Succulent Pavilion

A Senior Project Presented to

The Faculty of the Architectural Engineering Department

California Polytechnic State University, San Luis Obispo

In Partial Fulfillment

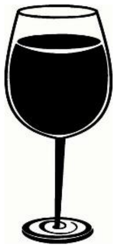
of the Requirements for the Degree

Bachelor of Science

by

Abby King

December 2019



WINE HISTORY PROJECT PAVILION

SAUSILITO CANYON VINYARD, SAN LUIS OBISPO

~ SUCCULENT PAVILION ~

A TRANSIENT, TEMPORARY STRUCTURE WITH A LITTLE BIT OF WINE HISTORY

ABBY KING

STRUCTURAL CALCULATION PACKET

SENIOR PROJECT SUBMITTAL

DECEMBER 6TH, 2019

CALIFORNIA POLYTECHNIC STATE UNIVERSITY, SAN LUIS OBISPO

FALL 2019

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Introduction

San Luis Obispo is a region on the central California coast very well-known for the many wineries that sprawl across the backcountry of this small college town. The Wine History Project is a team that studies the importance of the viticulture in the San Luis Obispo area including everything from wine agriculture, land use, crop selection, equipment, economy, and evolution. It places a special importance on the relationship between the wineries and the residents of the area. Over several months, they have accumulated wine and viticulture related artifacts that I hope to display in its own, unique space at several vineyards and tasting rooms in the area. They came to Cal Poly in search of the perfect pavilion to display the artifacts. The pavilion is meant to be transient and light enough to be transported by only man power of a construction team.

PROJECT DESCRIPTION

Objective: Design, Analyze, and Construct a Pavilion the follows the following Design Criteria:

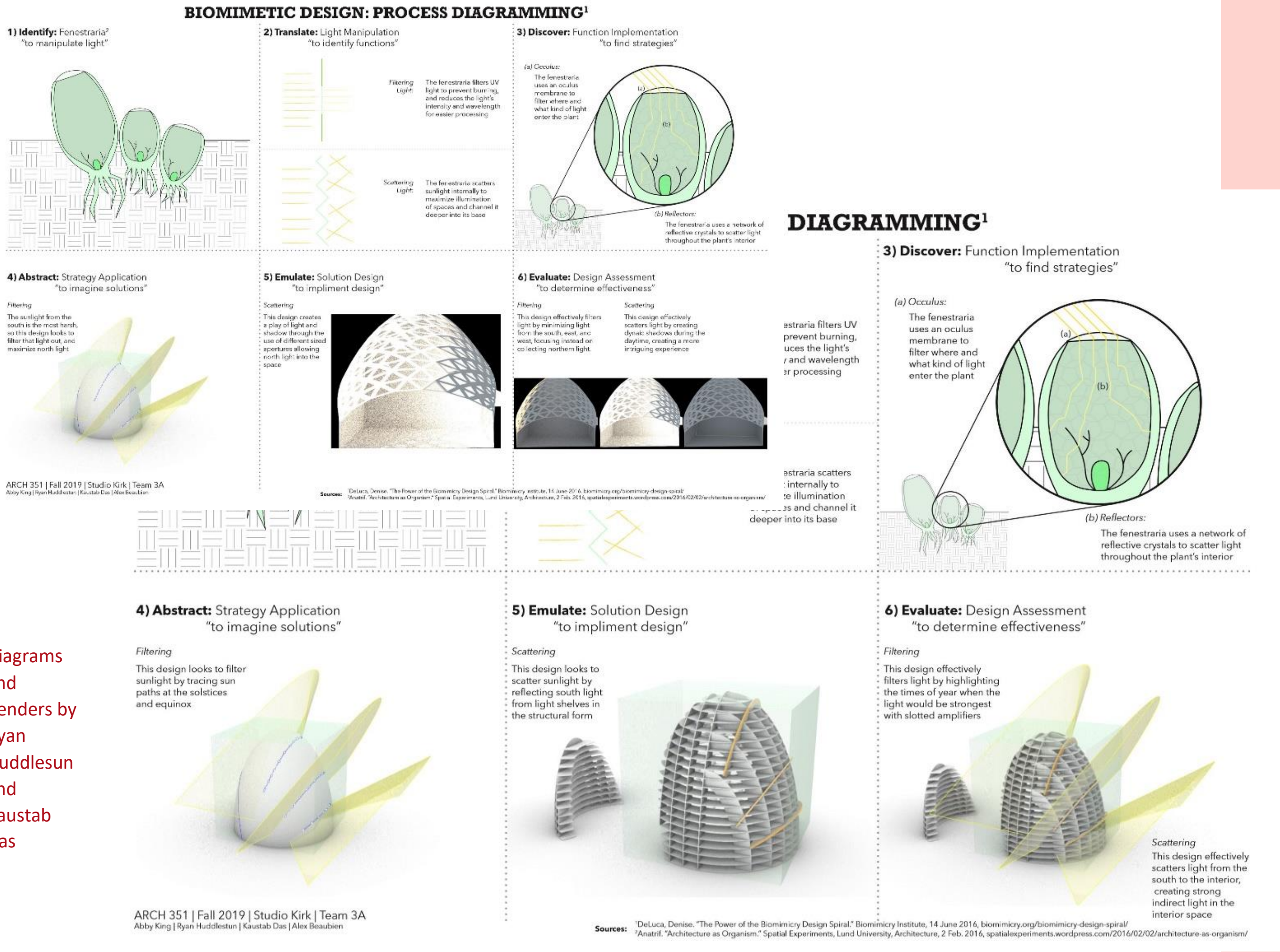
- Transient
- Can be deconstructed at one site, moved, and re-constructed at another site
- Light enough to be carried by humans without machines or equipment
- Light enough to be carried by humans without machines or equipment
- Not necessary to obtain permits
- Accessible to all vineyard visitors
- Provides a nice and easy place to display wine history artifacts

