# Final Report

University of Central Florida's Academic Villages

Samuel Ávila
Structural Option
April 3, 2006

Advisor: Dr. Thomas Boothby

# University of Central Florida's Academic Villages

## Orlando, FL

### Samuel Avila

### Structural

## PROJECT OVERVIEW

| | |
|---|---|
| **•Occupancy:** | Undergraduate Student housing |
| **•Dates of Construction:** | August 2000 – September 2002 |
| **•Overall Project Cost:** | $63 million |
| **•Stories high:** | 4 stories with height of 40 feet |

## PROJECT TEAM

| | |
|---|---|
| **Owner:** | University of Central Florida<br>www.ucf.edu |
| **Architect:** | Hanburry Evans Wright Vlattas<br>www.hewv.com |
| **Engineer:** | TLC Engineering<br>www.tlc-engineers.com |
| **Geotechnical Engineer:** | Nodarse & Assoc.<br>www.nodarse.com |
| **Delivery Method:** | Design-Bid-Build |

## STRUCTURAL

•Shallow foundation system consisting of strip and stepped footings

•8" cmu interior and exterior lateral shear walls

•2" 22 gage galvanized Epicore metal decking with cast in place concrete slab floor system

•Concrete columns on base floor / light gage metal built-up columns on remaning floors

•Light gage metal trusses with 1" 20-gage galvanized G-90 metal decking roof system

## ARCHITECTURAL

•10 separate buildings varying in size and layout, the smallest around 14,000 sq. ft. and the largest about 22,000 sq. ft.

•Exterior façade consisted of stucco over bricks to give a traditional Spanish "villa" appearance

## MECHANICAL

•Constant volume of air throughout ductwork to provide natural ventilation to each building

•Each apartment unit is equipped with its own heat pump

•Central system on roof provides main public spaces with conditioned air

## ELECTRICAL/LIGHTING

•Primary Switchboard: 277/480V 3 phase 4 wire

•Stepped down to 120/208V when needed

•Fluorescent lighting

# T a b l e   o f   C o n t e n t s

# Acknowledgements

TLC Engineering
For providing the plans for my building and answering all my questions throughout the year.

Dr. Thomas Boothby
For carefully evaluating and providing input during all the stages of this project.

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For all the time devoted to helping me develop a better understanding of post-tensioned systems.

Dr. Moses Ling
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Entire AE Faculty
For helping me grow through study and research.

My Wife, Franchesca
For her tireless love and confidence in me.

My Family and Friends
For their continuous support throughout my career at Penn State.



# Executive Summary

The University of Central Florida's Academic Villages located in Orlando, Florida is a complex of 7 separate dormitories built to accommodate approximately 500 new freshman students. Each building is 4 stories tall and range from approximately 14,000 to 22,000 square feet in area. Each floor typically has between eleven and fifteen 24 ft x 28 ft apartment units.

The existing structure in the Academic Villages is a fully composite steel deck floor system accompanied by a lateral system of masonry shear walls throughout the building.

This report addresses possible changes to the Academic Villages. An investigation was carried out on the existing floor system based on layout flexibility and other criteria. As a result, a new system using a one-way post-tensioned concrete slab was designed, which satisfied the selected criteria. The existing shear walls, which were found to be insufficient with the new system, were redesigned to meet the new loads as well.

The existing mechanical system employed in the academic villages is a Water Source Heat Pump (WSHP) system. It was investigated based on performance costs. As a result, an Energy Reduction Ventilator (ERV) system was proposed to satisfy this criteria. It was found that after 9/10 years, an installed ERV system will save more than the existing system.

The building was checked to make sure that it met IBC 2000 code requirements. It did not and an acoustic subflooring material was recommended to meet code requirements.

Lastly, another acoustic check was done. There was concern that several apartment units located next to mechanical rooms would receive transmission sounds greater than what was allowable. A check proved that the existing system was more than capable to resist additional noise from the mechanical rooms.

# Background Information

The University of Central Florida's Academic Villages called the "Nike Community" is a complex of seven separate dormitories built in Orlando Florida to accommodate 800 new freshman students in 2003. The building footprints are various sizes ranging from 14,000 square feet to 22,000 square feet. All of the buildings are 4 stories tall and 44'-8" above the ground. Each floor has between eleven and fifteen 24 ft x 28 ft apartment units.

**Figure 1:** Sky view of Academic Village complex
(Courtesy of Hanbury Evans Wright Vlattas & Co.)

| Primary Project Team | |
|---|---|
| Owner | University of Central Florida |
| Architect | Hanbury Evans Wright Vlattas |
| Structural Engineer | TLC Engineering |
| Geotechnical Engineer | Nodarse & Associates |
| Mechanical Engineer | TLC Engineering |
| Design Consultant | Ensite, Inc. |
| Civil Engineer | Vanasse Hangen Brustlin, Inc. |

The Academic Villages are living and learning community designed in the style of a "Contemporary Mediterranean Hill Town." Retail and social spaces on the first floors of each building open up to a central plaza, which is the center of student activity in the Villages. The construction and completion of the community was divided into two phases. The first phase started in August of 1999 and was completed in September of 2001. The second phase was completed in July of 2002.

**Figure 2:** View of central plaza
(courtesy of Hanbury Evans Wright Vlattas & Co.)

# E x i s t i n g S t r u c t u r a l S y s t e m

## BUILDING DESCRIPTION

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 2" 22 GA. Epicore MSR metal decking with a 4 ¼" concrete topping with W6x6 W2.1xW2.1 WWF reinforcement. The slab has a 28 day strength of 3000 psi. It spans between interior and exterior load bearing CMU walls in the east-west direction 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 for this floor type is 12 feet. The typical bay for this floor system is shown in figure 3 below.

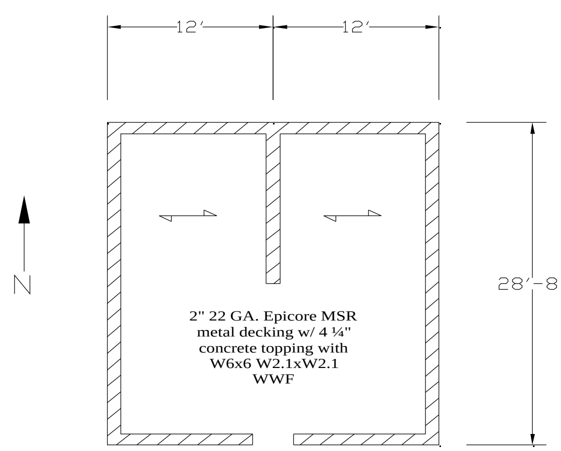



**Figure 3:** Typical bay

## Building Footprint

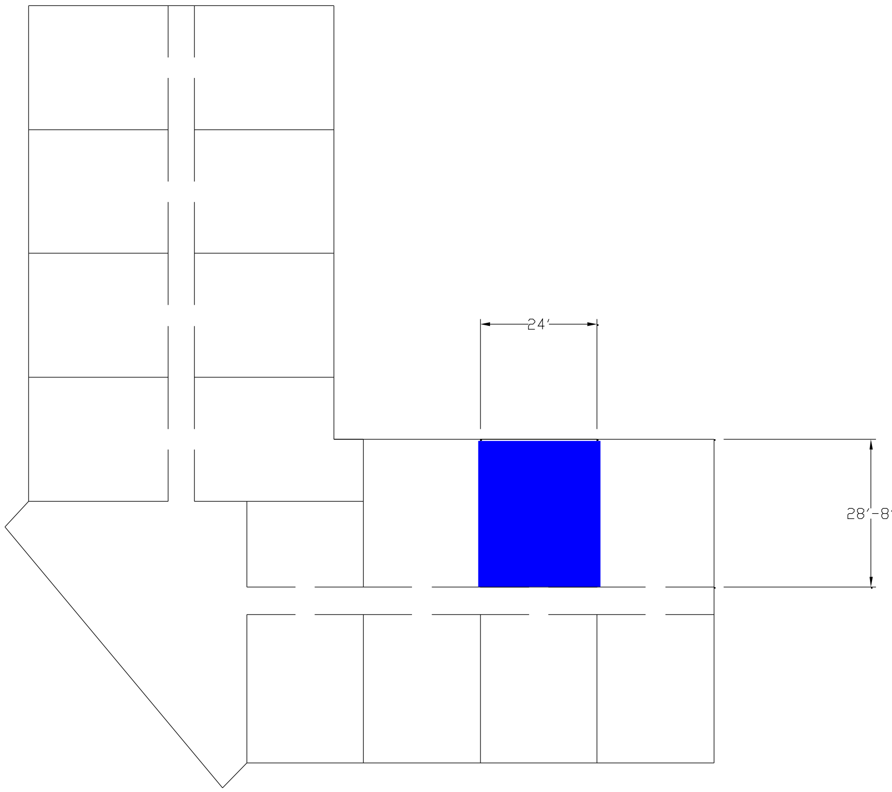



**Figure 4:** Building Footprint

## LATERAL SYSTEM

The lateral system for the Academic Villages uses both exterior and interior masonry shear walls in both N-S and E-W directions to resist seismic and wind forces. All shear walls are typically 8" masonry units with Type S mortar and #5@24" reinforcement. See figure 5 below for the location of the shear walls at every level.

## SHEAR WALLS

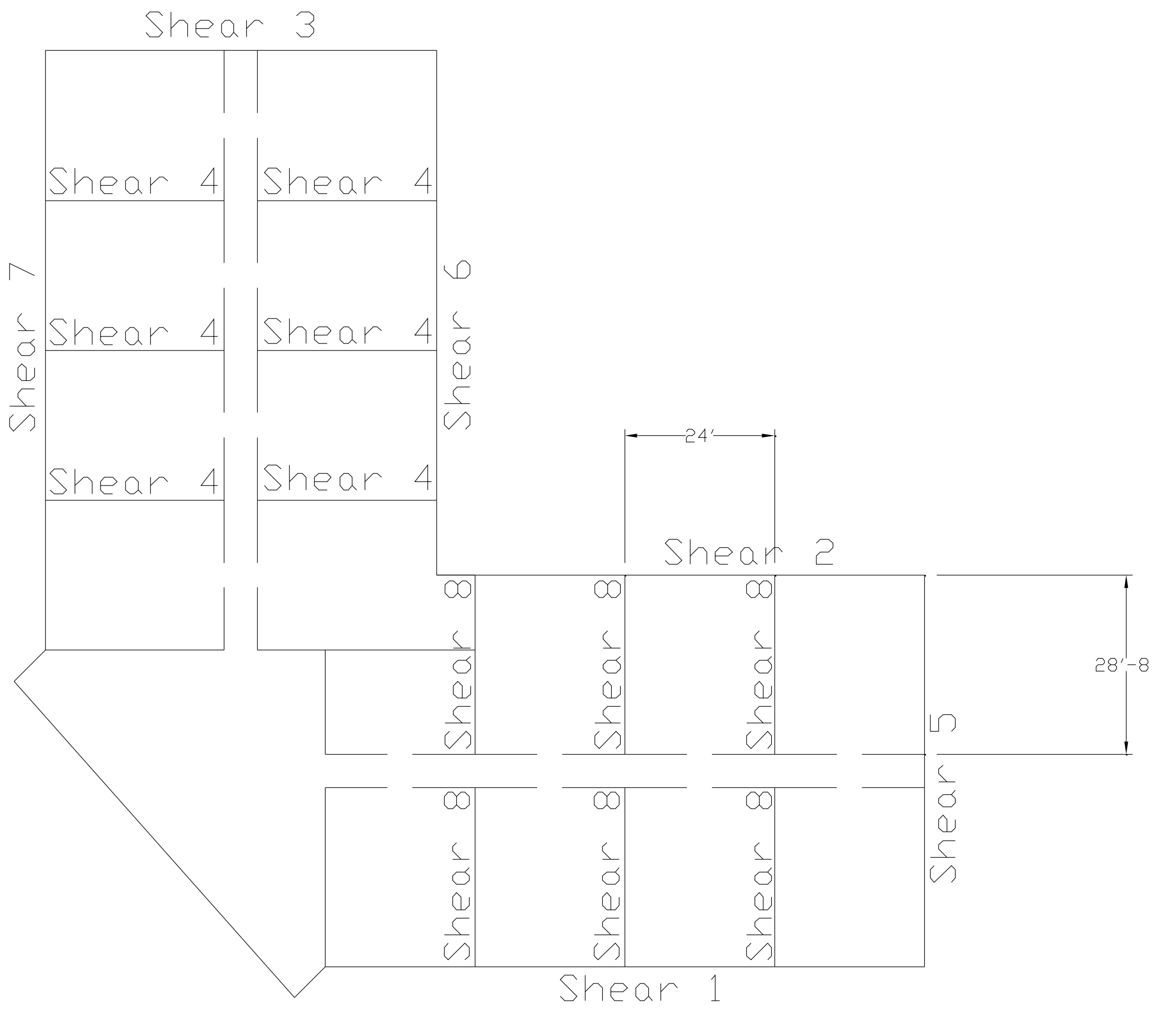



**Figure 5:** Location of Shear Walls

**Shear Wall Force Schedule (kips)**

| | Shear 1 | | Shear 2 | | Shear 3 | | Shear 4 | |
|---|---|---|---|---|---|---|---|---|
| | **Each Floor** | **Total** | **Each Floor** | **Total** | **Each Floor** | **Total** | **Each Floor** | **Total** |
| **4th Floor** | 7.21 | 7.21 | 6.01 | 6.01 | 2.56 | 2.56 | 1.07 | 1.07 |
| **3rd Floor** | 13.52 | 20.73 | 11.27 | 17.28 | 4.79 | 7.35 | 1.97 | 3.04 |
| **2nd Floor** | 13.48 | 34.21 | 11.23 | 28.51 | 4.77 | 12.12 | 1.98 | 5.02 |
| | **Shear 5** | | **Shear 6** | | **Shear 7** | | **Shear 8** | |
| | **Each Floor** | **Total** | **Each Floor** | **Total** | **Each Floor** | **Total** | **Each Floor** | **Total** |
| **4th Floor** | 2.1 | 2.1 | 6.04 | 6.04 | 5.18 | 5.18 | 1.07 | 1.07 |
| **3rd Floor** | 3.94 | 6.04 | 11.32 | 17.36 | 9.7 | 14.88 | 1.97 | 3.04 |
| **2nd Floor** | 3.93 | 9.97 | 11.28 | 28.64 | 9.67 | 24.55 | 1.98 | 5.02 |

**Table 1:** Shear Wall Forces

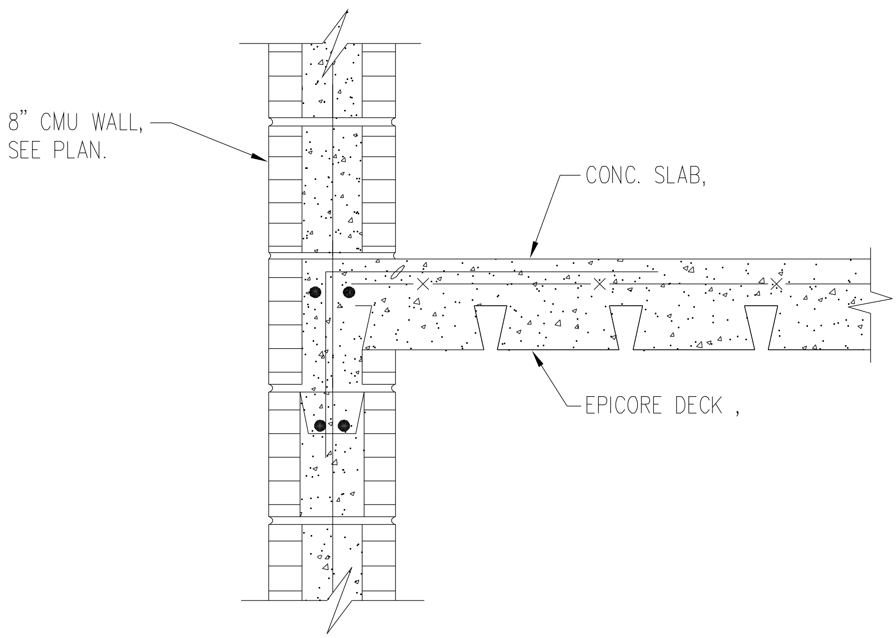



**Figure 6:** Typical Shear wall/Composite Deck Connection

## ROOF SYSTEM

The roof of the Academic Villages is a hip roof consisting of hip trusses, girder trusses and light gage metal trusses spaced 4' o.c. All trusses are shop fabricated and have a minimum yield strength of 33 ksi. Metal roof decking is

11" - 2Ø Gauge Galvanized G-9Ø spanning a minimum of 3 spans. Several of the buildings have flat roofs. The roofs of these buildings consist of the same Epicore metal decking and concrete slab found in the floor systems.

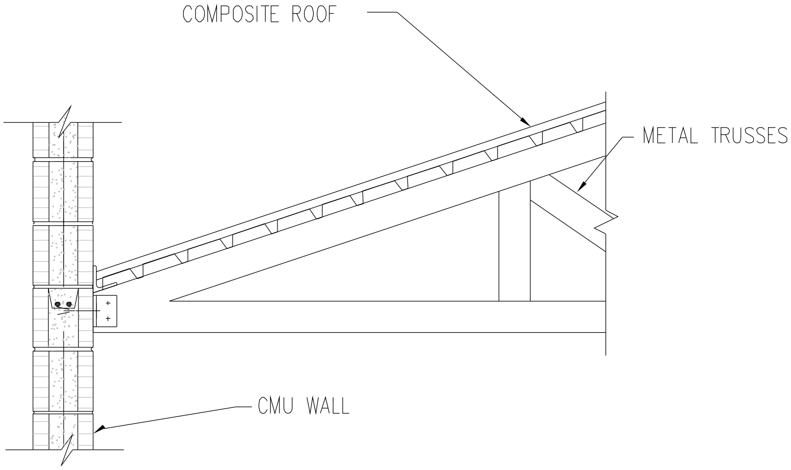



**Figure 7:** Typical Roof Connection

## COLUMN SYSTEM

Concrete Columns with a 28 day compressive strength of 4000 psi span only between the foundation and the first floor. The columns are reinforced with Grade 60 #6 bars and #3 ties at various spacings. In addition to the concrete columns, there are also light gage metal built-up columns incorporated within the metal stud walls. These columns are found on every floor.

## FOUNDATION SYSTEM

The foundation used in the Academic Villages is a shallow foundation system consisting of continuous strip footings to support 8" masonry shear walls



and stepped footings of various sizes centered under the interior concrete columns. The footings were designed to take the maximum soil bearing pressure of 2000 psi. The footings work together with a 4" concrete slab on grade. Both the footings and the slab have a 28 day strength of 3000 psi.

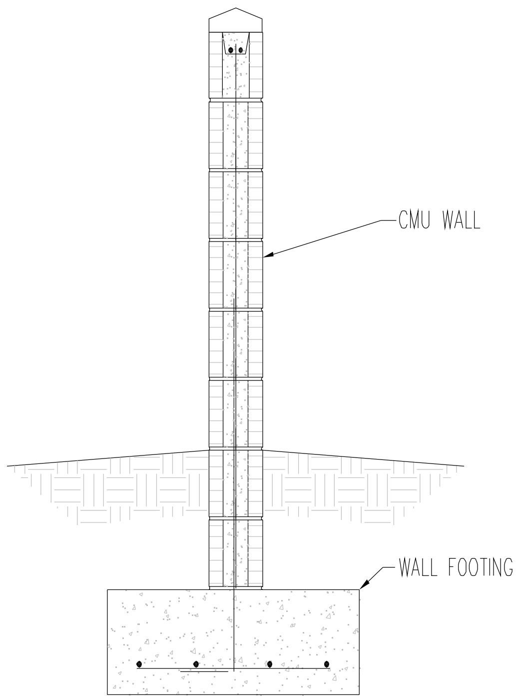



**Figure 8:** Typical Footing Connection

## DESIGN CODES

| Design Codes |
|---|
| American Institute of Steel Construction (AISC) |
| Load and Resistance Factor Design (LRFD) |
| American Society for Testing and Materials (ASTM) |
| Specifications for Structural Concrete (ACI 301) |
| Specifications for Masonry Structures (ACI 530.1) |
| American With Disabilities Act (ADA) |
| Florida Accessibility Code |

**Table 2:** Design Codes

## REQUIRED LOADS

| Design Live Loads | |
|---|---|
| Roof | 20 psf |
| Corridors | 80 psf |
| Mechanical Rooms | 150 psf |
| Stairs, Public Areas, Lobby | 100 psf |
| All Other Rooms | 40 psf |
| **Superimposed Dead Loads** | |
| M/E/P | 10 psf |
| Partitions | 20 psf |

**Table 3:** Required Loads

# P r o p o s a l



# Proposal

## PROBLEM STATEMENT

There are many different design solutions that can work for one particular building. Some designs work better than others based on which design considerations are most important to the owner. For my proposed thesis, I decided that building flexibility was the most important design consideration to be taken into account. The existing system of a 2" metal deck and 4 ½" concrete slab allows for a 12 foot span in the east-west direction forcing an interior bearing wall to be included in the middle of each bay. This design essentially divides each 24 ft x 28 ft apartment unit in half and does not allow for a greater level of flexibility which is desired in dwelling units such as apartments and dormitories.

