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STRUCTURAL TECHNICAL REPORT 2
PRO-CON STRUCTURAL STUDY OF ALTERNATE FLOOR SYSTEMS
EXECUTIVE SUMMARY
OCTOBER 31, 2005

For this technical assignment, the existing floor system and 4 alternative floor systems were evaluated for the University of Central Florida's Academic Villages. The existing system is a composite deck with a 4" slab. Below are the 4 alternative systems that were analyzed:

1. Post-Tensioned Concrete system in North South Direction
2. Post-Tensioned Concrete system in East-West Direction
3. Precast Hollow Core Planks
4. Precast Double Tee Planks

Both of the Post-Tensioned Concrete systems are viable options as possible floor systems for this structure. A much thinner slab was found when using a post-tensioned system which would result in less weight due to concrete. This will produce a much lighter building w/ less load on the foundation, which can be a benefit in high wind areas such as Florida. Also, the existing system needs additional concrete columns and beams on the first floor to provide additional support for the load bearing stud walls which are not adequate to carry the entire weight of the floors above on their own. Using a Post-tensioned system will provide lighter loads and those extra beams and columns may be able to be eliminated completely upon further analyses. The final two alternatives, while providing a lighter structure than the existing floor system, were ruled out because they are too deep for this type of structure.

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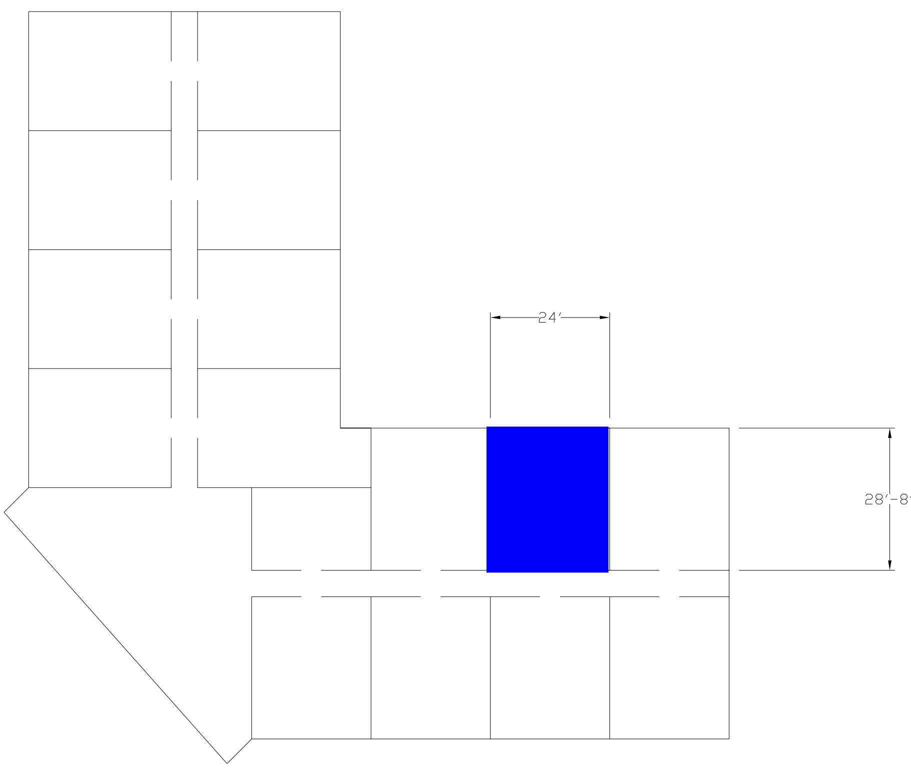
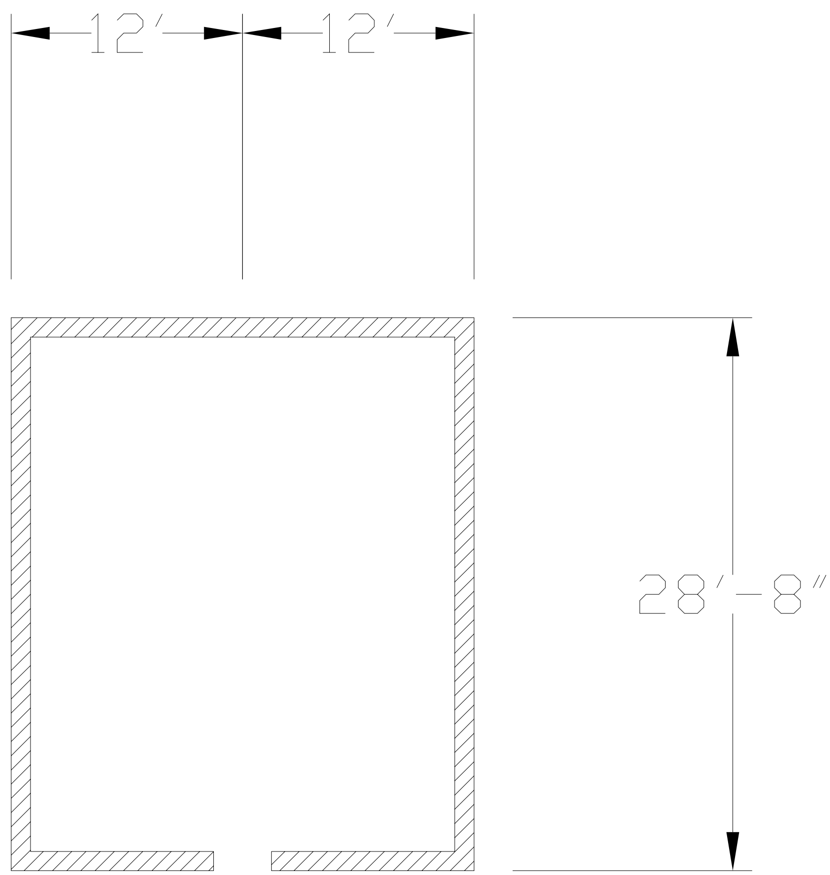
Existing System:

The existing floor system for the University of Central Florida's Academic Villages is called the "Infinity System." This is a composite floor system with Epicore MSR metal decking and 4" concrete slab. It spans between interior and exterior load bearing CMU walls and load bearing metal stud wall panels. Epicore MSR has triangular dovetail shaped ribs spaced 8" on center that allow for longer spans and higher concrete strength. The bottom flutes are completely closed which allows for the deck to have a flat bottom profile. This makes it ideal to combine with load bearing stud walls because it distributes the load evenly over the metal studs eliminating the need for load distribution devices. The typical span in this building is 24 feet. The typical bay that I chose to analyze is 24' x 28'8".

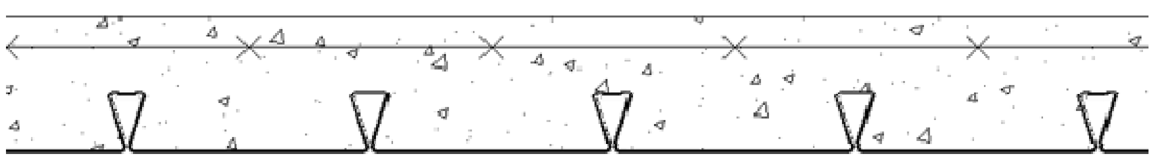
Building Footprint



Typical Bay



Epicore MSR metal deck Section

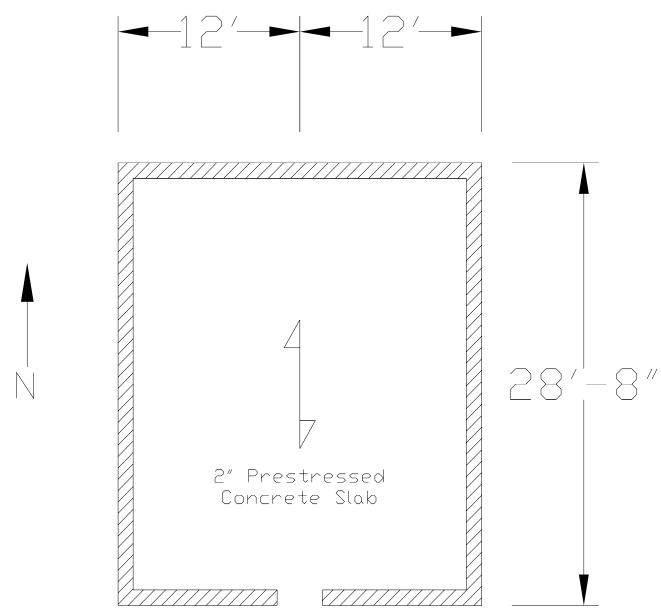


The Underwriters Laboratories fire rating for the Epicore composite deck system varies between 1 to 2 hours depending on the slab depth and weight of the concrete. The system used in the Academic Villages has a 4 inch slab and regular weight concrete (147 pounds per cubic foot) giving it a 1-hour fire rating.