The Wine History Project turned to the Students of the College of Architecture and Environmental Design at California Polytechnic State University to come up with the solution. 8 teams composed of architecture majors, an architectural engineering major, and a construction management major set out to take on the challenge. Over the past fall quarter (12 weeks), the teams have been slaving away putting together models, details, and diagrams to make something work. The following report is to showcase just on of the projects I was able to be apart of. As an architectural engineering major, I was assigned to two separate projects because of low staffing. The report will be of the findings for the Succulent Pavilion Project

Design Professionals:

- Architects: Ryan Huddlestun and Kaustab Das
- Architectural Engineer: Abby King
- Construction Manager: Alex Beaubien

Project Inspiration and Evolution



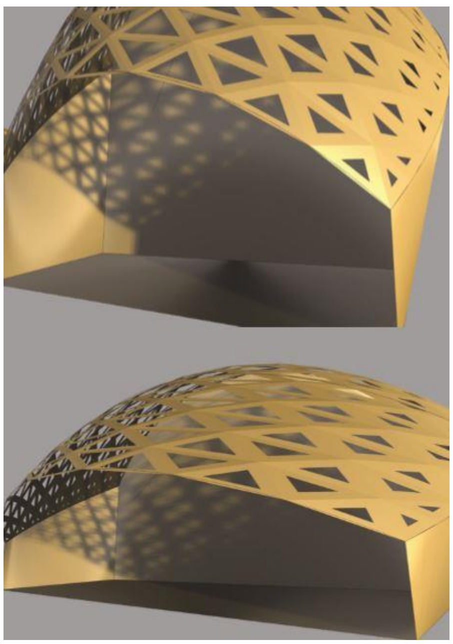
Diagrams and Renders by Ryan Huddlesun and Kaustab Das

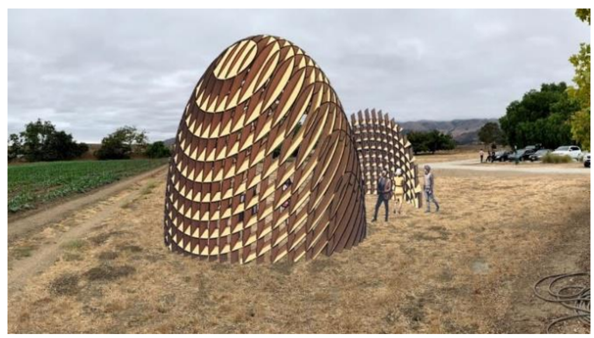
To give the visitors at each winery the most interesting and memorable experience, my group came up with the light scattering as an effective method to enhance the pavilion. Th assignment called for us to look into biomimicry. Where we discovered the organism known as the fenestraria. The fenestraria can filer light using an oculus and scatters it using reflective crystals. With a sunlight study by Huddlestun and Das, we designed using the fenestraria as inspiration would be the most interesting and productive path to choose.

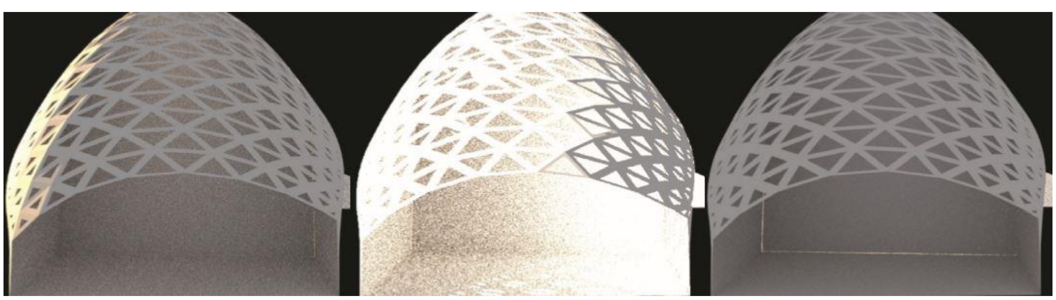
Project Inspiration and Evolution

PRELIMINARY IDEAS

Below is a collective of Team 3a's preliminary models on the road to designing the Succulent Pavilion



