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

SMILOW CANCER CENTER – YALE-NEW HAVEN HOSPITAL

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EXECUTIVE SUMMARY

After studying each of the three alternatives to the existing floor system of Smilow Cancer Center, it is evident that there are some viable options to be considered further, while some systems would simply not work for this type of building. All of the alternate systems investigated for Tech Report 2 were found to be capable in terms of strength issues; problems in *serviceability* were what determined which systems warranted further study. The most obvious instance of this is the girder-slab floor system. Although the system could be designed to maintain the bay size of 30'x28', the high cost of the D-Beams involved would make the system inefficient. Furthermore, the floor depth and therefore story heights would be relatively high, which would drive the costs of finishes, curtain walls, etc. As shown in the calculations, the bay size was reduced to 30'x14' to remedy the problem of deep beams. The issue with this solution is the subsequent re-organizing of the spaces due to the additional columns put in place—a rather messy process as any architect would testify.

Despite the elimination of the girder-slab system as a viable alternative, there are still two other systems left in the running. Both the flat plate and post-tensioned systems were found to be feasible options for changing the structural floor system of Smilow Cancer Center. Each system's design was able to maintain the original bay size and configuration while keeping the floors to a reasonable depth (8" – 10" compared to the existing 25" – 30"). Of course, that 10" depth is relatively uniform throughout the plan, while the 24" deep girders are located only along the girder grid. Nonetheless, further investigation of these two floor systems is justified and would include comparative costs, availability in the region, construction methods, etc.

In summary, Tech Report 2 was a preliminary investigation of an alternate *overall* structural system for Smilow Cancer Hospital. Subsequent reports and proposals would use the information and data gathered in this report to support future designs for an alternate structure.

INTRODUCTION

The Pro-con Structural Study of Alternate Floor Systems Report (Tech Report 2) is an analysis/design and discussion of the existing floor system of Smilow Cancer Center as well as three possible alternate systems. The composite slab on metal deck and steel framing system in the current design is analyzed for strength (i.e. bending, shear) and serviceability/practicality (i.e. deflection, vibration, fire rating, etc.). In addition, three other floor systems are designed and analyzed for the criteria mentioned previously. The pros and cons of each floor system are then weighed against each other to get an idea of which would be a viable option in considering an alternate overall structural system for future reports/proposals.

BACKGROUND INFORMATION: Overall Structural System

The existing structural system of Smilow Cancer Center consists of a concrete slab on metal deck floor system supported on a steel framing system (moment, lateral braced, and regular gravity frames) and four reinforced concrete (RC) shear walls. On the first level, concrete beams of varying sizes run along three edges of the building. The floor slab and steel beams act in composite action with each other, while the moment frames and shear walls share the lateral load. The whole structure rests on a 4-foot thick mat slab foundation (the slab is 8 feet thick at shear wall locations). A relatively simple structure, the footprint of the building through the first five levels is almost square (210 ft x 176 ft). At the beginning of the seventh floor, however, the northeast “corner” of the building ends in a rooftop garden, and the rest of the building rises to the roof as an L-shape.

Normal weight concrete is used for the shear walls and the foundation, while lightweight concrete is used for the floor slabs. Concrete strength ranges from 3000 psi to 8000 psi depending on the location and use. All reinforcement is A615 Grade 60 steel. A range of steel W-shapes are used for the framing system, but all are of the standard A992 grade steel (F_y = 50 ksi). Additionally, Hollow Structural Shapes (HSS) conform to ASTM A500 Grade B, while all other steel shapes (i.e. plates, channels, etc.) conform to ASTM A36 (F_y = 36 ksi).

EXISTING FLOOR SYSTEM: Composite Slab on Metal Deck + Steel Framing

-refer to A1 through A6 of the Appendix for existing floor system analysis-

As mentioned in Tech Report 1, the typical floor slab for Smilow Cancer Center is a 4-1/2" thick lightweight concrete slab on a 3" deep, galvanized, 18 gage composite steel floor deck with a 3 span minimum. Reinforcement consists of one layer of 6 x 6 – D4 x D4 welded bar mesh and top reinforcing bars. The slab is supported on steel framing and concrete shear walls at some locations. As per ASCE 05, the floor slabs are considered as rigid diaphragms when taking into account lateral loads.

The bay analyzed for this report (shown in Figure 1) is a 30 ft x 28 ft *interior* bay located on the fourth floor of the hospital. This bay has wide flange columns at the corners, W24x55 girders along three edges, and three W18x35 beams—two within the bay and one on the fourth edge. Pages A1-A6 of the Appendix shows the calculations for strength and serviceability of the existing floor system. As determined in Tech Report 1 and again here, the existing member sizes (i.e. slab thickness, beam and girder sizes) are more than adequate to support the gravity loads on the structure. The only criterion not met by the floor system is the deflection on the supporting W24 girder. Of course, the girder was treated as a stand-alone beam when calculating deflections; composite action was not considered in the calculations.

In terms of other serviceability issues, the composite slab on metal deck system seems a sensible option seeing as it is the system chosen by the building's designers. According to the Fire Resistance Directory published by Underwriters Laboratories (UL), the 4-1/2" slab exceeds the minimum thickness of 3-1/4" to achieve a 2-hour fire rating without having to spray the metal deck. The extra thickness may be due to a higher fire rating requirement or other factors that might control.

