Post-Tensioned One-Way Slab

INTRODUCTION

The existing Infinity System is a composite floor system made with Epicore MSR (multi-story residential) deck and a concrete slab. It is fairly lightweight and can achieve up to a max span of 20'0" and max slab of 8" using 4000 psi regular weight concrete. This span however, provides a limit on each apartment units flexibility since each unit is 24'0" wide. A preliminary analysis showed that by using a conventional one-way slab system, longer spans can be achieved without increasing the slab thickness and thus, increasing each of the unit's layout flexibility.

DESIGN CRITERIA

There are three criteria which must be considered for the design of a conventional one-way slab system:

1. *The proposed slab system must meet the current code.* The codes governing the design of the one-way slab will be ACI 318-02 and IBC 2003.
2. *The proposed slab system must be able to be constructed at a reasonable cost.* A cost analysis will be provided based on data from RS Means.
3. *Will the proposed slab system bring up other additional issues that need to be addressed?* A comparison will also need to be conducted between the existing composite deck system and the proposed system.

If the first criterion is not met, a one-way slab system cannot even be considered, and the existing system will be accepted as the best solution for the project. The remaining two criteria will only be effective once the first criterion is met.

LOAD ANALYSIS

In order to evaluate the loads on the building effectively, it was divided up into three sections:

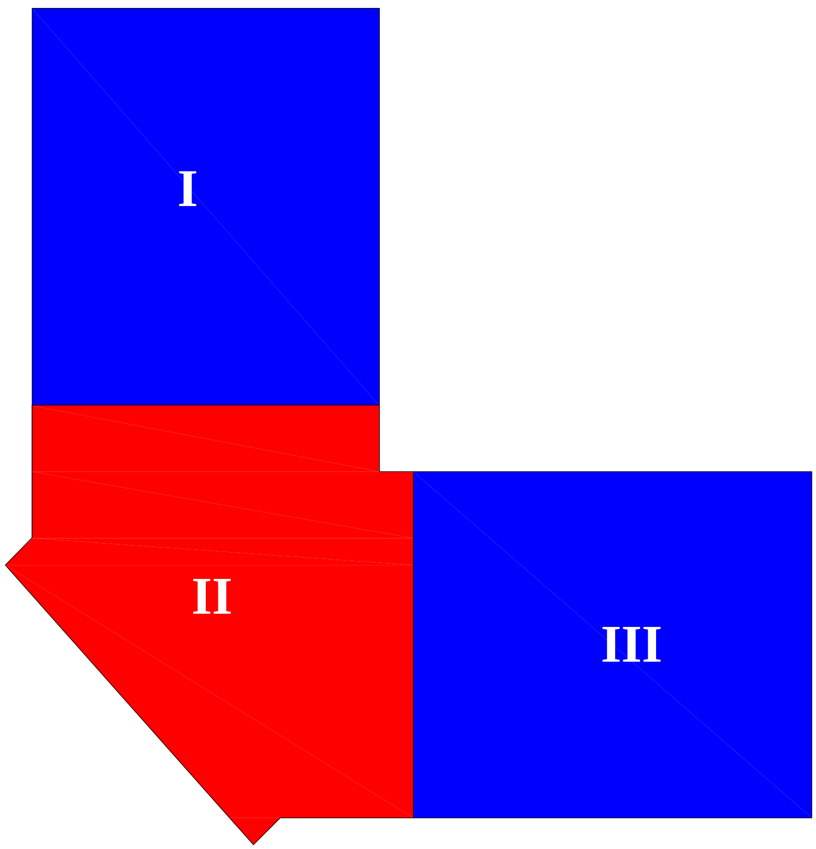

Figure 10: Three sections evaluated for design

The first and third sections are the critical sections and are identical in opposite directions. There are four apartment units side by side in a row, each with a 24’0” span giving each section a total length of 96’0”. The middle section which does not contain any apartment units is made up of smaller spans, the max being 15’6”. Each of these sections has its own design criteria which must be satisfied based on the code. In order to simplify the design process, the max/critical condition in each section will be calculated and the results will be applied to all similar locations in that section.