Alternative 1: Post-Tensioned Concrete in N-S direction:

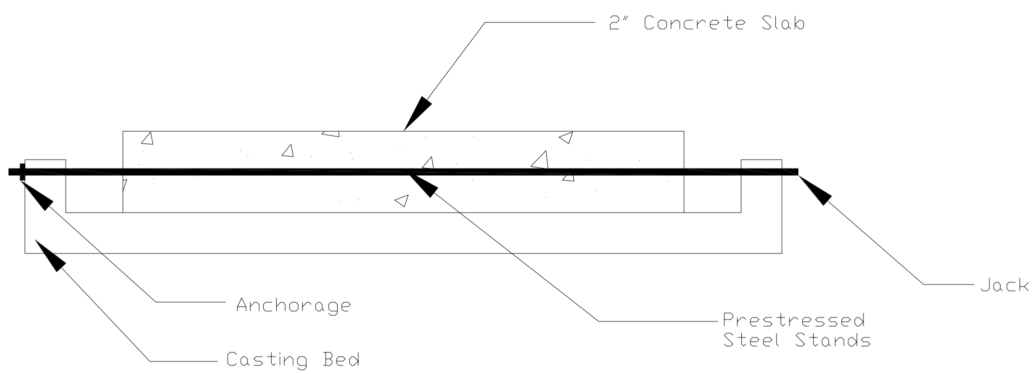
A post-tensioned concrete system is a system where the concrete is reinforced with high strength steel stands. These strands are tightened to a specified stress prior to the concrete being poured. Once cured, the strands provide additional tensile stress to the bottom of the concrete slab. A post-tensioned system allows for smaller slab thicknesses, longer clear spans. It is an “active” reinforced system, which means that deflection and cracking are greatly decreased since the steel strands are constantly loaded, unlike “passive” concrete systems where the slab deflects and cracks before the reinforcement provides the additional tension needed. By reducing the slab thickness, the buildings weight is also greatly reduced. This greatly reduces the amount of load the foundation experiences which can be a huge benefit in high wind areas like Orlando. Post-tensioned concrete can span the length of the entire structure instead of stopping at every column. This provides a great deal of flexibility with the building layout as well. Some of the downsides of post-tensioned concrete are that it requires a higher level of construction sophistication. A highly skilled labor force should be present to be sure that the strands are installed correctly. Buildings which are constantly being structurally modified should not use this system since the high stress steel strands make it very dangerous to cut into the slab. Shrinkage is also an issue with post-tensioned concrete since it is enhanced to the axial stresses acting on the side.

Typical Bay Post-Tensioned Concrete Slab (N-S)



Assumptions:

- Unfactored Service Load = 70 psf (DL = 30 psf, LL = 40psf)
- F'_c = 4000 psi
- F_y = 60,000 psi
- Cross section is homogenous
- Strand stress f_{py} = 270 ksi
- Strand area $A_{ps} = 0.153\ in^2$
- Concrete is uncracked → Class U → $f_{tallowable}$ = 474 psi
- Fiber stress in compression is due to prestress plus total load → $f_{callowable}$ = 2400 psi
- Span = 24'0"
- Length = 28'8"



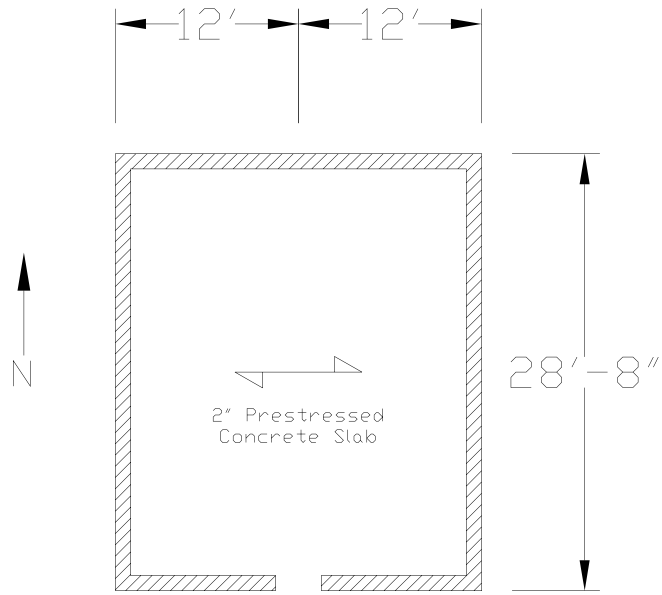
Results:

Using the allowable stresses of $f_{tallowable}$ = 474 psi and $f_{callowable}$ = 2400 psi calculated from ACI 318-02 sections 18.3.3 and 18.4.2 and setting them equal to the actual stresses and solving for the concrete slab thickness t; I found that $t_{required} \geq 1.37"$. By using a post-tensioned system, the slab can be reduced by more than 2" from 4" in the composite deck system to a 2" slab if necessary when using post-tensioned concrete under the same conditions. (see appendix for calculations)

Alternative 2: Post-Tensioned Concrete in E-W direction:

When using post-tensioned concrete in the east west direction, the largest span is 28'8" and the length is 24'0". All other assumptions are the same as Alternative 1.

Typical Bay Post-Tensioned Concrete Slab (E-W)



Assumptions:

- Unfactored Service Load = 70 psf (DL = 30 psf, LL = 40psf)
- F'_c = 4000 psi
- F_y = 60,000 psi
- Cross section is homogenous
- Strand stress f_{py} = 270 ksi
- Strand area A_{ps} = 0.153 in^2
- Concrete is uncracked → Class U → $f_{tallowable}$ = 474 psi
- Fiber stress in compression is due to prestress plus total load
  → $f_{callowable}$ = 2400 psi
- Span = 28'8"
- Length = 24'0"

Results:

Using the allowable stresses of $f_{tallowable}$ = 474 psi and $f_{callowable}$ = 2400 psi calculated from ACI 318-02 sections 18.3.3 and 18.4.2 and setting them equal to the actual stresses and solving for the concrete slab thickness t; I found that $t_{required} \geq 1.27$". This is a little less than the previous alternative which had a $t_{required} \geq 1.37$" but is relatively the same since the minimum slab thickness will govern in both of these cases. (see appendix for calculations)

Alternative 3: Precast Hollow Core Plank System

Precast hollow core planks can range anywhere between 6 inches thick to 16 inches thick depending mostly on how large a span is desired. A 6" hollow core plank with a 100 psf superimposed load can usually support a 20-22 foot span while 16" planks can support uphold 50 foot spans under the same load. The hollow core allows for a reduction of the weight by approximately 60% of the same section if it were solid making it much more economical than cast in place concrete. Construction time is greatly reduced when using precast panels since the concrete has already been cured. Precast panels can also be erected any time of the year unlike cast in place concrete which needs certain conditions to cure properly. Precast panels also have an excellent fire rating. Depending on the thickness, up to 4 hour endurance can be achieved. Precast panels are much deeper than cast in place concrete system since the smallest thickness available is 6". Many use an additional 2" concrete topping which further reduces the amount space available. The system that will be looked at here was designed using the Nitterhouse Concrete Products Manual. Based on the 24' span in the typical bay, a trial 8"x 4' panel was selected.

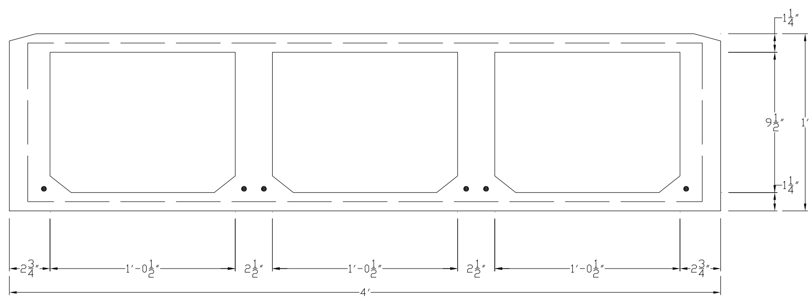
Assumptions:

- F'c =5000 psi at 28 days
- Maximum tensile stress = 6 * $(f'c)^{0.5}$ = 424 psi
- Span = 24 ft
- No concrete cover used at this time
- Precast wt = 57.5 psf (8"x 4')
- M/E/P = 10 psf
- Partitions = 20 psf
- Live load = 80 psf

Results:

Using the Nitterhouse Concrete Products Manual for a 8"x 4' Spandeck UL-J917, it was found that a span of 24' did not meet the calculated superimposed load of 233 psf. In order to gain more strength, I switched to a 12"x 4' section (wt = 77.5 psf), 6 strands, and found that that superimposed load of 257 psf was less than allowable load of 278 psf for a 24' span with no topping. (see appendix for calculations)