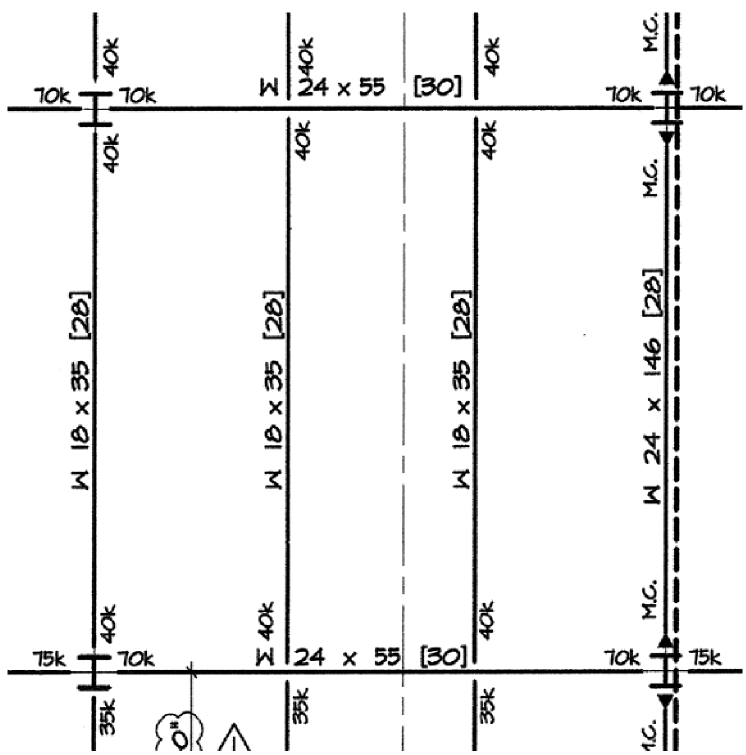


Figure 1: Typical Interior Bay on Fourth Floor

ALTERNATE FLOOR SYSTEM DESIGN 1: Girder-Slab System

-refer to A7 through A9 of the Appendix for girder-slab design/calculations-

The first alternate floor system examined by this report is the relatively recent girder-slab floor system. Though most commonly used for mid- to high-rise residential buildings, the girder-slab system could be ideal because of its efficient use of both structural steel and precast concrete hollow core planks. The system consists of a D-Beam (dissymmetric beam) girder with hollow core planks abutting either side of it. The cores of the plank are then filled with grout to bond the planks to the girder (see Figure 2). Practical advantages of this system include a faster, more efficient method of construction, since the precast floor planks are *assembled*, not *cast*, in place. Hence, construction can take place in all sorts of weather conditions; it also allows for faster access for other trades to begin their work.

For help in designing a girder-slab floor system, Girder-Slab Technologies, LLC offers the Design Guide v1.4. This guide is available on the company's website (www.girder-slab.com) and was referenced extensively in the design of the alternate floor system for Smilow Cancer Center. As can be seen in the calculations in the Appendix, the major drawback of converting to a girder-slab floor system is the relatively short span lengths of D-Beams. As such, the bay size would have to be decreased to 30' x *14*' to avoid beam depths of 24 or even 30 inches. Taller floor heights would mean more curtain wall area and higher costs. On the other hand, decreasing the bay size would increase the number of columns and amount of space taken up within the building. It is because of this compromise that the girder-slab would *not* be a very viable option for an alternate floor system.

Figure 2: A cross-section of a D-Beam with part of the hollow core planks still attached

ALTERNATE FLOOR SYSTEM DESIGN 2: Reinforced Concrete Two-way Flat Plate

-refer to A10 through A15 of the Appendix for flat plate design/calculations-

Another alternate floor system considered by Tech Report 2 is the reinforced concrete (RC) two-way flat plate supported on 24"x24" concrete columns. Because of its relatively long span capacities and open ceilings (no beams, drop panels, or column capitals), this system would be well-suited for a hospital with its many MEP equipment and fixtures running along the ceiling cavities. And because of concrete's inherent proficiency in fire protection, a 10-1/2" thick slab, such as the one determined in the calculations, would easily achieve a 2-hour fire rating. Although the slab may seem relatively thick, it is still significantly thinner than the 30+ inch deep girder-deck-slab combination of the original floor system.

Going through the design steps outlined in ACI 318-05 shows that punching shear is the controlling factor, increasing the slab thickness from the assumed 8 inches to 10-1/2 inches. Also, the increased thickness meets the minimum requirement of Table 9.5c of the ACI Code; therefore, no deflection calculations are required. The final design for the two-way flat plate is illustrated in page A15 of the Appendix.

ALTERNATE FLOOR SYSTEM DESIGN 3: Two-way Post-tensioned Floor Slab

-refer to A16 through A21 of Appendix for post-tensioned slab design/calculations-

The third and final alternative to the composite slab and metal deck floor system of Smilow Cancer Center is a two-way post-tensioned (PT) floor slab supported on 24"x24" concrete columns. This type of system makes use of as much of the concrete as possible by eliminating most portions in tension. In this way, slabs do not have to be as thick as conventional reinforced concrete. This offsets the cost of the post-tensioning strands and also reduces the overall weight of the building. Similar to the flat plate floor system, a PT slab can easily achieve a 2-hour fire rating with an adequate slab thickness. But despite the advantages over conventional flat slabs/plates, PT construction does have its drawbacks. For one thing, the system is relatively expensive. Also, on-site construction has a higher risk when post-tensioning is involved: the PT cables are under a great deal of tension and can be very volatile if snapping should occur.

For the preliminary design of a PT floor slab for Smilow Cancer Center, this report uses the design methods presented in ACI 318-05 and IBC 2003. First, a trial slab thickness of 8 inches was determined using a limit on the ratio of span length to slab thickness. Then, by calculating loads/stresses and checking the configuration of the PT strand within the slab itself, it was determined that one strand per foot (approx.) of slab width would be adequate. The final design (for this report) of the PT floor slab is illustrated in page A21 of the Appendix.

SUMMARY: Comparison Table

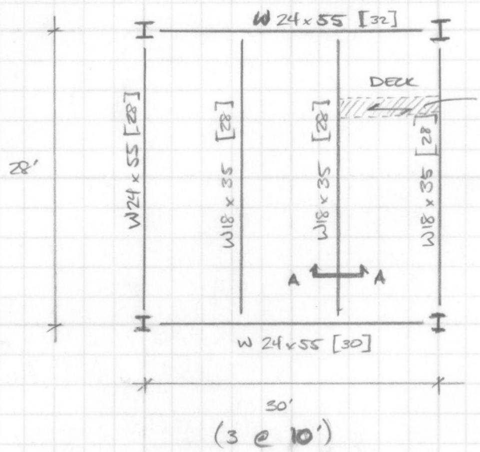
The following table summarizes basic information and key features of each type of alternate floor system plus the existing system. Note that weights were calculated using dead loads calculated in each system's design/analysis.

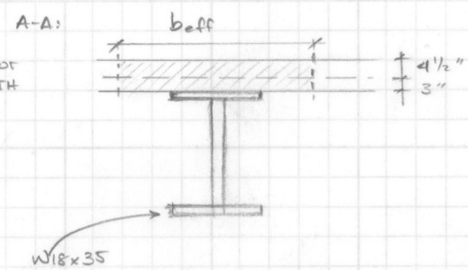
FLOOR SYSTEM TYPE	**FLOOR DEPTH**	**WEIGHT**	**2-HOUR FIRE RATING**	**RELATIVE COST**	**FURTHER STUDY**
Existing Composite Slab and Metal Deck	~30"	93 psf	Yes	Moderate	Existing
Girder-Slab	9"	85 psf	Yes	Low	Not Justified
RC Two-way Flat Plate	10.5"	~125 psf	Yes	Low	Justified
Two-way PT Slab	8"	100 psf	Yes	High	Justified

Appendix: Hand Calculations and Sketches

ANALYSIS OF EXISTING FLOOR SYSTEM:

4½" LIGHTWEIGHT CONCRETE SLAB ON 3" DEEP (GALV.), 18 GAGE, COMPOSITE STEEL FLOOR DECK, 3 SPAN MIN., BY UNITED STEEL DECK, INC. OR EQUAL (7½" TOTAL DEPTH), REINFORCED W/ ONE LAYER 6x6 - D4 x D4 WELDED BAR MESH AND TOP REINFORCING, SUPPORTED ON STEEL FRAMING; CONNECTED WITH (1) ¾"ø SHEAR STUD per ft.