The loads used in these calculations were:

- Live Load =100 psf (From Table 4-1 in ASCE 7-02 à max residential loading)
- Mechanical/Electrical/Plumbing = 15 psf
- Superimposed Dead Load = 10 psf
- Normal Weight Concrete (150 pcf)

Post-Tension Analysis (flexural strength)

A recommended thickness estimation for a simple span post-tensioned section is about 1/32* the clear span was given by Prestressed Concrete Analysis and Design Fundamentals by Antoine Namaan. In the case of a 24’0” span, the recommended thickness would be 9”. This was obviously much higher than I would have liked since the existing composite deck system only requires a 4 ½“ slab. As a result, 4 separate cases will be evaluated to try to reduce the slab thickness to about 5”.

The Four Case Investigations:

1. One-Way Simple Span Class U (uncracked) (ACI 318-02 18.3.3)
2. One-Way Simple Span Class T (transition) (ACI 318-02 18.3.3)
3. One-Way Continuous Span Class U (uncracked) (ACI 318-02 18.3.3)
4. One-Way Continuous Span Class T (transition) (ACI 318-02 18.3.3)

Material Properties
Concrete Compressive Strength, f'_c = 5000 psi
Initial Concrete Compressive Strength, f'_{ci} = 3500 psi
Ultimate Stress in Prestress Strand, f_{pu} = 270 ksi
Initial Stress in Prestress Strand = 0.7 x f_{pu} = 199.8 ksi

Table 4: Material Properties

Allowable Stresses (from ACI 318-02 chapter 18)		
Extreme Fiber Stress in Tension, • $_{ts}$ • 7.5• f'$_c$ (Class U) =	530 psi	(18.3.3)
Extreme Fiber Stress in Tension, • $_{ts}$ • 12• f'$_c$ (Class T) =	849 psi	(18.3.3)
Extreme Fiber Stress in compression, • $_{cs}$ • 0.6f'$_c$ =	3000 psi	(18.4.2)
(due to prestress and total load)		
Extreme Fiber Stress in compression, • $_{csus}$ • 0.45f'$_c$ =	2250 psi	(18.4.2)
(due to prestress and sustained load)		
Extreme Fiber Stress in compression, • $_{ci}$ • 0.6f'$_{ci}$ =	2100 psi	(18.4.1)
(immediately after prestress transfer)		
Extreme Fiber Stress in Tension, • $_{ti}$ • 3• f'$_{ci}$ =	177.5 psi	(18.4.1)
(immediately after prestress transfer)		

Table 5: Allowable Stresses

In order to find the required force and eccentricity, a feasible domain was set up using a program developed in excel for various slab thicknesses. The basis for the feasible domain comes from that combination of two extreme loadings (M_{min}, M_{max}) and two allowable stresses (tension, compression) will give 4 inequality conditions. The following stress conditions were used:

