# Parametric Study of New Diaphragm Design Methods

ARCE 453 Fall 2021

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## Introduction:

Large retail buildings and warehouses are typically a one-story concrete or masonry walled structure with a panelized wood roof. These buildings fall under the category of “RWFD”, or “Rigid Wall Flexible Diaphragm”. There are two preexisting methods that can be utilized in designing flexible diaphragms, but there is a third being introduced in the new ASCE 7-22 code. Given this code is unreleased, there really is no guidance to the user as far as which method is the most time efficient or cost effective.

## Purpose:

The purpose of this project is to analyze the same building using each design method in ASCE 7-22 and determine or estimate which approach is appropriate. The next step is to alter small things like size, seismic zone, and Response Modification Factor to get further information. Each of these scenarios produces a design force and a nailing pattern for the panelized diaphragm. These nailing patterns can then be analyzed under a cost-effective scope by reviewing the quantity of nails.

## Understanding Panelized Wood Diaphragms:

A “Panelized diaphragm”, also in this case a “Panelized roof”, has a few defining characteristics. These systems typically involve a repetitive layout of girders, purlins, and sub purlins. On top of these Purlins are 4’ x 8’ sheets of plywood that run with a continuous joint parallel to framing.

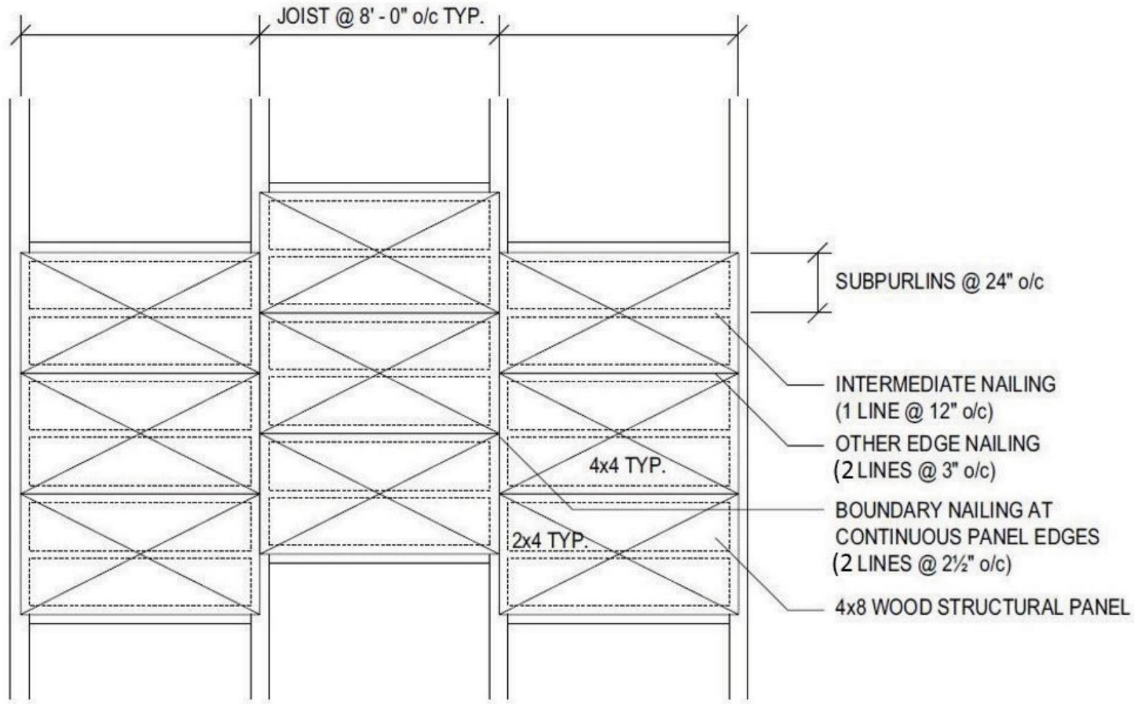



**Figure 1: Panelized Wood Diaphragm components**

There were a few assumptions made in order to analyze these hypothetical situations. Throughout all three methods, 15/32" thick, Structural I plywood with 10d common nails were assumed.

## Design Methods:

The methods to compute the applied force in ASCE 7-22 roughly follow the same process, but there are some key differences to note.

1.Force determination per ASCE 7-22:

12.10.1:

This method uses an R value of the vertical system used below the diaphragm in order to calculate the seismic coefficient Cs. 12.10.1 utilizes Eq. 12.8-2

$$C_s = \frac{S_{DS}}{\left(\frac{R}{I_e}\right)} \qquad (12.8\text{-}2)$$

12.10.3:

This method used the same process as 12.10.1 to find Cs but takes things a step further by using an R value of 3 for the diaphragm. Then, a new C value is determined using Eq. 12.10-7

$$F_{px} = \frac{C_{px}}{R_s} w_{px} \qquad (12.10\text{-}4)$$

Then,

For a 1-story building ($N = 1$), Figure 12.10-2 indicates $C_{px} = C_{pn}$ where

$$C_{pn} = \sqrt{(\Gamma_{m1}\Omega_0 C_s)^2 + (\Gamma_{m2} C_{s2})^2} \qquad \text{ASCE 7 Eq 12.10-7}$$

For a 1-story building ($\Gamma_{m1} = 1.0$, $\Gamma_{m2} = 0$, $C_{s2} = 0$)

Rs = 3 (ASCE7-16 12.10-3)

12.10.4:

This method is new to the code. The purpose of this new introduction is to have the R value fully based on the appropriate lateral system and it's period. The R value is set at 4.5 and uses a new equation to solve for different forces in both the north-south and east-west direction.

$$F_{px} = C_{s\text{-}diaph}(w_{px})$$ ASCE 7 Eq 12.10-15

$$C_{s\text{-}diaph} = \frac{S_{DS}}{R_{diaph} / I_e}$$

Maximum Cs-diaph value:

$$C_{s\text{-}diaph} = \frac{S_{D1}}{T_{diaph}\left(R_{diaph} / I_e\right)}$$

$$T_{diaph} = 0.002L_f$$

This Cs-diaph calculation needs to be done in both the East-West and North-South direction. Another key difference in this method is a 1.5x design shear increase on 0.1L around the perimeter.

2. Building Characteristics

The building was then characterized with wall thicknesses, wall heights and weights. These would remain constant throughout each method. Using statics, the unit shear in both the north-south and east-west direction could be solved for.

3. Nail Zoning

The purpose of nail zoning is to decrease the number of nails as the force diminishes around the center of the diaphragms span. Using the same nailing for the diaphragm's entirety would be ineffective in both time and money. Using different nail spacings, different zones can be defined.

The newest version of the SPDWS includes lateral forces (seismic and wind) in SPDWS table 4.2A or 4.2B.