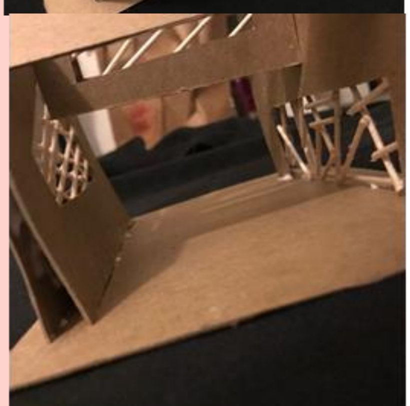




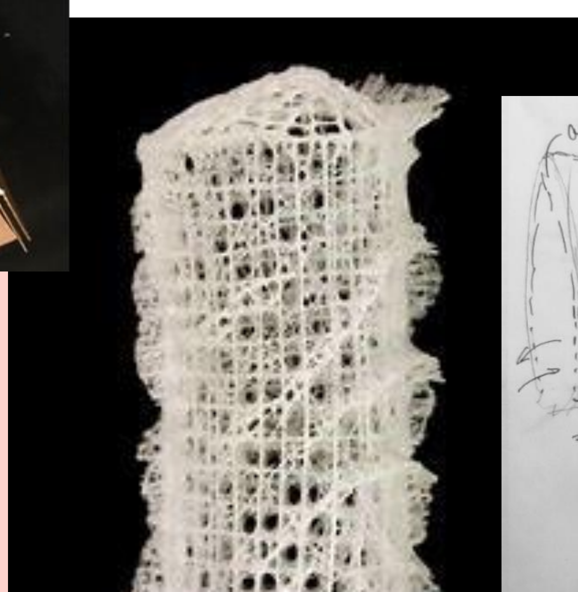
RENDERS AND MODELS BY RYAN HUDDLESTUN AND KAUSTAB DAS

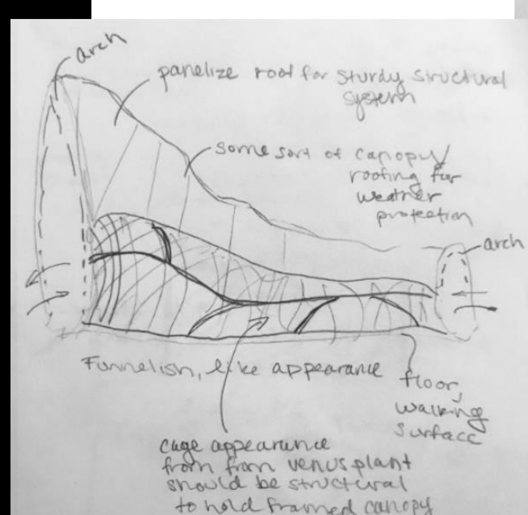
PERSONAL EXPLORATION MODELS

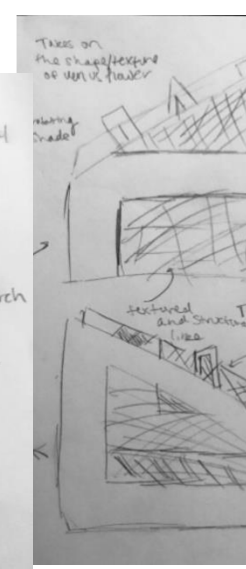
Below is a collective of my own preliminary physical models on the road to designing the Succulent Pavilion

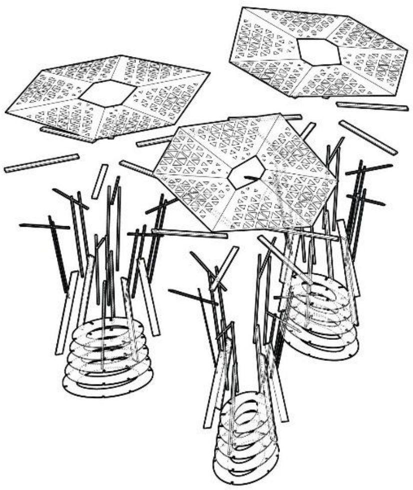


With my knowledge of light scattering, I was pulled to the idea of a tunnel of some sort of grid patter around the outside. I thought this would allow an ease of design when it came to structural stability design. I thought this we be a good staring place to incorporate the light scattering we were working at, but also visualize a workable structure that I could design under the given circumstances. Along with the fenestraria, group 3a was also gathering ideas from the basket flower that lives in water and is woven like pattern shell. I based my physical models of this grid.