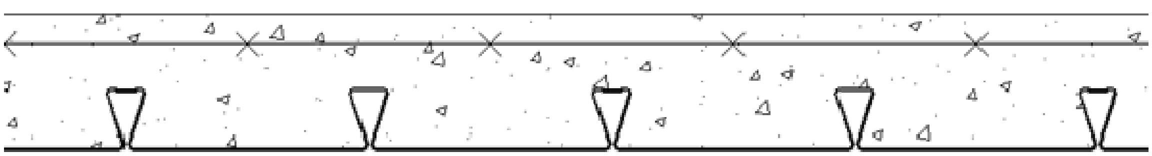


**Figure 9:** Existing Epicore MSR metal deck Section



## DESIGN CRITERIA

The main controlling factor in this proposed solution is to incorporate a floor system with a longer span. Other factors such as cost, constructability, availability, and overall performance will be taken into consideration after flexibility when evaluating this proposed structure. After looking at alternative structural systems in Tech 2, I discovered that there were several feasible alternative solutions. However, after consulting with Dr. Boothby, I am proposing a post-tensioned system as a replacement for the existing slab on metal deck system. I will explore whether a post-tensioned system will give me the flexibility that I'm looking for by allowing for a longer span while maintaining the slab thickness at a reasonable and profitable level. In doing so, the interior masonry bearing wall in the middle of each bay will no longer be needed and the floorplan becomes much more flexible.

# 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:

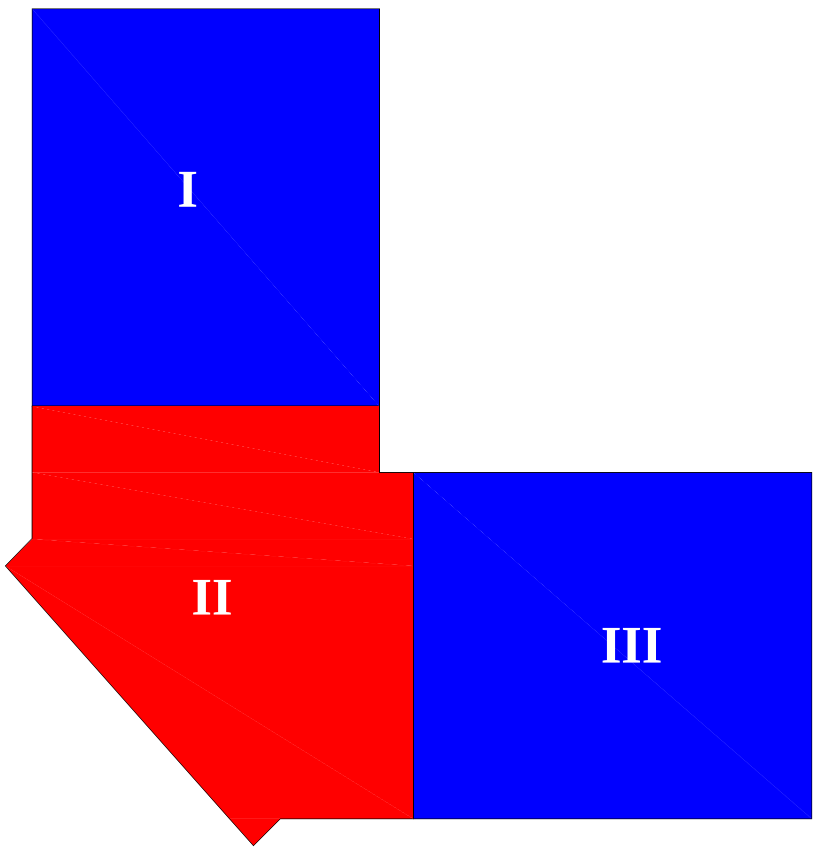



**Figure 10:** Three sections evaluated for design

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, •$_{cs}$ • 0.6$f'_c$ = | 3000 psi | (18.4.2) |
| (due to prestress and total load) | | |
| Extreme Fiber Stress in compression, •$_{csus}$ • 0.45$f'_c$ = | 2250 psi | (18.4.2) |
| (due to prestress and sustained load) | | |
| Extreme Fiber Stress in compression, •$_{ci}$ • 0.6$f'_{ci}$ = | 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. $e_o \bullet y_b - (d_c)_{min}$

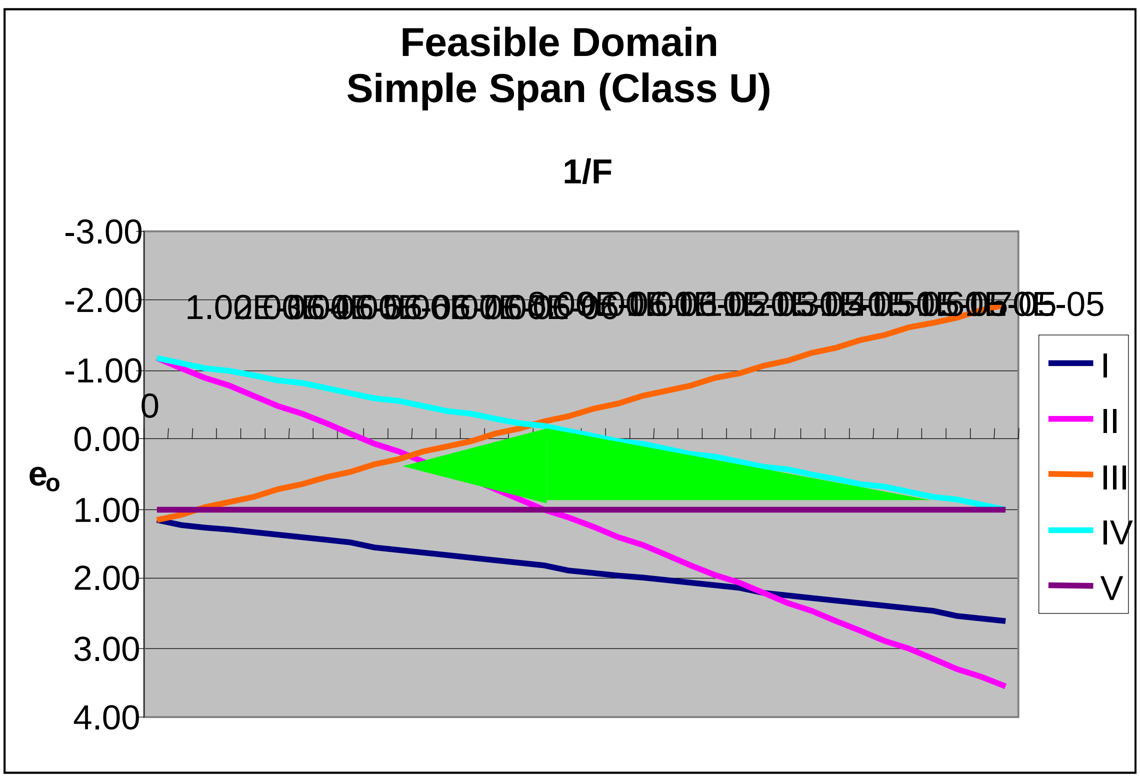



**Figure 11:** Feasible Domain of Simple Span



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.

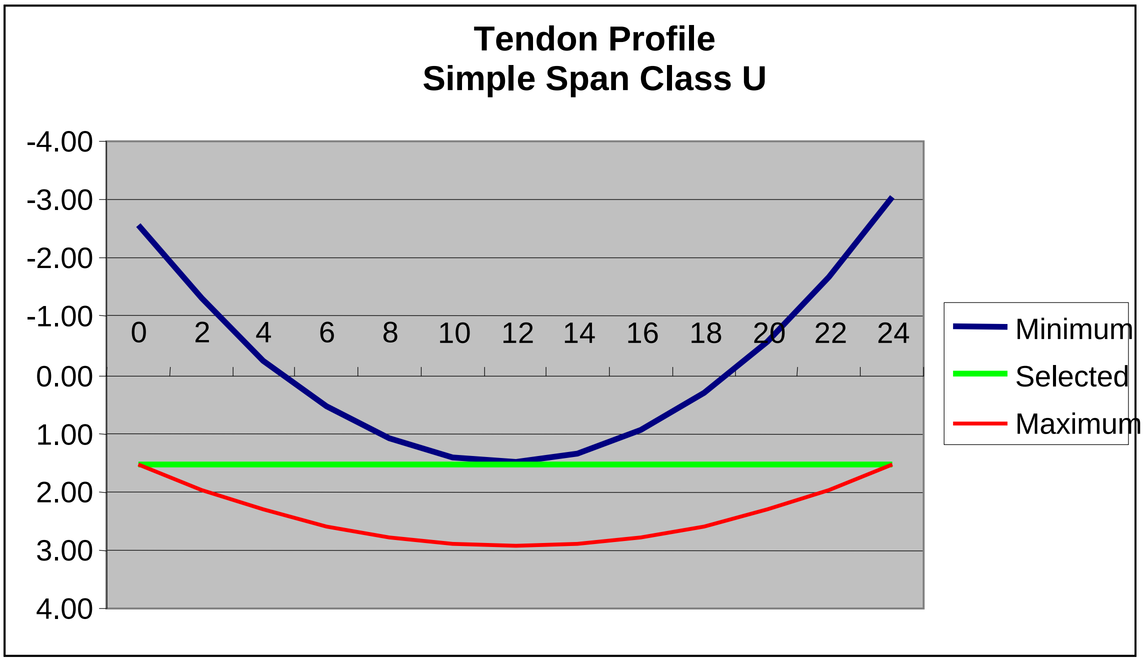



**Figure 12:** Tendon Profile for Simple Span

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.

## Post-Tension Analysis (Deflection)

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.

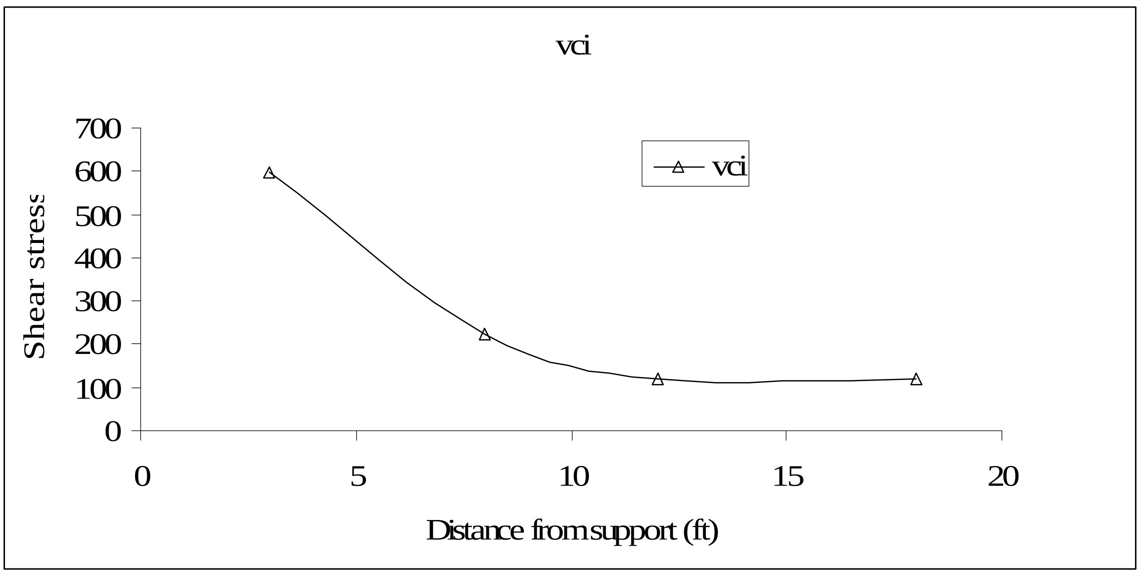



**Figure 13:** Shear Distribution

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

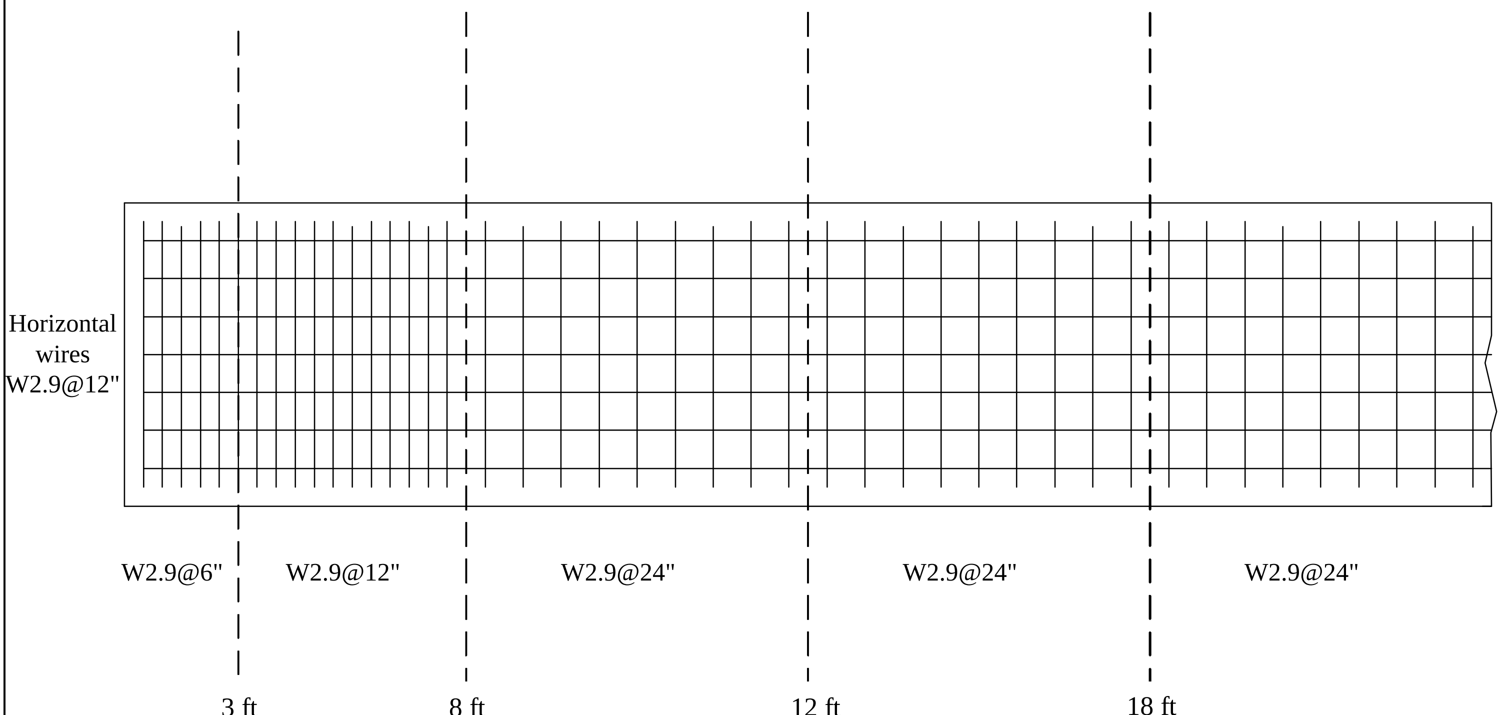



**Figure 14:** Shear reinforcement distribution

## 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.

# Shear Wall Design



## Introduction

The existing lateral system used in UFC’s Academic Villages is composed entirely of interior and exterior masonry shear walls. The shear walls are present on every level and resist lateral forces due to wind in both N/S and E/W directions. In the existing structure, the designer found the most critical shear case in the entire structure, (wall 1 on the second floor in this case, please refer back to the shear diagram on page 7 for location of the existing shear walls) and designed all the walls for that one particular case. As a result, each wall was an 8” masonry unit with #5 @ 24” reinforcement. Please refer to Table 10 below for shear wall values at every level.

| **Lateral Forces (kips)** | | | | | | |
|---|---|---|---|---|---|---|
| | **Wall 1** | | **Wall 4** | | **Wall 7** | |
| | **Shear Force** | **Total** | **Shear Force** | **Total** | **Shear Force** | **Total** |
| **4th Floor** | 7.21 | 7.21 | 1.07 | 1.07 | 5.18 | 5.18 |
| **3rd Floor** | 13.52 | 20.73 | 1.97 | 3.04 | 9.7 | 14.88 |
| **2nd Floor** | 13.48 | 34.21 | 1.98 | 5.02 | 9.67 | 24.55 |
| | **Wall 2** | | **Wall 5** | | **Wall 8** | |
| | **Shear Force** | **Total** | **Shear Force** | **Total** | **Shear Force** | **Total** |
| **4th Floor** | 6.01 | 6.01 | 2.1 | 2.1 | 1.07 | 1.07 |
| **3rd Floor** | 11.27 | 17.28 | 3.94 | 6.04 | 1.97 | 3.04 |
| **2nd Floor** | 11.23 | 28.51 | 3.93 | 9.97 | 1.98 | 5.02 |
| | **Wall 3** | | **Wall 6** | | | |
| | **Shear Force** | **Total** | **Shear Force** | **Total** | | |
| **4th Floor** | 2.56 | 2.56 | 6.04 | 6.04 | | |
| **3rd Floor** | 4.79 | 7.35 | 11.32 | 17.36 | | |
| **2nd Floor** | 4.77 | 12.12 | 11.28 | 28.64 | | |

**Table 10:** Shear Forces

 Consultant: Boothby



Since the bearing wall that is bearing removed in each unit was not included in the lateral analysis, the lateral forces on each wall due to wind will remain the same for the new design. However, since the clear span is being increased from 12 feet to 24 feet between each wall, each of the shear/bearing walls is taking nearly twice the gravitational loads in the proposed system than in the existing system.

## Design Criteria

The following criteria which must be considered for the design of a lateral shear wall system:

1. *The proposed lateral system must meet the current code.* The codes governing the design the shear walls will be the MSJC Code and IBC 2003.
2. *Will the proposed slab system bring up other additional issues that need to be addressed?* Since no changes are being made to actual structure of the building except for additional weight to the bearing/shear walls, there shouldn't be any additional problems.

If the first criterion is not met, the proposed lateral system cannot even be considered and the post-tensioned system will not be a reasonable solution. The existing system will then be accepted as the best solution for the project. The remaining criterion will only be effective once the first criterion is met.

## Design Analysis

Since the locations of the shear walls are already known from the existing structure and the height of each wall was also known is also known, the thickness of each wall could be estimated using the a slenderness ration of h/30, where h = the height in inches. Each walls stiffness was then determined from the known properties.

| Wall | Direction | L (ft) | W (ft) | H (ft) | A ($ft^2$) | I ($in^4$) | k (k/in) |
|---|---|---|---|---|---|---|---|
| **Wall 1** | N/S | 96 | 0.833 | 44.5 | 79.968 | 1157811 | 1107 |
| **Wall 2** | N/S | 78 | 0.833 | 44.5 | 64.974 | 1157811 | 1098 |
| **Wall 3** | N/S | 52 | 0.833 | 44.5 | 43.316 | 1157811 | 1056 |
| **Wall 4** | N/S | 24 | 1 | 44.5 | 24 | 1389929 | 985 |
| **Wall 5** | E/W | 52 | 0.833 | 44.5 | 43.316 | 1157811 | 1056 |
| **Wall 6** | E/W | 78 | 0.833 | 44.5 | 64.974 | 1157811 | 1098 |
| **Wall 7** | E/W | 96 | 0.833 | 44.5 | 79.968 | 1157811 | 1107 |
| **Wall 8** | E/W | 24 | 1 | 44.5 | 24 | 1389929 | 985 |

**Table 11:** Shear Wall Properties

Once the stiffness in each wall was known, a stiffness analysis was performed to find the building's center of rigidity. Due to symmetry, the center of rigidity was very close to the center of gravity which greatly limits torsional effects on the building due to uneven wind loading. See Appendix 3 for the complete spreadsheet calculated with excel.