**Table 4.2A Nominal Unit Shear Capacities for Sheathed Wood-Frame Diaphragms**

**Blocked Wood Structural Panel Diaphragms[1,2,3,4,6]**

| Sheathing Grade | Common Nail Size[5] Length (in.) x Shank diameter (in.) x Head diameter (in.) | Minimum Nail Bearing Length in Framing Member or Blocking, $\ell_m$ (in.) | Minimum Nominal Panel Thickness (in.) | Minimum Nominal Width of Nailed Face at Adjoining Panel Edges and Boundaries (in.) | Nail Spacing (in.) at diaphragm boundaries (all cases), at continuous panel edges parallel to load (Cases 3 & 4), and at all panel edges (Cases 5 & 6) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 6 | | | 4 | | | 2-1/2 | | | 2 | | |
| | | | | | Nail Spacing (in.) at other panel edges (Cases 1,2,3, & 4) | | | | | | | | | | | |
| | | | | | 6 | | | 6 | | | 4 | | | 3 | | |
| | | | | | $v_n$ (plf) | $G_a$ (kips/in.) | | $v_n$ (plf) | $G_a$ (kips/in.) | | $v_n$ (plf) | $G_a$ (kips/in.) | | $v_n$ (plf) | $G_a$ (kips/in.) | |
| | | | | | | OSB | PLY | | OSB | PLY | | OSB | PLY | | OSB | PLY |
| Structural I | 6d (2 x 0.113 x 0.266) | 1-1/4 | 5/16 | 2 | 520 | 15 | 12 | 700 | 8.5 | 7.5 | 1050 | 12 | 10 | 1175 | 20 | 15 |
| | | | | 3 | 590 | 12 | 9.5 | 785 | 7.0 | 6.0 | 1175 | 9.5 | 8.5 | 1330 | 17 | 13 |
| | 8d (2-1/2 x 0.131 x 0.281) | 1-3/8 | 3/8 | 2 | 755 | 14 | 11 | 1010 | 9.0 | 7.5 | 1485 | 13 | 10 | 1680 | 21 | 15 |
| | | | | 3 | 840 | 12 | 10 | 1120 | 7.5 | 6.5 | 1680 | 10 | 9.0 | 1890 | 18 | 13 |
| | 10d (3 x 0.148 x 0.312) | 1-1/2 | 15/32 | 2 | 895 | 24 | 17 | 1190 | 15 | 12 | 1790 | 20 | 15 | 2045 | 31 | 21 |
| | | | | 3 | 1010 | 20 | 15 | 1345 | 12 | 9.5 | 2015 | 16 | 13 | 2295 | 26 | 18 |
| Sheathing and Single-Floor | 6d (2 x 0.113 x 0.266) | 1-1/4 | 5/16 | 2 | 475 | 15 | 10 | 630 | 9.0 | 7.0 | 940 | 13 | 9.5 | 1065 | 21 | 13 |
| | | | | 3 | 530 | 12 | 9.0 | 700 | 7.0 | 6.0 | 1065 | 10 | 8.0 | 1205 | 17 | 12 |
| | | | 3/8 | 2 | 520 | 13 | 9.5 | 700 | 7.0 | 6.0 | 1050 | 10 | 8.0 | 1175 | 18 | 12 |
| | | | | 3 | 590 | 10 | 8.0 | 785 | 5.5 | 5.0 | 1175 | 8.5 | 7.0 | 1330 | 14 | 10 |
| | 8d (2-1/2 x 0.131 x 0.281) | 1-3/8 | 3/8 | 2 | 670 | 15 | 11 | 895 | 9.5 | 7.5 | 1345 | 13 | 9.5 | 1525 | 21 | 13 |
| | | | | 3 | 755 | 12 | 9.5 | 1010 | 7.5 | 6.0 | 1510 | 11 | 8.5 | 1710 | 18 | 12 |
| | | | 7/16 | 2 | 715 | 14 | 10 | 950 | 8.5 | 7.0 | 1415 | 12 | 9.5 | 1610 | 20 | 13 |
| | | | | 3 | 800 | 11 | 9.0 | 1065 | 7.0 | 6.0 | 1595 | 10 | 8.0 | 1805 | 17 | 12 |
| | | | 15/32 | 2 | 755 | 13 | 9.5 | 1010 | 7.5 | 6.5 | 1485 | 11 | 8.5 | 1680 | 19 | 13 |
| | | | | 3 | 840 | 10 | 8.5 | 1120 | 6.0 | 5.5 | 1680 | 9.0 | 7.5 | 1890 | 15 | 11 |
| | 10d (3 x 0.148 x 0.312) | 1-1/2 | 15/32 | 2 | 810 | 25 | 15 | 1080 | 15 | 11 | 1610 | 21 | 14 | 1835 | 33 | 18 |
| | | | | 3 | 910 | 21 | 14 | 1205 | 12 | 9.5 | 1820 | 17 | 12 | 2060 | 28 | 16 |
| | | | 19/32 | 2 | 895 | 21 | 14 | 1190 | 13 | 9.5 | 1790 | 18 | 12 | 2045 | 28 | 17 |
| | | | | 3 | 1010 | 17 | 12 | 1345 | 10 | 8.0 | 2015 | 14 | 11 | 2295 | 24 | 15 |