$b_{eff} \leq \frac{10(12)}{2} = 60 \text{ in}$

$\leq \frac{28(12)}{8} = \boxed{42 \text{ in}}$

▷ LOADS: [SEE LOAD DIAGRAMS]

LIVE LOAD = 80 psf
S.I. DEAD LOAD = 25 psf

SLAB + METAL DECK SELF-WEIGHT:

58 psf (UNITED STEEL DECK CATALOG, p. 40)

FACTORED LOAD: (ON 1' WIDE STRIP OF DECK)

$w_u = 1.2(58 + 25) + 1.6(80) = 228 \text{ psf} = 0.228 \text{ ksf}$

$M_u = \frac{(0.228 \times 1')(10')^2}{8} = 2.85 \text{ ft-k} = \underline{34.2 \text{ in-k}}$

ANALYSIS OF EXISTING FLOOR SYSTEM (cont'd.):

▶ CHECK AGAINST NOMINAL MOMENT CAPACITY:

FROM USD CATALOG:

18 GAGE DECK, 3" LOK-FLOOR, 7.5" TOTAL SLAB DEPTH:

MIN. # of STUDS PER FOOT TO OBTAIN FULL RESISTING MOMENT, ϕM_{nf}:

0.79 STUDS per FOOT < 1.00 STUDS per FOOT PROVIDED

$\Rightarrow \phi M_{nf} = 126.40$ in-k $> M_u = 34.2$ in-k

∴ COMPOSITE DECK OK FOR GRAVITY.

▶ CHECK MAX. SPANS (ASSUME UNSHORED CONSTRUCTION):

FROM USD CATALOG:

3 SPAN: MAX. SPAN = 12.16 ft > 10 ft PROVIDED SPAN

∴ SPAN LENGTH OK.

NOTE: ACCORDING TO USD CATALOG, THE MAX UNSHORED SPAN CALCULATION CONSIDERS COMBINED BENDING, SHEAR, AND DEFLECTION.

∴ COMPOSITE DECK DESIGN IS ADEQUATE.

▶ CHECK COMPOSITE BEAM DESIGN. (W18 x 35)

$w_u = (0.228 \times 10') + 1.2(0.035) = 2.322$ k/ft

$$M_u = \frac{2.322(28)^2}{8} = 228 \text{ ft-k}$$

FROM TABLE 3-19 OF AISC STEEL MANUAL, 13TH ED.:

ϕM_p OF BARE STEEL $= 249$ ft-k > 228 ft-k $= M_u$

∴ COMPOSITE BEAM OK FOR BENDING.

cont'd →

ANALYSIS OF EXISTING FLOOR SYSTEM (cont'd.)

▶ CHECK BEAM (W18x35) FOR CONSTRUCTION LOADS & DEFLECTION:

- CONSTRUCTION LOADS: WET CONCRETE, FORMWORK, EQUIPMENT, etc.

ASSUME $w_{CONSTR.} = 20\text{ psf}$

$$\rightarrow w_u = \underbrace{1.2(58\text{ psf} \times 10')}_{\text{CONC + DECK}} + \underbrace{1.2(35\text{ plf})}_{\text{WIDE FLANGE}} + \underbrace{1.6(20\text{ psf} \times 10')}_{\text{CONSTR. LOAD}}$$

$w_u = 1058\text{ plf} = 1.058\text{ klf}$

$$\Rightarrow M_u = \frac{1.058(28)^2}{8}$$

$M_u = 104^{ft\text{-}k} < 228^{ft\text{-}k} = M_u$ FOR SERVICE LOADS.

∴ W18x35 IS ADEQUATE FOR CONSTRUCTION LOADS.

- CONSTRUCTION DEFLECTION:

CONSIDER ONLY UNFACTORED DEAD LOAD ⇒ $w = \underset{\text{(DECK)}}{0.580} + \underset{\text{(BEAM)}}{0.035} = 0.615$

$I_{W18x35} = 510\text{ in}^4$

$$\Delta = \frac{5}{384}\frac{(0.615)(28)^4(12)^3}{29000(510)} = 0.575''$$

$\rightarrow \Delta \leq 1''$

$\leq L/360 = \frac{(28 \times 12)}{360} = 0.933''$

$\rightarrow \Delta = 0.575'' < 0.933''$

∴ W18x35 OK FOR CONSTR. DEFL.

ANALYSIS OF EXISTING FLOOR SYSTEM (cont'd.):

▷ CHECK LIVE LOAD DEFLECTION:

* CHECK BARE STEEL FIRST FOR SIMPLICITY:

$w_u = 80\text{ psf} = 0.080\text{ ksf}$

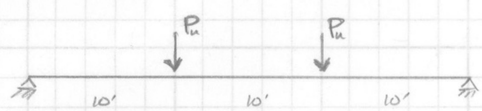
$$\Delta_u = \frac{5}{384}\frac{(0.080\times10')(28)^4(12)^3}{(29000)(510)} = 0.748''$$

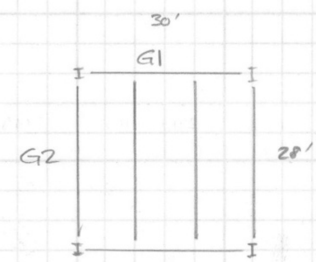
LIMIT Δ_u TO $L/360 = (28\times12)/360 = 0.933'' > 0.748''$

$\therefore$ W18×35 OK FOR LL DEFLECTION.

▷ CHECK GIRDER MOMENT CAPACITY: (W24×55)

G1:





$P_u = w_u L_{beam} = 0.228(28')$
(FROM BEAM)

$P_u = 6.384^k$

* G1 & G2 ARE BOTH W24×55s, BUT EACH HAS DIFFERENT LOAD CASES.

* PAGE S1051 OF DRAWINGS DENOTES THAT GIRDER SHOULD BE DESIGNED FOR (2) 80 k POINT LOADS AT THIRD-SPAN (40^k × 2 SIDES = 80 k).

$\therefore P_u = 80^k$

$\Rightarrow M_u = P_u a = 80^k(10^{ft})$

$M_u = 800^{ft\text{-}k}$

G2: – COMPARE W/ G2 MOMENT:

$w_u = (0.228\times10') + (1.2\times0.055) = 2.35\text{ k/f}$

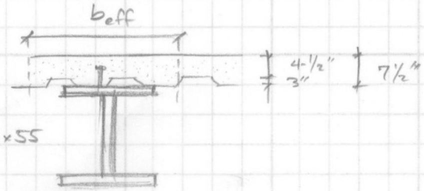
$$M_u = \frac{2.35(30')^2}{8} = 264.4^{ft\text{-}k}$$

$\therefore M_u = 800$ ft-k CONTROLS.

CONT'D →

ANALYSIS OF EXISTING FLOOR SYSTEM (cont'd.)

