TOWER 333

Technical Assignment 2

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Paul Parfitt

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Pennsylvania State University

Faculty Advisor: Dr. Andres Lepage

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Executive Summary:

The purpose of this report is to determine through analytical methods and a comparison of industry system information, possible alternatives to the existing floor system for Tower 333. The existing system is a composite concrete deck supported by long span composite steel beams and girders.

Existing System:

The existing floor system is a 2-1/2" concrete slab on a 3" deep metal composite deck with an f'c of 4,000psi and WWF 6x6 W3.5xW3.5 reinforcing. Supporting the slab are W18x40 composite beams which span 42' N-S in a typical bay. The beams frame into composite girders on the interior which are typically W18x97 spanning E-W.

Alternative Systems:

When analyzing the alternative floor systems, criteria such as the overall weight of the system, vibration control, fire proofing, ease of construction and relative cost were considered. These alternative systems were then compared to the criteria performance of the existing floor system.

The following are the alternative floor systems considered:

1. Existing steel beam framing with light weight concrete deck.
2. Open web steel bar joists with thinner concrete deck.
3. 2-way flat slab with drop panels
4. 2 way post tensioned slab

Conclusion:

The main idea taken into consideration in this report was to develop a system that will allow for a core only design of Tower 333's lateral system. This lateral system would be utilizing the pre-existing concrete core of a previously abandoned construction project. Therefore the biggest factor considered was overall weight of each of the systems. Lowering the weight will decrease the seismic loads on the building, thus eliminating the need for the moment frames on the exterior of the building and turning it into a core only design. This slimming down of the building weight does have its consequences however in the form of costs, less fire protection and vibration control. It is important to note that elimination of the exterior moment frames will result in the need to carefully investigate any torsional movements of the overall building framing. While this is out of the scope of this particular report, it will be investigated in more detail in Technical Report 3.

The 2-way flat slab and post tensioned slab systems are ideal for controlling vibration and perform well for fire ratings due to their large mass. However, it is because of their heavy weights that they are almost immediately eliminated as a good alternative compared to the existing system. The steel bar joists on the other hand, have the advantage of being a less expensive (structural costs) and extremely light system. The downside to open web bar joists, especially with a thinner concrete slab is its vulnerability to vibration, which can be a major issue to ignore when designing an office environment. Open web bar joists were found to be the best alternative floor system to eliminate weight, but still require adequate fire protection. In conclusion, the best viable system that performs well under all the listed criteria is the existing composite framing utilizing a light weight concrete deck.

Existing Structural System:

Introduction:

Tower 333 is an 18 story office building with 8 levels of below ground parking. The building is scheduled to be completed in December of 2007. The code used to design Tower 333 was the IBC 2003 with reference to ASCE-7 02' for load values. For this analysis, ASCE -7 05' was used as an update. Floor loadings used were 50psf live load, 20psf partitions, 5psf mechanical, and 5psf miscellaneous.

Existing Floor System:

The typical bay of the upper office floors of Tower 333 are supported by 42' long W18x40 composite beams with a camber of 1-1/2" and 30' long W18x97 composite girders with a camber of ¾". Both have a strength of 50ksi. These members in turn support a 2-1/2" concrete slab on a 3" deep composite metal deck with the strength of the concrete being 4,000psi. To control expansion and contraction of the concrete there is WWF 6x6 W3.5xW3.5 reinforcing in the slab. The floor to floor height is 13'-10" and the overall weight of this system is 58 psf with a framing depth of 24". The finished floor to finished ceiling height is 10' which allows 2-10" of plenum clearance space. This plenum space is utilized for the mechanical equipment which incorporates a variety of 12" and 14" deep ducts to transport air to strip diffusers along the perimeter of the building. Refer to Figure 1 for a framing plan of the existing system.

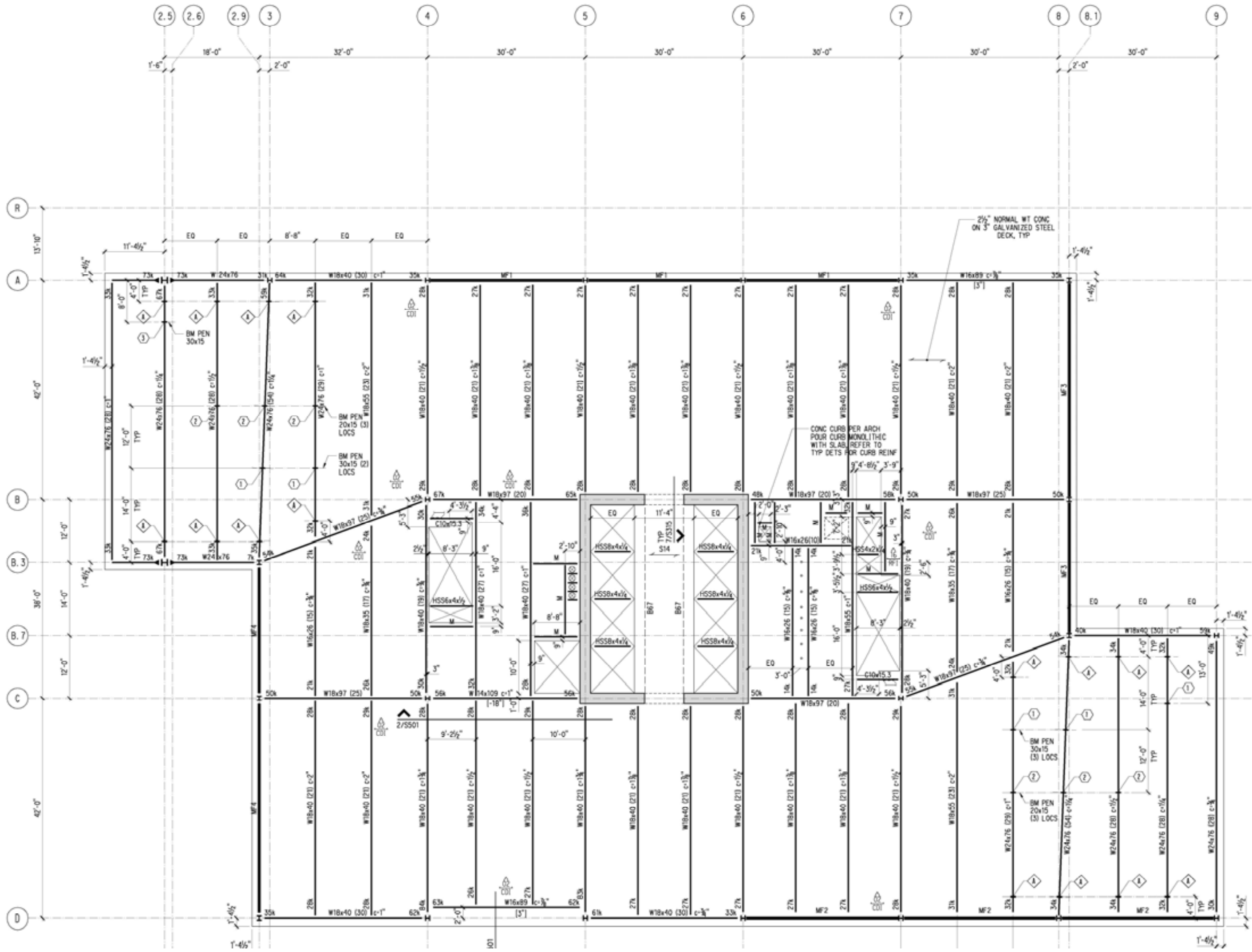

Figure 1:
Existing Structural Steel Floor Framing

Alternative System #1: Existing Framing with Lightweight Concrete

With the idea of lighter is better for this study and with the convenience of using the existing framing, using lightweight concrete is a viable alternative to the existing floor system. The drop in concrete deck weight from 50 psf to 39 psf is a considerable advantage in weight. For 23,000sq.ft floor plates a savings of 253 kips per floor is realized. With seventeen additional floors, over 4,300 kips of dead weight can be eliminated. This does not account for the smaller beam and girder sizes that also result from the lower slab weight. This loss of dead weight could have a substantial impact on eliminating the moment frames and reaching a core only lateral system. Keeping the slab the same thickness, and utilizing the same type of steel framing, the 2 hour fire protection criterion remains the same as the existing system. The disadvantages to the light weight concrete are that it will be more expensive to produce. The lighter system might also pose a problem with vibration control. However, the cost and time savings of eliminating the exterior moment frames from the structure could outweigh the additional cost of utilizing lightweight concrete. In conclusion, this would be an advantageous alternative system and should be analyzed further.