I. $e_o \bullet k_b + (1/F_i)(M_{min} – (\bullet_{ti})(Z_t))$

II. $e_o \bullet k_t + (1/F_i)(M_{min} + (\bullet_{ci})(Z_b))$

III. $e_o \bullet k_b + (1/\bullet F_i)(M_{max} – (\bullet_{cs})(Z_t))$

IV. $e_o \bullet k_t + (1/\bullet F_i)(M_{max} + (\bullet_{ts})(Z_b))$

V. $e_o \bullet y_b – (d_c)_{min}$

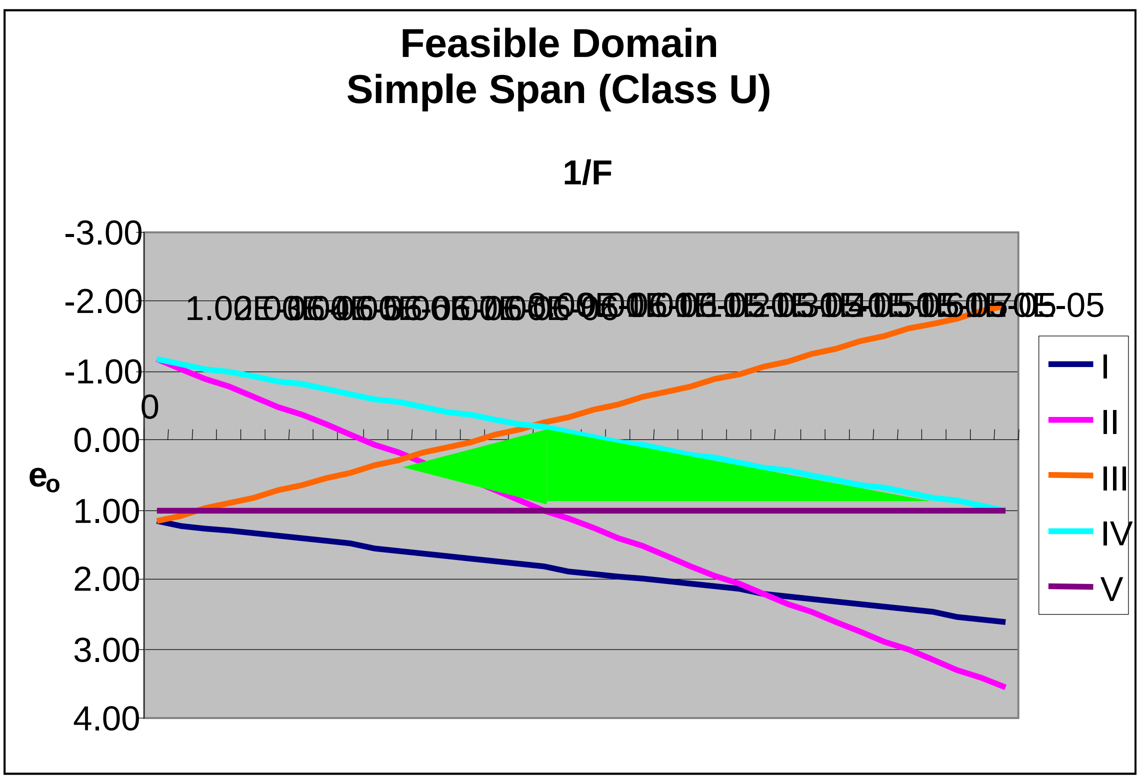

Figure 11: Feasible Domain of Simple Span

The area in green in Figure 11 shows the feasible domain of the simple span post-tensioned system for a given slab depth. The data found in the feasible domain provides three types of information:

1. It provides the ultimate required strand force allowed given the max eccentricity for a given slab thickness.
2. It provides all allowable eccentricities for any given strand force and vice versa.
3. It provides eccentric boundary information to design the tendon profile.

It was assumed that due the thin slab thickness, deflection would control the design. The equation for long term deflection varies with different tendon profiles. Using data from the feasible domain, the following eccentric parameters were formed in Table 6:

Distance	**Eccentricities(in**		**Tendon**
(ft)	**Min**	**Max**	**Profile**
0	-2.57	1.54	1.52
2	-1.29	1.97	1.52
4	-0.26	2.32	1.52
6	0.54	2.59	1.52
8	1.10	2.78	1.52
10	1.42	2.90	1.52
12	1.50	2.94	1.52
14	1.34	2.90	1.52
16	0.94	2.78	1.52
18	0.31	2.59	1.52
20	-0.57	2.32	1.52
22	-1.68	1.97	1.52
24	-3.03	1.54	1.52

Table 6: Tendon Profile Parameters

From the above parameters, a *straight* tendon profile was formed. The simple span class U was the only case in which a straight tendon profile was developed. All three remaining cases yielded one draped point at the midspan.