COMPOSITE GIRDER:



W24×55

SHEAR STUDS:

PARALLEL TO GIRDER, (30) 3/4" Ø STUDS, ASSUME 1 STRONG STUD PER RIB. $w_r/h_r < 1.5$ (ASSUMED); LIGHTWEIGHT CONCRETE, $f'_c = 4^{ksi}$

FROM TABLE 3-21 OF STEEL MANUAL: $q_n = 18.3$ k

$$\Sigma Q_n = 18.3\text{ k}\,(30\text{ studs}) = 549^{k}$$

$$b_{eff} \le \frac{10'(12)}{2} = 60\text{ in}$$

$$\frac{30'(12)}{8} = \boxed{45\text{ in}}$$

$$a = \frac{\Sigma Q_n}{0.85 f'_c b} = \frac{549}{0.85(4)(45)} = 3.59''$$

$$Y_2 = Y_{con} - \frac{a}{2} = 7.5'' - \frac{3.59''}{2} = 5.71'' \approx 5.5''$$

FROM TABLE 3-19 of STEEL MANUAL:

$Y_2 \approx 5.5''$; $\Sigma Q_n \approx 545^{k}$ (BOTH CONSERVATIVE)

$\Rightarrow \phi M_p = 937^{ft\cdot k} > M_u = 800^{ft\cdot k}$

$\therefore$ COMPOSITE BEAM W24×55 OK FOR BENDING.

▷ CHECK W24×55 GIRDER FOR CONSTRUCTION LOAD DEFLECTION & LIVE LOAD DEFLECTION.

NOTE: SINCE CALCULATED POINT LOADS FROM BEAMS ARE MUCH SMALLER THAN THOSE IN DRAWINGS, ASSUME $P_{CL} = 0.60 P_u$ AND $P_{LL} = 0.80 P_u$. (60% AND 80% ARE APPROXIMATELY EQUAL TO PROPORTIONS OF CONSTR. LOAD AND LIVE LOAD TO SERVICE LOAD FOR W18×35 BEAM.)

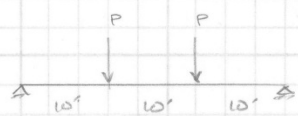
$\Rightarrow P_{CL} = 0.60(80^{k}) = 48^{k}$

$P_{LL} = 0.80(80^{k}) = 64^{k}$

CONT'D →

ANALYSIS of EXISTING FLOOR SYSTEM (cont'd.)

- LIMIT Δ_{CL} TO SMALLER OF $L/360$ AND 1":



$$\Delta_{CL} = \frac{Pa}{24EI}\left(3L^2 - 4a^2\right)$$

$$= \frac{48\left(10\times12\right)}{24(29000)(1350)}\left(3(30\times12)^2 - 4(10\times12)^2\right)$$

$I_{W24\times55} = 1350 \text{ in}^4$

$\Delta_{CL} = 2.03'' > 1''$ ∴ NO GOOD.

- LIMIT Δ_{LL} TO $L/360$.

$$\Delta_{LL} \leq \frac{30(12)}{360} = 1''$$

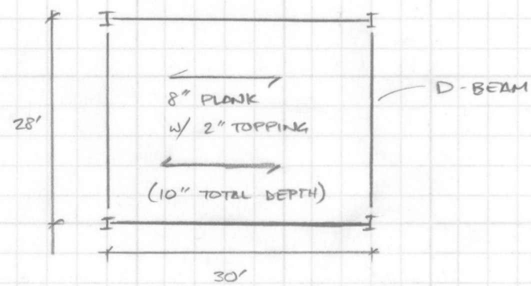
∴ OBVIOUSLY NO GOOD SINCE $P_{LL} > P_{CL}$.

- END -

ALTERNATE FLOOR SYSTEM DESIGN 1:

GIRDER-SLAB SYSTEM

MAINTAIN 30' x 28' BAY SIZE:



ASSUMPTIONS:

PLANK DL = 60 psf
S.I. DL = 25 psf
LIVE LOAD = 80 psf

TOPPING DL = 25 psf

f'_c { PLANK = 5 ksi ; GROUT = 4 ksi }

PLANK SPAN = 30'
D-BEAM SPAN = 28'

▸ CHECK INITIAL LOAD (BEFORE COMPOSITE ACTION):

$$M_{DL} = \frac{0.060 \text{ ksf} (30')(28')^2}{8} = 176.4 \text{ ft-k}$$

FROM GIRDER-SLAB TECHNOLOGIES WEBSITE, D-BEAM PROPERTIES TABLE:

LARGEST ALLOWABLE MOMENT FOR 9" DEEP D-BEAM = 84 ft-k

DB9 x 46

• FIND MAX. SPAN LENGTH:

$$84 \text{ ft-k} \geq \frac{0.060(30)(l_1)^2}{8}$$

$$l_1 \leq 19.3 \text{ ft}$$

∴ CHANGE BAY SIZE TO **30' x 14'** & SWITCH TO **DB9x41**

$$M_{DL} \overset{?}{\leq} M_{ALLOW.}$$

$$\frac{0.060(30)(14)^2}{8} \overset{?}{\leq} 61 \text{ ft-k}$$

$$44.1 \text{ ft-k} < 61 \text{ ft-k} \quad \therefore \text{ OK}$$

cont'd →

ALTERNATE FLOOR SYSTEM DESIGN 1:

GIRDER-SLAB SYSTEM.

- CHECK INITIAL DEFLECTION.

$$\Delta_{DL} = \frac{5}{384} \frac{(0.060)(30')(14)^4(1728)}{(29000)(159\ in^4)}$$

$$\Delta_{DL} = 0.34''$$

$$\Delta_{allow.} = \frac{L}{360} = \frac{(14 \times 12)}{360} = 0.47''$$

$$\Rightarrow \Delta_{DL} < \Delta_{allow.} \quad \therefore OK.$$

▷ CHECK TOTAL LOAD (COMPOSITE ACTION AFTER GROUT CURES):

$$M_{SI\ LOADS} = (\underset{SI\ DL}{0.025} + \underset{LL}{0.080} + \underset{TOPPING}{0.025})(30')(14')^2\left(\frac{1}{8}\right)$$

$$= 96^{ft\text{-}k}$$

$$M_{TOT} = 44.1^{ft\text{-}k} + 96^{ft\text{-}k} \approx 140^{ft\text{-}k}$$

$$\rightarrow S_{req} = \frac{(140^{ft\text{-}k} \times 12)}{(0.60 \times 50ksi)} = 56\ in^3$$

$S_t = 62.1\ in^3$ ⟶ [FROM D-BEAM PROPERTIES TABLE]

$$S_t > S_{req} \quad \therefore OK$$

- CHECK TOTAL LOAD DEFLECTION (MORE CONSERVATIVE THAN Δ_{LL})

$$\Delta_{TL} = \frac{5}{384} \frac{(0.025 + 0.080 + 0.025)(30')(14')^4(1728)}{(29000)(332\ in^4)}$$

$$\Delta_{TL} = 0.35'' < \Delta_{allow} = 0.47'' \quad \therefore OK$$

CONT'D. →

ALTERNATE FLOOR SYSTEM DESIGN 1:

GIRDER-SLAB SYSTEM:

▹ CHECK COMPRESSIVE STRESS ON CONCRETE

- CONVERT STEEL SECTION TO CONCRETE SECTION

$$N_{VALUE} = \frac{E_s}{E_c} = \frac{29{,}000{,}000\ psi}{57000\sqrt{4000\ psi}} = 8.04$$

$$\Rightarrow S_{tc} = NS_t = 8.04\,(62.1\ in^3) = 499.3\ in^3$$

$$f_c = \frac{M_{SI\ LOADS}}{S_{tc}} = \frac{(96\ ft\text{-}k \times 12)}{499.3\ in^3} = 2.31\ ksi$$

$$F_c = 0.45\,(5\ ksi) = 2.25\ ksi$$

$$\Rightarrow f_c > F_c \quad \therefore \text{ NO GOOD!}$$

∴ SWITCH BACK TO DB9x46 : $S_t = 68.6\ in^3$

$$\Rightarrow S_{tc} = 8.04\,(68.6\ in^3) = 551.5\ in^3$$

$$f_c = \frac{96 \times 12}{551.5} = 2.09\ ksi < F_c = 2.25\ ksi \quad \therefore \text{ OK}$$

▸ CHECK BOTTOM FLANGE TENSION STRESS (UNDER TOTAL LOAD)

$$f_b = \frac{M_{DL}}{S_{bot\ st.}} + \frac{M_{SI\ LOAD}}{S_{bot\ trans.\ section}} = \frac{44.1(12)}{50.8} + \frac{96(12)}{80.6}$$

$$f_b = 24.7\ ksi$$

$$F_b = 0.9\,(50\ ksi) = 45\ ksi > f_b = 24.7\ ksi \quad \therefore \text{ OK}$$

▹ CHECK SHEAR CAPACITY:

TOTAL LOAD = 0.060 + 0.025 + 0.080 + 0.025 = 0.190 ksf

$$w = 0.190\ ksf\,(30') = 5.70\ k/ft$$

$$\text{REACTION} = \frac{5.70\,(14')}{2} = 39.9\ k = V$$

$$f_v = \frac{V}{A_v} = \frac{39.9\ k}{0.375''(5.75'')} = 18.5\ ksi$$

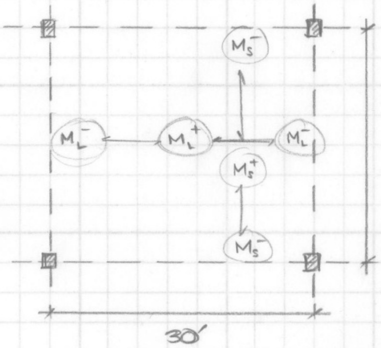
$$F_v = 0.4\,(50\ ksi) = 20\ ksi > f_v = 18.5\ ksi \quad \therefore \text{ OK}$$

-END-

ALTERNATE FLOOR SYSTEM DESIGN 2:

REINFORCED CONCRETE (RC) TWO-WAY FLAT PLATE:

MAINTAIN BAY SIZE (30' x 28'):



ASSUMPTIONS:

$f'_c = 5000$ psi ; $t = 8''$

$f_y = 60{,}000$ ksi

$LL = 0.080\,(1.6) = 0.128$ ksf

$DL = 0.025\,(1.2) = 0.030$ ksf
(SI)

$\rightarrow w_u = 0.158 \text{ ksf} + \frac{8''}{12''}(0.150 \text{ kcf})$

$w_u = 0.260$ ksf

* NOTE: ASSUME ALL COLUMNS ARE 24"x 24". THIS ASSUMPTION IS FOR THE FLOOR SYSTEM CALCS. ONLY AND WILL BE CHECKED IN A LATER REPORT.

▹ DETERMINE TOTAL STATIC MOMENT:

LONG DIR: $M_o = \dfrac{0.260 \text{ ksf}\,(28')\left(30' - \frac{24}{12}\right)^2}{8} = 714^{\text{ ft-k}}$

SHORT DIR: $M_o = \dfrac{0.260 \text{ ksf}\,(30')\left(28' - \frac{24}{12}\right)^2}{8} = 659^{\text{ ft-k}}$

▹ DISTRIBUTE MOMENT TO INTERIOR SPAN:

[SEE DIAGRAM ABOVE]

$M_L^- = 0.65\,(714^{\text{ ft-k}}) = 464^{\text{ ft-k}}$
$M_L^+ = 0.35\,(714 \text{ ft-k}) = 250^{\text{ ft-k}}$
} LONG DIR.

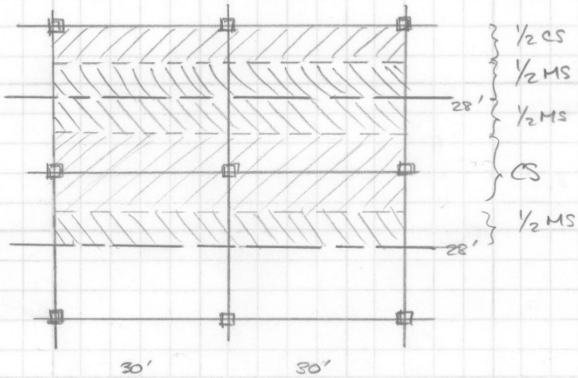
$M_S^- = 0.65\,(659^{\text{ ft-k}}) = 428^{\text{ ft-k}}$
$M_S^+ = 0.35\,(659^{\text{ ft-k}}) = 231^{\text{ ft-k}}$
} SHORT DIR.

CONT'D →

ALTERNATE FLOOR SYSTEM DESIGN 2:

RC TWO-WAY FLAT PLATE.

▷ DISTRIBUTE MOMENTS TO COLUMN STRIP (CS) & MIDDLE STRIP (MS):



* NOTE: SINCE NO BEAMS ARE USED, α & $\alpha \frac{\ell_2}{\ell_1}$ BOTH EQUAL 0.

* ASSUME #5 BARS FOR REINF.