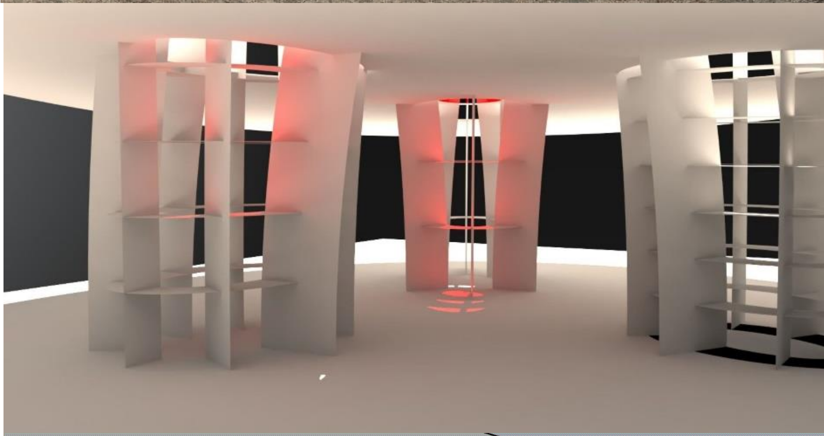


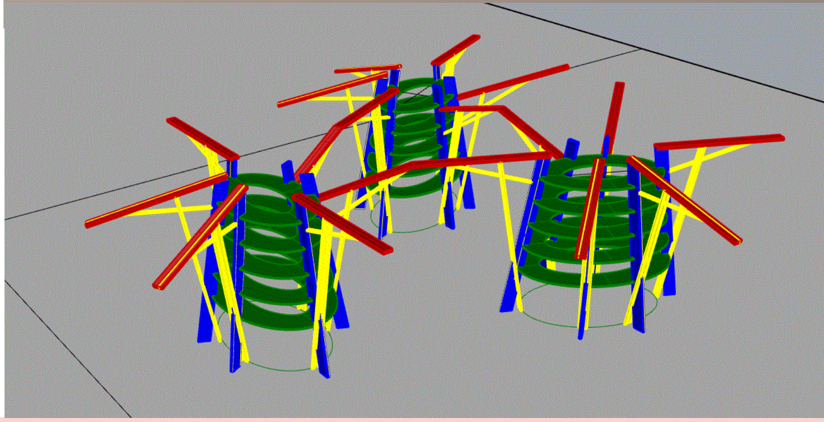
Team 3a decided on 3 separate self-supporting units each with:

- Pressure Treat Lumber Fins
- Plywood Rings for Shelving and Lateral Support
- Aluminum and Glow-in-the-Dark Acrylic Roof Panels
- Steel Bolt and Plate Connections
-

SEE STRUCTURAL SECTION IN NEXT PAGES FOR MATERIAL AND MEMBER SIZE METHODOLOGY AND DETERMINATION

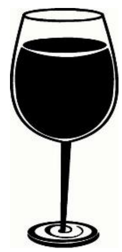
RENDERS BY RYAN HUDDLESUN AN KAUSTAB DAS