## Drift Analysis

Due to the fact that the proposed lateral system uses larger blocks than the existing system and also that the lateral forces on each shear wall is the same for both systems, the drift analysis can be omitted since the existing system satisfied drift requirements.

## Conclusion

The shear walls were strengthened to carry the additional loads provided by the proposed one way slab system according to the code. The final design can be found in Table 12 below.

| | **Direction** | **# of walls** | **Thickness (in)** | **Reinforcement** |
|---|---|---|---|---|
| **Shear 1** | N/S | 1 | 10 | 5 @ 24" |
| **Shear 2** | N/S | 1 | 10 | 5 @ 24" |
| **Shear 3** | N/S | 1 | 10 | 5 @ 24" |
| **Shear 4** | N/S | 6 | 12 | 5 @ 24" |
| **Shear 5** | E/W | 1 | 10 | 5 @ 24" |
| **Shear 6** | E/W | 1 | 10 | 5 @ 24" |
| **Shear 7** | E/W | 1 | 10 | 5 @ 24" |
| **Shear 8** | E/W | 6 | 12 | 5 @ 24" |

**Table 12:** Shear Wall Results



# Acoustical Analysis



## Introduction

Acoustical requirements should always be considered at the earliest stages of design. The performance of an acoustical system for any type of construction is extremely important for buildings with multiple residents. Sounds traveling through the walls, floors, and openings can seriously reduce the resident's level of comfort. Since the Academic Villages are college dormitories, acoustics is a major concern in these buildings due to student's general loud behavior. In the process of designing a new floor system, the metal decking from the existing composite deck is no longer present. The 4 ½" slab from the existing system is relatively the same as the proposed 5" slab post-tensioned system. The main objective of this analysis is to verify that the proposed post-tensioned system works sufficiently with the existing walls to keep the sound transmission to a minimum.

## Goals:

The following two goals will be evaluated:

1. The existing system was designed using the BOCA 99 code with STC and IIC rating limits of 45 dB. However, the IBC 2000 requires STC and ICC ratings of 50 dB. The *proposed* system will be evaluated along with the existing walls to make sure it meets IBC 2000 requirements.

2. There are two rooms that share a common wall with the mechanical room. The air handling unit in the mechanical room is rated for 975 cfm.

## Analysis I – IBC 2000 Requirements

According to the IBC 2000, the required STC and IIC sound transmission requirements can be no less than 50 dB. The Sound Transmission Class (STC) is the single number rating of the air-borne sound transmission loss TL performance measured at various frequencies. The STC rating was developed to correlate noise level with interference of speech activities. The IIC is the single number rating given to impact sounds. The higher the STC and IIC values are for a particular structure, the more efficient that structure will be in resisting sound transmissions. For this project, the following surfaces were analyzed:

| Surface | Materials | STC | ICC |
|---|---|---|---|
| Walls | 8" cmu blocks | 58 | N/A |
| Floor/Ceiling | 5" concrete slab | 48 | 25 |
| Interior wall | 2x4 steel studs 16" o.c. w/ 5/8" gypsum board both sides | 52 | N/A |

**Table 13:** STC/IIC Ratings

(See full table in Appendix 4) The interior stud walls and exterior bearing/shear walls satisfied IBC 2000 requirements. The proposed post-tensioned slab however did not. Consequently, a new acoustic floor system will be integrated with the post-tensioned slab in order to meet IBC requirements.

## Solution

A solution for this issue was found at the Acoustic Product Division (AMI). The use of ACOUSTIK acoustic subflooring between the concrete slab and carpet in each apartment unit will increase the STC rating to 65 dB and the IIC rating to 55 dB, easily satisfying IBC 2000 requirements. The ACOUSTIK comes in 2' x 2' tiles and is only 5/16" thick. It can be applied with DURO ACOUSTICAL ADHESIVE to further increase the IIC rating but that is not required in this case.

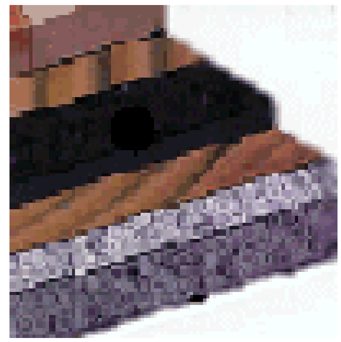


**Figure 15:** ACOUSTIK acoustic subflooring

## Analysis II – Mechanical Room

In order to calculate the required transmission loss for the common wall next to the mechanical room, the source power level, $L_{source}$, of the air handling unit needed to be calculated in decibels. This was done using an acoustics program called TAP. The results are listed in the table below. The following equations were used to find the actual transmission loss through the common wall:

$$\mathbf{SA \times \bullet = a}$$

$$\mathbf{NR = L_1 - L_2}$$

$$\mathbf{TL_{actual} = NR - 10(\log(a/S))}$$

where:

SA = total surface area of the apartment ($ft^2$)
• = absorption coefficient
a = absorption (sabins)



NR = Noise Criteria
S = surface area of common wall ($ft^2$)

The RC level for apartments is between 25-35. For the apartment, I chose an RC value of 30. Please see Appendix 4 for the complete RC table. All calculations for the

| **Frequency (Hz)** | **$L_{source}$ (dB)** | **RC-value** | **$TL_{required}$** |
|---|---|---|---|
| 125 | 86 | 45 | 41 |
| 250 | 85 | 30 | 55 |
| 500 | 84 | 35 | 49 |
| 1000 | 83 | 30 | 53 |
| 2000 | 82 | 25 | 57 |
| 4000 | 80 | 20 | 60 |

**Table 14:** $TL_{required}$

| **Frequency (Hz)** | **• (sabins)** | **S ($ft^2$)** | **$TL_{actual}$** |
|---|---|---|---|
| 125 | 106.25 | 216 | 44 |
| 250 | 70.08 | 216 | 60 |
| 500 | 85.44 | 216 | 53 |
| 1000 | 94.08 | 216 | 57 |
| 2000 | 111.36 | 216 | 60 |
| 4000 | 96 | 216 | 64 |

**Table 15:** $TL_{actual}$

## Conclusion

Since the actual transmission loss is greater than the required loss for all frequency levels between 125 and 4000 Hz, the current system is adequate for resisting sound from the adjacent mechanical room.

# Mechanical Analysis
# Energy Recovery Ventilator



## Introduction

A study was conducted to see if incorporating an Energy Recovery Ventilator (ERV) is a feasible opportunity to reduce the buildings cooling/exhaust operational costs. ERV Systems are strongly encouraged for areas such as Florida, where cooling loads place heavy demands on the building's HVAC system.

The current exhaust system employed in the Academic Villages is a Water Source Heat Pump (WSHP) system. There are two heat pumps on the ground floor bringing in 5050 cfm of outdoor air (*100 cfm to each room*) and 11 exhaust fans emitting a total 2880 cfm of exhaust (*60 cfm from each room*). The remaining 2170 cfm of air (*40 cfm from each room*) is lost through openings in the rooms (windows and doorways).

In the proposed ERV system, both the ventilator and the heat pump on located on the top floor. In order to simplify the calculations to make a comparison between the current WSHP system and proposed ERV system, it will be assumed that the only difference between the two systems are the two ventilators and exhaust fans. The heat pumps and piping will be the same for both systems. See Figures 16 and 17 for the layout of both systems. Also, see Appendix 5 for detailed calculations.



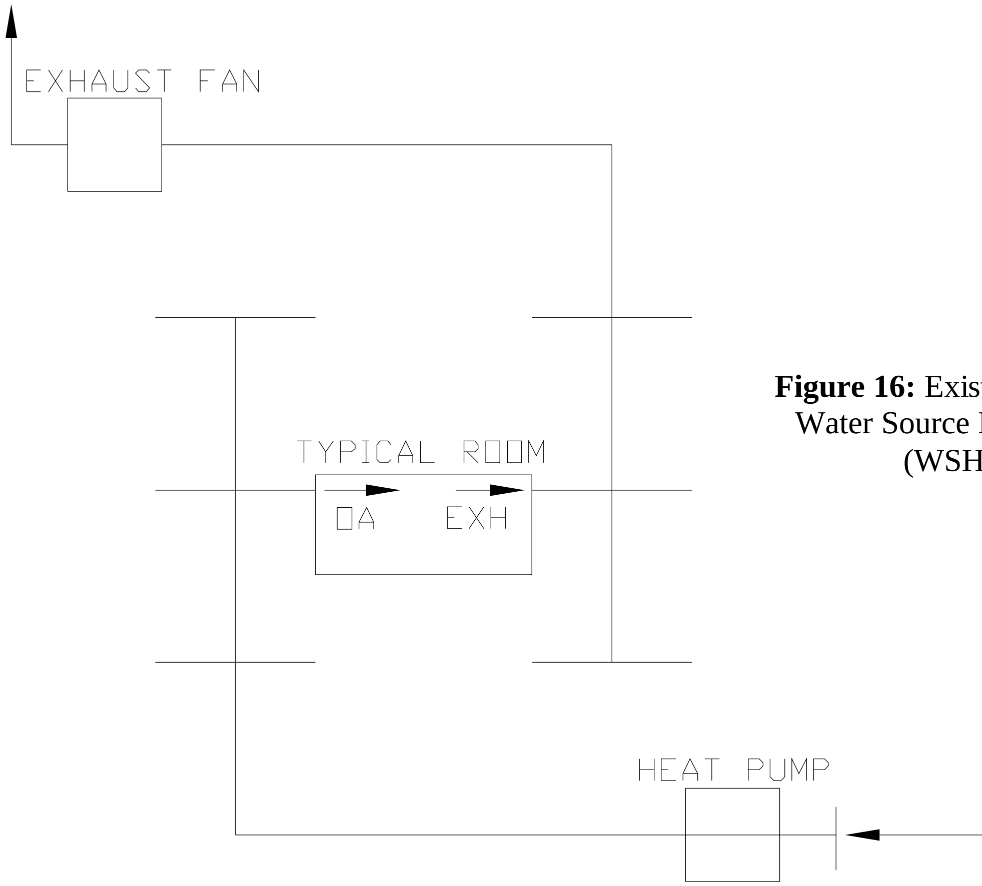



**Figure 16:** Existing System: Water Source Heat Pump (WSHP)

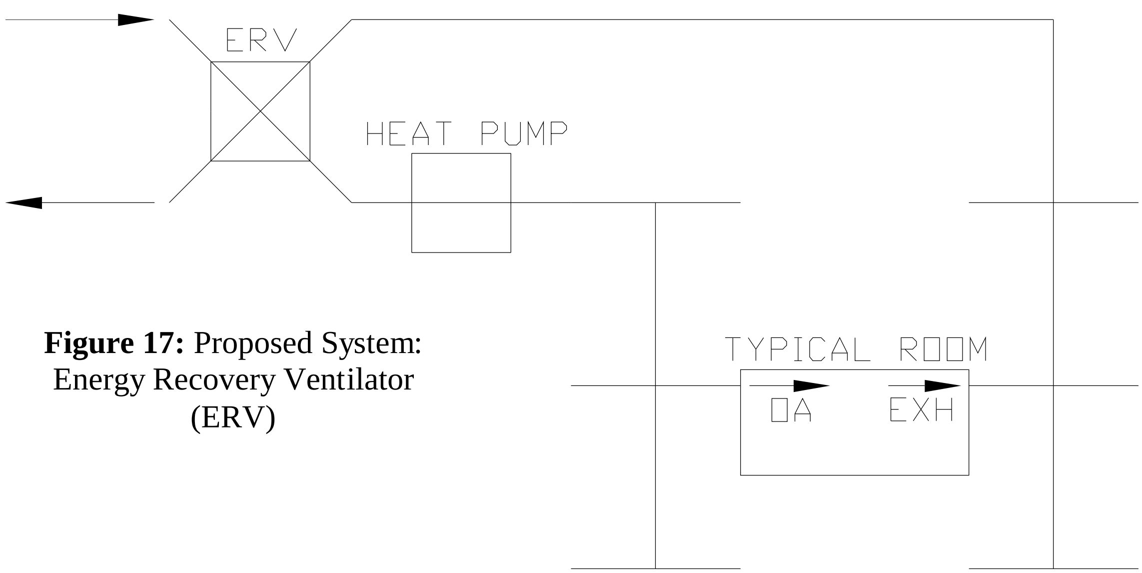



**Figure 17:** Proposed System: Energy Recovery Ventilator (ERV)



## Solution

Using RS means to estimate the cost of the exhaust fans ($400 per 320 cfm), I found that the total cost for all 11 of the exhaust fans to be $3600. This is money saved when installing an ERV system. However, the estimated cost for the actual ERV unit plus installation from RS Means is $3200. Since a ventilator must be paired with each of the two heat pumps, two ventilators totals $6400. This is $2800 more than what would be saved from eliminating the exhaust fans. To find the amount of energy saved, the following formula was used for sensible heat:

$$q = 1.08 \times cfm \times \bullet T$$

The average temperature in Orlando for the summer months is around 90° F. Assuming that the indoor temperature will be about 70° F, the sensible heat for the existing exhaust system will be about 62,208 Btu/hr. Since the ERV is 50% more efficient than the existing system, 31,104 Btu/hr will be savings @ 1 kw per ton. Assuming the energy cost in Orlando is around $.10 per kw, approximately $0.26 per hour will be saved. This translates to 10,810 operating hours to make a profit using an ERV system. Further assuming that it is 90° F for 8 hours per day and there are about 150 days per year when it's at least 90 degrees in Orlando, it will take approximately 9-10 years before a profit is made using the Energy Recovery Ventilator system. This is a very feasible solution since the average life span of the ERV motor is approximately 100,000 hours, about 4 times the time it takes before savings take over.



# A p p e n d i x I



## Single Span (Class U)

| | |
|---|---|
| **$A_c$ (in$^4$) =** | 94 |
| **I (in$^3$) =** | 343 |
| **$Z_t$ (in$^3$) =** | 98 |
| **$Z_b$ (in$^3$) =** | 98 |
| **$K_t$ (in) =** | -1.17 |
| **$K_b$ (in) =** | 1.17 |
| **$y_t$ (in) =** | 3.5 |
| **$y_b$ (in) =** | 3.5 |
| **$M_{min}$ (k-in) =** | 64.8 |
| **$M_{max}$ (k-in) =** | 151.2 |

| | |
|---|---|
| **• $_{ts}$ (psi) =** | -530 |
| **• $_{ci}$ (psi) =** | 2100 |
| **• $_{sus}$ (psi) =** | 2250 |
| **• $_{cs}$ (psi) =** | 3000 |
| **• $_{ti}$ (psi) =** | -<br>177.5 |
| **• =** | 0.8 |
| **$w_{LL}$ (plf) =** | 100 |
| **$w_{sup}$ (plf) =** | 10 |
| **$w_{wt}$ (plf) =** | 75 |
| **$w_{Tot}$ (plf) =** | 185 |

## Feasible Domain Inequalities

| | | | | | |
|---|---|---|---|---|---|
| **I** | $e_o$ < | 1.17 | + | (1/$F_i$) * | 8.22E+04 |
| **II** | $e_o$ < | -1.17 | + | (1/$F_i$) * | 2.71E+05 |
| **III** | $e_o$ > | 1.17 | + | (1/$F_i$) * | -<br>1.79E+05 |
| **IV** | $e_o$ > | -1.17 | + | (1/$F_i$) * | 1.24E+05 |
| **V** | $e_o$ < | 1 | | | |

| **1/F** | **I** | **II** | **III** | **IV** | **V** |
|---|---|---|---|---|---|
| 0 | 1.17 | -1.17 | 1.17 | -1.17 | 1.00 |
| 5.00E-07 | 1.21 | -1.03 | 1.08 | -1.11 | 1.00 |
| 1.00E-06 | 1.25 | -0.90 | 0.99 | -1.05 | 1.00 |
| 1.50E-06 | 1.29 | -0.76 | 0.90 | -0.98 | 1.00 |

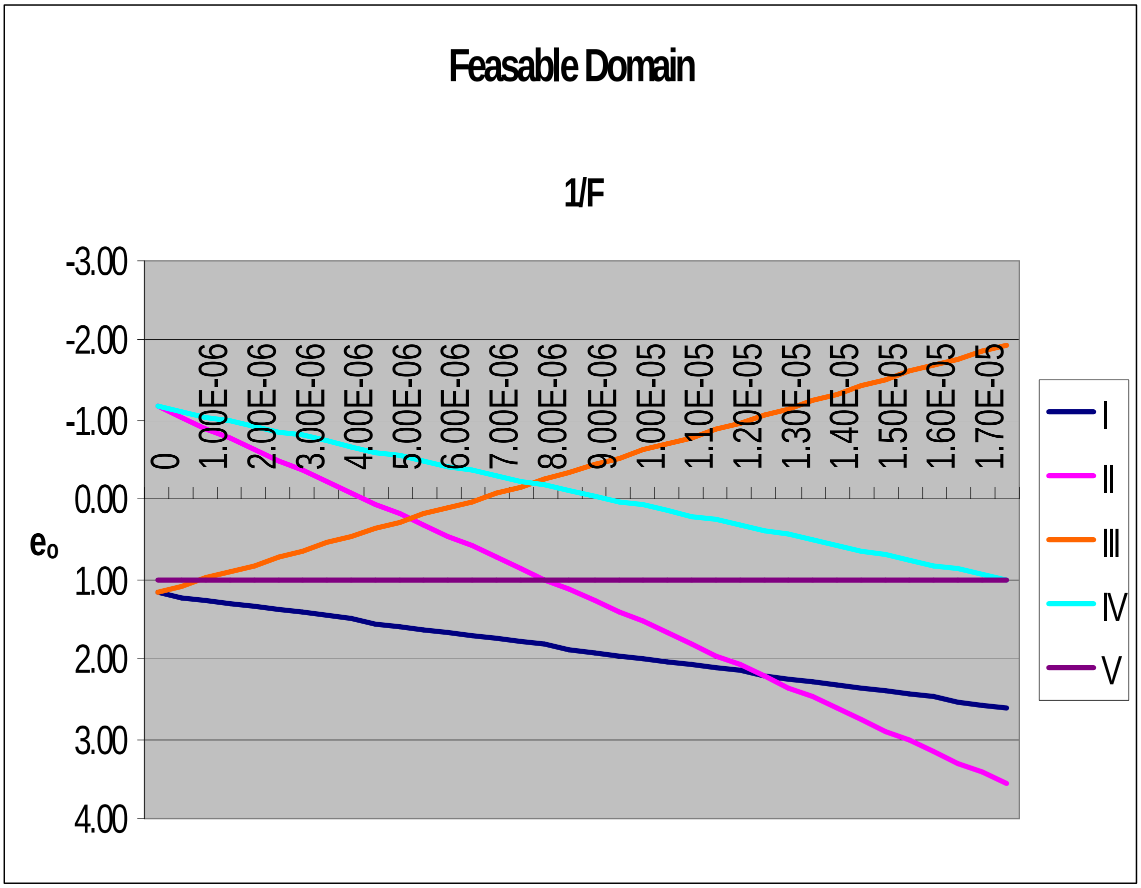
| | | | | | |
|---|---|---|---|---|---|
| 2.00E-06 | 1.33 | -0.63 | 0.81 | -0.92 | 1.00 |
| 2.50E-06 | 1.38 | -0.49 | 0.72 | -0.86 | 1.00 |
| 3.00E-06 | 1.42 | -0.36 | 0.63 | -0.80 | 1.00 |
| 3.50E-06 | 1.46 | -0.22 | 0.55 | -0.74 | 1.00 |
| 4.00E-06 | 1.50 | -0.09 | 0.46 | -0.67 | 1.00 |
| 4.50E-06 | 1.54 | 0.05 | 0.37 | -0.61 | 1.00 |
| 5.00E-06 | 1.58 | 0.18 | 0.28 | -0.55 | 1.00 |
| 5.50E-06 | 1.62 | 0.32 | 0.19 | -0.49 | 1.00 |
| 6.00E-06 | 1.66 | 0.45 | 0.10 | -0.43 | 1.00 |
| 6.50E-06 | 1.70 | 0.59 | 0.01 | -0.36 | 1.00 |
| 7.00E-06 | 1.75 | 0.72 | -0.08 | -0.30 | 1.00 |
| 7.50E-06 | 1.79 | 0.86 | -0.17 | -0.24 | 1.00 |
| 8.00E-06 | 1.83 | 0.99 | -0.26 | -0.18 | 1.00 |
| 8.50E-06 | 1.87 | 1.13 | -0.35 | -0.12 | 1.00 |
| 9.00E-06 | 1.91 | 1.27 | -0.44 | -0.05 | 1.00 |
| 9.50E-06 | 1.95 | 1.40 | -0.53 | 0.01 | 1.00 |
| 1.00E-05 | 1.99 | 1.54 | -0.62 | 0.07 | 1.00 |
| 1.05E-05 | 2.03 | 1.67 | -0.70 | 0.13 | 1.00 |
| 1.10E-05 | 2.07 | 1.81 | -0.79 | 0.19 | 1.00 |
| 1.15E-05 | 2.12 | 1.94 | -0.88 | 0.26 | 1.00 |
| 1.20E-05 | 2.16 | 2.08 | -0.97 | 0.32 | 1.00 |
| 1.25E-05 | 2.20 | 2.21 | -1.06 | 0.38 | 1.00 |
| 1.30E-05 | 2.24 | 2.35 | -1.15 | 0.44 | 1.00 |
| 1.35E-05 | 2.28 | 2.48 | -1.24 | 0.51 | 1.00 |
| 1.40E-05 | 2.32 | 2.62 | -1.33 | 0.57 | 1.00 |
| 1.45E-05 | 2.36 | 2.75 | -1.42 | 0.63 | 1.00 |
| 1.50E-05 | 2.40 | 2.89 | -1.51 | 0.69 | 1.00 |
| 1.55E-05 | 2.44 | 3.02 | -1.60 | 0.75 | 1.00 |
| 1.60E-05 | 2.49 | 3.16 | -1.69 | 0.82 | 1.00 |
| 1.65E-05 | 2.53 | 3.29 | -1.78 | 0.88 | 1.00 |
| 1.70E-05 | 2.57 | 3.43 | -1.86 | 0.94 | 1.00 |
| 1.75E-05 | 2.61 | 3.57 | -1.95 | 1.00 | 1.00 |