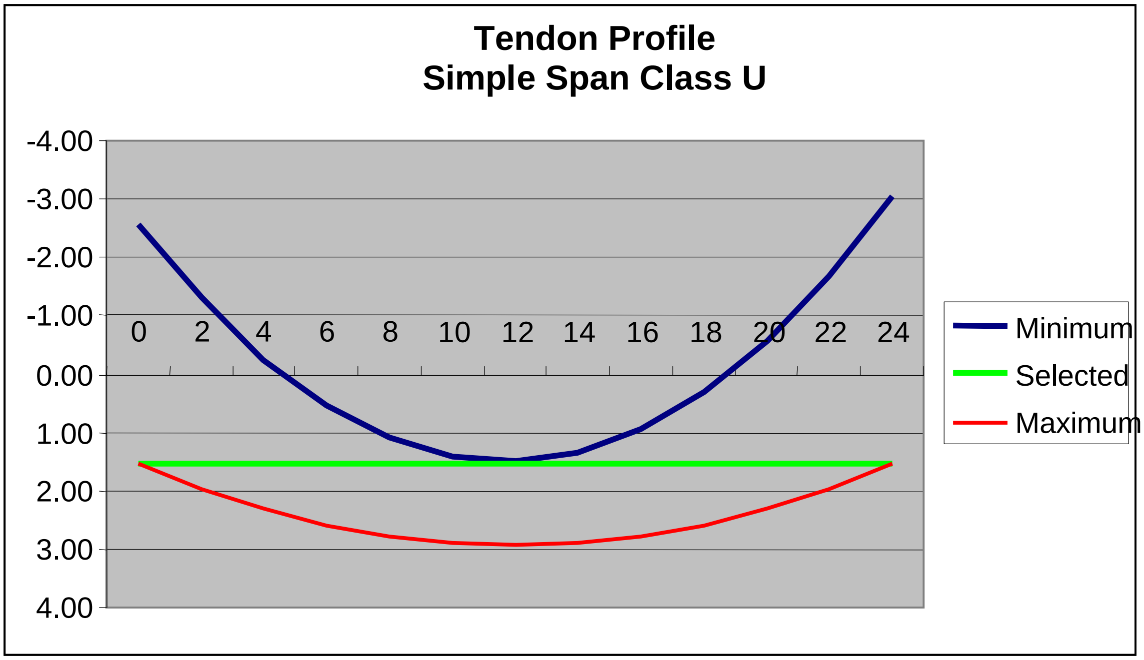

Figure 12: Tendon Profile for Simple Span

All reinforcement due to flexture is *<u>½" Ø 7-wire low-lax steel strands ASTM Grade 270.</u>* See Appendix 1 for additional cases and calculations.

<u>Post-Tension Analysis (Deflection)</u>

Given the tendon profile, the deflection can be calculated based on the following equations:

Straight Tendon Profile è • $= - Fe_1L^2/8EI$

Draped Tendon Profile è • $= - FL^2/24EI * [2e_1 + e_2]$

Where e_1 = eccentricity at midspan

e_2 = eccentricity at the supports

$\bullet_{Total} = \bullet_i + \bullet_{add}$

Where $\bullet_i$ = the immediate deflection that occurs once the load was applied

$\bullet_{add}$ = the long term deflection

Using the Branson equation as a rule of thumb, the equation to calculate long term deflection is the following:

$\bullet_{add} = 1.8(\bullet_i)_{Fi} + 2.2(\bullet_i)_G + 2(\bullet_i)_{SD}$

In cracked sections, the effective moment of inertia was used:

$I_e = I_{cr} + [M_{cr}/M_a]3(I_g - I_{cr}) \bullet I_g$

By using the Information provided by the feasible domain in the flexural analysis, I was able to find the thinnest slab thickness for each of the 4 case investigations using a program developed in excel. Please refer to Appendix 1 for extensive calculations.

Case Investigation	**Slab Thickness**	**Force Required / ft**
Simple Span Class U	7.5"	46.5 K/ft
Simple Span Class T	7"	56.5 K/ft
Continuous Span Class U	6"	68.3 K/ft
Continuous Span Class T	5"	70.7 K/ft

Table 7: Case Results

The Continuous Span Class T case proved to be the best solution for using a post-tensioned concrete system in critical Zones I and III. The slab spanned four bays, a total length of 96'0" which was less the than the 100'0" limit specified by ACI 318-02. (2) ½" Ø 7-wire low-lax steel strands ASTM Grade 270 were used every foot. The eccentricity at the support was 0.5" down at the supports and 1.2" down at the midspan of each of the 24' bays.