Using the Vulcraft steel roof and floor deck catalog, and the AISC Manual of Steel Design LRFD 2005, it was determined that the new system would use a 2-1/2" lightweight concrete slab on a 3" composite deck with a recommended WWF of 6x6-W1.4xW1.4. Supporting the slab should be a W18x35 beam with a total of 26 shear studs. The girders would be W18x60 with a total of 24 shear studs. Camber on both girders and beams will be approximately the same as the original design. This alternative is reflected in Figures 2 and 3 that follow.

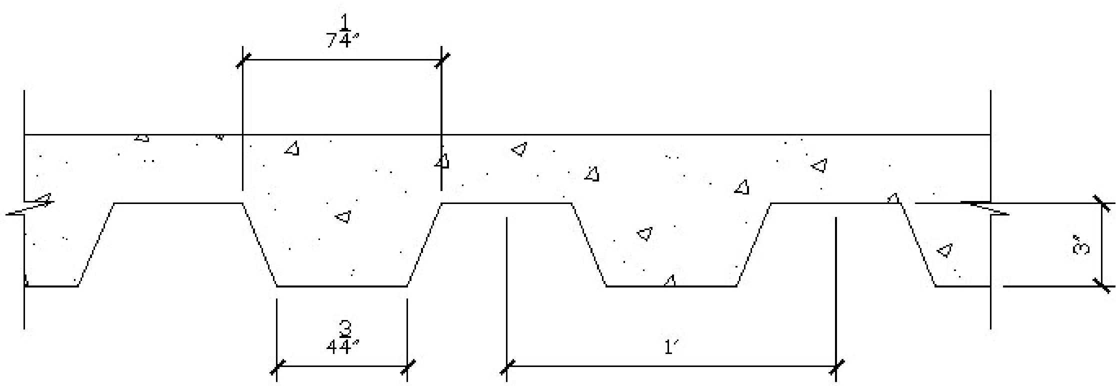

Figure 2: Composite Deck with Lightweight Concrete.

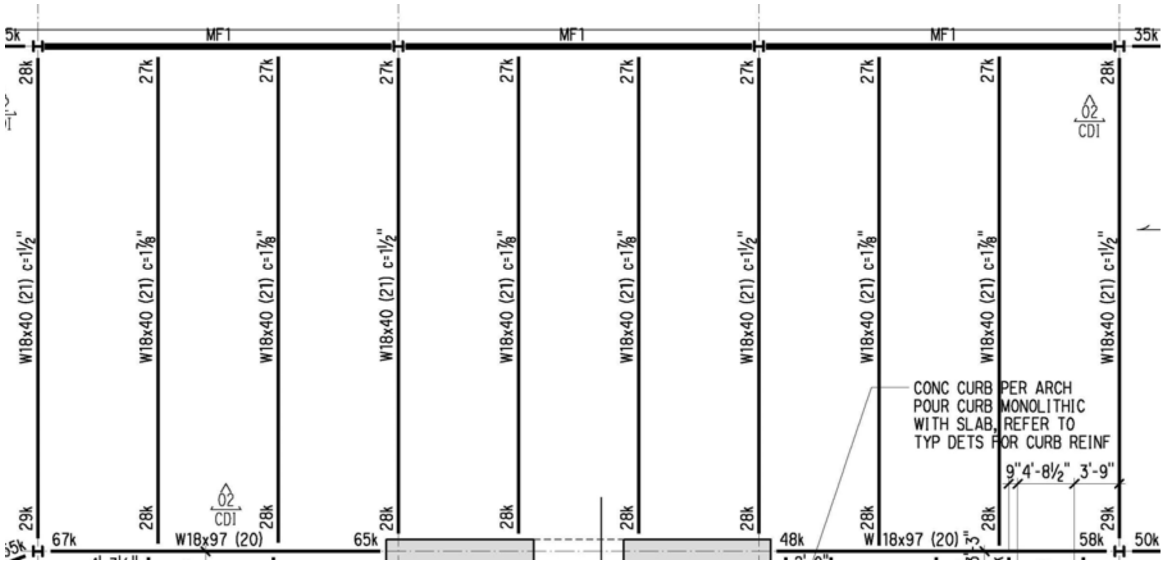

Figure 3: Existing Framing System Typical Bay

Alternative System #2: Open Web Steel Joists with 2-1/2” Deck

If weight is used as the overall controlling concern, then open web steel joists would be a good alternative floor system. Their extremely light weight construction would reduce the deadweight even further than the light weight concrete of alternative system #1. Having a total dead weight of 35 psf, including the 2-1/2” concrete slab, with the joists spaced at 24” on center, the open web joists are the lightest of all five systems. This would likely provide the best chance at achieving a core only lateral system.

Open web joists are also very economical to construct especially considering that the 2-1/2” slab eliminates 3” worth of concrete over the whole floor. However, with the 42’ spans and their light weight construction, the ease at which this system will resist vibration is going to be a big disadvantage. Another disadvantage is the fact that this system will be over 24” deep, including the slab, joists and girders. This deep system will leave the mechanical system, including distribution ducts and equipment with very little room, which might force the finished floor to ceiling height to drop below the 10’. This change in architecture of the building might not be beneficial for the building especially considering that the 10’ floor to ceiling heights, in conjunction with high windows, have an impact on the building’s LEED rating regarding daylight penetration. The complications of fireproofing open web joists also pose a disadvantageous issue. Thus it can be determined that due to floor vibrations and a deeper floor depth that this system is not going to be an advantage over the existing system.

Using the Vulcraft steel roof and floor deck catalog, the New Columbia Joist Company catalog and the AISC LRFD 05' manual, the joist system designed is a 2-1/2" normal weight concrete slab on a 9/16" non-composite deck, with 24K9 joists spanning 42' at 24" on center. The girders supporting the joists were determined to be W24x76 non composite. It is worthy to note that if sacrificing weight in the girder is not an issue; a shallower W-shape can be achieved with a W21x83, W18x86 or a W16x100.

Figures 4 and 5 that follow provide additional detail on the open web joist alternative for Tower 333.