COLUMN STRIP	LONG DIR. M^-	LONG DIR. M^+	SHORT DIR. M^-	SHORT DIR. M^+
1. TOTAL STATIC MOMENT (ft-k)	-464	250	-428	231
2. COLUMN STRIP MOMENT (ft-k) $\{M^- = 0.75 M_o;\ M^+ = 0.60 M_o\}$	-348	150	-321	139
3. CS WIDTH, "b" (in.)	168	168	180	180
4. EFFECTIVE DEPTH, "d" (in) $\{d = t - CLR - 1.5(d_{\#5}) = 8'' - ¾'' - 1.5(0.625) = 6.31''\}$	6.31	6.31	6.31	6.31
5. $M_n = \frac{M_u}{\phi} = \frac{M_u}{0.9}$ (ft-k)	-387	167	-357	154
6. DESIGN MOMENT PER FOOT $M_n^{ft} = M_n \times \frac{12}{b}$ $\left(\frac{ft\text{-}k}{ft}\right)$	-27.6	11.9	-23.8	10.3
7. $R = \frac{M_n}{bd^2}$ (psi)	694	300	598	258

CONT'D →

ALTERNATE FLOOR SYSTEM DESIGN 2:

RC TWO-WAY FLAT PLATE:

COLUMN STRIP	LONG DIR. M^-	LONG DIR. M^+	SHORT DIR. M^-	SHORT DIR. M^+
8. ρ FROM TA.5a OF TEXT.	0.0130	0.0055	0.0110	0.0045
* VALUES CHOSEN ARE CONSERVATIVE (i.e. NO INTERPOLATION)				
9. $A_s = \rho b d$ (in^2)	13.8	5.83	12.5	5.11
10. $A_{S_{min}} = 0.002bt$ (in^2)	2.69	2.69	2.88	2.88
11. NUMBER of BARS, N $\left\{ N \approx \frac{\text{LARGER of \#9 \& 10}}{A_{\#5}} \right\}$	45	19	41	17
12. MIN. NO. of BARS, N_{min} $\left\{ N_{min} = \frac{b}{2t} \right\}$	11	11	12	12

MIDDLE STRIP	LONG DIR. M^-	LONG DIR. M^+	SHORT DIR. M^-	SHORT DIR. M^+
1. TOTAL STATIC MOMENT (ft-k)	-464	250	-428	231
2. MS MOMENT (ft-k)	-116	100	-107	92
3. MS WIDTH (in)	168	168	180	180
4. EFFECTIVE DEPTH (in)	6.31	6.31	6.31	6.31
5. $M_n = \frac{M_u}{\phi} = \frac{M_u}{0.9}$ (ft-k)	-129	111	-119	102
6. $M_n^{ft.} = M_n \times \frac{12}{b}$ $\left(\frac{ft\text{-}k}{ft}\right)$	-9.21	7.93	-7.13	6.13
7. $R = \frac{M_n}{bd^2}$ (psi)	231	199	199	171

CONT'D →

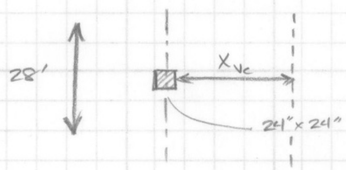
ALTERNATE FLOOR SYSTEM DESIGN 2:

RC TWO-WAY FLAT PLATE

MIDDLE STRIP	LONG DIR M^-	LONG DIR M^+	SHORT DIR M^-	SHORT DIR M^+
8. ρ FROM TA.5a OF TEXT	0.0040	0.0035	0.0035	0.0030
9. $A_s = \rho bd$ (in^2)	4.24	3.71	3.98	3.41
10. $A_{s_{min}}$ (in^2)	2.69	2.69	2.88	2.88
11. N (#5 BARS)	14	12	13	11
12 N_{min}	11	11	12	12

▷ CHECK SHEAR CAPACITIES

- WIDE-BEAM ACTION



$$X_{V_c} = \frac{30'}{2} - \frac{24''}{12(2)} - \frac{d_{AVG}}{12}$$

$$\Rightarrow d_{AVG} = \frac{d_{LONG} + d_{SHORT}}{2} = \frac{6.31'' + 6.94''}{2}$$

$$d_{AVG} = 6.63$$

$$X_{V_c} = 13.45'$$

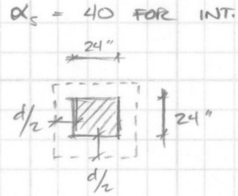
$$V_u = w_u A_v = 0.260 \text{ ksf } (28')(13.45') = 98^k$$

$$\varnothing V_c = 0.75(2)\sqrt{5000}\ (28' \times 12)(6.31)\left(\frac{1}{1000}\right)$$

$$\varnothing V_c = 225^k > V_u = 98^k \quad \therefore \text{OK}$$

- PUNCHING SHEAR

$\alpha_s = 40$ FOR INT. COL. ; $\beta_c = \frac{24''}{24''} = 1$; $b_o = 4(24'' + 6.31'') = 121''$



CONT'D →

ALTERNATE FLOOR SYSTEM DESIGN 2:

RC TWO-WAY FLAT PLATE

- PUNCHING SHEAR CHECK (cont'd.)

$$V_u = w_u A_v = 0.260\text{ ksf}\left(30' \times 28' - \left(\frac{24+6.31}{12}\right)^2\right) = 217^k$$

EQ. 1:

$$V_c = 4\sqrt{5000}\,(121'')(6.31'')\left(\frac{1}{1000}\right) = \boxed{216^k} \quad \text{CONTROLS}$$

EQ. 2:

$$V_c = \left(2 + \frac{4}{1}\right)\sqrt{5000}\,(121'')(6.31'')\left(\frac{1}{1000}\right) = 324^k$$

EQ. 3

$$V_c = \left(\frac{\alpha_s}{b_o/d} + 2\right)\sqrt{5000}\,(121'')(6.31'')\left(\frac{1}{1000}\right) = 221^k$$

$\therefore\ \phi V_c < V_c < V_u = 217^k \quad \therefore$ NO GOOD.

→ FIND $d_{req.}$

$$\phi V_c \geq V_u$$

$$0.75(4)\sqrt{5000}\,(121)(d_{req}) \geq 217000 \text{ lbs}$$

$$d_{req} \geq 8.45''$$

$\therefore$ INCREASE SLAB THICKNESS TO t:

$$t = 8.45'' + 1.5(0.625'') + 0.75''$$

$$t = 10.14'' \approx 10.5''$$

USE $t = 10.5''$

[SEE EXCEL SPREADSHEET FOR REVISED REINF. DESIGN TABLES]

CONT'D →

	Long Direction		Short Direction	
COLUMN STRIP	M^-	M^+	M^-	M^+
Total Static Moment (ft-k)	464	250	428	231
Column Strip Moment (ft-k)	348	150	321	139
CS Width (in)	168	168	180	180
Slab Thickness (in)	10.5	10.5	10.5	10.5
Effective Depth (in)	8.81	8.81	8.81	8.81
Design Moment (ft-k)	387	167	357	154
Design Moment per foot (ft-k/ft)	27.6	11.9	23.8	10.3
R (psi)	356	153	306	132
ρ	0.0065	0.0030	0.0055	0.0025
A_s	9.62	4.44	8.72	3.97
$A_{s\ min.}$	3.53	3.53	3.78	3.78
Number of #5 bars	31	14	28	13
Minimum # of bars	8	8	9	9