**Table 4.2B Nominal Unit Shear Capacities for Sheathed Wood-Frame Diaphragms**

**Blocked Wood Structural Panel Diaphragms Utilizing Multiple Rows of Fasteners (High Load Diaphragms)[1,2,3,4,6]**

| Sheathing Grade | Common Nail Size[5] Length (in.) x Shank diameter (in.) x Head diameter (in.) | Minimum Nail Bearing Length in Framing Member or Blocking, $\ell_m$ (in.) | Minimum Nominal Panel Thickness (in.) | Minimum Nominal Width of Nailed Face at Adjoining Panel Edges and Boundaries (in.) | Lines of Nails | Nail Spacing (in.) at diaphragm boundaries (all cases), at continuous panel edges parallel to load (Cases 3 & 4), and at all panel edges (Cases 5 & 6) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 4 | | | 4 | | | 2-1/2 | | | 2-1/2 | | |
| | | | | | | Nail Spacing (in.) at other panel edges (Cases 1, 2, 3, & 4) | | | | | | | | | | | |
| | | | | | | 6 | | | 4 | | | 4 | | | 3 | | |
| | | | | | | $v_n$ (plf) | $G_a$ (kips/in.) | | $v_n$ (plf) | $G_a$ (kips/in.) | | $v_n$ (plf) | $G_a$ (kips/in.) | | $v_n$ (plf) | $G_a$ (kips/in.) | |
| | | | | | | | OSB | PLY | | OSB | PLY | | OSB | PLY | | OSB | PLY |
| Structural I | 10d (3 x 0.148 x 0.312) | 1-1/2 | 15/32 | 3 | 2 | 1695 | 40 | 24 | 2280 | 53 | 28 | 2450 | 50 | 27 | 3220 | 56 | 29 |
| | | | | 4 | 2 | 1960 | 33 | 21 | 2560 | 48 | 27 | 2815 | 44 | 25 | 3610 | 51 | 28 |
| | | | | 4 | 3 | 2450 | 50 | 27 | 3415 | 61 | 30 | 3600 | 59 | 30 | 3905 | 70 | 32 |
| | | | 19/32 | 3 | 2 | 1875 | 36 | 23 | 2465 | 52 | 29 | 2700 | 47 | 27 | 3515 | 54 | 29 |
| | | | | 4 | 2 | 2185 | 29 | 20 | 2770 | 46 | 27 | 3110 | 40 | 25 | 4030 | 48 | 27 |
| | | | | 4 | 3 | 2700 | 47 | 27 | 3695 | 60 | 31 | 3935 | 57 | 30 | 5010 | 64 | 32 |
| | | | 23/32 | 3 | 2 | 2045 | 33 | 22 | 2675 | 50 | 29 | 2940 | 45 | 27 | 3820 | 53 | 30 |
| | | | | 4 | 2 | 2395 | 26 | 19 | 2995 | 43 | 27 | 3390 | 37 | 24 | 4380 | 45 | 27 |
| | | | | 4 | 3 | 2940 | 45 | 27 | 4005 | 59 | 32 | 4270 | 56 | 31 | 5040 | 68 | 34 |
| Sheathing and Single-Floor | 10d (3 x 0.148 x 0.312) | 1-1/2 | 15/32 | 3 | 2 | 1470 | 43 | 21 | 2030 | 55 | 23 | 2140 | 53 | 23 | 2830 | 58 | 24 |
| | | | | 4 | 2 | 1695 | 36 | 19 | 2280 | 50 | 22 | 2450 | 46 | 21 | 3095 | 55 | 23 |
| | | | | 4 | 3 | 2140 | 53 | 23 | 3040 | 62 | 24 | 3165 | 61 | 24 | 3345 | 72 | 26 |
| | | | 19/32 | 3 | 2 | 1820 | 34 | 19 | 2410 | 49 | 23 | 2620 | 45 | 22 | 3430 | 52 | 23 |
| | | | | 4 | 2 | 2115 | 27 | 16 | 2700 | 43 | 21 | 3025 | 37 | 20 | 3835 | 46 | 22 |
| | | | | 4 | 3 | 2620 | 45 | 22 | 3610 | 57 | 24 | 3820 | 55 | 24 | 4160 | 68 | 26 |
| | | | 23/32 | 3 | 2 | 1990 | 30 | 18 | 2620 | 46 | 23 | 2855 | 42 | 22 | 3740 | 50 | 24 |
| | | | | 4 | 2 | 2310 | 24 | 16 | 2940 | 40 | 21 | 3290 | 34 | 20 | 4045 | 45 | 23 |
| | | | | 4 | 3 | 2855 | 42 | 22 | 3920 | 56 | 25 | 4145 | 53 | 25 | 4380 | 71 | 28 |

These forces must be divided by 2.8 to give a design value. Using similar triangles, zoning can be determined and aligned with framing transitions to the nearest 8' in the north-south direction and 4' in the east-west direction. These zones may overlap in the north-south and east-west direction, which must be accounted for, so the area isn't double counted. At this point, the area of each zone can be converted into a quantity of nails by looking at the edge nailing, continuous nailing, and intermediate nailing in SPDWS table 4.2A or 4.2B.

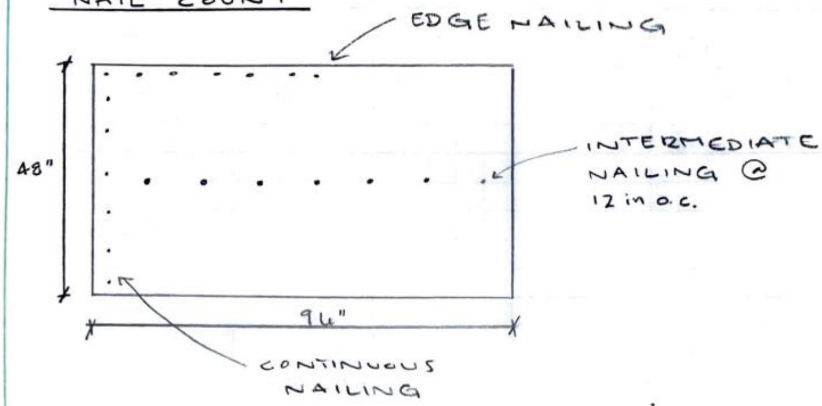
The quantity of nails could be further analyzed and converted to a dollar value if regional pricing is available.

There are 7 zones total defined in this process:

| Zone | Nominal Panel Thickness | Framing width (nominal) | Lines of Nails | Nominal Shear | Nail Spacing(in.) at diaphragm boundaries, at continuous panel edges parallel to load, and at all panel edges | Nail Spacing(in.) at other panel edges |
|---|---|---|---|---|---|---|
| Zone 7 | 19/32 | 4 | 2 | 5010 | 2.5 | 3 |
| Zone 6 | 15/32 | 4 | 2 | 3610 | 2.5 | 3 |
| Zone 5 | 15/32 | 4 | 2 | 2815 | 2.5 | 4 |
| Zone 4 | 15/32 | 3 | 1 | 2295 | 2 | 3 |
| Zone 3 | 15/32 | 2 | 1 | 1790 | 2.5 | 4 |
| Zone 2 | 15/32 | 2 | 1 | 1190 | 4 | 6 |
| Zone 1 | 15/32 | 2 | 1 | 895 | 6 | 6 |

## 4.Nail count:

NAIL COUNT

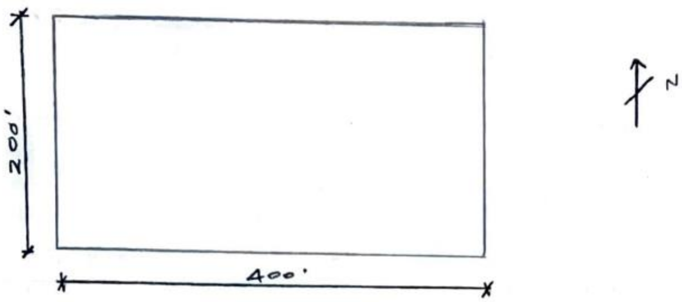



| ZONE | CN | EN | FN | SUM |
|---|---|---|---|---|
| 7 | 48/2.5 = 19.2 | 96/3 = 32 | 7 | 2[(2×20)+(2×32)]+7 = 215 |
| 6 | 48/2.5 = 19.2 | 96/3 = 32 | 7 | 215 |
| 5 | 48/2.5 = 19.2 | 96/4 = 24 | 7 | 2[(2×20)+(2×24)]+7 = 183 |
| 4 | 48/2 = 24 | 96/3 = 32 | 7 | = (2×24)+(2×32)+7 = 119 |
| 3 | 48/2.5 = 19.2 | 96/4 = 24 | 7 | = (2×20)+(2×24)+7 = 95 |
| 2 | 48/4 = 12 | 96/6 = 16 | 7 | = (2×12)+(2×16)+7 = 63 |
| 1 | 48/6 = 8 | 96/6 = 16 | 7 | = (2×8)+(2×16)+7 = 55 |

**Hand Calculations:**

To verify thorough understanding of each method, I went through each by hand. Reviewing both examples and solutions, I was able to recreate three examples with the same building but using a different method each time. This process provided me a reference to building the excel spreadsheet.

12.10.1




$S_{DS} = 1$ $S_{D1} = .6$ SEISMIC CAT. D

RISK CAT II $\rho = 1$

JOISTS @ 8' O.C.