12" SpanDeck Cross Section



Alternative 4: Prestressed Concrete Double Tee

The prestressed concrete double tee forms a structural suspended floor than can range anywhere from 24” to 32” in depth and can be supplied in either 8’ or 12’ widths. The span can range anywhere between 20’ and 100’ depending on the thickness of the member and whether or not there’s an additional concrete topping. It require a large number of personnel to erect these large units and like hollow core planks, construction time

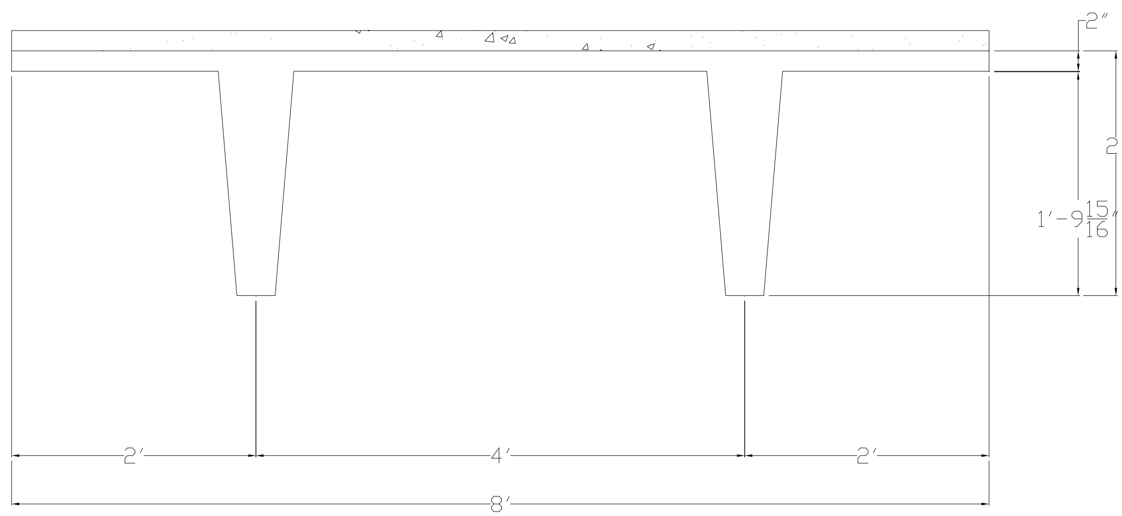
Assumptions:

- F’c = 6000 psi at 28 days
- Maximum tensile stress = 12 * $(f'c)^{0.5}$ = 930 psi
- Span = 28 feet
- Length = 24 feet
- M/E/P = 10 psf
- Partitions= 20 psf
- Live load = 80 psf

Results:

Using the Nitterhouse Concrete Products Manual, I found that very few products were available for a 24’ span. So I tried to span east to west instead using a span of 28’ and length of 24’. The 24’ length is also divisible by the 8’ widths, so no tee will have to undergo any major adjustments to fit properly. The 24”x 8’ section 24-88 PT double tee with a 2” concrete cover was sufficient to carry the superimposed load of 264 psf. (see appendix for calculations)

24”x 8’ Double Tee Cross Section



Conclusion

In conclusion to the analysis of these 5 structures, it has been determined that the existing structure while a good choice for the structural floor system may not be the best. Concrete columns and beams are present on the first load because the steel stud bearing walls can not carry the weight of the floor system alone. By using a post-tensioned concrete system such as explained in Alternative 1, those extra beams and columns may be able to be eliminated from the design, simplifying the structure. Alternatives 3 and 4 were eliminated because even though the hollow core and double tee sections will provide a structure with less weight than the existing system, they are much too deep for this building. The double tee system also needed an additional 2" concrete topping in order to have sufficient strength but also takes away its weight advantage when compared to the existing structure. Further analysis will be taken to decide if a post-tensioned concrete system is a better choice than the existing system. The following chart shows the results of this report.