Post-Tension Analysis (Shear strength)

Using the shear design method found in the PCI Design Handbook Precast and Prestressed Concrete 6th Edition, the shear values were calculated at 3 ft, 8 ft, 12 ft and 18 ft from the support. The following graph in Figure 13 was made to show the shear distribution along the post-tensioned slab.

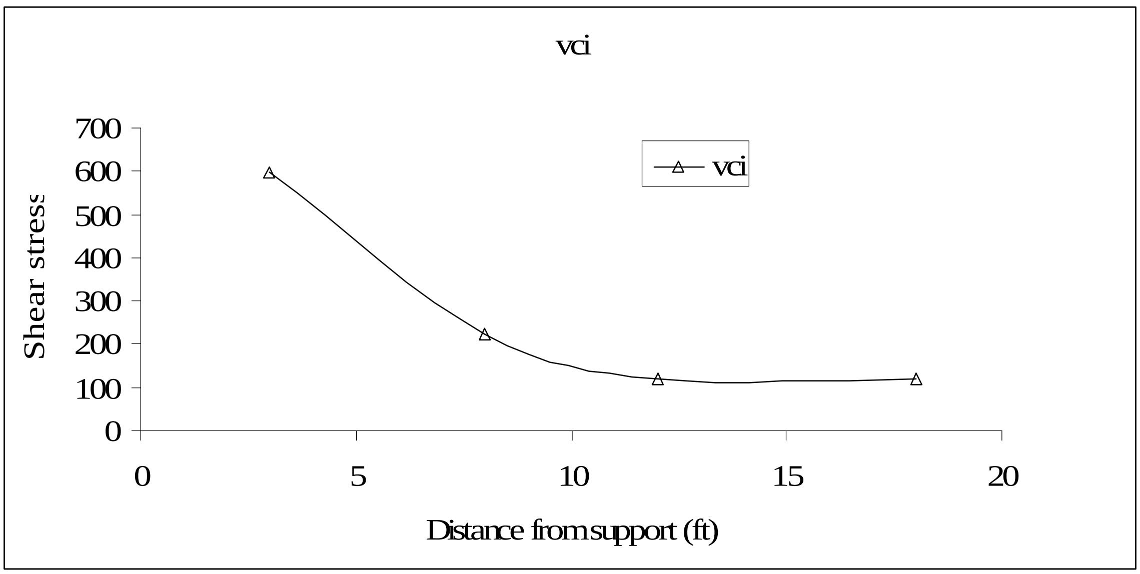

Figure 13: Shear Distribution

Due to the thin slab thickness, I felt that welded wire reinforcement (WWR) would provide the best results for the proposed system. Sample calculations the shear at 9 feet from the support are provided in Appendix 2. Please refer to table 8 below for the shear reinforcement specifications.

Distance from support (ft)	Wire designation	Area of shear reinforcement (in^2)	Spacing of vertical wire (in)
3	W2.9	0.058	6
8	W2.9	0.058	12
12	W2.1	0.058	24
18	W2.1	0.058	24

Distance from support (ft)	Vu (psi)			
3	297.5	vc_1 (psi)	vc_2 (psi)	1.7 sqrt(fc') (psi)
8	242	594.8	400	120
12	131	222	400	120
18	75	120.1	400	120