DF/L DL = 12 PSF

WALLS = 150 PCF
$t = 9.25''$
$h = 30'$
$h_{PARAPET} = 33'$

## BASE SHEAR

$V = C_s W$

$$C_s = \frac{S_{DS}}{R/I_e}$$

$S_{DS} = 1$ (GIVEN)

$R = 4$ (ASCE 12.2.1 INTERMEDIATE PRECAST)

$I_e = 1$ (ASCE 1.5.2)

$$C_s = \frac{1}{(4/1)} = .25$$

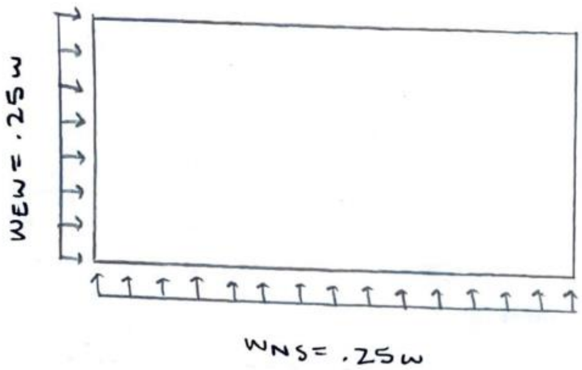
## DIAPHRAGM FORCE

$F_{px} = .25w$

$F_{pMAX} = .4 S_{DS} I_e w = .4(1)(1)w = .4w$

$F_{pMIN} = .2 S_{DS} I_e w = .2(1)(1)w = .2w$

$.2w < .25w < .4w$ ✓




D = 12 PSF

$$\text{WALL WEIGHT} = 150\left(\frac{9.25}{12}\right) = 116\text{ PSF}$$

$$W_{NS} = .25(12)(200) + 2\left[(.25)(116)(33)\left(\frac{33}{2}\right)\left(\frac{1}{30}\right)\right]$$

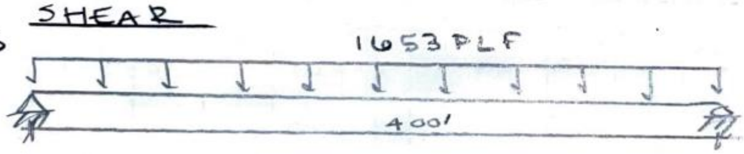
$$W_{NS} = 1653\text{ PLF}$$

$$W_{EW} = .25(12)(400) + 2\left[(.25)(116)(33)\left(\frac{33}{2}\right)\left(\frac{1}{30}\right)\right]$$

$$W_{EW} = 2253\text{ PLF}$$

SHEAR

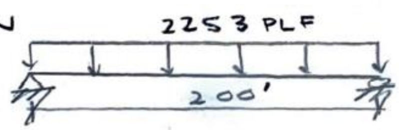
N-S




$$\frac{1653(400)}{2} = 330.6K$$

$$V = \frac{330.6}{200} = 1653\text{ PLF}$$

E-W




$$\frac{2253(200)}{2} = 225.3K$$

$$V = \frac{225.3}{400} = 563\text{ PLF}$$

ZONES → SEE TABLE

5010 / 2.8 = 1790 PLF
3610 / 2.8 = 1290 PLF
2815 / 2.8 = 1005 PLF
2295 / 2.8 = 820 PLF
1790 / 2.8 = 640 PLF
1190 / 2.8 = 425 PLF
895 / 2.8 = 320 PLF

ZONE 7:

$$.7(330{,}600 - (1653)x) = 1790(200)$$

$$x = -109 \rightarrow 0$$

ZONE 6:

$$.7(330{,}600 - (1653)x) = 1290(200)$$

$$x = -23 \rightarrow 0$$

ZONE 5:

$$.7(330{,}600 - (1653)x) = 1005(200)$$

$x = 26 \rightarrow 32'$ (ROUND TO NEAREST 8')

ZONE 4:

$$.7(330{,}600 - (1653)x) = 820(200)$$

$$x = 58 \rightarrow 64'$$

ZONE 3:

$$.7(330{,}600 - (1653)x) = 640(200)$$

$$x = 89 \rightarrow 96'$$

ZONE 2:

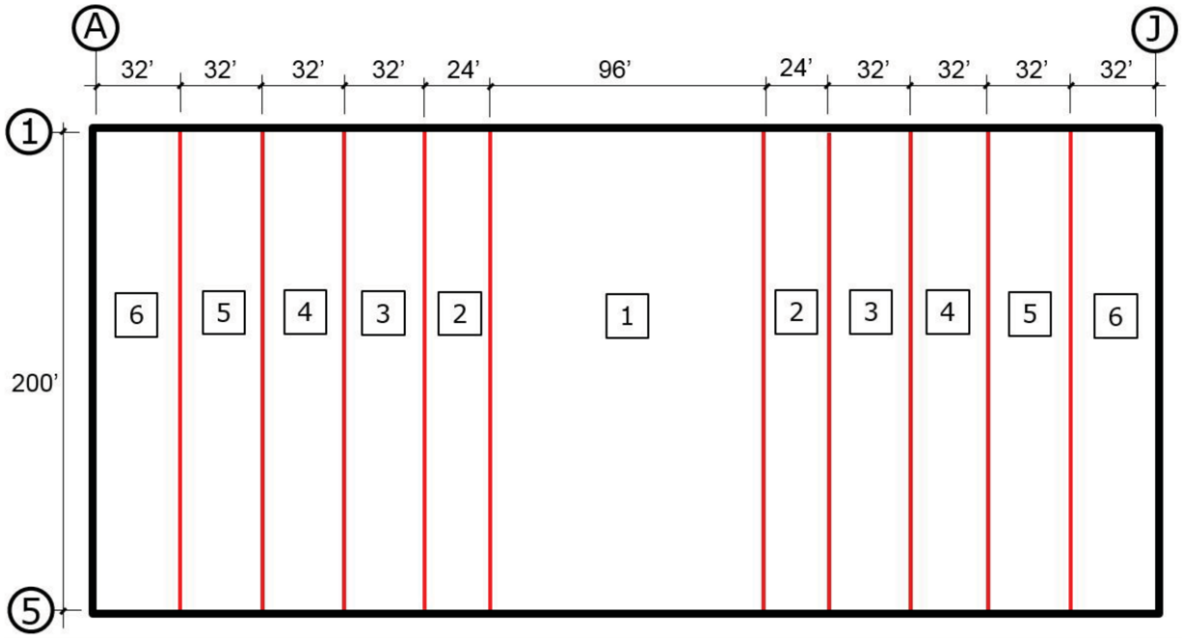
$$.7(330{,}600 - (1653)x) = 425(200)$$

$$x = 126 \rightarrow 128'$$

ZONE 1:

$$.7(330{,}600 - (1653)x) = 320(200)$$

$$x = 145 \rightarrow 152'$$


A
J
32'
32'
32'
32'
24'
96'
24'
32'
32'
32'
32'
1
5
200'
6
5
4
3
2
1
2
3
4
5
6

**Excel:**

In order to avoid recalculating dozens of archetypes, I created an excel spreadsheet that includes each method. Each one of these spreadsheets includes the method to finding Cs, calculation of the unit shear, nail zoning and nail counting. Having the ability to change the diaphragm's size, R value and "Seismic Design Category" allowed for a comparison of the methods. Each method has maximum and minimum limits on Cs values, meaning that the graphic analysis shows flatlines before and after certain points.