	Long Direction		Short Direction	
MIDDLE STRIP	M^-	M^+	M^-	M^+
Total Static Moment (ft-k)	464	250	428	231
Column Strip Moment (ft-k)	116	100	107	92
MS Width (in)	168	168	180	180
Slab Thickness (in)	10.5	10.5	10.5	10.5
Effective Depth (in)	8.81	8.81	8.81	8.81
Design Moment (ft-k)	129	111	119	103
Design Moment per foot (ft-k/ft)	9.21	7.94	7.93	6.84
R (psi)	119	102	102	88
ρ	0.0020	0.0020	0.0020	0.0015
A_s	2.96	2.96	3.17	2.38
$A_{s\ min.}$	3.53	3.53	3.78	3.78
Number of #5 bars	11	11	12	12
Minimum # of bars	8	8	9	9

ALTERNATE FLOOR SYSTEM DESIGN 2:

RC TWO-WAY FLAT PLATE:

▷ CHECK DEFLECTION:

FROM TABLE 9.5(c) OF ACI 318:

MIN. THICKNESS, t, OF SLAB w/o DROP PANELS FOR INT. PANEL: (& $f_y = 60{,}000$ psi)

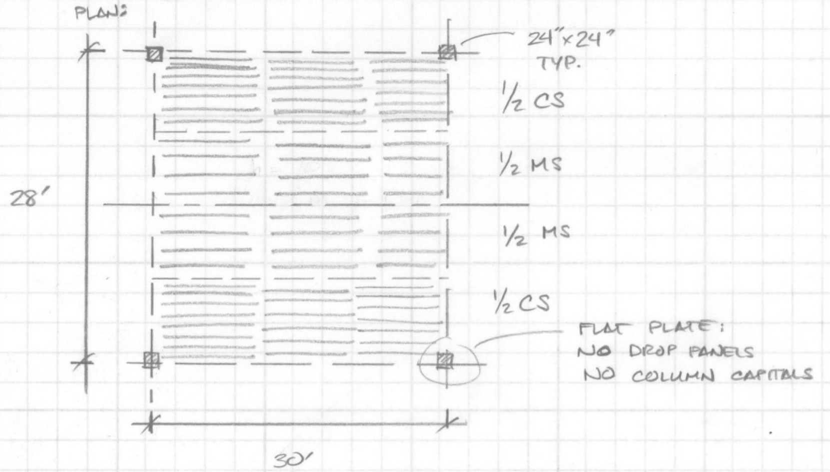
$$t_{min} = \frac{l_n}{33} = \frac{(30' \times 12) - 24''}{33} = 10.18''$$

$$t_{PROV} = 10.5'' > t_{min} = 10.18''$$

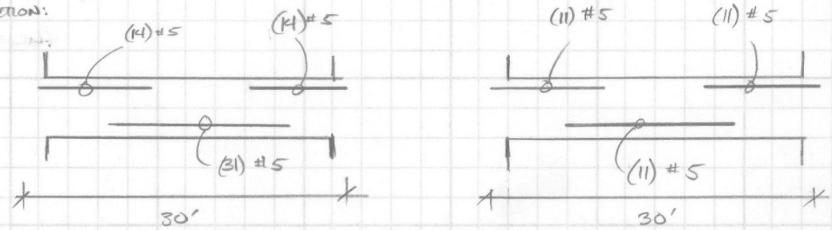
∴ NO DEFLECTION CALCS. NECESSARY.

▷ FINAL DESIGN: (NOTE: ONLY REINF IN LONG DIRECTION SHOWN. SHORT. DIR IS SIMILAR BUT WITH DIFFERENT # OF BARS)

PLAN:



SECTION:



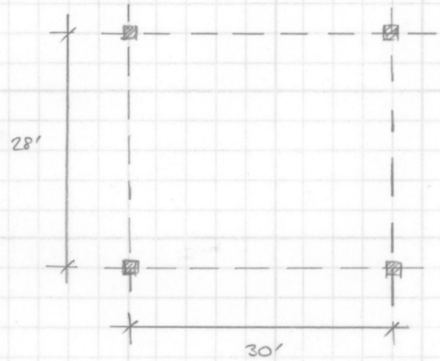
COLUMN STRIP | MIDDLE STRIP

– END –

ALTERNATE FLOOR SYSTEM DESIGN 3:

TWO-WAY POST-TENSIONED (PT) FLOOR SLAB:

MAINTAIN 30'x28' BAY SIZE:



ASSUMPTIONS:

f'_c = 5000 psi f'_{ci} = 3000 psi

f_y = 60,000 psi

LL = 80 psf
SI.DL = 25 psf

NORMAL WEIGHT CONCRETE (150 pcf)

POST-TENSION CABLES:
UNBONDED TENDONS
½" Ø, 7-WIRE STRANDS, $A = 0.153 in^2$
f_{pu} = 270 ksi

PRE-STRESS LOSS ≈ 15 ksi
$f_{se} = 0.7(270^{ksi}) - 15^{ksi} = 174^{ksi}$

$P_{eff} = A f_{se} = 0.153(174) = 26.6$ k/TENDON

* ALSO ASSUME 24"x24" COLS.
(AS IN ALT. FLOOR SYSTEM DESIGN 2)

▷ DETERMINE PRELIMINARY SLAB THICKNESS:

$$\frac{L}{h} \leq 45 \Rightarrow h \geq \frac{30' \times 12}{45} \Rightarrow h \geq 8"$$

∴ START w/ THICKNESS h = 8"

▷ CALCULATE / REDUCE LOADS

SELFWEIGHT = 150pcf $\left(\frac{8"}{12}\right)$ = 100 psf
SI DL = 25 psf
LL_o = 80 psf

* ASSUME NO LIVE LOAD REDUCTIONS ALLOWED.

→ $w_u = 1.2(100+25) + 1.6(80) = 278$ psf = 0.278 ksf

CONT'D →

ALTERNATE FLOOR SYSTEM DESIGN 3:

TWO-WAY PT FLOOR SLAB:

▷ DESIGN INTERIOR FRAME IN LONG DIRECTION. (30' SPAN, 28' WIDTH)

BAY WIDTH = 28' = 336"
IGNORE COLUMN STIFFNESS FOR SIMPLICITY

$LL/DL = 80/125 = 0.64 < 0.75 \Rightarrow$ NO PATTERN LOADING REQ'D.