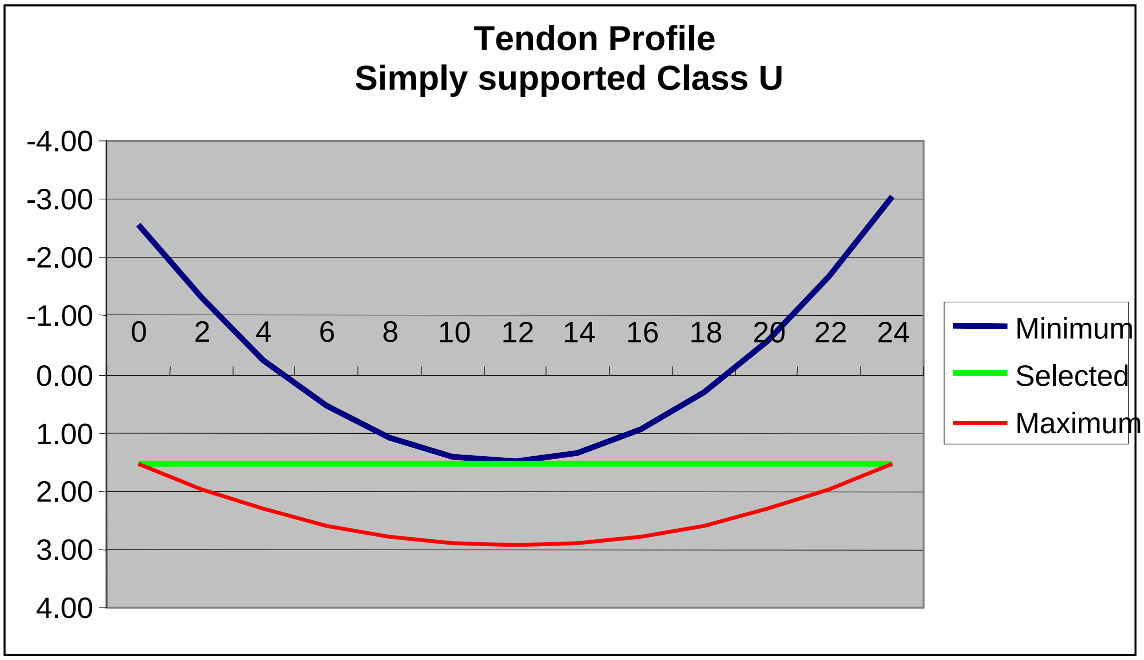
| **Distance** | **$M_{min}$** | **$M_{max}$** | **I** | **II** | **III** | **IV** | **V** |
|---|---|---|---|---|---|---|---|
| **(ft)** | **(k-in)** | **(k-in)** | **$e_o <$** | **$e_o <$** | **$e_o >$** | **$e_o >$** | **$e_o <$** |
| 0 | 0 | 0 | 1.54 | 3.26 | -6.73 | -2.57 | 1.00 |
| 2 | 19.8 | 47.4 | 1.97 | 4.28 | -5.46 | -1.29 | 1.00 |
| 4 | 36 | 85.92 | 2.32 | 5.10 | -4.42 | -0.26 | 1.00 |
| 6 | 48.6 | 115.56 | 2.59 | 5.74 | -3.63 | 0.54 | 1.00 |
| 8 | 57.6 | 136.32 | 2.78 | 6.19 | -3.07 | 1.10 | 1.00 |
| 10 | 63 | 148.2 | 2.90 | 6.44 | -2.75 | 1.42 | 1.00 |
| 12 | 64.8 | 151.2 | 2.94 | 6.51 | -2.67 | 1.50 | 1.00 |
| 14 | 63 | 145.32 | 2.90 | 6.38 | -2.83 | 1.34 | 1.00 |
| 16 | 57.6 | 130.56 | 2.78 | 6.06 | -3.22 | 0.94 | 1.00 |
| 18 | 48.6 | 106.92 | 2.59 | 5.56 | -3.86 | 0.31 | 1.00 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 20 | 36 | 74.4 | 2.32 | 4.86 | -4.73 | -0.57 | 1.00 |
| 22 | 19.8 | 33 | 1.97 | 3.97 | -5.85 | -1.68 | 1.00 |
| 24 | 0 | -17.28 | 1.54 | 2.88 | -7.20 | -3.03 | 1.00 |

## Tendon Profile Parameters

| 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 |


Feasable Domain
1/F
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
e₀
0
1.00E-06
2.00E-06
3.00E-06
4.00E-06
5.00E-06
6.00E-06
7.00E-06
8.00E-06
9.00E-06
1.00E-05
1.10E-05
1.20E-05
1.30E-05
1.40E-05
1.50E-05
1.60E-05
1.70E-05
I
II
III
IV
V


Tendon Profile
Simply supported Class U
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
0
2
4
6
8
10
12
14
16
18
20
22
24
Minimum
Selected
Maximum

## Simple Span (Class T)

| | |
|---|---|
| $A_c$ ($in^4$) = | 72 |
| I ($in^3$) = | 216 |
| $Z_t$ ($in^3$) = | 72 |
| $Z_b$ ($in^3$) = | 72 |
| $K_t$ (in) = | -1 |
| $K_b$ (in) = | 1 |
| $y_t$ (in) = | 3 |
| $y_b$ (in) = | 3 |
| $M_{min}$ (k-in) = | 64.8 |
| $M_{max}$ (k-in) = | 151.2 |

| | |
|---|---|
| • $_{ts}$ (psi) = | - 848.5 |
| • $_{ci}$ (psi) = | 2100 |
| • $_{sus}$ (psi) = | 2250 |
| • $_{cs}$ (psi) = | 3000 |
| • $_{ti}$ (psi) = | - 177.5 |
| • = | 0.8 |
| $w_{LL}$ (plf) = | 100 |
| $w_{sup}$ (plf) = | 10 |
| $w_{wt}$ (plf) = | 75 |
| $w_{Tot}$ (plf) = | 185 |

## Feasible Domain Inequalities

| | | | | | |
|---|---|---|---|---|---|
| I | $e_o$ < | 1 | + | $(1/F_i)$ * | 7.76E+04 |
| II | $e_o$ < | -1 | + | $(1/F_i)$ * | 2.16E+05 |
| III | $e_o$ > | 1 | + | $(1/F_i)$ * | - 8.10E+04 |
| IV | $e_o$ > | -1 | + | $(1/F_i)$ * | 1.13E+05 |
| V | $e_o$ < | 1 | | | |

| 1/F | I | II | III | IV | V |
|---|---|---|---|---|---|
| 0 | 1.00 | -1.00 | 1.00 | -1.00 | 1.00 |
| 5.00E-07 | 1.04 | -0.89 | 0.96 | -0.94 | 1.00 |
| 1.00E-06 | 1.08 | -0.78 | 0.92 | -0.89 | 1.00 |
| 1.50E-06 | 1.12 | -0.68 | 0.88 | -0.83 | 1.00 |
| 2.00E-06 | 1.16 | -0.57 | 0.84 | -0.77 | 1.00 |
| 2.50E-06 | 1.19 | -0.46 | 0.80 | -0.72 | 1.00 |

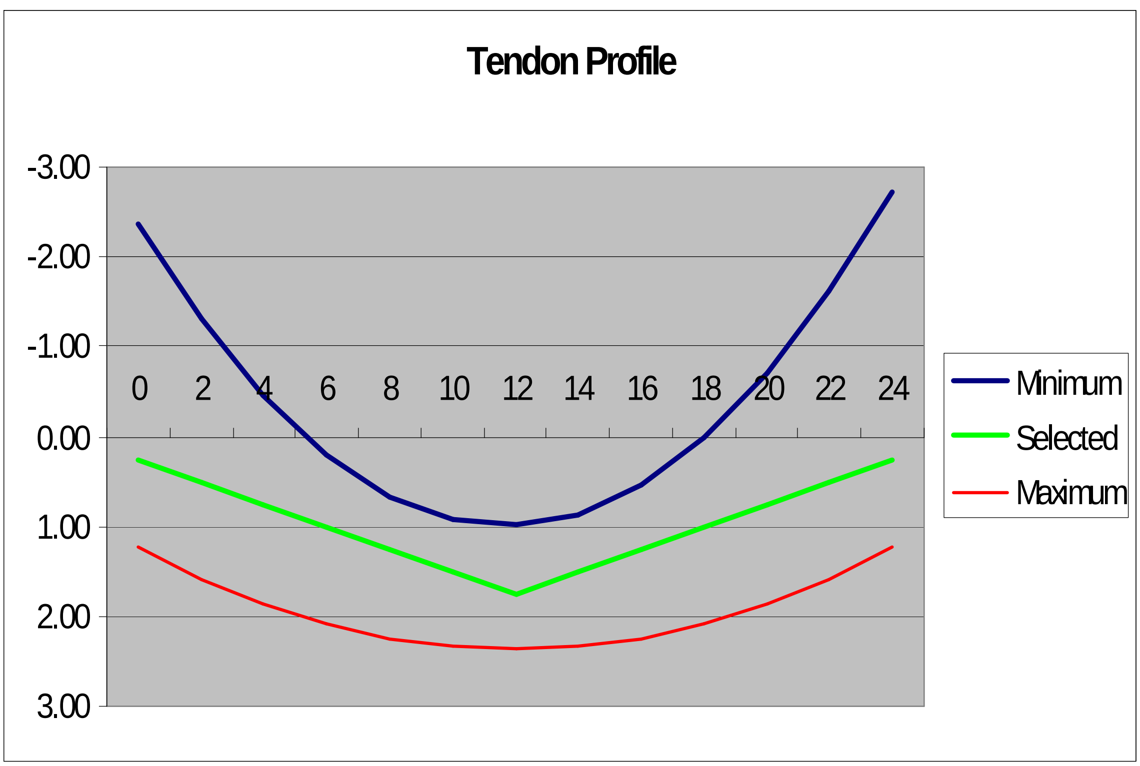


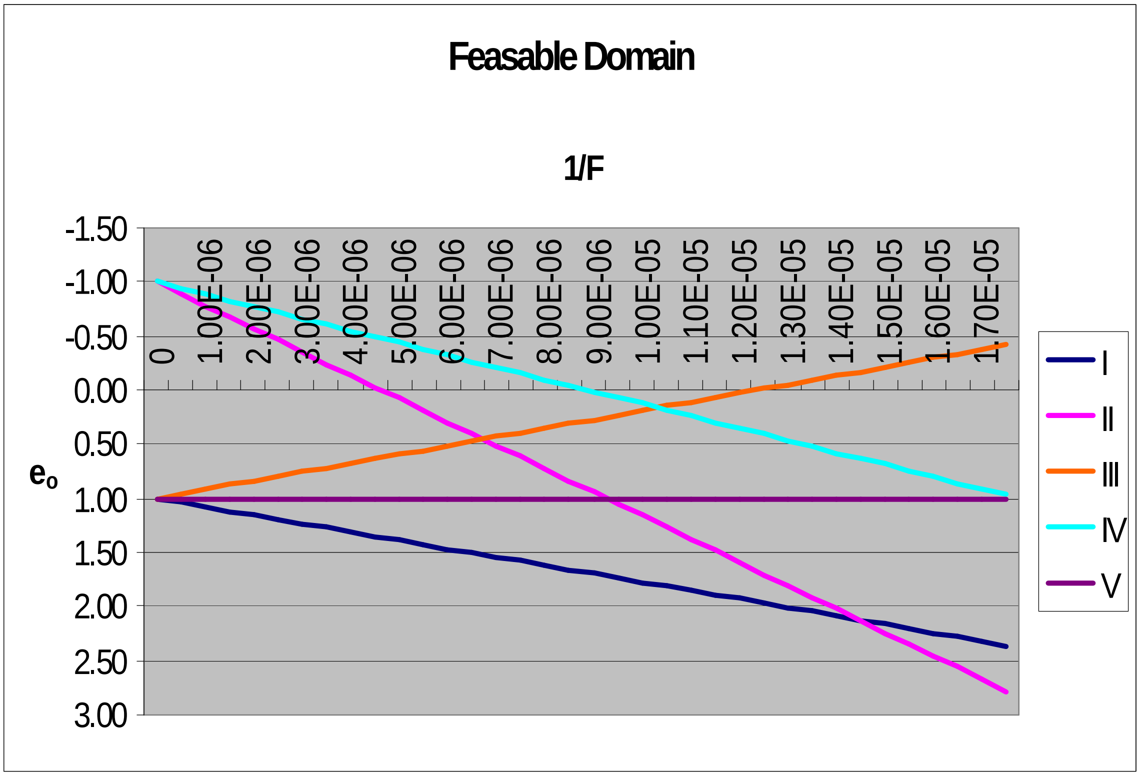
| | | | | | |
|---|---|---|---|---|---|
| 3.00E-06 | 1.23 | -0.35 | 0.76 | -0.66 | 1.00 |
| 3.50E-06 | 1.27 | -0.24 | 0.72 | -0.61 | 1.00 |
| 4.00E-06 | 1.31 | -0.14 | 0.68 | -0.55 | 1.00 |
| 4.50E-06 | 1.35 | -0.03 | 0.64 | -0.49 | 1.00 |
| 5.00E-06 | 1.39 | 0.08 | 0.60 | -0.44 | 1.00 |
| 5.50E-06 | 1.43 | 0.19 | 0.55 | -0.38 | 1.00 |
| 6.00E-06 | 1.47 | 0.30 | 0.51 | -0.32 | 1.00 |
| 6.50E-06 | 1.50 | 0.40 | 0.47 | -0.27 | 1.00 |
| 7.00E-06 | 1.54 | 0.51 | 0.43 | -0.21 | 1.00 |
| 7.50E-06 | 1.58 | 0.62 | 0.39 | -0.16 | 1.00 |
| 8.00E-06 | 1.62 | 0.73 | 0.35 | -0.10 | 1.00 |
| 8.50E-06 | 1.66 | 0.84 | 0.31 | -0.04 | 1.00 |
| 9.00E-06 | 1.70 | 0.94 | 0.27 | 0.01 | 1.00 |
| 9.50E-06 | 1.74 | 1.05 | 0.23 | 0.07 | 1.00 |
| 1.00E-05 | 1.78 | 1.16 | 0.19 | 0.13 | 1.00 |
| 1.05E-05 | 1.81 | 1.27 | 0.15 | 0.18 | 1.00 |
| 1.10E-05 | 1.85 | 1.38 | 0.11 | 0.24 | 1.00 |
| 1.15E-05 | 1.89 | 1.48 | 0.07 | 0.30 | 1.00 |
| 1.20E-05 | 1.93 | 1.59 | 0.03 | 0.35 | 1.00 |
| 1.25E-05 | 1.97 | 1.70 | -0.01 | 0.41 | 1.00 |
| 1.30E-05 | 2.01 | 1.81 | -0.05 | 0.46 | 1.00 |
| 1.35E-05 | 2.05 | 1.92 | -0.09 | 0.52 | 1.00 |
| 1.40E-05 | 2.09 | 2.02 | -0.13 | 0.58 | 1.00 |
| 1.45E-05 | 2.12 | 2.13 | -0.17 | 0.63 | 1.00 |
| 1.50E-05 | 2.16 | 2.24 | -0.22 | 0.69 | 1.00 |
| 1.55E-05 | 2.20 | 2.35 | -0.26 | 0.75 | 1.00 |
| 1.60E-05 | 2.24 | 2.46 | -0.30 | 0.80 | 1.00 |
| 1.65E-05 | 2.28 | 2.56 | -0.34 | 0.86 | 1.00 |
| 1.70E-05 | 2.32 | 2.67 | -0.38 | 0.91 | 1.00 |
| 1.75E-05 | 2.36 | 2.78 | -0.42 | 0.97 | 1.00 |

| **Distance** | **$M_{min}$** | **$M_{max}$** | **I** | **II** | **III** | **IV** | **V** |
|---|---|---|---|---|---|---|---|
| **(ft)** | **(k-in)** | **(k-in)** | **$e_o$ <** | **$e_o$ <** | **$e_o$ >** | **$e_o$ >** | **$e_o$ <** |
| 0 | 0 | 0 | 1.23 | 1.68 | -3.78 | -2.35 | 1.00 |
| 2 | 19.8 | 47.4 | 1.58 | 2.52 | -2.73 | -1.30 | 1.00 |
| 4 | 36 | 85.92 | 1.86 | 3.20 | -1.88 | -0.45 | 1.00 |
| 6 | 48.6 | 115.56 | 2.09 | 3.72 | -1.22 | 0.21 | 1.00 |
| 8 | 57.6 | 136.32 | 2.25 | 4.09 | -0.76 | 0.66 | 1.00 |
| 10 | 63 | 148.2 | 2.34 | 4.30 | -0.50 | 0.93 | 1.00 |
| 12 | 64.8 | 151.2 | 2.37 | 4.35 | -0.43 | 0.99 | 1.00 |
| 14 | 63 | 145.32 | 2.34 | 4.25 | -0.56 | 0.86 | 1.00 |
| 16 | 57.6 | 130.56 | 2.25 | 3.99 | -0.89 | 0.54 | 1.00 |
| 18 | 48.6 | 106.92 | 2.09 | 3.57 | -1.41 | 0.01 | 1.00 |
| 20 | 36 | 74.4 | 1.86 | 2.99 | -2.13 | -0.71 | 1.00 |
| 22 | 19.8 | 33 | 1.58 | 2.26 | -3.05 | -1.62 | 1.00 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 24 | 0 | -17.28 | 1.23 | 1.37 | -4.16 | -2.73 | 1.00 |

| Distance | Eccentricities(in | | Tendon |
|---|---|---|---|
| (ft) | Min | Max | Profile |
| 0 | -2.35 | 1.23 | 0.25 |
| 2 | -1.30 | 1.58 | 0.50 |
| 4 | -0.45 | 1.86 | 0.75 |
| 6 | 0.21 | 2.09 | 1.00 |
| 8 | 0.66 | 2.25 | 1.25 |
| 10 | 0.93 | 2.34 | 1.50 |
| 12 | 0.99 | 2.37 | 1.75 |
| 14 | 0.86 | 2.34 | 1.50 |
| 16 | 0.54 | 2.25 | 1.25 |
| 18 | 0.01 | 2.09 | 1.00 |
| 20 | -0.71 | 1.86 | 0.75 |
| 22 | -1.62 | 1.58 | 0.50 |
| 24 | -2.73 | 1.23 | 0.25 |