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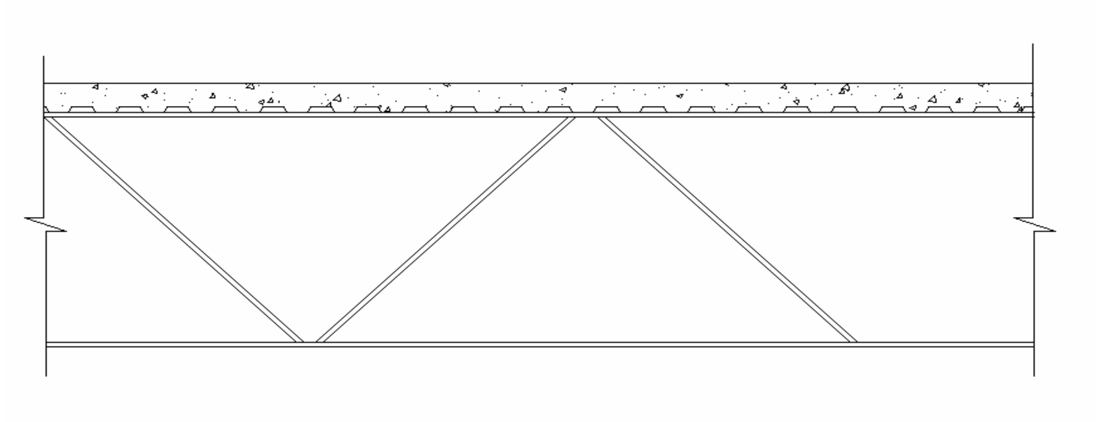


Figure 4: 24K9 Open Web Bar Joists with 2-1/2" Concrete Deck

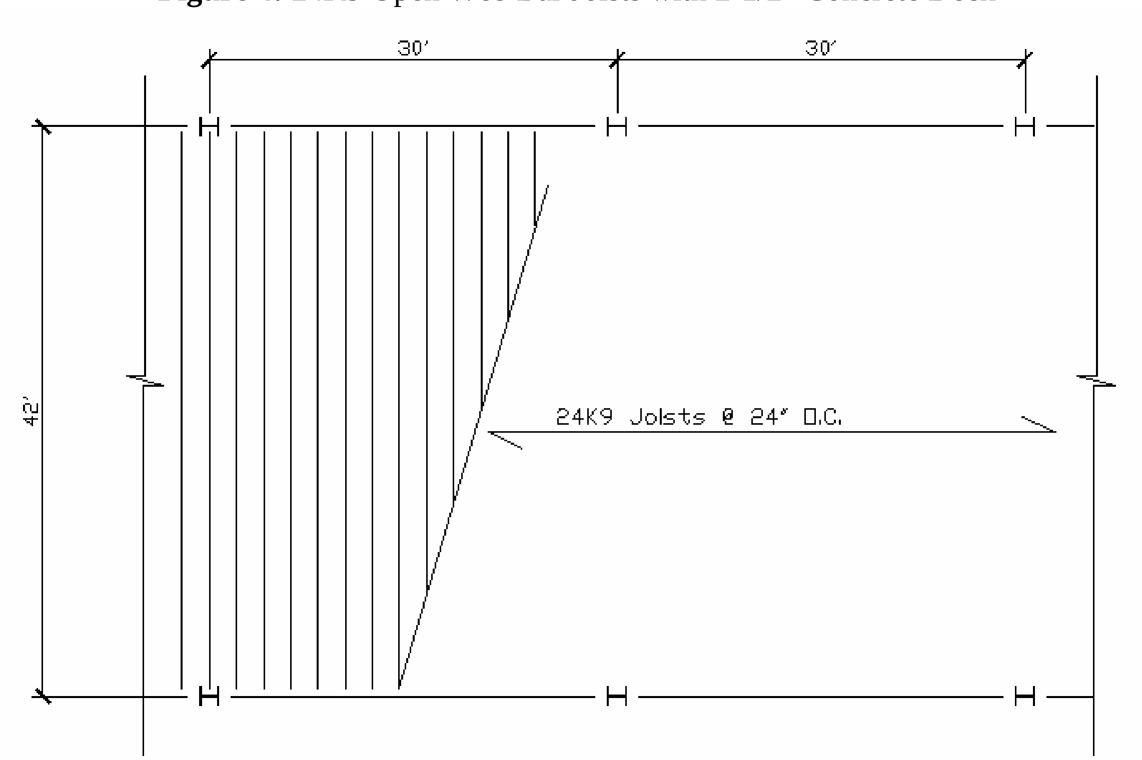


Figure 5: Typical Bay for Open Web Bar Joists

Alternative System #3: 2-Way Flat Slab with Drop Panels

Despite Tower 333 being a steel framed building, one alternative would be to consider concrete framing. A 2-way flat slab might be an efficient floor system. However, with the typical bay of the existing structure being 30'x42', additional columns would have to be added to achieve a smaller bay size for economy reasons. A square bay size would be the most advantageous alternative. This adding of columns could pose two problems. One being that the addition of columns into the middle of the floor eliminates rentable floor space as well as the open plan design. The second problem is that these columns will add additional cost and require a retrofit of the existing foundations.

One advantage to a flat slab is its ease of constructability. With the exception to the drop panels, very little formwork is needed. This allows these systems to be built efficiently and at low cost. This 2-way slab design for Tower 333 results in the slab having a depth of 10.5" and drop panels 9" deep. Therefore the overall depth of the floor system is less than 24". This decrease in floor depth allows the mechanical equipment more room in the plenum space while still maintaining the 10' high floors the architect has specified.

The main disadvantage to this system is its weight. The dead weight of this system with 30'x30' bays is approximately 150psf which is more than double the previous two systems. For 20'x20' bays the dead weight is 116psf. With typical bays in Tower 333 being 20'x30' we can then reason that the dead weight of the system would be somewhere between 116psf and 150psf. This increase in dead weight, along with the building located in a seismic zone and being 260ft high will immediately eliminate any possibility of using the existing core as a core only lateral system. Therefore system #3 has been eliminated from the list of viable alternative floor systems.

Using the CRSI 2002 design guide it was determined that for a 30'x30' square edge panel the slab thickness would need to be 10.5". A preliminary analysis and design of the slab is listed below:

30'x30' Square Edge Bay

	Reinforcing:		**Size of Drop Panel:**
	Col. Strip	Mid Strip	9" deep
Top. Ext.	14 #5	--------------	10' wide
Bottom	13 #8	11 #7	**Min. Sq. Column Size:** 16"
Top. Int.	18 #6	14 #5	**Conc. Weight:** 150psf

The design of a 20’x20’ square edge panel would require a minimum slab thickness of 9”.

20’x20’ Square Edge Bay

	Reinforcing:		Size of Drop Panel:
	Col. Strip	Mid Strip	2.5" deep
Top. Ext.	10 #4		6.67' wide
Bottom	12 #4	10 #4	**Min. Sq. Column Size:** 14"
Top. Int.	19 #4	10 #4	**Conc. Weight:** 116psf

Figures 6 and 7 that follow show the general design layout for this alternative system.