The purpose of the Excel was to attain a visual on Cs values and nail count. Putting this data side by side on a scatter plot displayed which method becomes more efficient at what point.

ASCE 12.10.1 Diaphragm Design

*one story wood framed building

**Base Shear Coefficient**

| | | |
|---|---|---|
| $S_{ds}$ = | 1 | |
| $S_{d1}$ = | 0.6 | |
| $S_1$ = | 0.5 | |
| R = | 4 | (ASCE 12.2.1) |
| $I_e$ = | 1 | (ASCE 1.5.2) |
| | | |
| Cs = | 0.25 | |

**Max and Min Cs**

Determine Period

| | | |
|---|---|---|
| $C_T$ = | 0.02 | (ASCE 12.8.2) |
| h = | 32.5 | (Given) |
| x = | 0.75 | (ASCE 12.8.2) |
| T = | 0.272234 | |
| | | |
| $C_{smax}$ = | 0.550996 | |
| $C_{smin}$ = | 0.044 | |

**Disphragm Force**

| | | |
|---|---|---|
| $F_{px}$ = | 0.25 | ($w_{px}$) |
| $F_{pmax}$ = | 0.4 | |
| $F_{pxmin}$ = | 0.2 | |
| $F_{final}$ = | 0.25 | |

**Weight of Walls**

| | | |
|---|---|---|
| conc. = | 150 | pcf |
| t = | 9.25 | in |
| height = | 33 | ft |
| parapet = | 3 | ft |
| NS dimension = | 200 | ft |
| EW dimension = | 400 | ft |
| Dead Load | 12 | psf |
| Wns = | 1649.297 | |
| Wew = | 2249.297 | |

**Unit Shear**

| | | |
|---|---|---|
| Vmaxns = | 329859.4 | |
| Vmaxew = | 224929.7 | |
| Unit Shear ns = | 1649.297 | |
| Unit Shear ew = | 562.3242 | |
| .7 * Uns = | 1154.508 | apply .7 from ASCE Load combo |
| .7 * Uew = | 393.627 | |

Zone Determination

| | | |
|---|---|---|
| Typical $V_{allow}$ | 5010 | lbs. |
| | 3610 | lbs. |
| | 2815 | lbs. |
| | 2295 | lbs. |
| | 1790 | lbs. |
| | 1190 | lbs. |
| | 895 | lbs. |

N-S

| Zone | x(ft) | Round up to Nearest 8ft | Distances |
|---|---|---|---|
| Zone 7 | -110 | -104 | 0 |
| Zone 6 | -23 | -16 | 0 |
| Zone 5 | 26 | 32 | 32 |
| Zone 4 | 58 | 64 | 64 |
| Zone 3 | 89 | 96 | 96 |
| Zone 2 | 126 | 128 | 128 |
| Zone 1 | 145 | 152 | 152 |

E-W

| Zone | x(ft) | Round up to Nearest 4ft | Distances |
|---|---|---|---|
| Zone 7 | -355 | -352 | 0 |
| Zone 6 | -228 | -224 | 0 |
| Zone 5 | -155 | -152 | 0 |
| Zone 4 | -108 | -104 | 0 |
| Zone 3 | -62 | -56 | 0 |
| Zone 2 | -8 | 0 | 0 |
| Zone 1 | 19 | 24 | 24 |

Nail Count

| | | |
|---|---|---|
| Zone 7 | 215 | Nails per sheet of ply |
| Zone 6 | 215 | Nails per sheet of ply |
| Zone 5 | 183 | Nails per sheet of ply |
| Zone 4 | 119 | Nails per sheet of ply |
| Zone 3 | 95 | Nails per sheet of ply |
| Zone 2 | 63 | Nails per sheet of ply |
| Zone 1 | 55 | Nails per sheet of ply |

| Zone | Area of Zone SF | Sheets of Plywood | # of Nails per Zone |
|---|---|---|---|
| Zone 7 | 0 | 0 | 0 |
| Zone 6 | 12800 | 400 | 86000 |
| Zone 5 | 12800 | 400 | 73200 |
| Zone 4 | 12800 | 400 | 47600 |
| Zone 3 | 12800 | 400 | 38000 |
| Zone 2 | 14208 | 444 | 27972 |
| Zone 1 | 14592 | 456 | 25080 |
| | | **TOTAL** | 297852 |

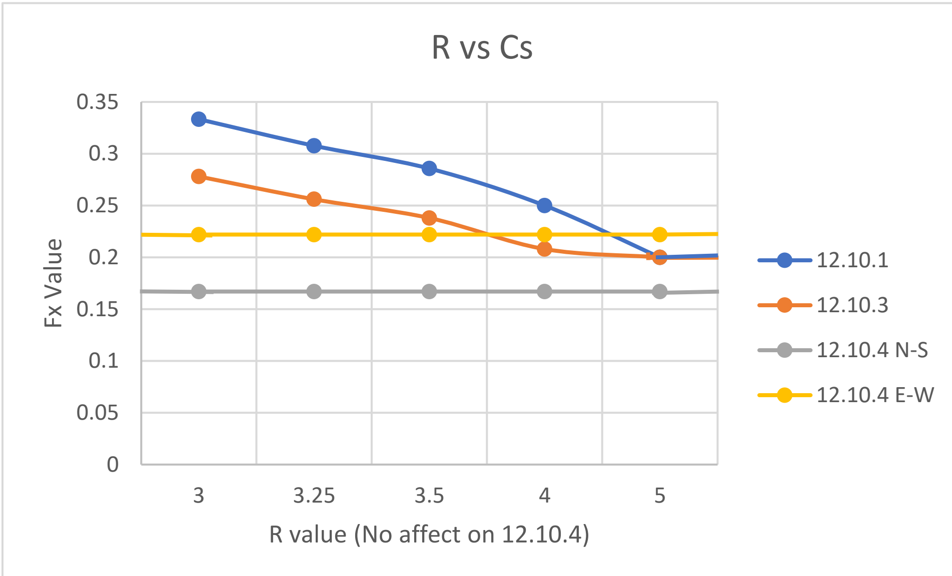
**Results:**

There were three variables we were interested in changing. The first was the R value, then the diaphragm length, then the seismic values Sds and Sd1 which could be implemented in unison with the two previous studies. This leaves us with four tables to analyze and plot: Various R values in a high seismic zone, various R values in a low seismic zone, various lengths in a high seismic zone and various lengths in a low seismic zone.