Compare/Contrast

System	Depth	Advantages	Disadvantages	Potential
Existing: Composite deck with slab	4"	Works well with steel studs Relatively low cost Long spans Good fire rating	Constuction time Heavy building Addition supports needed	N/A
Post-tensioned Concrete (N-S)	2"-4"	Long spans Thin slabs/less weight Fewer deflections Less cracking	Shrinkage Complex construction Need additional fire protection Construction time	YES
Post-tensioned Concrete (E-W)	2"-4"	Long spans Thin slabs/less weight Fewer deflections Less cracking	Shrinkage Complex construction Need additional fire protection	YES
Precast Hollow Core Planks	6" - 16"	Lightweight Fast construction Weather not a problem Allows for floor conduit	High cost Lead time for fabrication Deep system	NO
Precast Double Tee Planks	24" - 32"	Very long Spans Fast construction Weather not an issue	Very deep system High cost Lead time for fabrication Large staff needed to erect	NO

Design Calculations

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Project	Prepared by	Date
Subject/Title	Reviewed by	Date
	Calculation Number	Sheet of

Pre-tensioned Concrete (N-S)

From ACI 318-02

18.3.3 $\Rightarrow f_t \le 7.5\sqrt{f'c} \le 7.5\sqrt{4000} \le 474$ psi — class U

18.4.1 $\Rightarrow$ assume for MAX service loads

$\Rightarrow f_c \le 0.6f'c = 0.6(4000) = 2400$ psi

Assume

$f_{py} = 270$ ksi

$A_{ps} = 0.153$ in^2

$$M_{MAX} = \frac{wl^2}{8} = \frac{(70\text{ psf})(24')(28.67)^2(12''/1)}{8} = 2071.4 \text{ k-in}$$

$$f_{TOP} = -\frac{M}{S} - \frac{Pe}{A} \le f_{t\,allow}$$

$$= -\frac{6 \times 2071.4}{bd^2} - 270 \text{ ksi} \le 2.4 \text{ ksi}$$

$\Rightarrow bd^2 = -45.63 \Rightarrow d^2 = -1.9$

$\Rightarrow d \le -1.38''$

$$f_{bot} = \frac{M}{S} + \frac{Pe}{A} = \frac{6 \times 2071.4}{bd^2} + 270 \le 0.474 \text{ ksi}$$

$\Rightarrow bd^2 = 46.11 \Rightarrow d^2 = 46.11$

$d = 1.39''$

Design Calculations

Project	Prepared by	Date
Subject/Title	Reviewed by	Date
	Calculation Number	Sheet of

Prestressed Concrete E-W

$f_t \le 474$ psi (Class U)

$f_c \le 2400$ psi (MAX service loads)

$f_{py} = 270$ ksi

$A_{ps} = 0.153$ in^2

$f'c = 4000$ psi

Span = 28' 8"   w = 70 psf

L = 24'

$$M_{MAX} = \frac{wl^2}{8} = \frac{(70)(28.67)(24)^2(12)}{8} = 1733.96 \text{ "k}$$

$$f_{top} = -\frac{M}{S} - \frac{P_e}{A} \le 2.4 \text{ ksi}$$

$$-\frac{1733.96 \times 6}{bd^2} - 270 \le 2.4 \Rightarrow bd^2 = 38.2$$

$$d = 1.15"$$

$$f_{bottom} = \frac{M}{S} + \frac{P_e}{A} \le .474 \text{ ksi}$$

$$-\frac{1733.96 \times 6}{bd^2} + 270 \le .474 \Rightarrow bd^2 = 38.6$$

$$d = 1.27"$$

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Design Calculations

Project	Prepared by	Date
Subject/Title	Reviewed by	Date
	Calculation Number	Sheet of

Precast Hollow Core System (Nitterhouse)

8" x 4' SpanDeck O.L J917

WT = 230 plf or 57.4 psf

Dead Load)

M/E/P = 10 psf

Partitions = 20 psf

30 psf

LIVE LOADS

L = 80 psf

$\omega = 1.2(D) + 1.6(L)$

$= 1.2(57.4 + 30) + 1.6(80) = 233$ psf

Longest Span able to carry this load ⇒ 16' Span

Need more strength or must reduce Span

→ Try 12" x 4' w/ 6 Strand pattern (WT = 77.5 psf)

$w = 1.2(77.5 + 30) + 1.6(80)$

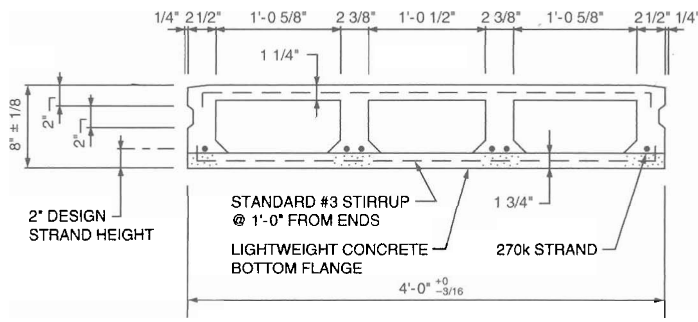
$= 257$ psf

$w_{ALLOWABLE} = 278$ psf > 257 psf ok

Form No. 9-324B

Prestressed Concrete
8" x 4' SpanDeck – U.L. – J952
(NO TOPPING)