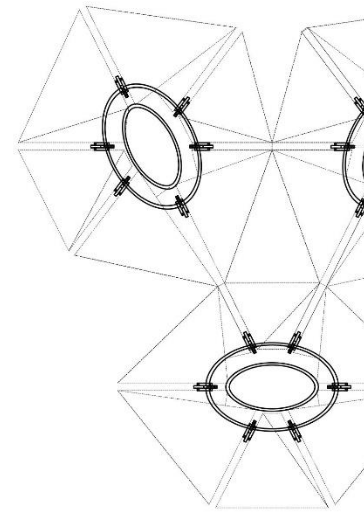


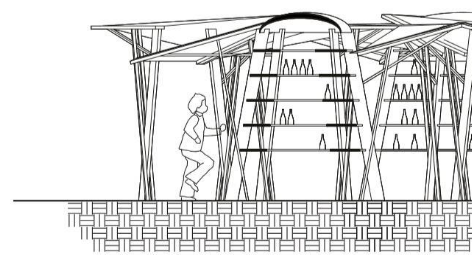


FINAL PROJECT

CONCLUSION







Section and Plan by Kaustab Das

STRUCTURAL CALCULATIONS

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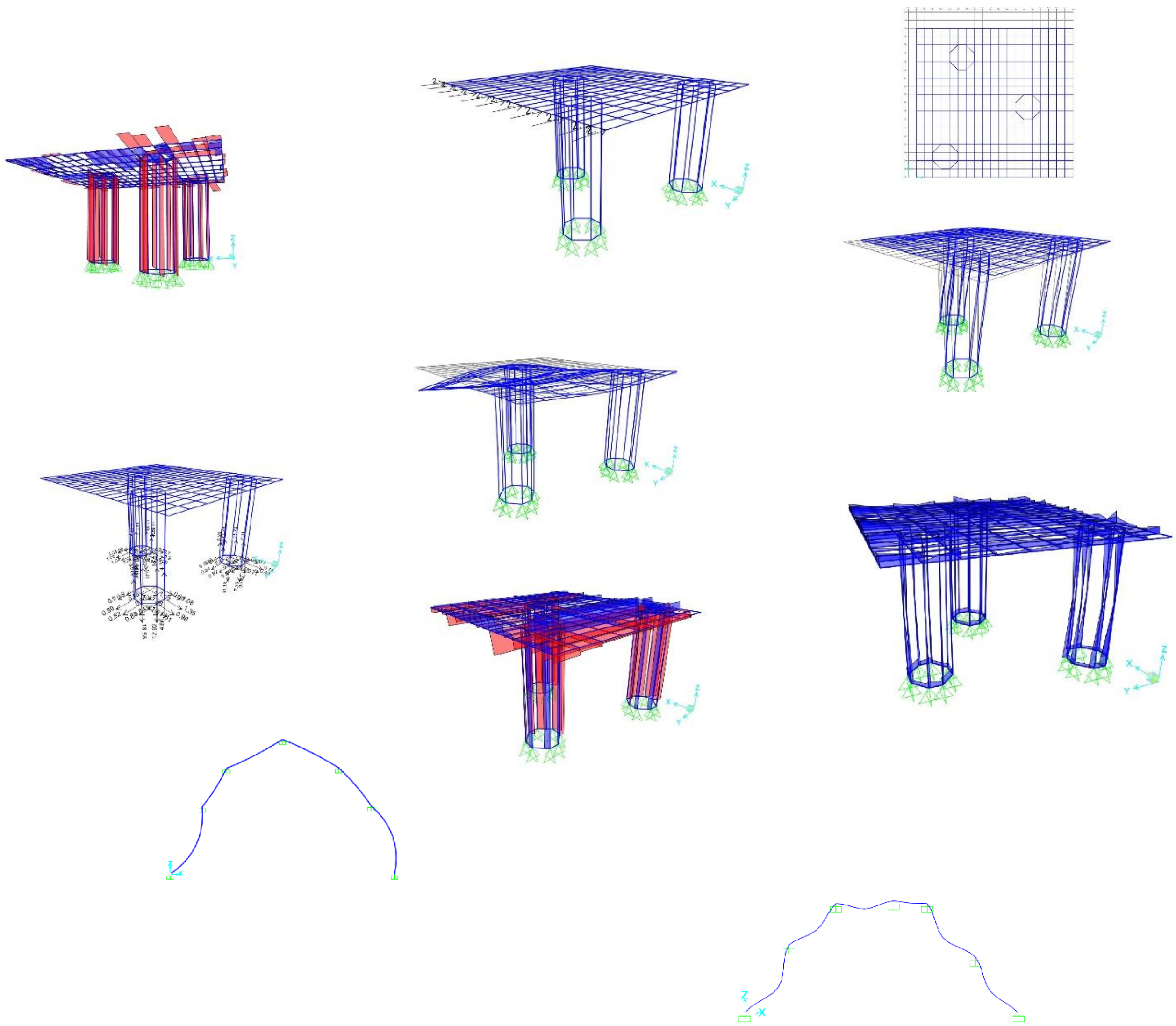
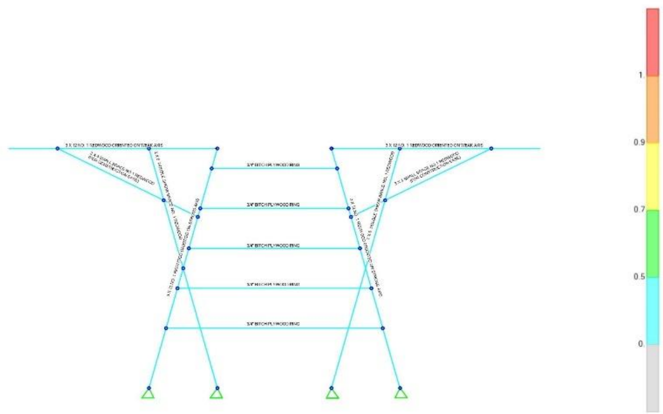
Explorative SAP2000 Models

Below are different form I have created in the SAP2000 program to determine design loads and analyze the best way to size the members and determine the best materials,

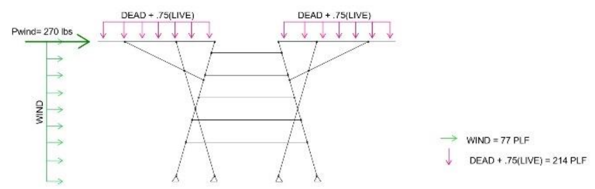


Due to the properties of the chosen structural material, pressure treated lumber. Please see hand calculations. SAP2000 was no longer a sufficient material for the form and material. The form also became easier to analyze on paper. See next series of pages for Structural Calculations

Final Force Diagrams



SUBJECTED TO WIND, DEAD, AN LIVE LOADING PER ASD LOAD COMBOS [ASCE-7 2.4.1]

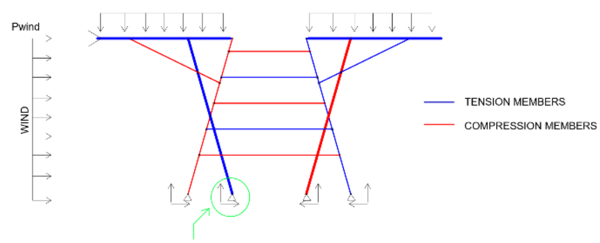


DEAD + .75(LIVE) + .6 (WIND) GOVERNING ASD LOAD COMBO FOR WIND, DEAD AND LIVE PER ASCE-7 2.4.1

.6(DEAD) + .6(WIND) GOVERNS FOR UP LIFT AT FOUNDATIONS PER ASCE 2.4.1

SEE TEAM 3A STRUCTURAL CALCULATIONS BY ABBY KING

PER HEIGHT TRIB AREA (H/2, WIND LOAD CAN BE APPLIED AS POINT LOAD AT ROOF BEAM 3 X 12 FOR ANALYSIS (Pwind= 270 lbs)