1. R values

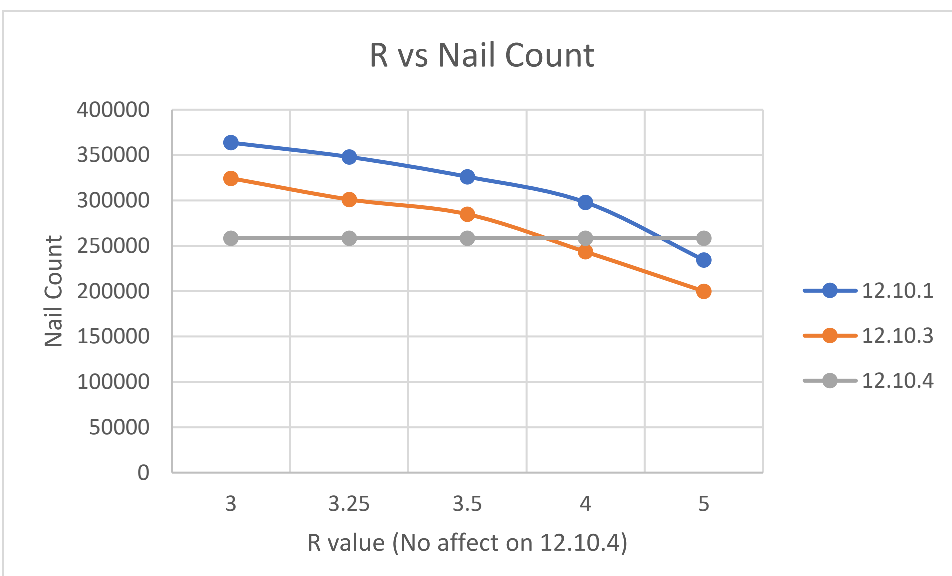
The R values being inputted into each method ranged from 3 to 5. It was determined that only certain systems could be implemented in this building type, meaning that only a total of five R values would be applicable based on a study of ASCE 7 Table 12.2-1.

## Various R Values (high seismic)




**R Value Case Study (Dmax)** Sds = 1 Sd1 = .6

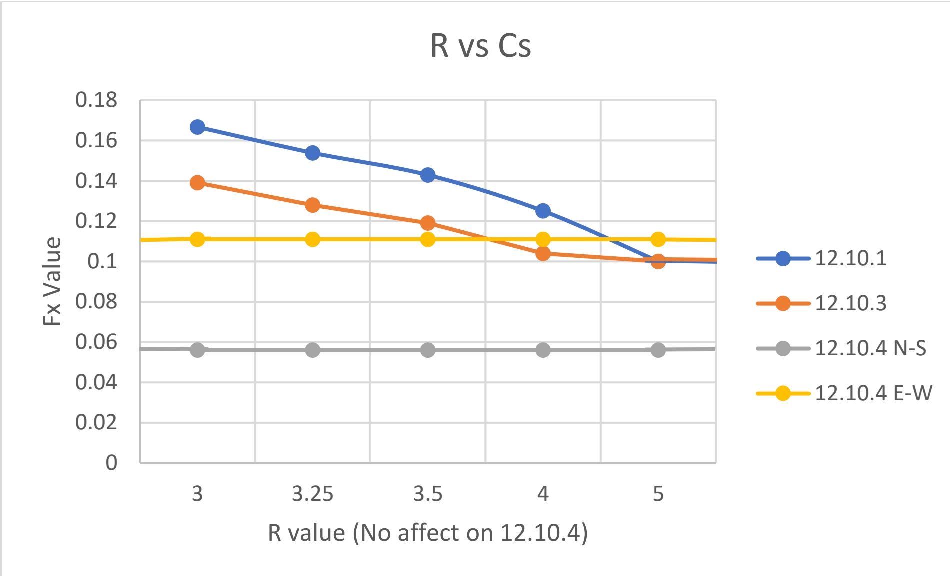
| R Values | 12.10.1 Method Fx | 12.10.1 Nail Count | R Value | 12.10.3 Method Fx | 12.10.3 Nail Count | R Value | 12.10.4 Method Fx N-S | 12.10.4 Method Fx E-W | 12.10.4 Nail Count |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 0.3333 | 363620 | For Method 12.10.3, the Rs value is fixed at R = 3 | 0.278 | 324372 | For Method 12.10.4, the R value is fixed at R = 4.5 | 0.167 | 0.222 | 258400 |
| 3.25 | 0.307692 | 347900 | | 0.256 | 301052 | | 0.167 | 0.222 | 258400 |
| 3.5 | 0.285714 | 326092 | | 0.238 | 284796 | | 0.167 | 0.222 | 258400 |
| 4 | 0.25 | 297852 | | 0.208 | 243356 | | 0.167 | 0.222 | 258400 |
| 5 | 0.2 | 234300 | | 0.2 | 199900 | | 0.167 | 0.222 | 258400 |

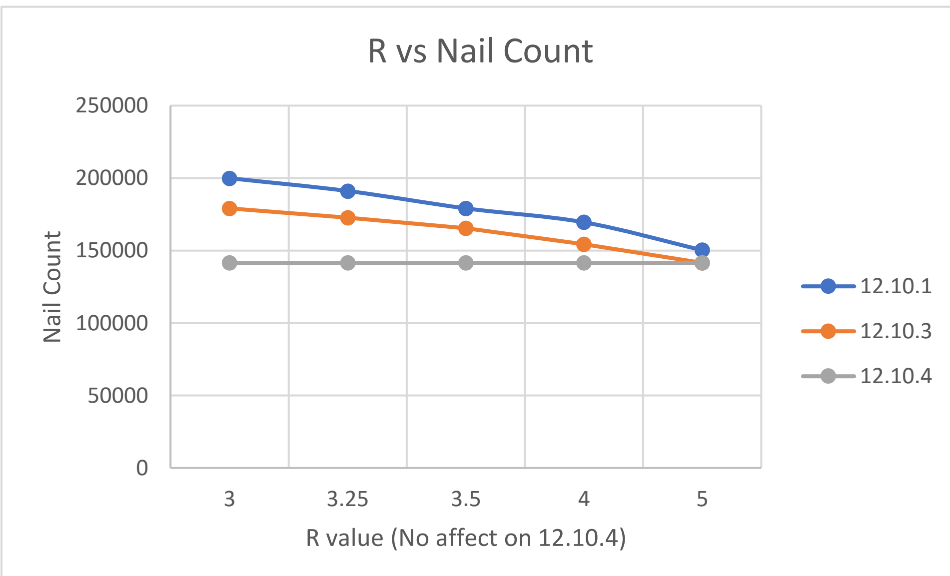


It can be seen in the graphs above that in high seismic zones, 12.10.3 is consistantly applying less force than 12.10.1. Both 12.10.1 and 12.10.3 have upper and lower limits. The upper limit does not apply to the R values we are analyzing, but after the R value hits 5, the lower limit (Cs=.2) applies, flatlining both 12.10.1 and 12.10.3. As the R value increases, it is seen that eventually, 12.10.3 and 12.10.1 use less nails than 12.10.4. In a high seismic zone, we can conclude that 12.10.4 is the most efficient, until R equals 5, then 12.10.3 becomes more efficient.