PHYSICAL PROPERTIES Precast					
A	=	199 in.^{2}	S_b	=	332 in.^{3}
I	=	1370 in.^{4}	S_t	=	354 in.^{3}
Y_b	=	4.13 in.	Wt.	=	230 PLF
Y_t	=	3.87 in.	Wt.	=	57.5 PSF
e	=	2.13 in.			



8" SPANDECK CROSS SECTION

UL FIRE RATED J952

DESIGN DATA

1. Precast Strength @ 28 days = 5000 PSI.
2. Precast Strength @ release = 3000 PSI.
3. Precast Density = 150 PCF (Top and Webs)
   = 115 PCF (Soffit)
4. Strand = 1/2"ø, 270 K Lo-Relaxation.
5. Strand Height = 2.00 in.
6. Ultimate moment capacities (when fully developed) . . .
   4 – 1/2"ø, 270K = 68.0'K
   6 – 1/2"ø, 270K = 96.3'K
7. Maximum bottom tensile stress is $6\sqrt{f'c} = 424$ 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. Shear values are the maximum allowable before shear reinforcement is required.
11. Deflection limits were not considered when determining allowable loads in this table.
12. All values in this table are based on ultimate strength and are not governed by service stress.

8" SPANDECK W/O TOPPING	ALLOWABLE SUPERIMPOSED LOAD (PSF)																						
STRAND PATTERN	SPAN (FEET)																						
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Flexure 4 – 1/2"ø	565	510	460	420	361	309	265	231	199	175	152	133	118	105	91	80	71	62	54	47	41	35	X
Shear 4 – 1/2"ø	429	383	345	313	286	263	241	225	209	195	177	159	143	130	118	110	104	95	88	79	72	66	X
Flexure 6 – 1/2"ø	825	745	675	619	531	456	395	344	302	265	236	209	186	167	149	134	120	107	96	86	78	70	63
Shear 6 – 1/2"ø	446	398	359	326	298	274	253	234	218	204	191	179	169	159	150	138	126	115	106	97	89	82	76

NITTERHOUSE
CONCRETE PRODUCTS

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.

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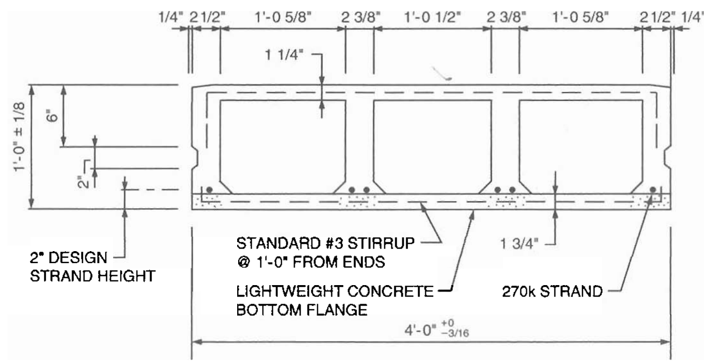
REVISED 12/93

Prestressed Concrete
12" x 4' SpanDeck – U.L. – J952
(NO TOPPING)

PHYSICAL PROPERTIES

Precast

A	= 238 in.^{2}	S_b	= 640 in.^{3}
I	= 3915 in.^{4}	S_t	= 666 in.^{3}
Y_b	= 6.12 in.	Wt.	= 310 PLF
Y_t	= 5.88 in.	Wt.	= 77.5 PSF



12" SPANDECK CROSS SECTION

UL FIRE RATED J952

DESIGN DATA

1. Precast Strength @ 28 days = 5000 PSI.
2. Precast Strength @ release = 3000 PSI.
3. Precast Density = 150 PCF (Top and Webs)
   = 115 PCF (Soffit)
4. Strand = 1/2"ø, 270 K Lo-Relaxation.
5. Strand Height = 2.00 in.
6. Ultimate moment capacities (when fully developed) . . .
   4 – 1/2"ø, 270K = 119.0'K
   6 – 1/2"ø, 270K = 171.7'K
7. Maximum bottom tensile stress is $6\sqrt{f'c}$ = 424 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. Shear values are the maximum allowable before shear reinforcement is required.
11. Deflection limits were not considered when determining allowable loads in this table.
12. All values in this table are based on ultimate strength and are not governed by service stress.