Feasable Domain
1/F
$e_o$
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
3.00
0
1.00E-06
2.00E-06
3.00E-06
4.00E-06
5.00E-06
6.00E-06
7.00E-06
8.00E-06
9.00E-06
1.00E-05
1.10E-05
1.20E-05
1.30E-05
1.40E-05
1.50E-05
1.60E-05
1.70E-05
I
II
III
IV
V



## Continuous Span (class U)

| | |
|---|---|
| **$A_c$ (in$^4$) =** | 66 |
| **I (in$^3$) =** | 166.4 |
| **$Z_t$ (in$^3$) =** | 60.5 |
| **$Z_b$ (in$^3$) =** | 60.5 |
| **$K_t$ (in) =** | -0.92 |
| **$K_b$ (in) =** | 0.92 |
| **$y_t$ (in) =** | 2.75 |
| **$y_b$ (in) =** | 2.75 |
| **$M_{min}$ (k-in) =** | 47.5 |
| **$M_{max}$ (k-in) =** | 123.6 |

| | |
|---|---|
| **• $_{ts}$ (psi) =** | -530 |
| **• $_{ci}$ (psi) =** | 2100 |
| **• $_{sus}$ (psi) =** | 2250 |
| **• $_{cs}$ (psi) =** | 3000 |
| **• $_{ti}$ (psi) =** | -177.5 |
| **• =** | 0.8 |
| **$w_{LL}$ (plf) =** | 100 |
| **$w_{sup}$ (plf) =** | 10 |
| **$w_{wt}$ (plf) =** | 68.75 |
| **$w_{Tot}$ (plf) =** | 178.75 |

## Feasible Domain Inequalities

| | | | | | |
|---|---|---|---|---|---|
| **I** | $e_o$ < | 0.92 | + | (1/$F_i$) * | 5.82E+04 |
| **II** | $e_o$ < | -0.92 | + | (1/$F_i$) * | 1.75E+05 |
| **III** | $e_o$ > | 0.92 | + | (1/$F_i$) * | - 7.24E+04 |
| **IV** | $e_o$ > | -0.92 | + | (1/$F_i$) * | 1.14E+05 |
| **V** | $e_o$ < | 0.75 | | | |

| **1/F** | **I** | **II** | **III** | **IV** | **V** |
|---|---|---|---|---|---|
| 0 | 0.92 | -0.92 | 0.92 | -0.92 | 0.75 |
| 5.00E-07 | 0.95 | -0.83 | 0.88 | -0.86 | 0.75 |
| 1.00E-06 | 0.98 | -0.75 | 0.85 | -0.81 | 0.75 |
| 1.50E-06 | 1.01 | -0.66 | 0.81 | -0.75 | 0.75 |
| 2.00E-06 | 1.04 | -0.57 | 0.78 | -0.69 | 0.75 |
| 2.50E-06 | 1.07 | -0.48 | 0.74 | -0.63 | 0.75 |
| 3.00E-06 | 1.09 | -0.40 | 0.70 | -0.58 | 0.75 |



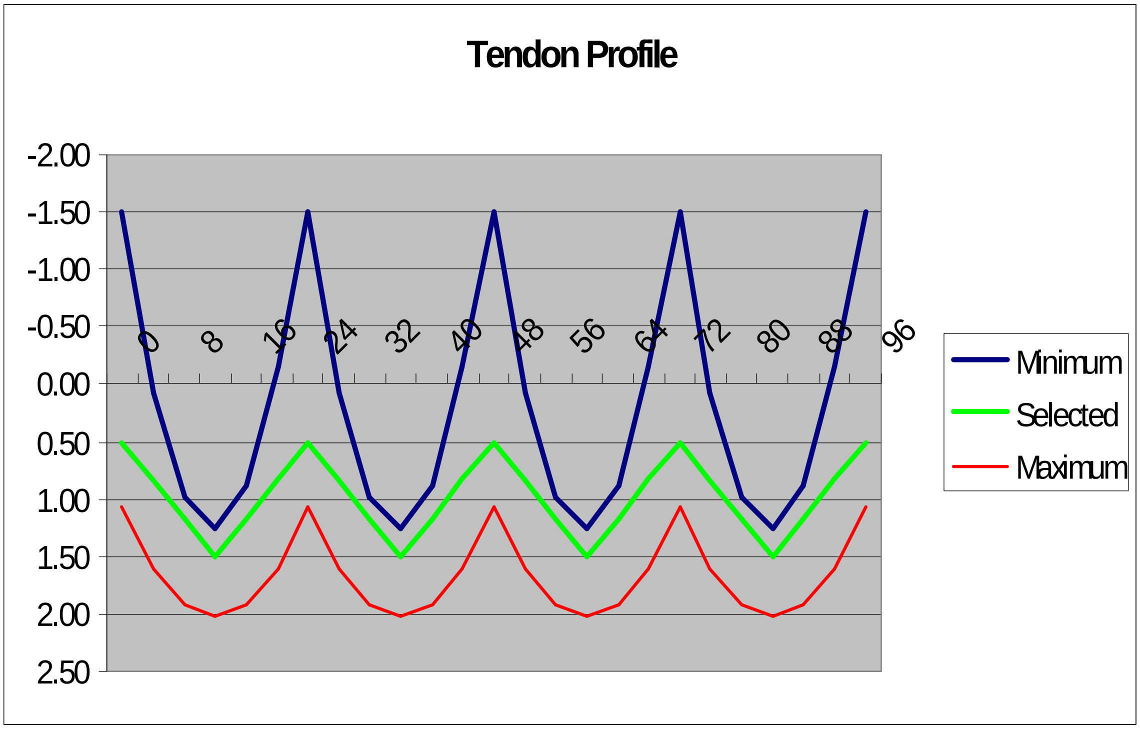
| | | | | | |
|---|---|---|---|---|---|
| 3.50E-06 | 1.12 | -0.31 | 0.67 | -0.52 | 0.75 |
| 4.00E-06 | 1.15 | -0.22 | 0.63 | -0.46 | 0.75 |
| 4.50E-06 | 1.18 | -0.13 | 0.59 | -0.41 | 0.75 |
| 5.00E-06 | 1.21 | -0.05 | 0.56 | -0.35 | 0.75 |
| 5.50E-06 | 1.24 | 0.04 | 0.52 | -0.29 | 0.75 |
| 6.00E-06 | 1.27 | 0.13 | 0.49 | -0.23 | 0.75 |
| 6.50E-06 | 1.30 | 0.21 | 0.45 | -0.18 | 0.75 |
| 7.00E-06 | 1.33 | 0.30 | 0.41 | -0.12 | 0.75 |
| 7.50E-06 | 1.36 | 0.39 | 0.38 | -0.06 | 0.75 |
| 8.00E-06 | 1.39 | 0.48 | 0.34 | 0.00 | 0.75 |
| 8.50E-06 | 1.42 | 0.56 | 0.30 | 0.05 | 0.75 |
| 9.00E-06 | 1.44 | 0.65 | 0.27 | 0.11 | 0.75 |
| 9.50E-06 | 1.47 | 0.74 | 0.23 | 0.17 | 0.75 |
| 1.00E-05 | 1.50 | 0.83 | 0.20 | 0.22 | 0.75 |
| 1.05E-05 | 1.53 | 0.91 | 0.16 | 0.28 | 0.75 |
| 1.10E-05 | 1.56 | 1.00 | 0.12 | 0.34 | 0.75 |
| 1.15E-05 | 1.59 | 1.09 | 0.09 | 0.40 | 0.75 |
| 1.20E-05 | 1.62 | 1.17 | 0.05 | 0.45 | 0.75 |
| 1.25E-05 | 1.65 | 1.26 | 0.02 | 0.51 | 0.75 |
| 1.30E-05 | 1.68 | 1.35 | -0.02 | 0.57 | 0.75 |
| 1.35E-05 | 1.71 | 1.44 | -0.06 | 0.62 | 0.75 |
| 1.40E-05 | 1.74 | 1.52 | -0.09 | 0.68 | 0.75 |
| 1.45E-05 | 1.76 | 1.61 | -0.13 | 0.74 | 0.75 |
| 1.50E-05 | 1.79 | 1.70 | -0.17 | 0.80 | 0.75 |
| 1.55E-05 | 1.82 | 1.79 | -0.20 | 0.85 | 0.75 |
| 1.60E-05 | 1.85 | 1.87 | -0.24 | 0.91 | 0.75 |
| 1.65E-05 | 1.88 | 1.96 | -0.27 | 0.97 | 0.75 |
| 1.70E-05 | 1.91 | 2.05 | -0.31 | 1.03 | 0.75 |
| 1.75E-05 | 1.94 | 2.13 | -0.35 | 1.08 | 0.75 |

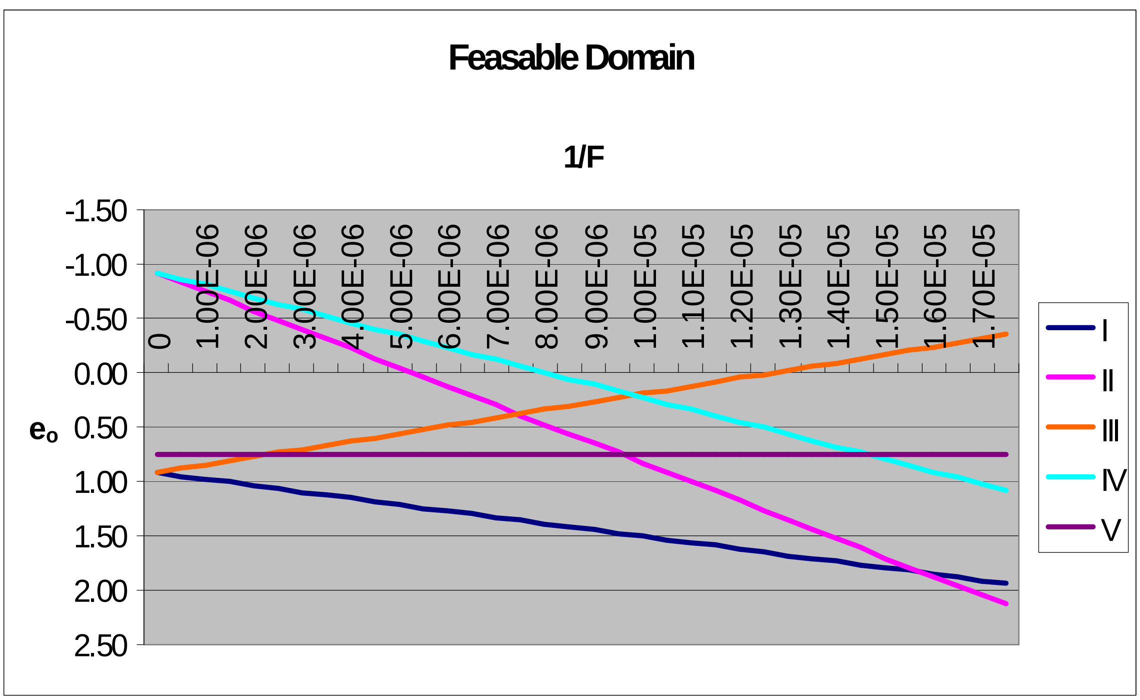
| **Distance** | **$M_{min}$** | **$M_{max}$** | **I** | **II** | **III** | **IV** | **V** |
|---|---|---|---|---|---|---|---|
| **(ft)** | **(k-in)** | **(k-in)** | **$e_o$ <** | **$e_o$ <** | **$e_o$ >** | **$e_o$ >** | **$e_o$ <** |
| 0 | 0 | 0 | 1.08 | 0.94 | -2.40 | -1.51 | 0.75 |
| 4 | 36 | 85.92 | 1.60 | 2.20 | -0.83 | 0.07 | 0.75 |
| 8 | 57.6 | 136.32 | 1.92 | 2.94 | 0.09 | 0.99 | 0.75 |
| 12 | 64.8 | 151.2 | 2.03 | 3.15 | 0.37 | 1.26 | 0.75 |
| 16 | 57.6 | 130.56 | 1.92 | 2.85 | -0.01 | 0.88 | 0.75 |
| 20 | 36 | 74.4 | 1.60 | 2.03 | -1.04 | -0.15 | 0.75 |
| 24 | 0 | 0 | 1.08 | 0.94 | -2.40 | -1.51 | 0.75 |
| 28 | 36 | 85.92 | 1.60 | 2.20 | -0.83 | 0.07 | 0.75 |
| 32 | 57.6 | 136.32 | 1.92 | 2.94 | 0.09 | 0.99 | 0.75 |
| 36 | 64.8 | 151.2 | 2.03 | 3.15 | 0.37 | 1.26 | 0.75 |
| 40 | 57.6 | 130.6 | 1.92 | 2.85 | -0.01 | 0.88 | 0.75 |
| 44 | 36 | 74.4 | 1.60 | 2.03 | -1.04 | -0.15 | 0.75 |
| 48 | 0 | 0 | 1.08 | 0.94 | -2.40 | -1.51 | 0.75 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 52 | 36 | 85.92 | 1.60 | 2.20 | -0.83 | 0.07 | 0.75 |
| 56 | 57.6 | 136.32 | 1.92 | 2.94 | 0.09 | 0.99 | 0.75 |
| 60 | 64.8 | 151.2 | 2.03 | 3.15 | 0.37 | 1.26 | 0.75 |
| 64 | 57.6 | 130.6 | 1.92 | 2.85 | -0.01 | 0.88 | 0.75 |
| 68 | 36 | 74.4 | 1.60 | 2.03 | -1.04 | -0.15 | 0.75 |
| 72 | 0 | 0 | 1.08 | 0.94 | -2.40 | -1.51 | 0.75 |
| 76 | 36 | 85.92 | 1.60 | 2.20 | -0.83 | 0.07 | 0.75 |
| 80 | 57.6 | 136.32 | 1.92 | 2.94 | 0.09 | 0.99 | 0.75 |
| 84 | 64.8 | 151.2 | 2.03 | 3.15 | 0.37 | 1.26 | 0.75 |
| 88 | 57.6 | 130.6 | 1.92 | 2.85 | -0.01 | 0.88 | 0.75 |
| 92 | 36 | 74.4 | 1.60 | 2.03 | -1.04 | -0.15 | 0.75 |
| 96 | 0 | 0 | 1.08 | 0.94 | -2.40 | -1.51 | 0.75 |

**Tendon Profile Parameters**

| Distance | Eccentricities (in) | | Tendon |
|---|---|---|---|
| **(ft)** | **Min** | **Max** | **Profile** |
| 0 | -1.51 | 1.08 | 0.50 |
| 4 | 0.07 | 1.60 | 0.83 |
| 8 | 0.99 | 1.92 | 1.17 |
| 12 | 1.26 | 2.03 | 1.50 |
| 16 | 0.88 | 1.92 | 1.17 |
| 20 | -0.15 | 1.60 | 0.83 |
| 24 | -1.51 | 1.08 | 0.50 |
| 28 | 0.07 | 1.60 | 0.83 |
| 32 | 0.99 | 1.92 | 1.17 |
| 36 | 1.26 | 2.03 | 1.50 |
| 40 | 0.88 | 1.92 | 1.17 |
| 44 | -0.15 | 1.60 | 0.83 |
| 48 | -1.51 | 1.08 | 0.50 |
| 52 | 0.07 | 1.60 | 0.83 |
| 56 | 0.99 | 1.92 | 1.17 |
| 60 | 1.26 | 2.03 | 1.50 |
| 64 | 0.88 | 1.92 | 1.17 |
| 68 | -0.15 | 1.60 | 0.83 |
| 72 | -1.51 | 1.08 | 0.50 |
| 76 | 0.07 | 1.60 | 0.83 |
| 80 | 0.99 | 1.92 | 1.17 |
| 84 | 1.26 | 2.03 | 1.50 |
| 88 | 0.88 | 1.92 | 1.17 |
| 92 | -0.15 | 1.60 | 0.83 |
| 96 | -1.51 | 1.08 | 0.50 |


Tendon Profile
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
0 8 16 24 32 40 48 56 64 72 80 88 96
Minimum
Selected
Maximum


Feasable Domain
1/F
e₀
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
0 1.00E-06 2.00E-06 3.00E-06 4.00E-06 5.00E-06 6.00E-06 7.00E-06 8.00E-06 9.00E-06 1.00E-05 1.10E-05 1.20E-05 1.30E-05 1.40E-05 1.50E-05 1.60E-05 1.70E-05
I
II
III
IV
V



## Continuous Span (Class T)

| | |
|---|---|
| **$A_c$ (in$^4$) =** | 60 |
| **I (in$^3$) =** | 125 |
| **$Z_t$ (in$^3$) =** | 50 |
| **$Z_b$ (in$^3$) =** | 50 |
| **$K_t$ (in) =** | -0.83 |
| **$K_b$ (in) =** | 0.83 |
| **$y_t$ (in) =** | 2.5 |
| **$y_b$ (in) =** | 2.5 |
| **$M_{min}$ (k-in) =** | 43.2 |
| **$M_{max}$ (k-in) =** | 119.2 |

| | |
|---|---|
| **•$_{ts}$ (psi) =** | - 848.5 |
| **•$_{ci}$ (psi) =** | 2100 |
| **•$_{sus}$ (psi) =** | 2250 |
| **•$_{cs}$ (psi) =** | 3000 |
| **•$_{ti}$ (psi) =** | - 177.5 |
| **• =** | 0.8 |
| **$w_{LL}$ (plf) =** | 100 |
| **$w_{sup}$ (plf) =** | 10 |
| **$w_{wt}$ (plf) =** | 62.5 |
| **$w_{Tot}$ (plf) =** | 172.5 |