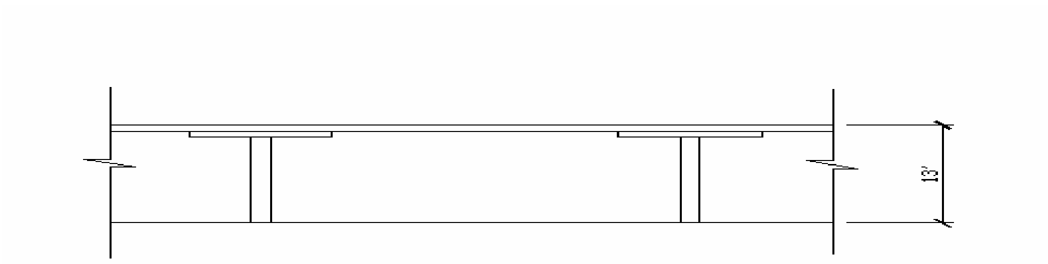


Figure 6: 2-Way Flat Slab with Drop Panels

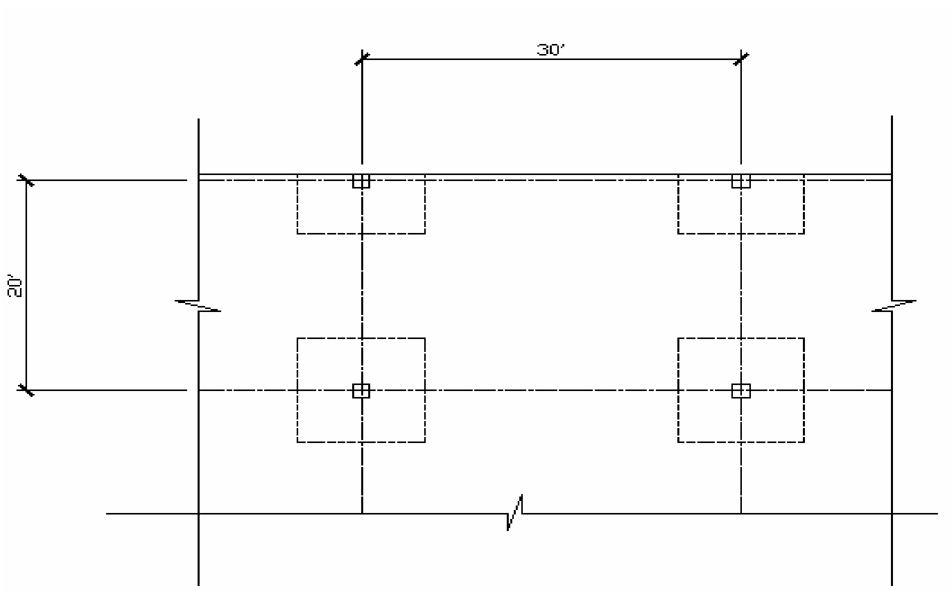


Figure 7: Typical Bay of 2-Way Flat Slab

Alternative System #4: 2-Way Post-Tensioned Slab

The 2-way post-tensioned slab alternative floor system is similar to the 2-way flat slab except for the fact that it does not need extra columns to create smaller bay sizes. Due to the post tensioning tendons, the slab is capable of spanning Tower 333's full bay spans of 30' and 42'. This advantage allows the retention of column free space for an open floor plan, which in turn means more rentable space and a higher quality space from a real estate perspective Another advantage is the depth of the slab. The overall floor depth, including the drop heads which were determined to be at least 7.5" deep, is 19". This leaves the mechanical equipment with over 2' of usable space.

One of the disadvantages to the 2-way post tensioned slab is the laying of the post-tensioned tendons. The laying of the tendons is a complicated process, which leaves little room for error. The large dead weight of the post-tensioned system is another negative factor in this system.

A calculated slab depth of 11.5", not counting the drop heads, results in the post-tensioned floor system weighing almost 150psf. This is more than double the weight of alternate systems #1 and #2. Also, given the long span of 42' which is slightly greater than the PTI recommended max span of 40' likely could result in the use of higher strength concrete and larger numbers of high strength tendons. Along with the heavy slab and long spans is the need for large drop heads to minimize deflection and conventional stresses. In summary, it was concluded that due to the large dead weight of the 2-way post tensioned slab which would generate additional seismic loads and the long span condition, that this alternate system would not fit the requirements for pursuing a core only lateral system.

Following the PTI design guide for post tensioned slabs and the Atlas Prestressing Corp. design workbook provided by Dr. Boothby for use in preliminary design, the resulting 2-way post tensioned slab was 11.5" deep with 20" square columns, 23 - ½" dia. tendons running in the 30' span and 44, ½" dia. tendons running in the 42' span. The heavy slab resulted in the need for drop heads of a minimum thickness of 7.5" primarily to accommodate punching shear. Had this system proven to be a viable alternative, further analysis would be performed to determine the width of the drop heads and the reinforcing needed in the slab. The tendon layout and resulting forces used for the design for the shorter span direction is shown in Figure 8.

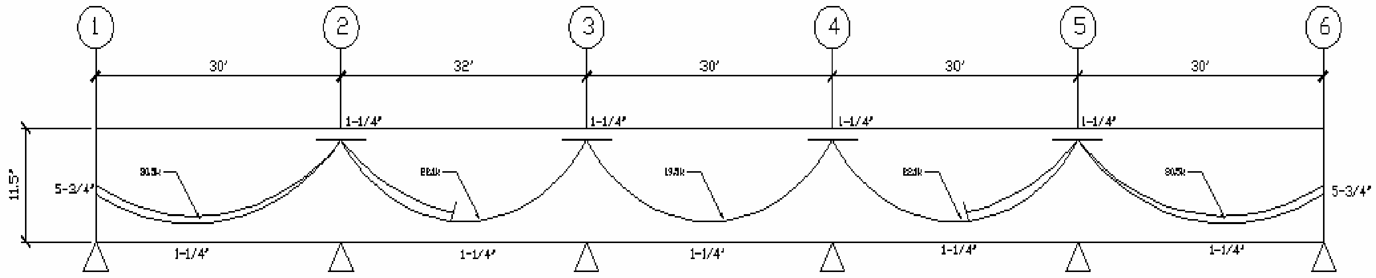


Figure 8: Draping Diagram with Tendon Forces

Summary and Conclusions:

Alternative System Comparison:

The results of the alternative floor system analysis and preliminary design for Tower 333 are shown in the comparison chart that follows (Figure 9).

	Open Web Joists	Lightweight Concrete & Steel Beams	2-Way Flat Slab	2-Way Post-Tensioned Slab	Normal Weight Concrete & Steel Beams
Weight	35psf	39psf	116-150psf	144psf	50psf
Max Depth	26.5 inches	23.7 inches	19.5 inches	19 inches	23.7 inches
Column Free Floor Plate?	YES	YES	NO	YES	NO
Vibration	YES	NO	NO	NO	NO
Additional Fire Proofing	YES	YES	NO	NO	YES
Constructability	Easy	Medium	Easy	Medium	Medium
Relative Cost	High	Medium	Low	Low	Medium
Alternative to Existing?	NO	YES	NO	NO	Existing System

Figure 9
Alternative System Comparison Chart

All four systems analyzed in this report would in fact work for Tower 333 given the right circumstances and requirements. The main criterion which resulted in the largest effect was the weight of each system. The eventual goal is to achieve a core only lateral system. This would be achieved by utilizing the existing core and foundation system previously abandoned by a different owner of the site due to financial issues. The existing system of composite W shapes, and concrete on composite metal deck already requires the use of moment frames on the exterior of the building in conjunction with the existing core system. Thus, any system that produces substantially higher dead weights was immediately recognized as at a disadvantage and quickly eliminated from the list of viable alternatives.

The 2-way flat slab does have the advantage of thinner floors and ease of constructability with no need for additional fire protection. However the addition of columns to create smaller bays creates the need for retrofitting the foundation as well as eliminating the open-plan floor plate. This in addition to the heavy weight of the 2-way flat slab eliminates it as an option.

The 2-way post tensioned slab also has the advantage of thinner floors and no additional fireproofing. The post tensioning system would allow column free floor plates and make the system ideal were it not for the increased weight and unusual long span. Thus due to the heavy weight and the 42' span being slightly larger than the PTI recommendation, the 2-way post tensioned slab is also eliminated.