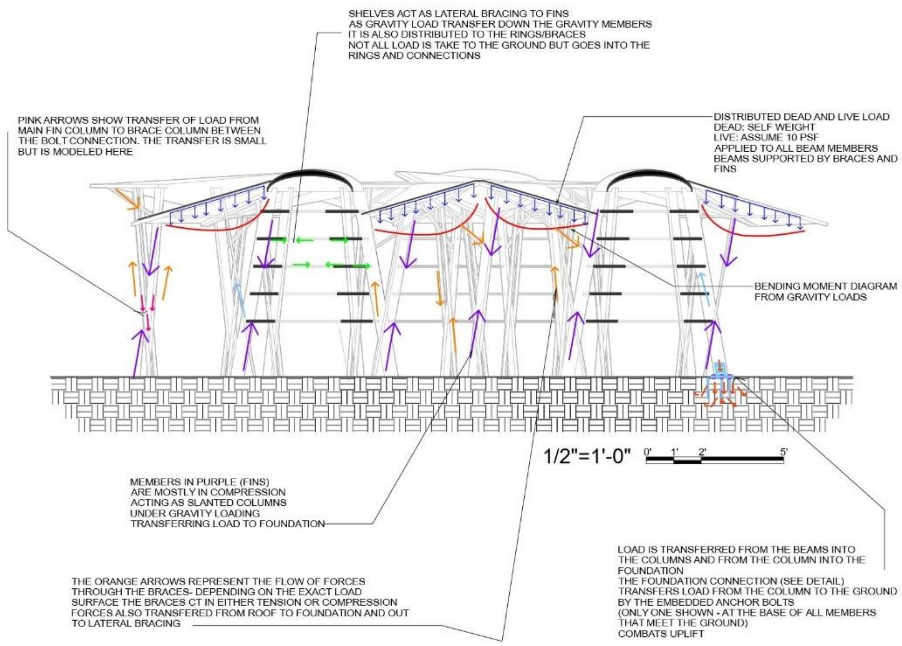


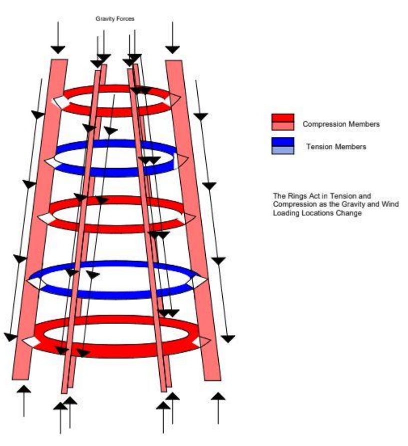
MOST OF WEIGHT AND REACTION GOES TO FIN SUPPORT - 3 X 12 MEMBER APPROX fy= 912 #

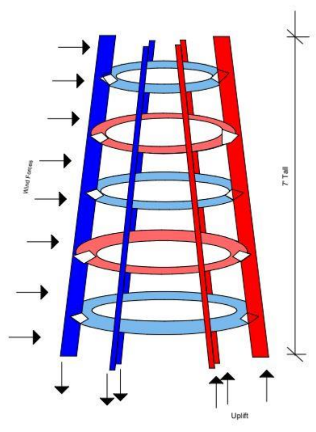
USE UPLIFT FORCES PER STRUCTURAL FORCES AND BEARING PRESSURE 1000 PSF TO DESIGN FOUNDATIONS

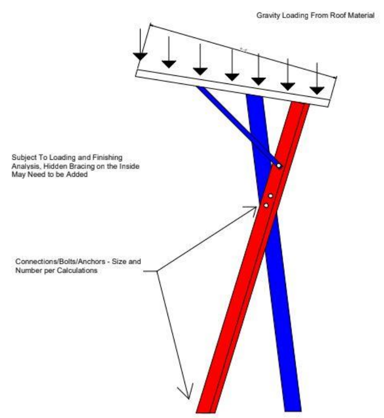
FOUNDATIONS OF STRUCTURE SHALL MATCH AESTHETIC TO LONG BRACES BUT LESS BOLTS AND HALF AUGERS INTO SOIL