12" SPANDECK W/O TOPPING										ALLOWABLE SUPERIMPOSED LOAD (PSF)													
STRAND PATTERN	SPAN (FEET)																						
	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Flexure 4 – 1/2"ø	369	324	286	253	225	201	179	160	143	128	114	102	91	81	72	64							
Shear 4 – 1/2"ø	353	328	309	291	271	247	225	206	189	174	160	148	141	134	124	115							
Flexure 6 – 1/2"ø	559	495	441	394	353	318	286	259	235	213	193	176	160	146	131	121	111	101	92	83	76	69	62
Shear 6 – 1/2"ø	373	349	327	307	289	273	259	245	233	220	203	188	175	162	150	139	129	120	112	105	98	94	90

NITTERHOUSE
CONCRETE PRODUCTS

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Design Calculations

Project	Prepared by	Date
Subject/Title	Reviewed by	Date
	Calculation Number	Sheet of

Precast Concrete Double Tee

24" x 8' Double Tee w/ 2" CIP Topping

WT = 82 psf

Dead Loads
MEP = 10 PSF
Partitions = 20 PSF
30 psf

LIVE LOADS
L = 80 psf

$w = 1.2(D) + 1.6(L)$

$= 1.2(38+82) + 1.6(80) = 263.6$ psf

⇒ Section 24-88 PT is sufficient for a 28' span $w_{allow} = 282$ psf

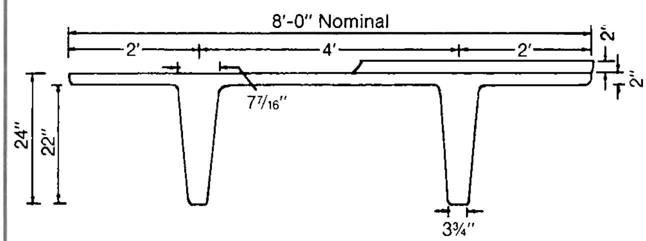
Use 24"x8' w/ 2" conc topping
24-88 PT for a 28' span

Prestressed Concrete
24" x 8' Double Tee
(2" C.I.P. TOPPING)

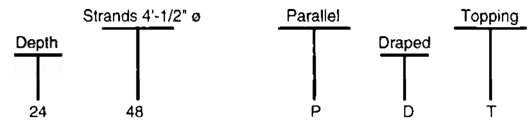
PHYSICAL PROPERTIES

Composite

A'= 587	in. ^{2}	S'$_b$= 1552	in. ^{3}
I'= 29,462	in.^{4}	S'$_t$ = 5892 (at top of D.T.)	in. ^{3}
Y'$_b$= 19	in.	S'$_{tt.}$= 4209 (at top of topping)	in ^{3}
Y'$_t$= 5	in. (to top of D.T.)	Wt'= 656	PLF
Y'$_{tt}$= 7	in. (to top of topping)	Wt'= 82	PSF



DESIGN DATA



1. Precast strength @ RELEASE = 3,500 PSI
2. Precast strength @ 28 days = 5,000 PSI
3. Precast Density = 150 PCF
4. Strand= 1/2" Ø 270k LO-relaxation
5. Composite Strength = 3,000 PSI
6. Composite Density = 150 PCF
7. Maximum bottom tensile stress is $12\sqrt{f'c}$= 848 PSI.
8. All superimposed load is treated as live load in the flexural strength analysis.
9. Flexural capacity is based on stress/strain strand relationships.
10. Maximum moment capacity is critical at midspan for parallel strands and is critical near 0.4 span for draped strands.
11. All loads shown refer to allowable loads after the topping has hardened.

Table of Safe Superimposed Loads (lbs. per sq. ft.)

Section	Ø M_n (in. Kips)	Span in Feet																				
		22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62
24-48 PT	3,372	224	219	177	143	116	94	75	60	47												
24-68 PT	4,649			269	223	185	155	129	108	91	75	61	50	40								
24-88 PT	5,603				282	239	202	170	144	122	104	88	74	62	51	42						
24-88 DT	6,791						252	215	184	158	136	117	101	86	74	63	53	44				
24-108 DT	8,243								240	209	182	159	139	121	106	92	80	69	60	51	43	
24-128 DT	9,704														136	120	105	92	82	71	62	55
24-148 DT	11,105																				80	70

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.

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