One alternative system that is extremely light is the open web joist system. The substantial decrease in dead weight of the system makes the open web joists ideal for the goal of turning Tower 333's lateral system into a core only system. However, due to the decreased weight, the open web joists are susceptible to vibration. The thin 2.5" deck, light weight joists and 42' long span drastically limit the amount of vibration the floor system will resist. Along with resistance to vibration is the disadvantage of fireproofing. Spray on fireproofing for open web joists is not only costly but difficult to do. The depth of the open web steel joists is also a factor. At over 24"deep the joists are pushing the limits of how much space the mechanical equipment will have. With these factors in mind, the open web joists are then scratched from the list of alternative floor systems.

The only alternative floor system that fits the criteria of lighter weight, resistance to fire and vibration, economical and minimum floor depth is the existing framing system with a lightweight concrete deck. By leaving the deck the same depth, a 2 hour fire rating is maintained while also resisting floor vibrations. Utilizing the same steel framing, with the exception of lighter W shapes, no additional costs to fireproofing the steel is needed. By using lightweight concrete on the composite deck, the dead loads are greatly reduced. These advantages lead to the lightweight concrete deck as the best possibility of a core only lateral system while still maintaining the functionality of the original existing system.

References:

AISC Manual of Steel Construction, LRFD, Thirteenth Edition 2005

Atlas Prestressing Corp. Post-Tensioned Concrete Design Workbook

Post-Tensioning Institute Design of Post-Tensioned Slabs

CRSI Handbook 2005

ACI 318 - 05

Appendix:

Calculations and Design Charts

(1.) EXISTING SYSTEM W/ LIGHT WEIGHT CONC.

BAY SIZE: 30' x 42'
SPAN: 10'
SUPERIMPOSED LOADS: 75 PSF
FIRE RATING 2 HR.
CONC. ON DECK. 2.5" w/ 3" DECK (COMPOSITE)

FROM VULCRAFT CATALOG

TOT. SLAB DEPTH 5.5" (39 PSF CONC. WT.)
DECK TYPE: 3VLI 22
LOAD CAPACITY: 85 PSF > 75 ∴ OK
RECOMMENDED WWF: 6x6-W1.4xW1.4

Cu. FT./SQ FT = .333
Yds./100 Sq. FT = 1.23

SIZE BEAM:

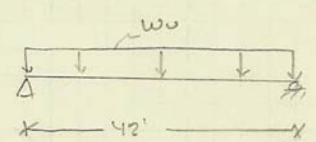
LOADING:
LL = 50 psf + 20 psf (PART.)
DL = 39 PSF
SDL = 5 PSF MECH + 5 PSF CARPET/MISC.

DL = 49 PSF
LL = 58.4 PSF ⟹ LL REDUCTION ON B1

$L = L_o\left(.25 + \frac{15}{\sqrt{K_{LL} A_T}}\right) = (50psf)\left(.25 + \frac{15}{\sqrt{(2)(420 ft^2)}}\right) = 38.4 psf + 20 psf$

FACTORED LOAD:

$1.2D + 1.6L = 1.2(49 PSF) + 1.6(58.4 PSF) = 152.2 PSF$



$W_u = 152.2 PSF \times 10' = 1.52^{K}/ft$

$W_u = 1.52^{K}/ft$ $M_u = \frac{WL^2}{8} = \frac{(1.52 klf)(42')^2}{8} = 335.2'^{K}$

$f_y = 50 ksi$
$f'_c = 4000 psi$

1

SYSTEM 1 Pg 2

ASSUME $a = 1''$ $b_{eff} = 10' = \underline{120''}$ or $\frac{42'(12'')}{4} = 126''$

$Y_2 = (5.5'') - \frac{1}{2}'' = 5''$

TRY W18X35 @ $Y_2 = 5''$ PNA @ TFL $\phi M_n = 535'^k > 335 \therefore ok$

$\Sigma Q_n = 515^k$

check assumption $a \sim 1.0''$

$a = \frac{515^k}{.85(4000psi)(120'')} = 1.26 \therefore$ NO GOOD

PNA @ BFL $\Sigma Q_n = 260^k$ $\phi M_n = 435 > 348 \therefore ok$

$a = \frac{260}{.85(4)(120)} = .63 \therefore ok.$

$Y_2 = 5.5 - \frac{.63}{2} = 5.2'' \therefore ok$ ASSUME SHEAR STUD HOLDS 21^k

$\Sigma Q_n = 260^k \rightarrow$ # OF STUDS 13 per SIDE TOT STUDS = 26

CHECK DEFLECTION

$\Delta_{max} = \frac{5wl^4}{384EI}$ $\Delta_{allow} = \frac{l}{240}$ TOTAL LOAD

$= \frac{l}{360}$ live only

$= \frac{l}{360}$ WET CONC. NON COMPOSITE $I = 510 in^4$

W_u TOT $= (107 PSF)(10') = 1.07 KLF$

W_u LIVE $= (58.4 PSF)(10') = .58 KLF$

$W_{u\ wet\ conc.} = (39 PSF)(10') = .39 KLF$

TABLE 3-20 LRFD

@ $Y_2 = 5.2''$ $I_{eff} = 1190 in^4$

$\Delta_{TOT} = \frac{5(1.07 klf)(42')^4(1728)}{384(29{,}000 ksi)(1190 in^4)} = 2.17''$ $\frac{l}{240} = 2.1'' \therefore OK$

$\Delta_{LIVE} = \frac{5(.58klf)(42')^4(1728)}{384(29{,}000)(1190 in^4)} = 1.17''$ $\frac{l}{360} = 1.4'' \therefore OK$

$\Delta_{wet\ conc.} = \frac{5(.39klf)(42')^4(1728)}{384(29{,}000)(510 in^4)} = 1.8$ $\frac{l}{240} = 2.1'' \therefore OK$

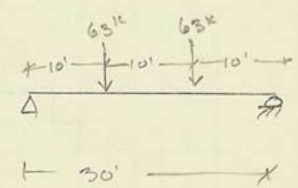
SYSTEM 1 | Pg 3

BEAM DESIGN

W18x35 w/ 26 STUDS & CAMBER OF 1.8"

∴ NEW SYSTEM IS LIGHTER THAN DESIGNERS OF W18x40

GIRDER CHECK:



$M_u = Pa = (63^k)(10') = 630'^k$

Assume $a = 1"$ $b_{eff} = 40' = 480"$ or $\frac{30'(12")}{4} = 90"$

$Y_2 = 5.5 - \frac{1}{2} = 5"$ TRY W18x46 @TFL $\phi M_n = 712'^k > 630'^k$

$\Sigma Q_n = 677$

Check assumption $a = 1.0$

$a = \frac{677^k}{.85(4000psi)(90")} = 2.2$ NO GOOD ⇒ TRY W18x50 @BFL $\phi M_n = 644$, $\Sigma Q_n = 306$

$a = \frac{306^k}{.85(4ksi)(90")} = 1.0$ ∴ OK. $Y_2 = 5"$ ∴ OK

OF STUDS $= \frac{306^k}{21^k/stud}$

= 15 STUDS ON EACH SIDE

∴ 30 STUDS TOTAL

SYSTEM 1 | Pg 4

CHECK DEFLECTIONS IN GIRDER

$P_{u\,TOT} = 45^k$
$P_{u\,LIVE} = 24.4^k$
$P_{u\,WET\,CONC.} = 16.4^k$

$\Delta_{max} = \frac{Pa}{24EI}(3l^2 - 4a^2)$

$I_{eff} = 1650$
$I = 800$

$\Delta_{TOT} = \frac{(45^k)(10')(3(30')^2 - 4(10')^2)(1728)}{24(29{,}000)(1650\,in^4)} = 3.3" > \frac{l}{240} = 1.5"$ ∴ NO GOOD