LOAD PATH EXPLORATION





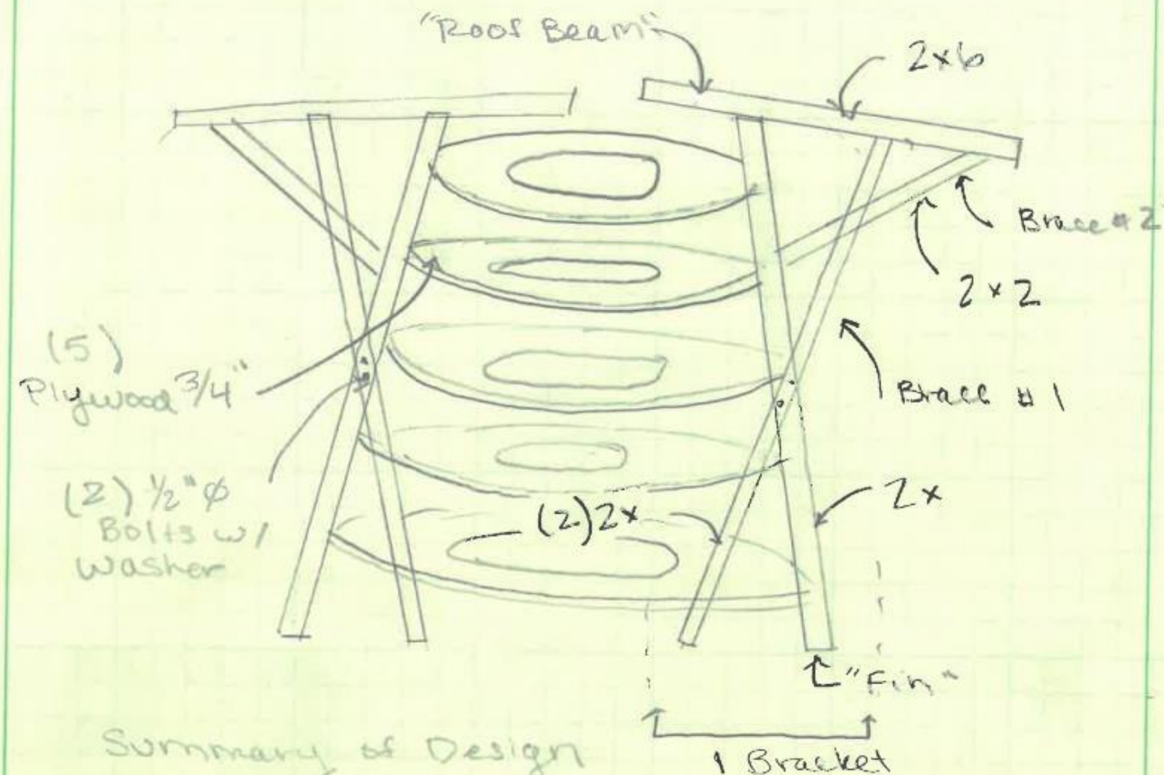




3a

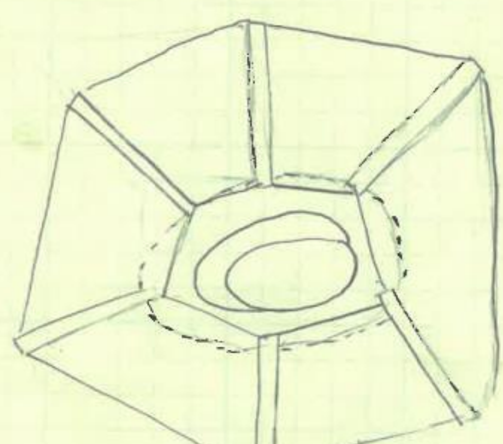
1

Team 3a Overview



Summary of Design

- 3 Separate structures
- All self-supporting
  - > essentially furniture
- Triangular Panels for Roof.
  - Aluminum - Sheet w/ holes
  - Acrylic for aesthetic
- Triangular Panels span Between Roof Beams
  - -connected to either w/ screws
- 6 Roof Panels
- 6 Brackets
- 5 Rings