## Feasible Domain Inequalities

| | | | | | |
|---|---|---|---|---|---|
| **I** | $e_o$ < | 0.83 | + | (1/$F_i$) * | 5.21E+04 |
| **II** | $e_o$ < | -0.83 | + | (1/$F_i$) * | 1.48E+05 |
| **III** | $e_o$ > | 0.83 | + | (1/$F_i$) * | - 3.85E+04 |
| **IV** | $e_o$ > | -0.83 | + | (1/$F_i$) * | 9.60E+04 |
| **V** | $e_o$ < | 0.5 | | | |

| **1/F** | **I** | **II** | **III** | **IV** | **V** |
|---|---|---|---|---|---|
| 0 | 0.83 | -0.83 | 0.83 | -0.83 | 0.50 |
| 5.00E-07 | 0.86 | -0.76 | 0.81 | -0.78 | 0.50 |
| 1.00E-06 | 0.88 | -0.68 | 0.79 | -0.73 | 0.50 |
| 1.50E-06 | 0.91 | -0.61 | 0.77 | -0.69 | 0.50 |
| 2.00E-06 | 0.93 | -0.53 | 0.75 | -0.64 | 0.50 |
| 2.50E-06 | 0.96 | -0.46 | 0.73 | -0.59 | 0.50 |



| | | | | | |
|---|---|---|---|---|---|
| 3.00E-06 | 0.99 | -0.39 | 0.71 | -0.54 | 0.50 |
| 3.50E-06 | 1.01 | -0.31 | 0.70 | -0.49 | 0.50 |
| 4.00E-06 | 1.04 | -0.24 | 0.68 | -0.45 | 0.50 |
| 4.50E-06 | 1.06 | -0.16 | 0.66 | -0.40 | 0.50 |
| 5.00E-06 | 1.09 | -0.09 | 0.64 | -0.35 | 0.50 |
| 5.50E-06 | 1.12 | -0.01 | 0.62 | -0.30 | 0.50 |
| 6.00E-06 | 1.14 | 0.06 | 0.60 | -0.25 | 0.50 |
| 6.50E-06 | 1.17 | 0.13 | 0.58 | -0.21 | 0.50 |
| 7.00E-06 | 1.19 | 0.21 | 0.56 | -0.16 | 0.50 |
| 7.50E-06 | 1.22 | 0.28 | 0.54 | -0.11 | 0.50 |
| 8.00E-06 | 1.25 | 0.36 | 0.52 | -0.06 | 0.50 |
| 8.50E-06 | 1.27 | 0.43 | 0.50 | -0.01 | 0.50 |
| 9.00E-06 | 1.30 | 0.50 | 0.48 | 0.03 | 0.50 |
| 9.50E-06 | 1.32 | 0.58 | 0.46 | 0.08 | 0.50 |
| 1.00E-05 | 1.35 | 0.65 | 0.45 | 0.13 | 0.50 |
| 1.05E-05 | 1.38 | 0.73 | 0.43 | 0.18 | 0.50 |
| 1.10E-05 | 1.40 | 0.80 | 0.41 | 0.23 | 0.50 |
| 1.15E-05 | 1.43 | 0.87 | 0.39 | 0.27 | 0.50 |
| 1.20E-05 | 1.45 | 0.95 | 0.37 | 0.32 | 0.50 |
| 1.25E-05 | 1.48 | 1.02 | 0.35 | 0.37 | 0.50 |
| 1.30E-05 | 1.51 | 1.10 | 0.33 | 0.42 | 0.50 |
| 1.35E-05 | 1.53 | 1.17 | 0.31 | 0.47 | 0.50 |
| 1.40E-05 | 1.56 | 1.24 | 0.29 | 0.51 | 0.50 |
| 1.45E-05 | 1.59 | 1.32 | 0.27 | 0.56 | 0.50 |
| 1.50E-05 | 1.61 | 1.39 | 0.25 | 0.61 | 0.50 |
| 1.55E-05 | 1.64 | 1.47 | 0.23 | 0.66 | 0.50 |
| 1.60E-05 | 1.66 | 1.54 | 0.21 | 0.71 | 0.50 |
| 1.65E-05 | 1.69 | 1.62 | 0.19 | 0.75 | 0.50 |
| 1.70E-05 | 1.72 | 1.69 | 0.18 | 0.80 | 0.50 |
| 1.75E-05 | 1.74 | 1.76 | 0.16 | 0.85 | 0.50 |

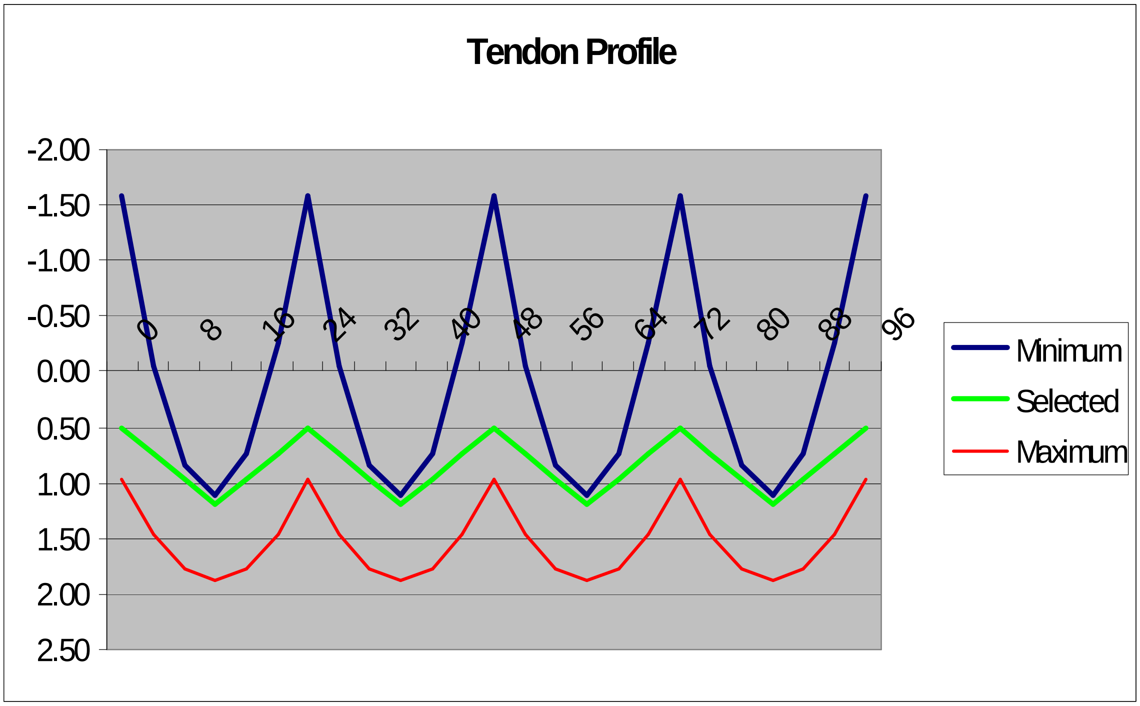
| **Distance** | **$M_{min}$** | **$M_{max}$** | **I** | **II** | **III** | **IV** | **V** |
|---|---|---|---|---|---|---|---|
| **(ft)** | **(k-in)** | **(k-in)** | **$e_o <$** | **$e_o <$** | **$e_o >$** | **$e_o >$** | **$e_o <$** |
| 0 | 0 | 0 | 0.96 | 0.67 | -1.85 | -1.59 | 0.50 |
| 4 | 36 | 85.92 | 1.47 | 1.90 | -0.31 | -0.05 | 0.50 |
| 8 | 57.6 | 136.32 | 1.78 | 2.62 | 0.59 | 0.85 | 0.50 |
| 12 | 64.8 | 151.2 | 1.88 | 2.83 | 0.85 | 1.11 | 0.50 |
| 16 | 57.6 | 130.56 | 1.78 | 2.54 | 0.48 | 0.74 | 0.50 |
| 20 | 36 | 74.4 | 1.47 | 1.73 | -0.52 | -0.26 | 0.50 |
| 24 | 0 | 0 | 0.96 | 0.67 | -1.85 | -1.59 | 0.50 |
| 28 | 36 | 85.92 | 1.47 | 1.90 | -0.31 | -0.05 | 0.50 |
| 32 | 57.6 | 136.32 | 1.78 | 2.62 | 0.59 | 0.85 | 0.50 |
| 36 | 64.8 | 151.2 | 1.88 | 2.83 | 0.85 | 1.11 | 0.50 |
| 40 | 57.6 | 130.6 | 1.78 | 2.54 | 0.48 | 0.74 | 0.50 |



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 44 | 36 | 74.4 | 1.47 | 1.73 | -0.52 | -0.26 | 0.50 |
| 48 | 0 | 0 | 0.96 | 0.67 | -1.85 | -1.59 | 0.50 |
| 52 | 36 | 85.92 | 1.47 | 1.90 | -0.31 | -0.05 | 0.50 |
| 56 | 57.6 | 136.32 | 1.78 | 2.62 | 0.59 | 0.85 | 0.50 |
| 60 | 64.8 | 151.2 | 1.88 | 2.83 | 0.85 | 1.11 | 0.50 |
| 64 | 57.6 | 130.6 | 1.78 | 2.54 | 0.48 | 0.74 | 0.50 |
| 68 | 36 | 74.4 | 1.47 | 1.73 | -0.52 | -0.26 | 0.50 |
| 72 | 0 | 0 | 0.96 | 0.67 | -1.85 | -1.59 | 0.50 |
| 76 | 36 | 85.92 | 1.47 | 1.90 | -0.31 | -0.05 | 0.50 |
| 80 | 57.6 | 136.32 | 1.78 | 2.62 | 0.59 | 0.85 | 0.50 |
| 84 | 64.8 | 151.2 | 1.88 | 2.83 | 0.85 | 1.11 | 0.50 |
| 88 | 57.6 | 130.6 | 1.78 | 2.54 | 0.48 | 0.74 | 0.50 |
| 92 | 36 | 74.4 | 1.47 | 1.73 | -0.52 | -0.26 | 0.50 |
| 96 | 0 | 0 | 0.96 | 0.67 | -1.85 | -1.59 | 0.50 |

**Tendon Profile Parameters**

| Distance | Eccentricities (in) | | Tendon |
|---|---|---|---|
| (ft) | Min | Max | Profile |
| 0 | -1.59 | 0.96 | 0.50 |
| 4 | -0.05 | 1.47 | 0.73 |
| 8 | 0.85 | 1.78 | 0.97 |
| 12 | 1.11 | 1.88 | 1.20 |
| 16 | 0.74 | 1.78 | 0.97 |
| 20 | -0.26 | 1.47 | 0.73 |
| 24 | -1.59 | 0.96 | 0.50 |
| 28 | -0.05 | 1.47 | 0.73 |
| 32 | 0.85 | 1.78 | 0.97 |
| 36 | 1.11 | 1.88 | 1.20 |
| 40 | 0.74 | 1.78 | 0.97 |
| 44 | -0.26 | 1.47 | 0.73 |
| 48 | -1.59 | 0.96 | 0.50 |
| 52 | -0.05 | 1.47 | 0.73 |
| 56 | 0.85 | 1.78 | 0.97 |
| 60 | 1.11 | 1.88 | 1.20 |
| 64 | 0.74 | 1.78 | 0.97 |
| 68 | -0.26 | 1.47 | 0.73 |
| 72 | -1.59 | 0.96 | 0.50 |
| 76 | -0.05 | 1.47 | 0.73 |
| 80 | 0.85 | 1.78 | 0.97 |
| 84 | 1.11 | 1.88 | 1.20 |
| 88 | 0.74 | 1.78 | 0.97 |
| 92 | -0.26 | 1.47 | 0.73 |
| 96 | -1.59 | 0.96 | 0.50 |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-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
0
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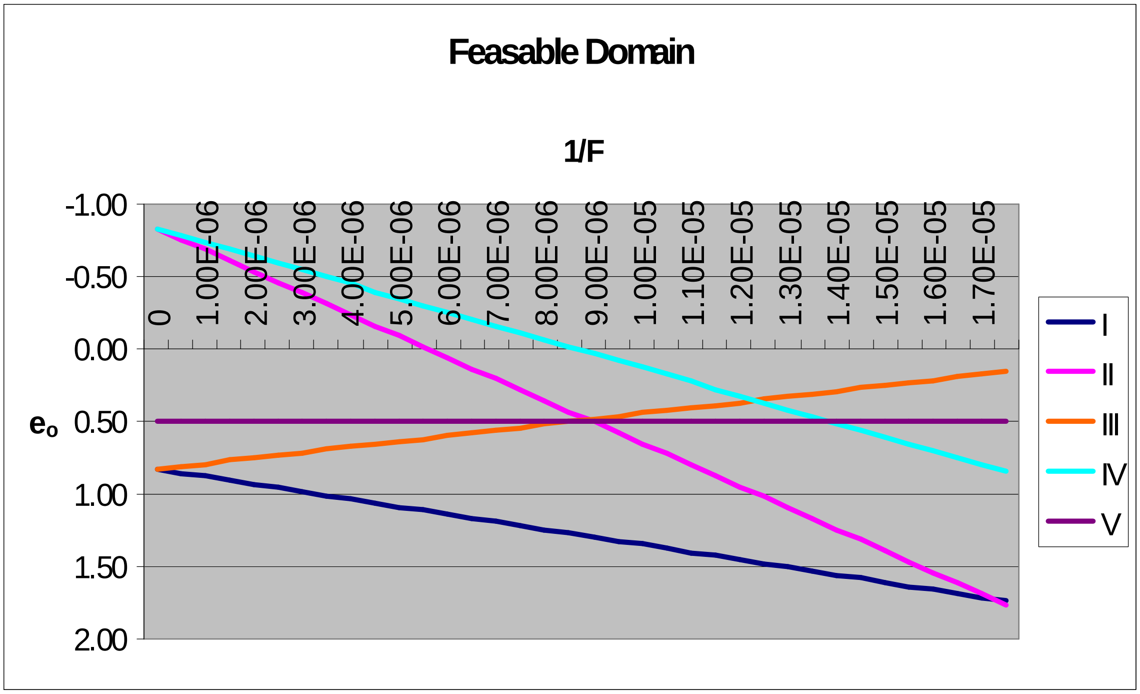
16
24
32
40
48
56
64
72
80
88
96
Minimum
Selected
Maximum


Feasable Domain
1/F
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-0.50
0.00
0.50
1.00
1.50
2.00
e
0
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2.00E-06
3.00E-06
4.00E-06
5.00E-06
6.00E-06
7.00E-06
8.00E-06
9.00E-06
1.00E-05
1.10E-05
1.20E-05
1.30E-05
1.40E-05
1.50E-05
1.60E-05
1.70E-05
I
II
III
IV
V

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## Design Calculations

| Project | Prepared by | Date |
|---|---|---|
| Subject/Title | Reviewed by | Date |
| Simple Span (Class U) | Calculation Number | Sheet 1 of |

$L = 24'$

$B = 1'$

$f'_c = 5000$ psi

$f'_{ci} = 3500$ psi

$f_{pu} = 270$ ksi

$LL = 100$ psf (residential)

$DL_{sup} = 10$ psf (superimposed)

$Weight = 150 \text{ pcf } (7''/12)$ (weight assumption)

$= 75$ psf

$w_{LL} = 100 \text{ psf} \times 1' = 100 \text{ plf}$

$w_{sup} = 10 \text{ psf} \times 1' = 10 \text{ plf}$

$w_{wt} = 75 \text{ psf} \times 1' = 75 \text{ plf}$

$$M_{min} = \frac{wx(l-x)}{2} = \frac{75x(24-x)}{2} = 900x - 37.5x^2$$

$= 5400$ lb-ft $= 64.8$ k-in @ midspan

$$M_{MAX} = \frac{wx(l-x)}{2} = \frac{185x(24-x)}{2} = 2160x - 92.5x^2$$

$= 12600$ lb-ft $= 151.2$ k-in @ midspan

$b = 12''$

$$I = \frac{bh^3}{12} = \frac{12(7)^3}{12} = 343 \text{ in}^4$$

$$Z_t = Z_b = I/y_t = 343/3.5 = 98 \text{ in}^3$$

$y_t = y_b = 3.5''$

$A_c = 12'' \times 7'' = 84 \text{ in}^2$

$K_t = -Z_b/A_c = -98/84 = -1.17''$   $K_b = 1.17''$

## Design Calculations

| Project | Prepared by | Date |
|---|---|---|
| Subject/Title | Reviewed by | Date |
| | Calculation Number | Sheet 2 of |

Allowable Stresses (ACI)

$\bar{\sigma}_{ts} = 7.5\sqrt{f'c} = 7.5\sqrt{5000} = -530$ psi (18.3.3) (class U)

$\bar{\sigma}_{ci} = 0.6f'ci = 0.6(3500) = 2100$ psi (18.4.1)

$\bar{\sigma}_{sus} = 0.45f'c = 0.45(5000) = 2250$ psi (18.4.2)

$\bar{\sigma}_{cs} = 0.6f'c = 0.6(5000) = 3000$ psi (18.4.2)

$\bar{\sigma}_{ti} = 3\sqrt{f'ci} = 3\sqrt{3500} = -177.5$ psi (18.4.1)

Feasible Domain

I $e_o \leq k_b + (1/F)(M_{min} - \bar{\sigma}_{ti} Z_t)$

$\leq 1.17 + (1/F)(64.8 - (-.18)(98))$

$\leq 1.17 + (1/F)(82.44)$

II $e_o \leq k_t + (1/F)(M_{min} + \bar{\sigma}_{ci} Z_b)$

$\leq -1.17 + (1/F)(64.8 + (2.1)(98))$

$\leq -1.17 + (1/F)(270.6)$

III $e_o \geq k_b + (1/F)(M_{MAX} - \bar{\sigma}_{cs} Z_t)(1/\eta)$

$\geq 1.17 + (1/F)(151.2 - (3)(98)(1/.8))$

$\geq 1.17 + (1/F)(-178.5)$

IV $e_o \geq k_t + (1/F)(M_{MAX} + \bar{\sigma}_{ts} Z_b)(1/\eta)$

$\geq -1.17 + (1/F)(151.2 + (-.53)(98))(1/.8)$

$\geq -1.17 + (1/F)(124.1)$

V $e_o \leq y_b - (d_c) = 3.5 - 2 = 1.5''$

IV = V

$\Rightarrow 1.5 = -1.17 + (1/F)(124.1)$

$\Rightarrow F = 46.5^K$

ACI limit for $f_{pi} = 0.74 f_{pu} = .74(270) = 199.8$ ksi

$f_{pi} = \frac{F_i}{A_s} \Rightarrow A_s = \frac{F_i}{f_{pi}} = \frac{46.5}{199.8} = 0.23''$

using $1/2''\phi$ strands ($A = 0.19\ in^2$)

$\Rightarrow$ use 2 strands ($A = .38\ in^2$)

$F_i = 199.8 \times .38 = 75.9^K$

Check ultimate capacity

$M_u = 1.2\,DL + 1.6\,LL$

$= 1.2\left(\frac{85 \times 24^2}{8}\right) + 1.6\left(\frac{100 \times 24^2}{8}\right)$

$= 18{,}864$ lb-ft $= 226.4$ K-in @ midspan

$M_{cr} = F(e_o - k_t) - f_r Z_b$

$= 75.9(1.52 + 1.17) - (-7.5\sqrt{5000}) \times (98)/1000$

$= 256.14$ K-in @ midspan

$$f_{ps} = f_{pu}\left\{1 - \frac{\gamma_p}{\beta_1}\left[\rho_p \frac{f_{pu}}{f'_c}\right]\right\}$$

## Design Calculations

| Project | Prepared by | Date |
|---|---|---|
| Subject/Title | Reviewed by | Date |
| | Calculation Number | Sheet 4 of |

low-relaxation strands

$\Rightarrow \gamma_p = 0.28$, $\beta_1 = .75$

$$\rho_p = \frac{0.38}{(6'')(12'')} = 0.00528$$

$$f_{ps} = 270\left\{1 - \frac{.28}{.75}\left[0.00528 \times \frac{270}{5}\right]\right\} = 241.3 \text{ ksi}$$

$$a = \frac{A_{ps} f_{ps}}{.85 f'_c b} = \frac{(.38)(241.3)}{.85(5)(12)} = 1.79''$$

$$M_n = A_{ps} f_{ps}(d_p - a/2)$$
$$= (.38)(241.3)(5'' - 1.79/2)$$
$$= 376.4$$

$\phi M_N = 338.7 > M_u = 226.4$ k-in ok
$> 1.2 M_{cr} = 307.4$ k-in ok

No compressive steel needed

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# Design Calculations

| Project | Prepared by | Date |
|---|---|---|
| Subject/Title | Reviewed by | Date |
| Simple Span (class T) | Calculation Number | Sheet of |

$L = 24'$

$B = 1'$

$\omega_T = 150(6/12)$
$= 75 \text{ psf}$

$M_{min} = \frac{\omega x(l-x)}{2} = \frac{75x(24-x)}{2} = 900x - 37.5x^2 = 64.8 \text{ k-in}$

$M_{MAX} = 2160x - 92.5x^2 = 151.2 \text{ k-in}$

$b = 12''$

$I = \frac{bh^3}{12} = \frac{12(6)^3}{12} = 216 \text{ in}^4$

$Z_t = Z_b = I/y_t = 216/3 = 72 \text{ in}^3$

$A_c = 12 \times 6 = 72 \text{ in}^2$

$k_t = -1$ , $k_b = 1$

<u>Allowable Stresses</u>

$\bar{\sigma}_{ts} = -12\sqrt{5000} = -848.5 \text{ psi}$

$\bar{\sigma}_{ci} = 2100 \text{ psi}$

$\bar{\sigma}_{sus} = 2250 \text{ psi}$

$\bar{\sigma}_{cs} = 3000 \text{ psi}$

$\bar{\sigma}_{ti} = -177.5 \text{ psi}$

see excel for feasible domain

# Design Calculations

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| Project | Prepared by | Date |
|---|---|---|
| Subject/Title | Reviewed by | Date |
| | Calculation Number | Sheet 6 of |

$\text{IV} = \text{V}$

$e_0 = -1 + \frac{1}{F}(1.13 \times 10^5)$

$\Rightarrow F = 56.5^K$

$f_{pi} = \frac{F_i}{A_s} \Rightarrow A_s = \frac{F_i}{f_{pi}} = \frac{56.5}{199.8} = 0.28 \text{ in}^2$

$\Rightarrow$ Use 2 ½" ϕ Strands

$F_i = 199.8 \times .38 = 75.9^K$

$M_u = 226.4$ K-in

$M_{cr} = 56.5(1+1) + 12\sqrt{5000} \times 72/1000$

$= 174.1$ K-in

$f_{ps} = 241.3$ ksi

$a = 1.79''$

$M_N = (38)(241.3)(4 - 1.79/2) = 284.7$ k-in

$\phi M_N = 256 > M_u = 226.4$
$> 1.2 M_{cr} = 208.9$

} No compression steel needed.