1702

1044000 I = 3804019200 NEED I_{eff} of 3644 in⁴

TRY W18x60 PNA @ POINT 7 $\phi M_n = 838'^k$
$\Sigma Q_n = 251^k$

$a = \frac{288^k}{.85(4ksi)(90')} = .94$ ∴ OK

$\frac{251^k}{21} = 11.9 \Rightarrow 12$ STUDS Per Side
∴ 24 STUDS TOTAL

$Y_2 = 5.5 - \frac{.94}{2} = 5.03$ ∴ OK

DEFLECTION $I_{eff} = 1854$ @ $Y_2 = 5.03$
$I = 984$

$\Delta_{TOT} = \frac{(45^k)(10')(3(30')^2 - 4(10')^2)(1728)}{24(29{,}000)(1854)} = 1.38" < \frac{l}{24} = 1.5$ ∴ OK

$\Delta_{LIVE} = \frac{(24.4^k)(10')(3(30')^2 - 4(10')^2)(1728)}{24(29{,}000)(1854)} = .75 < \frac{l}{360} = 1.0"$ ∴ OK

$\Delta_{WET} = \frac{(16.4^k)(10')(3(30')^2 - 4(10')^2(1728)}{24(29{,}000)(1854)} = .95 < \frac{l}{360} = 1.0$ ∴ OK

USE W18x60 W 24 STUDS TOTAL.
THIS IS LIGHTER THAN ORIGIONAL SYSTEM OF W18x97

SYSTEM 2 | Pg 2

USE 24K9 JOISTS 2' O.C. w/ 0.6C28 CONFORM DECK
& 2.5" N.W. CONC.

GIRDER IS 24x 76
HOWEVER IF DEPTH IS ISSUE CAN DROP DOWN
TO SMALLER SIZE & MORE WEIGHT W18x86, W21x83
or
W16x100

SYSTEM 2 | Pg 1

② OPEN WEB STEEL JOISTS

SPAN: 42' @ 24" o.c.

FIRE RATING: 2hr ⟹ 2.5" CONC. ON 0.6C28 (CONFORM) N.W. CONC.

LOADS: 29PSF CONC. DECK. + 20 PSF PART. + 5psf MECH. + 5PSF MISC. + 50PSF LIVE

TOTAL = 109 psf

109 PSF @ 2' o.c = 218 PLF

FROM NCJ JOIST CATALOG

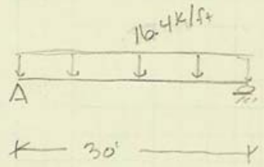
@42' w/ 218PLF ⟹ 24K9 W_u = 276PLF ∴ OK

MAX LL. FOR DEFLECTION = 140 < 151 ∴ OK

DEPTH 24" WT. 12 PLF → 6 PSF

50PSF LIVE ⟹ REDUCED = 34PSF

CHECK GIRDER:



DEAD

$1.2(29+5+5+6\,PSF) = 54\,PSF$

LIVE +

$1.6(34+20) = 86.4\,PSF$

TOT = 140PSF

$W_u = (140\,PSF)(2') = .280\,KLF$

$(.280KLF)(42') = 11.76^K \div 2'$

$W_u = 5.9^K/ft$

$f_y = 50ksi$

$f_c = 4000psi$

$M_u = \frac{w_u l^2}{8} = 664'^K$

BRACED ALONG EVERY 2' (TABLE 3-10 LRFD)

W24x76 $\phi M_n = 750'^K$ $I = 2100\,in^4$

$W_{u\,TOT} = .218\,KLF$

$\Delta_{max} = \frac{5(.218)(30')^4(1728)}{384(29,000)(2100)} = .07'' < \frac{L}{240} = 1.5''$

$W_{LIVE} = .108\,KLF$

$\Delta = \frac{5(.108)(30')^4(1728)}{384(29000)(2100)} \quad .032 < \frac{L}{360} = 1''$

W_{WET} = BY INSPECTION WON'T CONTROL

1670400

f'_c = 4,000 psi
Grade 60 Bars

FLAT SLAB SYSTEM
SQUARE EDGE PANEL — With Drop Panels — No Beams

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

h = 10.5 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS

SPAN c.-c. $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	Square Drop Panel Depth (in.)	Square Drop Panel Width (ft)	(3) Square Column Size (in.)	γ_f	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)	Bot. (+) (ft-k)	Int. (−) (ft-k)	Interior Panel 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)
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	100	12	14-#5	10-#5	10-#5	10-#5	2.29	0.931
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	200	18	18-#5	13-#5	10-#5	10-#5	2.67	0.931
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	300	21	15-#6	9-#7	9-#6	11-#5	3.39	0.944
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	400	23	12-#7	14-#6	15-#5	13-#5	3.82	0.958
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	500	26	26-#5	12-#7	10-#7	15-#5	4.41	0.995
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	600	26	12-#8	11-#8	11-#7	18-#5	5.19	0.995
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	100	12	16-#5	12-#5	10-#5	10-#5	2.40	0.931
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	200	18	14-#6	15-#5	12-#5	10-#5	2.85	0.944
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	300	22	15-#6	13-#6	10-#6	12-#5	3.40	0.958
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	400	23	18-#6	9-#8	9-#7	15-#5	4.24	0.958
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	500	26	12-#8	11-#8	14-#6	9-#7	4.93	0.995
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	100	12	16-#5	13-#5	11-#5	11-#5	2.48	0.944
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	200	18	15-#6	12-#6	13-#5	11-#5	3.07	0.944
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	300	22	13-#7	21-#5	16-#5	10-#6	3.75	0.958
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	400	24	15-#7	18-#6	10-#7	12-#6	4.51	0.995
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	500	27	13-#8	12-#8	12-#7	10-#7	5.25	0.995
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	100	12	18-#5	14-#5	11-#5	11-#5	2.52	0.944
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	200	19	15-#6	19-#5	10-#6	12-#5	3.13	0.958
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	300	22	26-#5	17-#6	10-#7	15-#5	4.01	0.958
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	400	24	13-#8	12-#8	12-#7	18-#5	4.95	0.995
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	100	12	18-#5	16-#5	12-#5	11-#5	2.57	0.958
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	200	19	17-#6	21-#5	16-#5	10-#6	3.43	0.958
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	300	22	16-#7	11-#8	14-#6	12-#6	4.48	0.958
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	400	26	14-#8	10-#9	10-#8	20-#5	5.16	0.995
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	100	12	20-#5	18-#5	14-#5	12-#5	2.77	0.958
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	200	19	26-#5	23-#5	13-#6	15-#5	3.60	0.958
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	300	22	17-#7	21-#6	12-#7	19-#5	4.68	0.958
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	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.