Various R Values (moderate seismic)

| **R Value Case Study (Cmax)** | | | Sds = .5 | Sd1 = .2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 12.10.1 | 12.10.1 Nail | R Value | 12.10.3 Method | 12.10.3 Nail | R Value | 12.10.4 Method Fx | | 12.10.4 Nail |
| R Values | Method Fx | Count | | Fx | Count | | N-S | E-W | Count |
| 3 | 0.166667 | 199900 | For Method 12.10.3, the R value is fixed at R = 3 | 0.139 | 179100 | For Method 12.10.4, the R value is fixed at R = 4.5 | 0.056 | 0.111 | 141500 |
| 3.25 | 0.153846 | 191100 | | 0.128 | 172700 | | 0.056 | 0.111 | 141500 |
| 3.5 | 0.142857 | 179100 | | 0.119 | 165500 | | 0.056 | 0.111 | 141500 |
| 4 | 0.125 | 169500 | | 0.104 | 154300 | | 0.056 | 0.111 | 141500 |
| 5 | 0.1 | 150300 | | 0.1 | 141500 | | 0.056 | 0.111 | 141500 |




It can be seen in the graphs above that in low seismic zones, 12.10.3 is consistently applying less force than 12.10.1. Both 12.10.1 and 12.10.3 have upper and lower limits. The upper limit does not apply to the R values we are analyzing, but after the R value hits 5 the lower limit (Cs=.1) applies, flatlining both 12.10.1 and 12.10.3. As the R value increases 12.10.4 uses consistently less nails than the prior methods, deeming 12.10.4 the most efficient in low seismic zones.

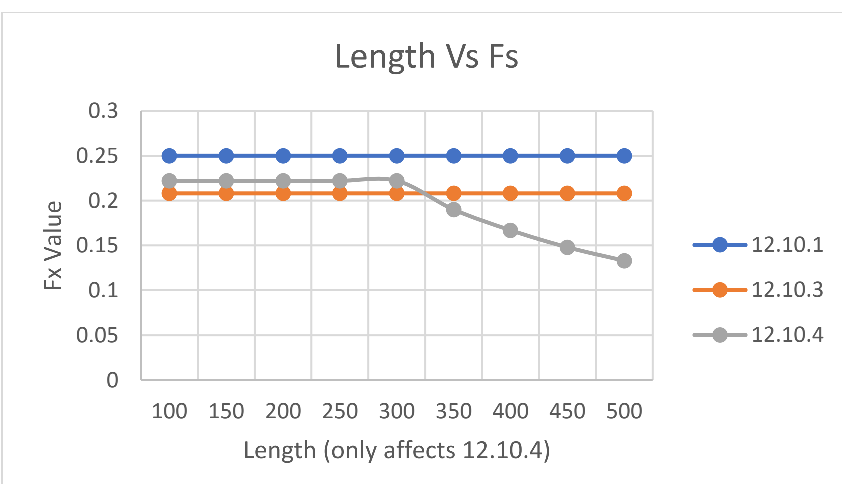
## 2. Diaphragm Length

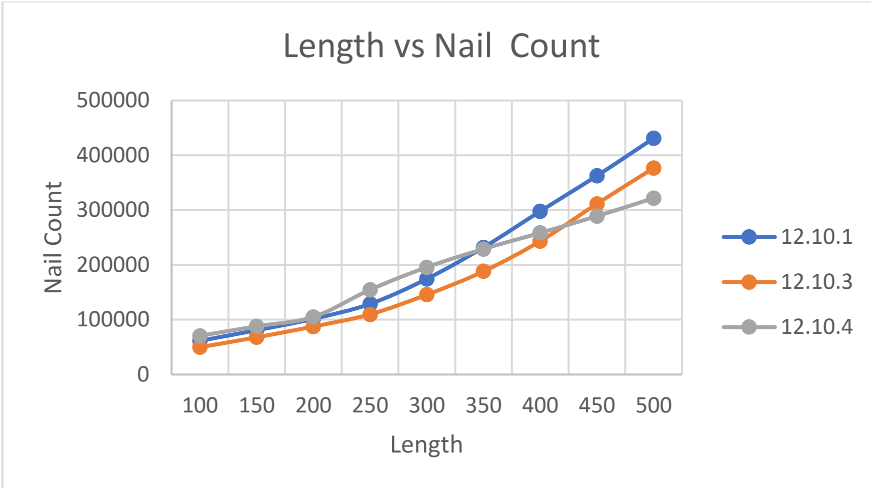
The span on a diaphragm changes per design. The length will change the size and quantity of nailing zones and will have no affect on the applied forces in 12.10.1 and 12.10.3. 12.10.4 is the only method in which the force will be directly affected.

### Various Lengths (high seismic)

**Change in Diaphragm Length Case Study (Dmax)** Sds = 1 Sd1 = .6

| Diaphragm Length | 12.10.1 Method Fx | 12.10.1 Nail Count | 12.10.3 Method Fx | 12.10.3 Nail Count | 12.10.4 Method Fx | 12.10.4 Nail Count |
|---|---|---|---|---|---|---|
| 100 | 0.25 | 61575 | 0.208 | 49975 | 0.222 | 70703 |
| 150 | 0.25 | 80899 | 0.208 | 67923 | 0.222 | 88082 |
| 200 | 0.25 | 101582 | 0.208 | 87610 | 0.222 | 105110 |
| 250 | 0.25 | 128890 | 0.208 | 109802 | 0.222 | 154722 |
| 300 | 0.25 | 174501 | 0.208 | 145717 | 0.222 | 195773 |
| 350 | 0.25 | 232036 | 0.208 | 188269 | 0.19 | 229113 |
| 400 | 0.25 | 297852 | 0.208 | 243356 | 0.167 | 258400 |
| 450 | 0.25 | 362672 | 0.208 | 311488 | 0.148 | 289044 |
| 500 | 0.25 | 431075 | 0.208 | 376675 | 0.133 | 321839 |






Since 12.10.4 is the only method whose force is effected by the diaphragms length, it will be the only one changing on the top graph. The force's maximum value is Fs=.222 according to the equation 12.10-16a.

$$C_{s\text{-}diaph} = \frac{S_{DS}}{R_{diaph} / I_e}$$

This value is consistent from 100ft to 300ft. This value begins to decrease after 300ft because the period of the diaphragm is increasing. Looking at 12.10.4's formula for Fs again,

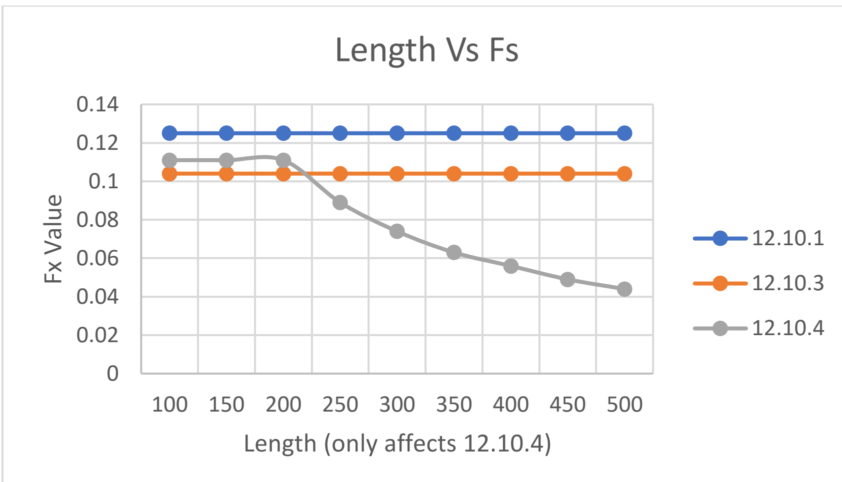
$$C_{s\text{-}diaph} = \frac{S_{D1}}{T_{diaph}\left(R_{diaph} / I_e\right)}$$