- SECTION PROPERTIES
  - → ASSUME UNCRACKED BEHAVIOR : CLASS U

$$A = bh = 336''(8'') = 2688 \text{ in}^2$$

$$S = \frac{bh^2}{6} = \frac{336(8)^2}{6} = 3584 \text{ in}^3$$

- DESIGN PARAMETERS

@ TIME OF JACKING:

$$f'_{ci} = 3000 \text{ psi}$$

$$C = 0.60 f'_{ci} = 0.6(3000 \text{ psi}) = 1800 \text{ psi}$$

$$T = 3\sqrt{f'_c} = 3\sqrt{3000} = 164 \text{ psi}$$

@ SERVICE LOADS:

$$f'_c = 5000 \text{ psi}$$

$$C = 0.45 f'_c = 0.45(5000) = 2250 \text{ psi}$$

$$T = 6\sqrt{f'_c} = 6\sqrt{5000} = 424 \text{ psi}$$

- AVERAGE PRECOMPRESSION LIMITS:

$$(P/A)_{min} = 125 \text{ psi}$$
$$(P/A)_{max} = 300 \text{ psi}$$
} PER ACI 18.12.4

- TARGET LOAD BALANCES,

ASSUME 75% OF SELFWEIGHT FOR SLABS

→ $0.75(100 \text{ psf}) = 75 \text{ psf}$

CONT'D. →

ALTERNATE FLOOR SYSTEM DESIGN 3:

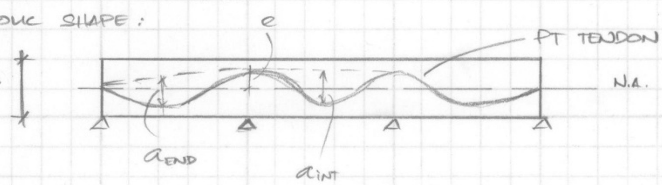
TWO-WAY PT FLOOR SLAB:

- COVER REQUIREMENTS:

  ASSUME RESTRAINED SLABS: COVER = 3/4" CLR @ BOTTOM of SLAB

▶ TENDON PROFILE:

- PARABOLIC SHAPE:



	TENDON LOCATION (in. FROM BOT. of SLAB)
EXT. SUPPORT - ANCHOR	4"
INT. SUPPORT - TOP	7"
INT. SPAN - BOTTOM	1"
END SPAN - BOTTOM	1.75"

$a_{INT} = 7'' - 1'' = 6''$

$a_{END} = \frac{1}{2}(4'' + 7'') - 1.75'' = 3.75''$

- PRESTRESS FORCE REQ'D TO BALANCE 0.75 DL:

  $W_B = 0.75(100\text{psf})(28') = 2100\text{plf} = 2.1\ ^k/_{ft}$

- FORCE IN TENDONS

  $$P = \frac{W_B L^2}{8 a_{END}} = \frac{2.1(30)^2}{8\left(\frac{3.75}{12}\right)} = 756^k$$

▶ CHECK PRECOMPRESSION ALLOWANCE:

- DETERMINE # OF TENDONS REQ'D:

  $$N = 756^k \left(\frac{1 \text{ TENDON}}{26.6^k}\right) = 28.4 \approx 28 \text{ TENDONS}$$

- ACTUAL FORCE FOR TENDONS:

  $P_{ACTUAL} = 28 \text{ TENDONS} \times 26.6^k = 745^k$

CONT'D →

ALTERNATE FLOOR SYSTEM DESIGN 3:

TWO-WAY PT FLOOR SLAB:

- ADJUST BALANCED LOAD:

$$w_B = \frac{745}{756}(2.1) = 2.07\ ^k/ft$$

- DETERMINE ACTUAL PRECOMPRESSION STRESS:

$$\frac{P_{ACTUAL}}{A} = \frac{745^k(1000)}{2688\ in^2} = 277\ psi$$

$$\underset{(min)}{125\ psi} < 277\ psi < \underset{(max)}{300\ psi} \quad \therefore OK$$

▷ CHECK INTERIOR SPAN FORCE

$$P = \frac{2.1\ ^k/ft\ (30')^2}{8\ (6''/12)} = 473^k < 745^k$$

∴ LESS FORCE IN INTERIOR BAY. (DESIGN FOR $P = 745^k$)

$$\rightarrow w_B = \frac{745^k (8)\left(\frac{6''}{12}\right)}{(30')^2} = 3.31\ ^k/ft.$$

$$\frac{w_B}{w_{DL}} = \frac{3.31}{0.125(28)} = \frac{3.31}{3.5} = 0.95 = 95\% < 100\% \quad \therefore OK$$

∴ INTERIOR FRAME IN LONG DIR.:

$P_{EFF} = 745^k$

USE (28) ½" ⌀, 7-WIRE STRANDS FOR LONG DIRECTION.

↳ 1 STRAND PER FOOT OF SLAB WIDTH.

CONT'D. ⟶

ALTERNATE FLOOR SYSTEM DESIGN 3:

TWO-WAY PT FLOOR SLAB:

▷ DESIGN INTERIOR FRAME IN SHORT DIRECTION (28' SPAN, 30' WIDTH)

- SECTION PROPERTIES (CLASS U BEHAVIOR):

$$A = (30' \times 12)(8'') = 2880 \text{ in}^2$$

$$S = \frac{(30 \times 12)(8)^2}{6} = 3840 \text{ in}^3$$

- PRESTRESS FORCE REQ'D TO BALANCE 0.75 DL

$$w_B = 0.75\,(100\,\text{psf})(30') = 2250\text{ plf} = 2.25\text{ klf}$$

- FORCE IN TENDONS

$$P = \frac{w_B L^2}{8 a_{END}} = \frac{2.25\,(28')^2}{8\left(\frac{3.75}{12}\right)} = 706^k$$

▷ CHECK PRECOMPRESSION ALLOWANCE

- DETERMINE # OF TENDONS REQ'D.

$$N = 706^k \left(\frac{1 \text{ TENDON}}{26.6^k}\right) \approx 26 \text{ TENDONS}$$

- ACTUAL FORCE FOR TENDONS:

$$P_{ACTUAL} = 26 \times 26.6^k = 692^k$$

- ADJUST BALANCED LOAD:

$$w_B = \frac{692}{706}(2.25) = 2.21$$

- DETERMINE ACTUAL PRECOMPRESSION STRESS:

$$\frac{P_{ACTUAL}}{A} = \frac{692(1000)}{2880} = 240\text{ psi}$$

$$\underset{(min.)}{125\text{ psi}} < 240\text{ psi} < \underset{(max.)}{300\text{ psi}} \quad \therefore \text{OK}$$

CONT'D →

ALTERNATE FLOOR SYSTEM DESIGN 3:

TWO-WAY PT FLOOR SLAB:

▸ CHECK INT. SPAN FORCE:

$$P = \frac{2.25\,(28')^2}{8\,(6''/12)} = 441^k < 692^k$$

∴ DESIGN FOR 692^k

$$\rightarrow w_B = \frac{692\,(8)\left(\frac{6}{12}\right)}{28^2} = 3.53\ ^k/ft.$$

$$\frac{w_B}{w_{DL}} = \frac{3.53}{0.125\,(30')} = \frac{3.53}{3.75} = 94\% < 100\% \quad \therefore OK$$

∴ INT. FRAME IN SHORT DIR.

$P_{EFF} = 692^k$

USE (26) $1/2''\phi$, 7-WIRE STRANDS FOR SHORT DIRECTION.

↳ 1 STRAND PER ~14" OF SLAB WIDTH.

– END –