f'_c = 4,000 psi
Grade 60 Bars

FLAT SLAB SYSTEM
SQUARE EDGE PANEL — With Drop Panels — No Beams

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

h = 9 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS

SPAN c.-c. $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	Square Drop Panel Depth (in.)	Square Drop Panel Width (ft)	(3) Square Column Size (in.)	γ_f	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)	Bot. (+) (ft-k)	Int. (−) (ft-k)	Interior Panel 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)
18	100	2.50	6.00	12	0.631	9-#4 1	9-#4	10-#4	6-#5	6-#5	1.85	43.7	87.5	117.8	100	12	10-#4	9-#4	6-#5	6-#5	1.86	0.773
18	200	2.50	6.00	14	0.628	9-#4 0	7-#5	9-#5	6-#5	6-#5	2.03	58.6	117.1	157.7	200	17	8-#5	9-#4	6-#5	6-#5	1.98	0.773
18	300	2.50	6.00	16	0.625	9-#4 1	9-#5	8-#6	6-#5	6-#5	2.25	73.8	152.4	198.6	300	18	16-#4	9-#4	6-#5	6-#5	2.13	0.773
18	400	2.50	6.00	18	0.728	10-#4 4	12-#5	10-#6	8-#5	6-#5	2.72	89.0	199.3	239.5	400	18	19-#4	12-#4	6-#5	6-#5	2.44	0.773
18	500	4.00	6.00	18	0.647	11-#4 2	11-#6	10-#6	10-#5	7-#5	3.25	105.0	250.4	282.7	500	18	9-#6	10-#5	10-#4	10-#4	2.81	0.787
18	600	5.50	6.00	18	0.628	11-#4 0	10-#7	10-#6	12-#5	8-#5	3.86	121.0	299.9	325.8	600	18	13-#5	9-#6	8-#5	8-#5	3.38	0.801
19	100	2.50	6.33	12	0.631	10-#4 0	10-#4	12-#4	10-#4	10-#4	1.91	51.8	103.5	139.4	100	12	11-#4	10-#4	10-#4	10-#4	1.92	0.773
19	200	2.50	6.33	14	0.695	10-#4 2	13-#4	16-#4	10-#4	10-#4	2.14	69.5	138.9	187.0	200	17	10-#5	10-#4	10-#4	10-#4	2.11	0.773
19	300	4.00	6.33	16	0.628	10-#4 2	16-#4	12-#5	7-#5	10-#4	2.35	87.3	174.7	235.0	300	19	16-#4	7-#5	10-#4	10-#4	2.20	0.787
19	400	4.00	6.33	18	0.626	11-#4 2	10-#6	10-#6	14-#4	7-#5	2.89	105.3	230.2	283.4	400	19	9-#6	14-#4	10-#4	10-#4	2.54	0.787
19	500	5.50	6.33	19	0.627	11-#4 0	13-#6	22-#4	12-#5	13-#4	3.56	123.6	288.9	332.8	500	19	10-#6	12-#5	8-#5	8-#5	3.14	0.801
19	600	5.50	7.60	19	0.694	13-#4 2	9-#8	9-#7	14-#5	7-#6	4.26	142.7	349.6	384.3	600	19	11-#6	15-#5	9-#5	7-#6	3.71	0.823
20	100	2.50	6.67	12	0.679	10-#4 1	11-#4	9-#5	10-#4	10-#4	1.90	60.7	121.5	163.5	100	12	13-#4	10-#4	10-#4	10-#4	1.89	0.773
20	200	2.50	6.67	14	0.777	10-#4 4	15-#4	19-#4	10-#4	10-#4	2.15	81.6	163.2	219.7	200	17	17-#4	10-#4	10-#4	10-#4	2.06	0.773
20	300	4.00	6.67	16	0.658	10-#4 3	9-#6	10-#6	8-#5	7-#5	2.55	102.2	204.4	275.1	300	20	12-#5	8-#5	10-#4	10-#4	2.27	0.787
20	400	5.50	6.67	18	0.628	11-#4 2	16-#5	22-#4	16-#4	13-#4	3.00	123.4	262.5	332.4	400	20	13-#5	16-#4	8-#5	7-#5	2.66	0.801
20	500	5.50	6.67	19	0.627	13-#4 1	11-#7	9-#7	13-#5	7-#6	3.82	144.8	325.2	389.9	500	20	11-#6	13-#5	9-#5	13-#4	3.25	0.801
20	600	7.00	8.00	20	0.628	13-#4 2	11-#8	18-#5	7-#8	17-#4	4.65	166.8	402.2	449.0	600	20	16-#5	12-#6	16-#4	8-#6	3.86	0.843
21	100	2.50	7.00	12	0.737	11-#4 1	13-#4	16-#4	7-#5	7-#5	2.05	70.7	141.3	190.2	100	12	10-#5	7-#5	7-#5	7-#5	2.03	0.773
21	200	4.00	7.00	15	0.629	11-#4 1	18-#4	19-#4	8-#5	7-#5	2.34	94.9	189.8	255.5	200	17	12-#5	12-#4	7-#5	7-#5	2.20	0.787
21	300	4.00	7.00	17	0.713	12-#4 3	15-#5	11-#6	7-#6	8-#5	2.81	118.7	237.4	319.6	300	20	22-#4	15-#4	11-#4	7-#5	2.48	0.787
21	400	5.50	7.00	18	0.628	13-#4 1	18-#5	12-#6	12-#5	7-#6	3.30	143.5	287.9	386.3	400	21	11-#6	18-#4	9-#5	8-#5	2.91	0.801
21	500	7.00	8.40	20	0.628	13-#4 2	17-#6	18-#5	11-#6	8-#6	4.03	168.5	380.6	453.7	500	21	16-#5	11-#6	16-#4	10-#5	3.44	0.843
21	600	7.00	8.40	21	0.649	10-#5 1	12-#8	20-#5	8-#8	13-#5	4.99	193.1	450.3	519.8	600	21	10-#7	10-#7	12-#5	12-#5	4.21	0.843
22	100	4.00	7.33	12	0.655	11-#4 1	15-#4	11-#5	11-#4	11-#4	2.01	81.9	163.7	220.4	100	12	10-#5	11-#4	11-#4	11-#4	1.92	0.787
22	200	4.00	7.33	15	0.702	11-#4 3	10-#6	22-#4	9-#5	11-#4	2.52	109.8	219.6	295.5	200	17	13-#5	9-#5	11-#4	11-#4	2.27	0.787
22	300	5.50	7.33	17	0.629	12-#4 2	9-#7	16-#5	8-#6	14-#4	2.99	137.7	275.4	370.7	300	20	15-#5	11-#5	13-#4	11-#4	2.60	0.801
22	400	5.50	7.33	19	0.744	10-#5 3	11-#7	10-#7	10-#6	8-#6	3.65	164.9	329.7	443.8	400	22	18-#5	13-#5	10-#5	13-#4	3.08	0.801
22	500	7.00	8.80	20	0.659	10-#5 1	11-#8	11-#7	17-#5	13-#5	4.40	194.5	420.3	523.7	500	22	10-#7	17-#5	12-#5	8-#6	3.76	0.843
22	600	8.50	8.80	21	0.629	16-#4 2	14-#8	11-#7	15-#6	8-#7	5.30	223.3	509.2	601.1	600	22	14-#6	15-#6	10-#6	10-#6	4.46	0.863

(Continued on next Page)

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.

SYSTEM 3 | Pg 1

(3)

ADD COLUMNS & CREATE 2-WAY FLAT SLAB w/ DROP PANELS

BAY SIZE 21' x 30' $f'_c = 4000_{psi}$, $f_y = 60ksi$

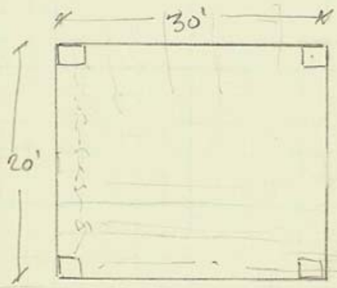
FACTORED SUPERIMPOSED LOAD:

1.2 (5psf mech + 5 psf misc.)

+

1.6 (50psf live + 20psf Parti.)