Table 8: Shear Stresses

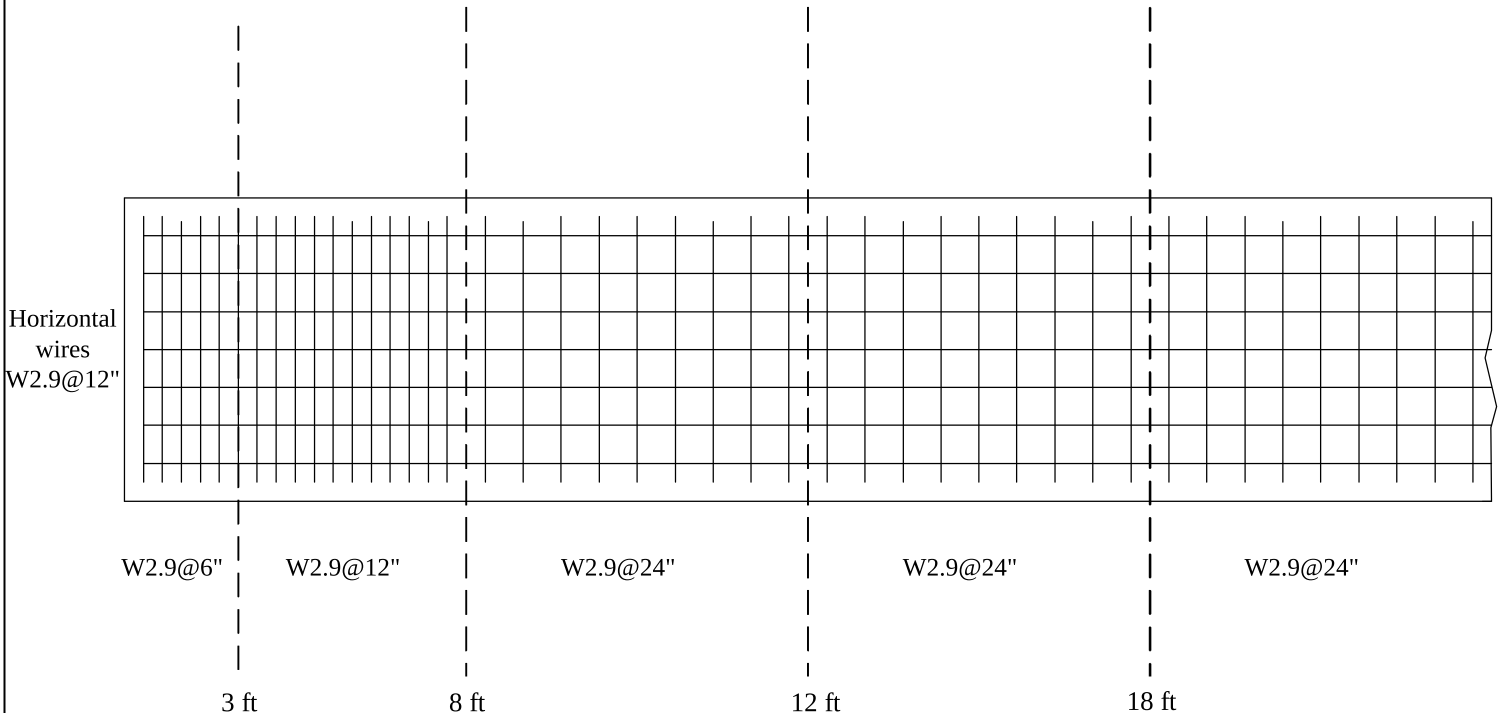

Figure 14: Shear reinforcement distribution

Cost Comparison

Using RS Means, an estimate was made to compare the two systems. Please view Table 9 below for the cost summary of each system.

Post-Tensioned Concrete	
Concrete (5000 psi)	$345,852.00
Reinforcement	$145,050.00
Formwork	$132,564.00
Total	$623,466.00

Epicore Deck System	
Concrete (5000 psi)	$276,055.00
Reinforcement	$90,560.00
Formwork	$80,540.00
Metal Deck	$135,220.00
Total	$582,375.00

Table 9: Cost Comparison

The Epicore Deck system was not as expensive as the one-way slab system due largely to the formwork costs for the post-tensioned slab. However, the overall cost of each is too close to be a major criteria in determining a one-way slab's feasibility.

Conclusion

The one-way slab meets all design and serviceability requirements for code. It is a feasible alternative for the current composite deck system even though it is slightly more costly.