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# Design Calculations

| Project | Prepared by | Date |
|---|---|---|
| Subject/Title | Reviewed by | Date |
| Continuous Span (class U) | Calculation Number | Sheet of |

$L = 96'$
$B = 1'$

$LL = 100$ psf
$DL = 10$ psf
$WT = 150 \times 5.5/12 = 68.75$ psf

From ACI chapter 8

$\frac{wl^2}{11}$ $\frac{wl^2}{16}$ $\frac{wl^2}{16}$ $\frac{wl^2}{14}$

0 $\frac{wl^2}{10}$ $\frac{wl^2}{11}$ $\frac{wl^2}{11}$ $\frac{wl^2}{11}$ $\frac{wl^2}{11}$ $\frac{wl^2}{10}$

24" 24 24 24

MIN (k-in)

43.2 29.7 29.7 33.9

0 47.5 43.2 43.2 43.2 43.2 47.5

MAX (k-in)

112.32 77.2 77.2 88.25

0 123.6 112.32 112.32 112.32 112.32 123.6 0

## Design Calculations

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

$h = 5.5''$

$b = 12''$ $\qquad A_c = 66 \text{ in}^2$

$y_t = y_b = 2.75''$ $\qquad K_t = -.92$

$I = \frac{bh^3}{12} = 166.4 \text{ in}^4$ $\qquad K_b = .92$

$Z_t = Z_b = 60.5 \text{ in}^3$

IV = V :

$-.92 + \frac{1}{F}(1.14 \times 10^5) = .75 \Rightarrow F = 68.3^k$

$f_{pi} = \frac{F_i}{A_s} = A_s = \frac{68.3}{199.8} = 0.34 \text{ in}^2 \Rightarrow$ ∴ use 2 ½" $\phi$ strands

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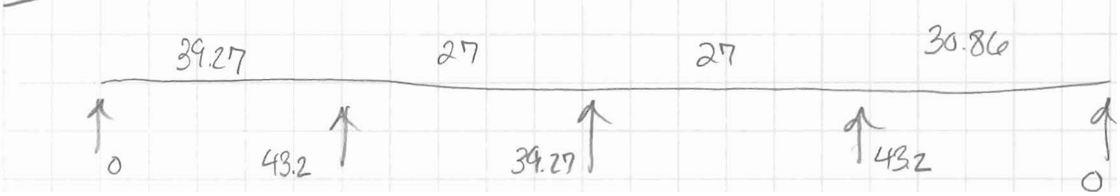
# Design Calculations

| Project | Prepared by | Date |
|---|---|---|
| Subject/Title | Reviewed by | Date |
| Continuous Class (T) | Calculation Number | Sheet of |

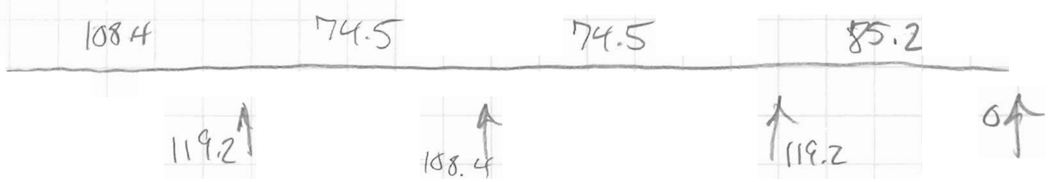
$L = 96'$ $\quad$ $WT = 62.5$ psf

$B = 1'$

MIN (k-in)




MAX




$b = 12''$

$y_t = y_b = 2.5''$

$I = \frac{bh^3}{12} = 125\ in^4$

$Z_t = Z_b = 50\ in^3$

$A_c = 60\ in^2$

$k_t = -.83$

$k_b = .83$

V = IV

$-.83 + \frac{1}{F}(9.6 \times 10^4) = .5 \Rightarrow F = 70.7^K$

$A_s = \frac{70.7}{199.8} = 0.35 \Rightarrow (2)\ \frac{1}{2}''\ \phi$ strands

# A p p e n d i x I I

# Post-Tensioned Shear Calculations (sample calculations at 9')

**Steps taken from the PCI Design Handbook Precast and Prestressed Concrete 6th Edition**

## Material Properties

$f_c'$ = 5000 psi, normal – weight concrete $\Rightarrow$ l $=1$
$f_{ci}'$ = 3500 psi
$f_{pu}$ = 270 ksi, (low-relaxation steel)
$f_{ps}$ = 240 ksi
$f_{pe}$ = 148 ksi $\Rightarrow$ $f_{pe} > 0.4\ f_{pu}$
$f_{yv}$ for stirrups = 60 ksi

## Sectional Properties

b=12"
$A_c$ = 60 in$^2$
$I_c$ = 125 in$^2$
h = 5 in
$y_b$ = 2.5
$y_t$ = 2.5 in
$Z_b$ = 50 in$^3$
$Z_t$ = 50 in$^3$
$2b_w$ = 24 in

*Use the same value for the effective depth $d_p$ for the midspan as well as other sections.*

## Tendon Properties

$e_e$ = 0.5 in
$e_c$ = 1.2 in
$A_{ps}$ = 18, ½ in (12.7 mm) dia strands = 18 x 0.153 in$^2$ = 2.754 in$^2$
F = $f_{pe}$ . $A_{ps}$ = 148 ksi x 2.754 in$^2$ = 407.6 kips

$k_b = Z_t/A_c$ = .833 in

$k_b = Z_t/A_c$ = .833 in

Assuming • = 0.8
h $= f_{pe}/f_{pi} = F/F_i = 0.8$

## Factored Loads

Factored dead load, superimposed dead load and live load:

$w_u = 1.2\ (w_D + w_{SDL}) + 1.6(w_L) = 1.2(\ 100) + 1.6(140) = 2615$ plf = 2.615 kip/ft

Factored superimposed dead load and live load:

• $w_u = 1.2\ (w_{SDL}) + 1.6(w_L) = 1.2 \times (80) + 1.6 \times (100) = 1392$ plf = 1.392 kip/ft

## ACI EQUATIONS

$e_{o@9ft} = 0.9"$
$d_{p@9ft} = e_{o@9ft} + y_t = 3.4$
For equation used in elaborate approach, $d_p$ is limited by 0.8h = 0.8 x 5 = 4 in
Taking $d_{p@mid}$ as mentioned in the question to be $d_{p@9ft}$, we have
$d_{p@9ft} = 4$ in

### Computation of the Flexure – Shear Resistance:

$$\begin{cases} \text{Flexure - shear stress resistance} \\ v_{ci} = 0.6\lambda\sqrt{f_c^{'}} + \dfrac{V_G}{b_w d_p} + \left(\dfrac{\Delta V_u \times \Delta M_{cr}}{\Delta M_u}\right)\dfrac{1}{b_w d_p} \geq 1.7\lambda\sqrt{f_c^{'}} \\ \text{Flexure - shear force resistance} \\ V_{ci} = 0.6\lambda\sqrt{f_c^{'}} b_w d_p + V_G + \left(\dfrac{\Delta V_u \times \Delta M_{cr}}{\Delta M_u}\right) \geq 1.7\lambda\sqrt{f_c^{'}} b_w d \end{cases}$$

where $V_G$ = shear force due to self – weight of member at section considered

$= w_G\left(\dfrac{l}{2} - x\right)$ = 1.019 kips/ft (12-9)ft = 26.5 kip

• $V_u$ = factored shear force due to superimposed dead load plus live load at section considered under same loading as • $M_u$

$= \Delta w_u\left(\dfrac{l}{2} - x\right) =$ 1.392 kips/ft (12-9) = 36.2 kip



• $M_u$ = factored bending moment due to superimposed dead load plus live load at section considered = $\Delta w_u \dfrac{x(l-x)}{2}$ = 1.392 x 9 (24-9)/2 = 382.104 kip-ft = 4582 kip-in

$M_G$ = moment due to self weight of member $= w_G \dfrac{x(l-x)}{2}$ = 1.019 x 9 (24-9)/2
= 279.72 kip-ft = 3357 kip-in

• $M_{cr}$ = moment in excess of self – weight moment, causing flexural cracking in the precompressed tensile fiber at section considered = $M_{cr}$ - $M_G$

$$= Z_b\left[6\sqrt{f_c^{'}} + \frac{F}{A_c}\left(1+\frac{e_o A_c}{Z_b}\right)\right] - M_G$$

= 5179 kip-in

Therefore:

$$\begin{cases}\begin{cases} v_{ci} = 0.6\times1\times\sqrt{5000}\,psi + \dfrac{26.5kip\times1000.}{12.5in\times30in} + \left(\dfrac{36.2kip\times5179kip-in}{4582kip-in}\right)\dfrac{1000}{12.5in\times30in} \\ = 42.426\,psi + 179.778\,psi = 222\,psi \ge 1.7\,l\sqrt{f_c^{'}} = 120\,psi \end{cases} \\ \begin{cases} V_{ci} = 0.6\times1\times\sqrt{5000}\,psi\times12.5in\times30in + \left[25.6 + \left(\dfrac{36.2kip\times5179kip-in}{4582kip-in}\right)\right]1000 \\ = 15910lb + 66517lb = 82427lb = 82.4kip \ge 1.7\,l\sqrt{f_c^{'}}b_w d_p = 45kip \end{cases}\end{cases}$$

$V_p$ = vertical component of prestressing force at section considered

=Fsin• = 10083 lb

Therefore:

$$\begin{cases} v_{cw} = 3.5\times1\times\sqrt{5000}\,psi + 0.3\times417\,psi + \dfrac{10083lb}{12.5in\times30in} = 400\,psi \\ V_{cw} = (3.5\times1\times\sqrt{5000}\,psi + 0.3\times417\,psi)\times12.5in\times30in + 10083lb = 150kip \end{cases}$$

The shear resistance is the smaller of $v_{ci}$ ($V_{ci}$) and $v_{cw}$ ($V_{cw}$) at 9ft.



Therefore nominal shear strength provided by concrete, $v_c$ = 222 psi (or $V_c$ = 82.4 kip)

## Computation of Design Shear Strength

$V_u$ = Design shear force resulting from factored loads

$$= w_u\left(\frac{l}{2} - x\right) = 2.615\frac{kip}{ft}(35-9)\,ft = 68kip = 68000lb$$

Therefore:

$$\begin{cases} \dfrac{V_u}{\phi} = \dfrac{68000lb}{0.75} = 90667lb \\ \dfrac{v_u}{\phi} = \dfrac{V_u}{\phi b_w d_p} = \dfrac{68000lb}{0.75\times 12.5in\times 30in} = 242\,psi \end{cases}$$

The value of $V_u/\phi$ (or $v_u/\phi$) is to be compared to $V_c/2$ (or $v_c/2$) and $V_c$. (or $v_c$) As $V_u/\phi$ = 90667 lb (or $v_u/\phi$ = 242 psi) is more than $V_c/2$ (or $v_c/2$) as well as $V_c$ (or $v_c$) the nominal shear strength to be provided by the shear reinforcement,

$$\begin{cases} V_s = \dfrac{V_u}{\phi} - V_c = 90667lb - 82427lb = 8240lb < 8\lambda\sqrt{f_c^{'}}b_w d_p = 212132lb \\ v_s = \dfrac{v_u}{\phi} - v_c = 242\,psi - 222\,psi = 20\,psi < 8\lambda\sqrt{f_c^{'}} = 566\,psi \end{cases}.$$

Therefore there is no need to change concrete cross-section (i.e., larger $b_w d_p$)

$$A_v = \frac{(V_u/\phi - V_c)s}{f_{vy}d} \Rightarrow \frac{(V_u/\phi - V_c)}{d} = \frac{A_v f_{vy}}{s} = 275lb/in$$

$$If \quad s = 12in, \quad \begin{cases} > 3in \\ \le 0.75h = 0.75\times 30 = 22.5in \quad HenceOK \\ \le 24in \end{cases}$$

$$A_v = \frac{275lb/in\times 12in}{60000\,psi} = 0.055in^2$$

**<u>Hence the amount of excess shear can be provided by using welded wire reinforcement W2.9 ($A_v$ = 0.058 $in^2$/ft ), at a spacing of 12 in.</u>**

# Appendix III

Shear Wall Properties

| Wall | Direction | L (ft) | W (ft) | H (ft) | A ($ft^2$) | I ($in^4$) | k (k/in) |
|---|---|---|---|---|---|---|---|
| **Wall 1** | N/S | 96 | 0.833 | 9.3 | 79.968 | 1157811 | 1107 |
| **Wall 2** | N/S | 78 | 0.833 | 9.3 | 64.974 | 1157811 | 1098 |
| **Wall 3** | N/S | 52 | 0.833 | 9.3 | 43.316 | 1157811 | 1056 |
| **Wall 4** | N/S | 24 | 1 | 9.3 | 24 | 1389929 | 985 |
| **Wall 5** | E/W | 52 | 0.833 | 9.3 | 43.316 | 1157811 | 1056 |
| **Wall 6** | E/W | 78 | 0.833 | 9.3 | 64.974 | 1157811 | 1098 |
| **Wall 7** | E/W | 96 | 0.833 | 9.3 | 79.968 | 1157811 | 1107 |
| **Wall 8** | E/W | 24 | 1 | 9.3 | 24 | 1389929 | 985 |

**Center of Rigidity**

| Wall | Direction | L (ft) | W (ft) | A ($ft^2$) | X | f'c (psi | Ec (psi) |
|---|---|---|---|---|---|---|---|
| **Wall 1** | N/S | 96 | 0.833 | 79.968 | 115 | 5000 | 420000 |
| **Wall 2** | N/S | 78 | 0.833 | 64.974 | 115 | 5000 | 420000 |
| **Wall 3** | N/S | 52 | 0.833 | 43.316 | 115 | 5000 | 420000 |
| **Wall 4** | N/S | 24 | 1 | 24 | 115 | 5000 | 420000 |
| **Wall 4** | N/S | 24 | 1 | 24 | 115 | 5000 | 420000 |
| **Wall 4** | N/S | 24 | 1 | 24 | 105 | 5000 | 420000 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Wall 4** | N/S | 24 | 1 | 24 | 105 | 5000 | 420000 |
| **Wall 4** | N/S | 24 | 1 | 24 | 95 | 5000 | 420000 |
| **Wall 4** | N/S | 24 | 1 | 24 | 95 | 5000 | 420000 |

| Wall | k (k/in) | %k | %k*L | di | kidi | kidi$^2$ |
|---|---|---|---|---|---|---|
| **Wall 1** | 1107 | 0.260716 | 25.02873 | 0 | 0 | 0 |
| **Wall 2** | 1098 | 0.258596 | 20.17051 | 0 | 0 | 0 |
| **Wall 3** | 1056 | 0.248705 | 12.93264 | 0 | 0 | 0 |
| **Wall 4** | 985 | 0.231983 | 5.567593 | 0 | 0 | 0 |
| **Wall 4** | 252 | 0.05935 | 1.424399 | 0 | 0 | 0 |
| **Wall 4** | 843 | 0.19854 | 4.764955 | 0 | 0 | 0 |
| **Wall 4** | 489 | 0.115167 | 2.764013 | 0 | 0 | 0 |
| **Wall 4** | 454 | 0.106924 | 2.56618 | 0 | 0 | 0 |
| **Wall 4** | 159 | 0.037447 | 0.898728 | 0 | 0 | 0 |

| Wall | Direction | L (ft) | W (ft) | A (ft$^2$) | Y | f'c (psi | Ec (psi) |
|---|---|---|---|---|---|---|---|
| **Wall 5** | E/W | 52 | 0.833 | 43.316 | 54 | 5000 | 420000 |
| **Wall 6** | E/W | 78 | 0.833 | 64.974 | 22.5 | 5000 | 420000 |
| **Wall 7** | E/W | 96 | 0.833 | 79.968 | 16.5 | 5000 | 420000 |
| **Wall 8** | E/W | 24 | 1 | 24 | 1.5 | 5000 | 420000 |
| **Wall 8** | E/W | 24 | 1 | 24 | -1.5 | 5000 | 420000 |
| **Wall 8** | E/W | 24 | 1 | 24 | -11.5 | 5000 | 420000 |
| **Wall 8** | E/W | 24 | 1 | 24 | -11.5 | 5000 | 420000 |
| **Wall 8** | E/W | 24 | 1 | 24 | -20.5 | 5000 | 420000 |
| **Wall 8** | E/W | 24 | 1 | 24 | -20.5 | 5000 | 420000 |

| Wall | k (k/in) | %k | %k*L | di | kidi | kidi$^2$ |
|---|---|---|---|---|---|---|
| **Wall 5** | 1056 | 0.248705 | 12.93264 | 698.3627 | 737471 | 515022238 |



| | | | | | | |
|---|---|---|---|---|---|---|
| **Wall 6** | 1098 | 0.258596 | 20.17051 | 453.8366 | 498312.5 | 226152442 |
| **Wall 7** | 1107 | 0.260716 | 25.02873 | 412.9741 | 457162.3 | 188796195 |
| **Wall 8** | 985 | 0.231983 | 5.567593 | 8.35139 | 8226.119 | 68699.522 |
| **Wall 8** | 233 | 0.054875 | 1.317004 | -1.97551 | -460.293 | 909.31171 |
| **Wall 8** | 1569 | 0.369524 | 8.868582 | -101.989 | -160020 | 16320258 |
| **Wall 8** | 455 | 0.10716 | 2.571832 | -29.5761 | -13457.1 | 398008.53 |
| **Wall 8** | 1165 | 0.274376 | 6.585021 | -134.993 | -157267 | 21229903 |
| **Wall 8** | 1612 | 0.379651 | 9.111634 | -186.789 | -301103 | 56242593 |
| | 4246 | | | | | |

| Wall | Direction | L (ft) | W (ft) | H (ft) | A ($ft^2$) | f'c (psi | Ec (psi) | I ($in^4$) | k (k/in) | EI | %k |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Wall 1** | N/S | 96 | 0.833 | 44.5 | 79.968 | 5000 | 420000 | 126843662 | 1107 | 5.327E+13 | 0.130358 |
| **Wall 2** | N/S | 78 | 0.833 | 44.5 | 64.974 | 5000 | 420000 | 126843662 | 1098 | 5.327E+13 | 0.1292982 |
| **Wall 3** | N/S | 52 | 0.833 | 44.5 | 43.316 | 5000 | 420000 | 126843662 | 1056 | 5.327E+13 | 0.1243523 |
| **Wall 4** | N/S | 24 | 1 | 44.5 | 24 | 5000 | 420000 | 152273304 | 985 | 6.395E+13 | 0.1159915 |
| **Wall 5** | E/W | 52 | 0.833 | 44.5 | 43.316 | 5000 | 420000 | 126843662 | 1056 | 5.327E+13 | 0.1243523 |
| **Wall 6** | E/W | 78 | 0.833 | 44.5 | 64.974 | 5000 | 420000 | 126843662 | 1098 | 5.327E+13 | 0.1292982 |
| **Wall 7** | E/W | 96 | 0.833 | 44.5 | 79.968 | 5000 | 420000 | 126843662 | 1107 | 5.327E+13 | 0.130358 |
| **Wall 8** | E/W | 24 | 1 | 44.5 | 24 | 5000 | 420000 | 152273304 | 985 | 6.395E+13 | 0.1159915 |