Tot = 124 psf



FOR 30x30 SQ. EDGE PANEL

10.5" SLAB THICKNESS

REINF.

	COL. STRIP	MID STRIP
TOP EXT.	14-#5	
BOTTOM	13-#8	11-#7
TOP INT.	18-#6	14-#5

SIZE OF DROP PANEL

9" DEEP

10' WIDE

MIN. SQ. COLUMN 16"

CONC. $\frac{ft^3}{sq.ft} = .958 \approx \frac{150 lb}{ft^2}$

FOR A 20x20 SQUARE END PANEL

REINF:

	COL. STRIP	MID STRIP
TOP EXT.	10-#4	
BOTTOM	12#4	10 #4
TOP INT.	19#4	10 #4

SIZE OF DROP PANEL

2.5" DEEP

6.67' WIDE

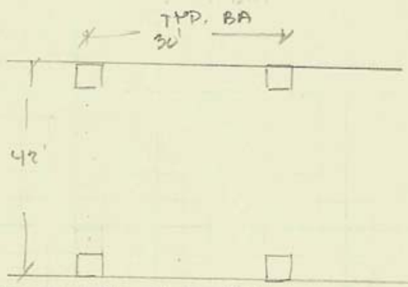
MIN. SQ. COLUMN: 14"

CONC: $\frac{ft^3}{sq\,ft} = .773 \approx 116psf$

ALT. SYST. #4 | Pg1

④ POST TENSIONED FLOOR SYSTEM (METHOD FROM ATLAS HANDOUT)

MAX SPAN = 42' TYP SPAN 38', 30', 32'



SPAN/DEPTH RATIO 45 PER PTI

$t = \frac{42' \times 12''}{45} = 11.2''$ SLAB ⇒ 11.5"

$f'_c = 5{,}500 psi$

ASSUME COL. SIZE 16x16" (SEE CALCS FOR ALT. SYSTEM 3.)

DET. LOAD TO BE BALANCED

$\frac{LL}{DL} = \frac{50}{174}$ = .29 < .75

NO PATTERN LOADING REQ.

11.5" SLAB = 144 PSF
MECH = 5 PSF
MISC. = 5 PSF
PART. = 20 PSF
LL = 50 PSF

TOT LOAD = 224 PSF

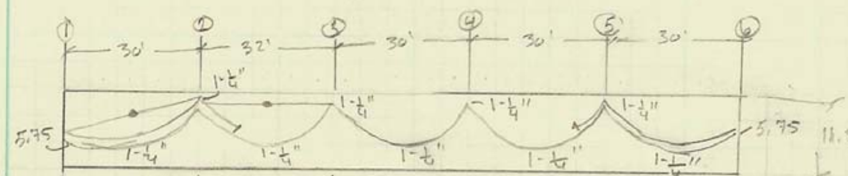
$W_{prest} = .9(144) = 129.6$

$W_{net} = 224 - 129.6 = 94.4 psf$

$A = 12'' \times 11.5'' = 138 in^2$

2-hr SLAB — REQ. COVER

1" CLEAR COVER TOP & BOT. (CONSERVATIVE VALUE



	TYP. INT	32' INT	TYP. INT
W_{pre}	129.6 PSF	129.6 PSF	129.6 PSF
M_{pre} 'k	14.6 'K	16.6 'K	14.6 'K
a (in)	5.75"	9"	9"
F (kips)	30.5 K	22.1 K	19.5 K
F/A (psi)	221 psi	160 psi	141 psi

30.5 K/ft × 42' = 1281 K
30.5 K/ft × 38' = 1160 K

22.1 K/ft × 42' = 928 K
22.1 K/ft × 38' = 840 K

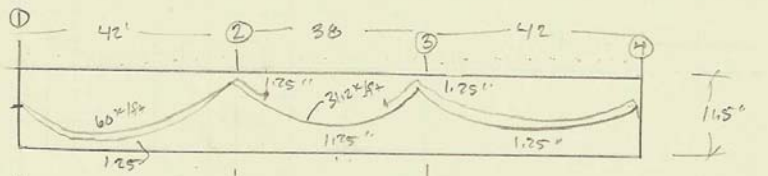
19.5 K/ft × 42' = 819 K
19.5 K/ft × 38' = 741 K

144

4.5

.479

ACT. SYST. #4 | Pg 2



W pre (PSF)	129.6 psf	129.6
M pre ('K)	28.6'K	23.4'K
a (in)	5.75"	9"
F (kips)	60K	31.2K
F/A psi	435 psi	226 psi

USING $\frac{1}{2}$" DIA TENDON

$A_T = .153 in^2$

60K/ft x 30' = 1800K

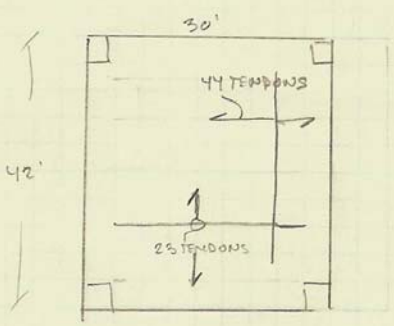
31.2K/ft x 30' = 936K

TYPICAL BAY 30'x42'

For $\frac{1}{2}$" Dia tendon

19.5K/ft x 42' = 928K ÷ 270ksi = 3.43 in² ÷ .153 in² = 22.5 ⟹ 23 tendons

60K/ft x 30' = 1800K ÷ 270ksi = 6.67 in² ÷ .153 in² = 43.5 ⟹ 44 TENDONS

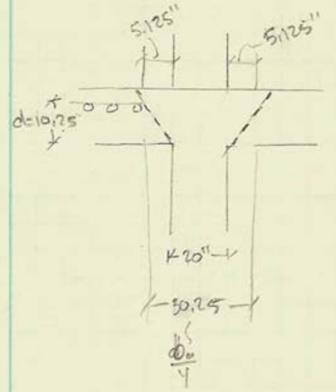


DEAD WT OF FLOOR SYSTEM:

SLAB THICK. = 11.5" ⟹ 144 PSF

ALT. SYST. #4 | Pg 3

CHECK PUNCHING SHEAR: ASSUME INTERIOR COLUMN



$V_c = 4\sqrt{f'_c}\,(b_o d)$

$V_c = 4\sqrt{5{,}500\,psi}\,(121'')(10.25'')$

~~367.9~~ $= 368^{kips}$ CONTROLLING

or

$V_c = \left(\frac{\alpha_s d}{b_o} + 2\right)\sqrt{f'_c}\,(b_o d)$

$V_c = \frac{(40)(10.25'')}{(125'')}\sqrt{5{,}500\,psi}\,(105'')(10.25'')$

$\alpha_s = 40$ (INT. COL.)

$= 1243^K$

$\phi = .75$

$\phi V_c = (.75)(368^K) = \underline{276^K}$

$A_T = 1200\,ft^2$

$DL = 1.2(144\,psf\ slab + 5\ mech + 5\ misc) = 185\,psf$

$LL = 1.6(50\,psf\ live + 20\ Part.) = 112\,psf$

TOT = 297 PSF

$V_u = (1200\,ft^2)(297\,psf) = 356.4\,K > 276^K$ ∴ NEED DROP PANEL

$356.4 \div .75 = 475.2$

$475.2 = 4\sqrt{5{,}500}\,(b_o)(10.25'')$ $\quad b_o = 156''$

$156'' = 4(b + d)$ $\quad 39 = b + d$ $\quad 39'' = 20'' + d$

$19'' = d$

$19'' - 11.5''_{slab} = 7.5''$

NEED MIN. 7.5" deep drop head.