M_n = 343.53$ FT·K

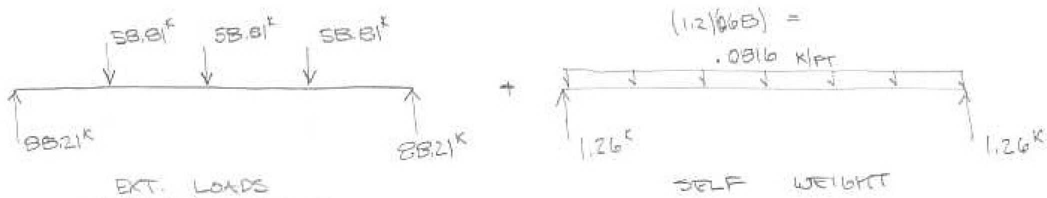
$\phi M_n = 309.2$ FT·K

$\geq$

227.9 FT·K

BEAM IS ADEQUATELY SIZED.

Appendix E - Composite Steel Deck on Composite Steel Beams



CHECK W24x68 GIRDER:

$M = 911.5$ K·FT

$M = \frac{.0816\,(31)^2}{8} = 9.802$ K·FT

$M_u = 921.302$ K·FT

$\Sigma Q_n = (13.3)(48) = 638.4^K$

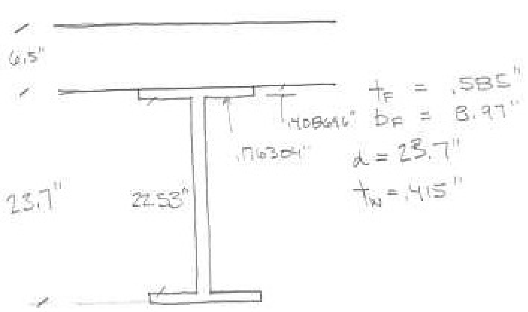
$b_{eff} = .5(31)(12) = 186.0''$
$\quad\;\; .125(31)(12) = 46.5''$

$b_{eff} = 93''$

$a = \frac{638.4}{.85(4)(93)} = 2.02''\downarrow$

$C_c = 638.4^K$ $\quad T_s = 50(20.1) = 1005^K$

$1005 - 638.4 = \frac{366.6}{2} = 183.3^K$



$M_n = 638.4(1.01) + 183.3(6.70435)$
$\quad - 79.07(6.99685) - 467.498(18.35)$
$\quad - 262.373(29.9075)$

$M_n = 1258.75$

$\phi M_n = 1132.8$ K·FT > 921.3 K·FT

GIRDER IS ACCEPTABLE.