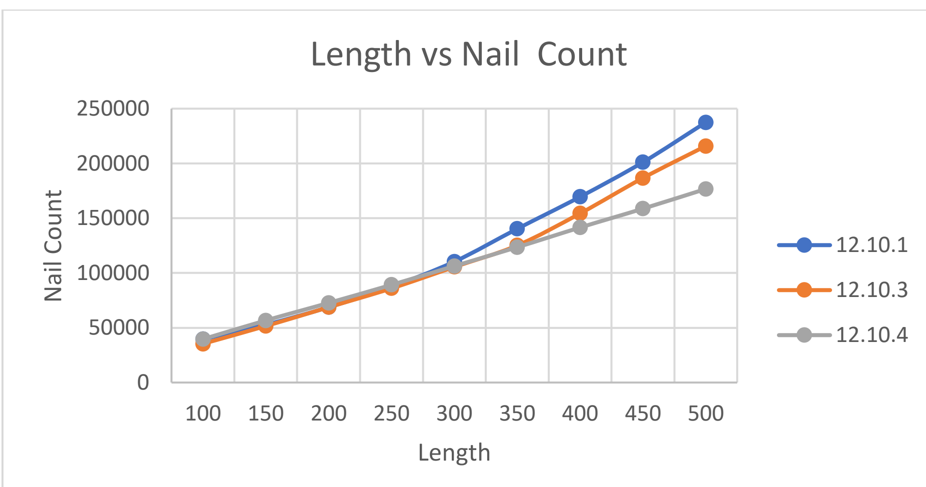
we can see why the Fs value decreases. As far as cost, 12.10.4 uses the most amount of nails until about 350ft, then the least amount of nails after 425ft. 12.10.4 then becomes more efficient for this case illustrating high seismic.

Various Lengths (moderate seismic)

**Change in Diaphragm Length Case Study (Cmax)** Sds = .5 Sd1 = .2

| Diaphragm Length | 12.10.1 Method Fx | 12.10.1 Nail Count | 12.10.3 Method Fx | 12.10.3 Nail Count | 12.10.4 Method Fx | 12.10.4 Nail Count |
|---|---|---|---|---|---|---|
| 100 | 0.125 | 39575 | 0.104 | 35375 | 0.111 | 39575 |
| 150 | 0.125 | 52763 | 0.104 | 51563 | 0.111 | 56663 |
| 200 | 0.125 | 68750 | 0.104 | 68750 | 0.111 | 72670 |
| 250 | 0.125 | 87538 | 0.104 | 85938 | 0.089 | 89146 |
| 300 | 0.125 | 110325 | 0.104 | 105525 | 0.074 | 106325 |
| 350 | 0.125 | 140313 | 0.104 | 125113 | 0.063 | 123513 |
| 400 | 0.125 | 169500 | 0.104 | 154300 | 0.056 | 141500 |
| 450 | 0.125 | 201088 | 0.104 | 186688 | 0.049 | 158688 |
| 500 | 0.125 | 237475 | 0.104 | 215875 | 0.044 | 176675 |




Again, 12.10.4 is the only method whose force is affected by the diaphragm's length, it will be the only one changing on the top graph. The force's maximum value is Fs=.111. This value is

consistent from 100ft to 200ft. This value begins to decrease after 200ft because the period of the diaphragm is increasing. As far as cost, all are about the same until about 350ft, then 12.10.4 becomes most efficient.

## Global Impact/Influence:

Though there are different types of building styles and types all over the globe, there are always some staples that we as engineers continue to see. The typical warehouse design for your department store is common everywhere. This design happens to fall under the category of panelized wood diaphragms. The design decisions made for “Rigid wall Flexible Diaphragm” not only can save peoples lives by ensuring the correct method is used, but can decrease the cost of the building, making the design more applicable in places with less funding.

## Cultural Impact/Influence:

. Using this research to create a more cost-efficient building allows for more funding to go elsewhere rather than nailing materials. American culture has unique priorities, in the fact that we put money before many things. From a young age we are told to do well in school, to then go to college, and then get a well-paying job. Through all this hard work, the controlling power is money. The fact is that no one wants to spend their hard-earned money on unnecessary things, let alone unnecessary building materials. I believe it is our job as engineers to create the most sustainable and efficient building, which will not only improve the engineers reputation but the satisfaction of his client.

Social Impact/Influence:

Not everyone knows all the details that go into designing a building. Most don't realize he little tweaks and changes can make a large impact on design and costs. As a client, or the owner of a building, they want to ensure that their money is being used effectively. These buildings are most of the time rather large as well. Occupants of local buildings notice when big warehouses are being built. It is important to people around this new site that the building is being built properly and cost effectively. If neighboring groups can understand the building is being built carefully and cost effectively, it may bring them peace. Most people aren't super happy about large new developments like warehouses. Having money to spare to make the building mesh with its environment will create a happier and more welcoming community. There is also the other argument of under designing buildings. The reason we have codes to follow is to prevent collapse and potential danger. Clients who do not understand engineering may insist on alternate solutions. It is crucial we find a balance between cost and design, appeasing both to the best of our abilities.

Environmental Impact/Influence:

Using less material is always better for a project. The less material used means the demand for this material is decreasing. The introduction of this new method could mean that globally, less nails are used, decreasing the demand. This means that factories will be producing less, then by default, decreasing the amount of pollution from production as well as decreasing the amount of packaging for the item. If we as engineers can gain knowledge and make these diaphragms larger spans, we could also reduce the amount of shear walls and other systems. Decreasing any production and material is better for the environment, something we must consider and preserve no matter what.

Economic Impact/Influence:

The main purpose of this research was to find the most effective method, including the new 12.10.4 method to design this specific type of system. This system is widely used all over the country. The specific research on this design will enable the user to use less materials, making buildings more cost effective. Though there are other ways to cut costs in buildings, each one is crucial and is what sets engineers apart. Implementing the correct diaphragm design in this type of building could cut the number of nails by tens of thousands.

Lifelong Learning Statement

Engineers will never stop trying to find more effective ways to design. It's an engineer's job to create a solution upon a problem. Sometimes there isn't even a problem, but there is a more effective way to go about something. Understanding these three methods of diaphragm design has made me really think about every building element. There is always going to be more than one way to design something, but there will most of the time be one that's better than the others. Being better than the others means using less material, less money and less time. Finding a way to do all three of these things is what sets apart engineers from good engineers. I've held myself accountable in this project, making sure that every step of the process has some sort of reference to the code or hand calculation to back things up. The hardest problem I had to solve was coding things in excel and making sure the right areas for zoning were produced. This took trial and error and lots of "if" statements.

Given this method is new, there was some new code I had to dive into. Reading unreleased code can be a bit daunting. I learned the importance of diving into these new things and trying to understand why they are being introduced. Though not in the report, I was able to understand a lot of the aspects as to why we need these new methods. Some engineers like to cut corners and though it doesn't always lead to collapse, it's not upholding the Engineer's core values. The reason that we need new code is because, as each mistake is made, we can update our rules and equations. I hope that my research here is able to guide future designers and help them create a cost effective and environmentally friendly structure.