**Stiffness Calculations**

# A p p e n d i x I V



Room Criteria (RC) Table

| Type of Room - Space Type | Recommended RC Level RC Curve | Equivalent Sound Level dBA |
|---|---|---|
| Apartments | 25-35 (N)[1)] | 35-45 |
| Assembly Halls | 25-30 (N) | 35-40 |
| Churches | 30-35 (N) | 40-45 |
| Courtrooms | 30-40 (N) | 40-50 |
| Factories | 40-65 (N) | 50-75 |
| Hotels/Motels | | |
| - Individual rooms or suites | 30-35 (N) | 35-45 |
| - Meeting or banquet rooms | 25-35 (N) | 35-45 |
| - Service and Support Areas | 40-45 (N) | 45-50 |
| - Halls, corridors, lobbies | 35-40 (N) | 50-55 |
| Offices | | |
| - Conference rooms | 25-30 (N) | 35-40 |
| - Private | 30-35 (N) | 40-45 |
| - Open-plan areas | 35-40 (N) | 45-50 |
| Hospitals and Clinics | | |
| - Private rooms | 25-30 (N) | 35-40 |
| - Operating rooms | 25-30 (N) | 35-40 |
| - Wards | 30-35 (N) | 40-45 |
| - Laboratories | 35-40 (N) | 45-50 |
| - Corridors | 30-35 (N) | 40-45 |
| - Public areas | 35-40 (N) | 45-50 |
| Schools | | |
| - Lecture and classrooms | 25-30 (N) | 35-40 |
| - Open-plan classrooms | 30-40 (N) | 45-50 |
| Movie motion picture theaters | 30-35 (N) | 40-45 |
| Libraries | 35-40 (N) | 40-50 |
| Legitimate theaters | 20-25 (N) | 30-65 |
| Private Residences | 25-35 (N) | 35-45 |
| Restaurants | 40-45 (N) | 50-55 |
| TV Broadcast studies | 15-25 (N) | 25-35 |
| Recording Studios | 15-20 (N) | 25-30 |
| Concert and recital halls | 15-20 (N) | 25-30 |
| Sport Coliseums | 45-55 (N) | 55-65 |

| Type of Room - Occupancy | | Noise Criterion - NC - | db(A) |
|---|---|---|---|
| Very quiet | Concert and opera halls, recording studios, theaters, etc. | 10 - 20 | 25 - 30 |
| | Private bedrooms, live theaters, television and radio studios, conference and lecture rooms, cathedrals and large churches, libraries, etc. | 20 - 25 | 25 - 30 |
| | Private living rooms, board rooms, conference and lecture rooms, hotel bedrooms | 30 - 40 | 30 - 35 |
| Quiet | Public rooms in hotels, small offices classrooms, courtrooms | 30 - 40 | 40 - 45 |
| Moderate noisy | Drawing offices, toilets, bathrooms, reception areas, lobbies, corridors, department stores, etc. | 35 - 45 | 45 - 55 |
| Noisy | Kitchens in hospitals and hotels, laundry rooms, computer rooms, canteens, supermarkets, office landscape, etc. | 40 - 50 | 45 - 55 |

**Absorbtion per frequency**

| | | | | | |
|---|---|---|---|---|---|
| **Freeguency = 125** | | | | | |
| **Surface area ($ft^2$)** | | | **•** | **a** | |
| **Walls** | 2(24 ft x 9 ft) = | 432 | 0.10 | 43.2 | |
| | 2(28 ft x 9 ft) = | 432 | 0.10 | 43.2 | |
| **Ceiling** | (28 ft x 24 ft) = | 672 | 0.01 | 6.72 | |
| **Floor** | (28 ft x 24 ft) = | 672 | 0.02 | 13.44 | |
| | | | **$a_{Total}$ =** | 106.56 | sabins |
| **Freeguency = 250** | | | | | |
| **Surface area ($ft^2$)** | | | **•** | **a** | |
| **Walls** | 2(24 ft x 9 ft) = | 432 | 0.05 | 21.6 | |
| | 2(28 ft x 9 ft) = | 432 | 0.05 | 21.6 | |
| **Ceiling** | (28 ft x 24 ft) = | 672 | 0.01 | 6.72 | |
| **Floor** | (28 ft x 24 ft) = | 672 | 0.03 | 20.16 | |
| | | | **$a_{Total}$ =** | 70.08 | sabins |
| **Freeguency = 500** | | | | | |
| **Surface area ($ft^2$)** | | | **•** | **a** | |

| | | | | | |
|---|---|---|---|---|---|
| **Walls** | 2(24 ft x 9 ft) = | 432 | 0.06 | 25.92 | |
| | 2(28 ft x 9 ft) = | 432 | 0.06 | 25.92 | |
| **Ceiling** | (28 ft x 24 ft) = | 672 | 0.02 | 13.44 | |
| **Floor** | (28 ft x 24 ft) = | 672 | 0.03 | 20.16 | |
| | | | **$a_{Total}$ =** | 85.44 | sabins |
| **Freeguency = 1000** | | | | | |
| **Surface area ($ft^2$)** | | | **•** | **a** | |
| **Walls** | 2(24 ft x 9 ft) = | 432 | 0.07 | 30.24 | |
| | 2(28 ft x 9 ft) = | 432 | 0.07 | 30.24 | |
| **Ceiling** | (28 ft x 24 ft) = | 672 | 0.02 | 13.44 | |
| **Floor** | (28 ft x 24 ft) = | 672 | 0.03 | 20.16 | |
| | | | **$a_{Total}$ =** | 94.08 | sabins |
| **Freeguency = 2000** | | | | | |
| **Surface area ($ft^2$)** | | | **•** | **a** | |
| **Walls** | 2(24 ft x 9 ft) = | 432 | 0.09 | 38.88 | |
| | 2(28 ft x 9 ft) = | 432 | 0.09 | 38.88 | |
| **Ceiling** | (28 ft x 24 ft) = | 672 | 0.02 | 13.44 | |
| **Floor** | (28 ft x 24 ft) = | 672 | 0.03 | 20.16 | |
| | | | **$a_{Total}$ =** | 111.36 | sabins |
| **Freeguency = 4000** | | | | | |
| **Surface area ($ft^2$)** | | | **•** | **a** | |
| **Walls** | 2(24 ft x 9 ft) = | 432 | 0.08 | 34.56 | |
| | 2(28 ft x 9 ft) = | 432 | 0.08 | 34.56 | |
| **Ceiling** | (28 ft x 24 ft) = | 672 | 0.02 | 13.44 | |
| **Floor** | (28 ft x 24 ft) = | 672 | 0.02 | 13.44 | |
| | | | **$a_{Total}$ =** | 96 | sabins |

# TL DATA FOR COMMON BUILDING ELEMENTS*

| Building Construction | Transmission Loss (dB) | | | | | | STC Rating | IIC Rating† |
|---|---|---|---|---|---|---|---|---|
| | 125 Hz | 250 Hz | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz | | |
| **Walls**[2-6]‡ | | | | | | | | |
| *Monolithic:* | | | | | | | | |
| 1. 3/8-in plywood (1 lb/ft²) | 14 | 18 | 22 | 20 | 21 | 26 | 22 | |
| 2. 26-gauge sheet metal (1.5 lb/ft²) | 12 | 14 | 15 | 21 | 21 | 25 | 20 | |
| 3. 1/2-in gypsum board (2 lb/ft²) | 15 | 20 | 25 | 31 | 33 | 27 | 28 | |
| 4. 2 layers 1/2-in gypsum board, laminated with joint compound (4 lb/ft²) | 19 | 26 | 30 | 32 | 29 | 37 | 31 | |
| 5. 1/32-in sheet lead (2 lb/ft²) | 15 | 21 | 27 | 33 | 39 | 45 | 31 | |
| 6. Glass-fiber roof fabric (37.5 oz/yd²) | 6 | 9 | 11 | 16 | 20 | 25 | 16 | |
| *Interior:* | | | | | | | | |
| 7. 2 by 4 wood studs 16 in oc with 1/2-in gypsum board both sides (5 lb/ft²) | 17 | 31 | 33 | 40 | 38 | 36 | 33 | |
| 8. Construction no. 7 with 2-in glass-fiber insulation in cavity | 15 | 30 | 34 | 44 | 46 | 41 | 37 | |
| 9. 2 by 4 staggered wood studs 16 in oc each side with 1/2-in gypsum board both sides (8 lb/ft²) | 23 | 28 | 39 | 46 | 54 | 44 | 39 | |
| 10. Construction no. 9 with 2 1/4-in glass-fiber insulation in cavity | 29 | 38 | 45 | 52 | 58 | 50 | 48 | |
| 11. 2 by 4 wood studs 16 in oc with 5/8-in gypsum board both sides, one side screwed to resilient channels. 3-in glass-fiber insulation in cavity (7 lb/ft²) | 32 | 42 | 52 | 58 | 53 | 54 | 52 | |
| 12. Double row of 2 by 4 wood studs 16 in oc with 3/8-in gypsum board on both sides of construction. 9-in glass-fiber insulation in cavity (4 lb/ft²) | 31 | 44 | 55 | 62 | 67 | 65 | 54 | |
| 13. 6-in dense concrete block, 3 cells, painted (34 lb/ft²) | 37 | 36 | 42 | 49 | 55 | 58 | 45 | |
| 14. 8-in lightweight concrete block, 3 cells, painted (38 lb/ft²) | 34 | 40 | 44 | 49 | 59 | 64 | 49 | |
| 15. Construction no. 14 with expanded mineral loose fill in cells | 34 | 40 | 46 | 52 | 60 | 66 | 51 | |
| 16. 6-in lightweight concrete block with 1/2-in gypsum board supported by resilient metal channels on one side, other side painted (26 lb/ft²) | 35 | 42 | 50 | 64 | 67 | 65 | 53 | |
| 17. 2 1/2-in steel channel studs 24 in oc with 5/8-in gypsum board both sides (6 lb/ft²) | 22 | 27 | 43 | 47 | 37 | 46 | 39 | |
| 18. Construction no. 17 with 2-in glass-fiber insulation in cavity | 26 | 41 | 52 | 54 | 45 | 51 | 45 | |
| 19. 3 5/8-in steel channel studs 16 in oc with 1/2-in gypsum board both sides (5 lb/ft²) | 26 | 36 | 43 | 51 | 48 | 43 | 43 | |
| 20. Construction no. 19 with 3-in mineral-fiber insulation in cavity | 28 | 45 | 54 | 55 | 47 | 54 | 48 | |
| 21. 2 1/2-in steel channel studs 24 in oc with two layers 5/8-in gypsum board one side, one layer other side (8 lb/ft²) | 28 | 31 | 46 | 51 | 53 | 47 | 44 | |
| 22. Construction no. 21 with 2-in glass-fiber insulation in cavity | 31 | 43 | 55 | 58 | 61 | 51 | 51 | |
| 23. 3 5/8-in steel channel studs 24 in oc with two layers 5/8-in gypsum board both sides (11 lb/ft²) | 34 | 41 | 51 | 54 | 46 | 52 | 48 | |
| 24. Construction no. 23 with 3-in mineral-fiber insulation in cavity | 38 | 52 | 59 | 60 | 56 | 62 | 57 | |
| *Exterior:* | | | | | | | | |
| 25. 4 1/2-in face brick (50 lb/ft²) | 32 | 34 | 40 | 47 | 55 | 61 | 45 | |
| 26. Two wythes of 4 1/2-in face brick, 2-in airspace with metal ties (100 lb/ft²) | 37 | 37 | 47 | 55 | 62 | 67 | 50 | |
| 27. Two wythes of plastered 4 1/2-in brick, 2-in airspace with glass-fiber insulation in cavity | 43 | 50 | 52 | 61 | 73 | 78 | 59 | |
| 28. 2 by 4 wood studs 16 in oc with 1-in stucco on metal lath on outside and 1/2-in gypsum board on inside (8 lb/ft²) | 21 | 33 | 41 | 46 | 47 | 51 | 42 | |
| 29. 6-in solid concrete with 1/2-in plaster both sides (80 lb/ft²) | 39 | 42 | 50 | 58 | 64 | 67 | 53 | |
| **Floor-Ceilings**[2,3] | | | | | | | | |
| 30. 2 by 10 wood joists 16 in oc with 1/2-in plywood subfloor under 25/32-in oak on floor side, and 5/8-in gypsum board nailed to joists on ceiling side (10 lb/ft²) | 23 | 32 | 36 | 45 | 49 | 56 | 37 | 32 |

| Building Construction | Transmission Loss (dB) 125 Hz | 250 Hz | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz | STC Rating | IIC Rating† |
|---|---|---|---|---|---|---|---|---|
| 31. Construction no. 30 with 5/8-in gypsum board screwed to resilient channels spaced 24 in oc perpendicular to joists | 30 | 35 | 44 | 50 | 54 | 60 | 47 | 39 |
| 32. Construction no. 31 with 3-in glass-fiber insulation in cavity | 36 | 40 | 45 | 52 | 58 | 64 | 49 | 46 |
| 33. 4-in reinforced concrete slab (54 lb/ft²) | 48 | 42 | 45 | 56 | 57 | 66 | 44 | 25 |
| 34. 14-in precast concrete tees with 2-in concrete topping on 2-in slab (75 lb/ft²) | 39 | 45 | 50 | 52 | 60 | 68 | 54 | 24 |
| 35. 6-in reinforced concrete slab (75 lb/ft²) | 38 | 43 | 52 | 59 | 67 | 72 | 55 | 34 |
| 36. 6-in reinforced concrete slab with 3/4-in T&G wood flooring on 1 1/2 by 2 wooden battens floated on 1-in glass fiber (83 lb/ft²) | 38 | 44 | 52 | 55 | 60 | 65 | 55 | 57 |
| 37. 18-in steel joists 16 in oc with 1 5/8-in concrete on 5/8-in plywood under heavy carpet laid on pad, and 5/8-in gypsum board attached to joists on ceiling side (20 lb/ft²) | 27 | 37 | 45 | 54 | 60 | 65 | 47 | 62 |
| **Roofs**[2] | | | | | | | | |
| 38. 3 by 8 wood beams 32 in oc with 2 by 6 T&G planks, asphalt felt built-up roofing, and gravel topping | 29 | 33 | 37 | 44 | 55 | 63 | 43 | |
| 39. Construction no. 38 with 2 by 4s 16 in oc between beams, 1/2-in gypsum board supported by metal channels on ceiling side with 4-in glass-fiber insulation in cavity | 35 | 42 | 49 | 62 | 67 | 79 | 53 | |
| 40. Corrugated steel, 24 gauge with 1 3/8-in sprayed cellulose insulation on ceiling side (1.8 lb/ft²) | 17 | 22 | 26 | 30 | 35 | 41 | 30 | |
| 41. 2 1/2-in sand and gravel concrete (148 lb/ft³) on 28 gauge corrugated steel supported by 14-in-deep steel bar joists with 1/2-in gypsum plaster on metal lath attached to metal furring channels 13 1/2 in oc on ceiling side (41 lb/ft²) | 32 | 46 | 45 | 50 | 57 | 61 | 49 | |
| **Doors**[2] | | | | | | | | |
| 42. Louvered door, 25 to 30% open | 10 | 12 | 12 | 12 | 12 | 11 | 12 | |
| 43. 1 3/4-in hollow-core wood door, no gaskets, 1/4-in air gap at sill (1.5 lb/ft²) | 14 | 19 | 23 | 18 | 17 | 21 | 19 | |
| 44. Construction no. 43 with gaskets and drop seal | 19 | 22 | 25 | 19 | 20 | 29 | 21 | |
| 45. 1 3/4-in solid-core wood door with gaskets and drop seal (4.5 lb/ft²) | 29 | 31 | 31 | 31 | 39 | 43 | 34 | |
| 46. 1 3/4-in hollow-core 16 gauge steel door, glass-fiber filled, with gaskets and drop seal (7 lb/ft²) | 23 | 28 | 36 | 41 | 39 | 44 | 38 | |
| **Glass**[1,2] | | | | | | | | |
| 47. 1/8-in monolithic float glass (1.4 lb/ft²) | 18 | 21 | 26 | 31 | 33 | 22 | 26 | |
| 48. 1/4-in monolithic float glass (2.9 lb/ft²) | 25 | 28 | 31 | 34 | 30 | 37 | 31 | |
| 49. 1/2-in insulated glass: 1/8- + 1/8-in double glass with 1/4-in airspace (3.3 lb/ft²) | 21 | 26 | 24 | 33 | 44 | 34 | 28 | |
| 50. 1/4- + 1/8-in double glass with 2-in airspace | 18 | 31 | 35 | 42 | 44 | 44 | 39 | |
| 51. Construction no. 50 with 4-in airspace | 21 | 32 | 42 | 48 | 48 | 44 | 43 | |
| 52. 1/4-in laminated glass, 30-mil plastic interlayer (3.6 lb/ft²) | 25 | 28 | 32 | 35 | 36 | 43 | 35 | |
| 53. Double glass: 1/4-in laminated + 3/16-in monolithic glass with 2-in airspace (5.9 lb/ft²) | 25 | 34 | 44 | 47 | 48 | 55 | 45 | |
| 54. Double glass: 1/4-in laminated + 3/16-in monolithic glass with 4-in airspace (5.9 lb/ft²) | 36 | 37 | 48 | 51 | 50 | 58 | 48 | |
| 55. Double glass: 1/4-in laminated + 1/4-in laminated with 1/2-in airspace (7.2 lb/ft²) | 21 | 30 | 40 | 44 | 46 | 57 | 42 | |

† IIC (*impact isolation class*) is a single-number rating of the impact sound transmission performance of a floor-ceiling construction tested over a standard frequency range. The higher the IIC, the more efficient the construction will be for reducing impact sound transmission. INR (*impact noise rating*) previously was used as the single-number rating of impact noise isolation. To convert the older INR data to IIC, add 51 to the INR number.

‡ A wide range of TL and STC performance can be achieved by gypsum wallboard constructions. Refer to ASTM E 90 laboratory report and literature from manufacturers for specific details such as type of gypsum board; gauge, width, and spacing of steel studs; glass-fiber or mineral-fiber insulation thickness and density; and complete installation recommendations.

# A p p e n d i x V

## Design Calculations

| Project | Prepared by | Date |
|---|---|---|
| Subject/Title | Reviewed by | Date |
| ERV calculations | Calculation Number | Sheet 1 of 2 |

**Exhaust (total)**

TX-A → (5) @ 180 cfm

TX-B → (5) @ 360 cfm

TX-D → (1) @ 180 cfm

2880 cfm

RS-Means

↳ 320 cfm = \$400

⇒ Exhaust cost

$= 2880 \times \frac{400}{320} = \$3600$

**ERV costs**

\$3200 x 2 = \$6400

\$6400

−\$3600

\$2800 ← Need to make up

**Sensible heat**

$\Delta T = (90° - 70°) = 20°$

$q = 1.08 \text{ cfm } \Delta T$

$= (1.08)(2880)(20°) = 62,208 \text{ BTu/hr}$

*ERV is 50% more efficient

⇒ 31,104 BTu/hr saving @ 1 Kw/ton

$\Rightarrow \frac{31,104}{12,000} = 2.59 \text{ Ton} \times 1 \text{ KW/ton} = 2.59 \text{ kw}$

cost is 10¢/KW

⇒ 25.9¢ saved per hour

SOUTHERN COMPANY
Energy to Serve Your World

# Design Calculations

| Project | Prepared by | Date |
|---|---|---|
| Subject/Title | Reviewed by | Date |
| | Calculation Number | Sheet 2 of 2 |

$$\frac{\$2800}{\$0.259/hr} = 10,810 \text{ hrs}$$

→ If running 8 hrs per day @ 90°

$$10810 \text{ hr} \times \frac{1 \text{ day}}{8 \text{ hr}} = 1351 \text{ days}$$

→ assume 150 days a year where its at least 90°

$$1351/150 = 9 \text{ years}$$