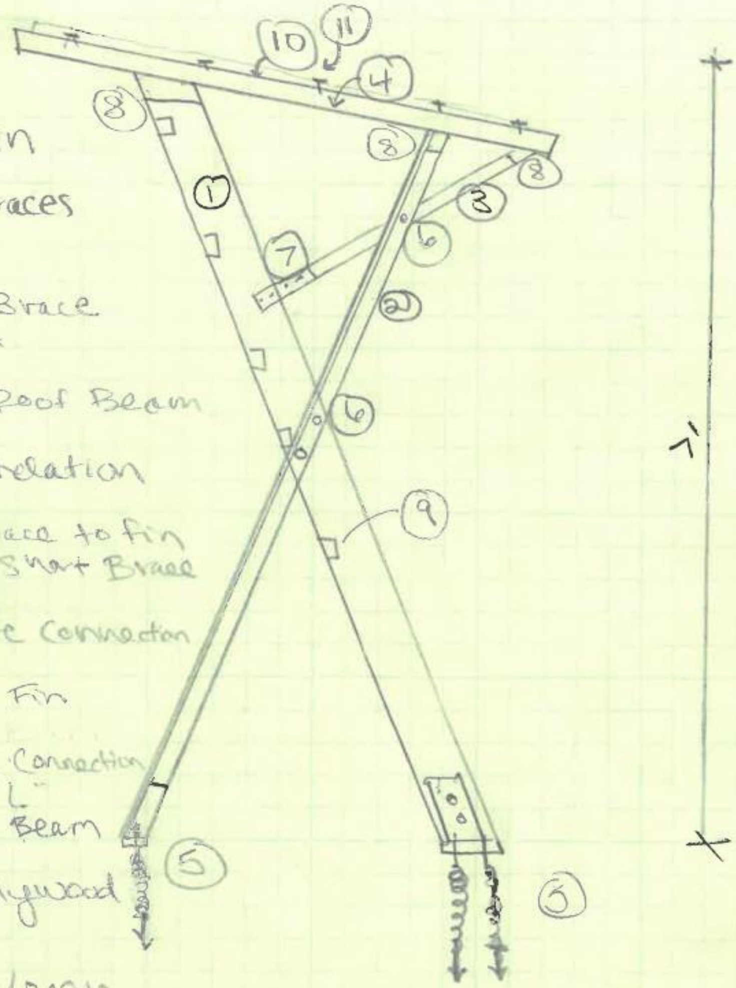


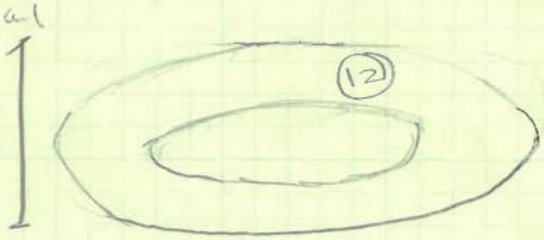
Approximate Plan view of

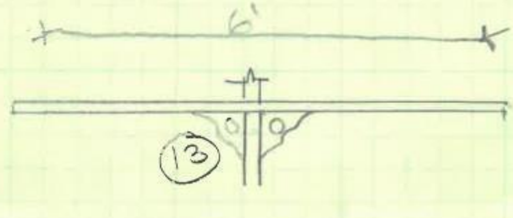
3a

Proposed Structure

1. (1) 2x10 Fin
2. (2) 2x6 Braces - Long
3. (1) 2x2 Brace - Short
4. (1) 2x10 Roof Beam
5. Auger Foundation
6. Bolts - Brace to Fin, Long to Short Brace
7. Steel Plate Connection For Bolts Brace to Fin
8. Steel Plate Connection Joint to "L" Brace to Beam
9. Slits for Plywood
10. Aluminum/Resin For Roof Material
11. Screws Roof to Roof Beam
12. Plywood Rings
13. Shelf (Ply) to Fin Bracket Connections







3a

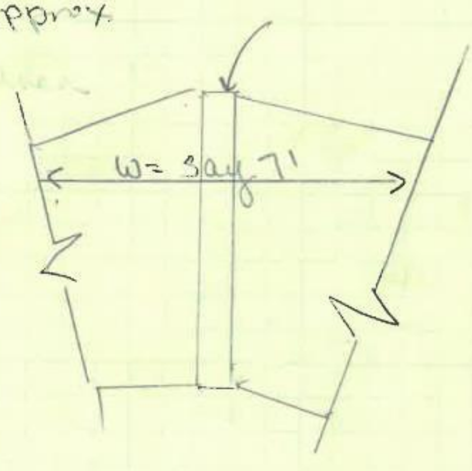
Table 4.3-1

Uninhabit w/o stora 3

Dead Load take off - Per 1 Structure

No	Item	Calculation or Source	Total Weight
12	2×6 Pressured Treated Red wood	Engineering Tool box	26'/1 = 3.7
12	2×10 Pressure Treated Red Wood	Pressure Treated Lumber Boards	44'/1 = 6.3
6	2×2 Pressure Treated Redwood	Table 17/1' 8' piece 2.4 for 2×4	2.0
5	3/4" Plywood Ring Birch pre Sanded	the plywood.com	3 psf
6	Acrylic Panels (1/8")	USP United States Plastic Corp Acrylic Weights	2.2 psf
6	Aluminum Panels (1/8)	.1285 gauge 8 Riverside Sheet Metal Gauge + weight Chart	1.8 psf
	Connections - (Misc)	+	4 psf
	Total		23 psf

Trib Width / Area Approx



Dead use

23 psf

Live Load - use 10 psf per ASCE-7 T 4.3-1

Uninhabital attic space w/ no storage

3a 4

Wind Loading

See ASCE Determination Figure

1. Region Central California Coast 92 mph
2. Risk Catagory II
   Exposure C

Ch. 29 "Wind Loads on Building Appurtenances + Other Structures
Building Open 26.2 MWF
Each wall is at least 80% open
My Build has no walls, very open

$A_o \geq A_g * .8$

structure - takes across loading (structure is open structure/frame
in accordance with 29.1.1 User Note

3. • Kd - wind directionality factor T. 26.6-1
   Kd = .95 Trussed towers/all other x-sections

• Exposure : C

• Kzt topographic factor 26.8 $H/L = 8'/16'$
  Escarpment $\approx .5$

$K_{zt} = (1 + K_1 K_2 K_3)^2$ 26.8.2

$K_1 = .43 \; (H/L = .5)$ 26.8-1

$K_2 = .75 \; (x/L_H = 1)$

$K_3 = (z/L_h; 8/16) = .29$

$K_{zt} = (1 + (.43)(.75)(.29))^2 = 1.2$ $K_{zt} = 1.2$

Wind continued

3. • Ke Ground Elevation Factor 26.9

San Luis Altitude = 285.4 ft Above S.L.

ft - 0 - ke = 1.00

• Gust Effect Factor G 26.11

G = .85 - For rigid Building or Structure

4. Velocity pressure exposure coefficient T26.10-1

Height above ground level 0-15 - C Exp. .85

$K_z/K_h = .85$

5. Velocity pressure q_z/q_h Eq. 26.10-1

$q_z = .00256\, K_z K_{zt} K_d K_e V^2 \; (lb/ft^2)$; ∴ q

$q_z = .00256(.85)(1.2)(.95)(1.0)(92)^2$

$q_z = 20.99 =$ 21 psf

6. C_f - force coefficient Fig. 29.4-3 Trussed Tower

C_f

Notes For towers with rounded members ... (3)

take $.51\epsilon^2 + .57$ but not >1.0

ϵ • Ratio of solid area to gross area of 1 solid tower face

Gross ≈ 48 ft² solid ≈ 13 13/48 = .27

$.51(.27)^2 + .57 = .61 < 1$ ok ✓

7. Wind Force/Pressure Eq. 29.4-1

$F = q_z G C_f A_f$ ~ pressure $q_z G C = 21(.85)(.61) = 10.88$

$\boxed{\text{wind pressure} = 11\text{ psf}}$ 29.4 ASCE

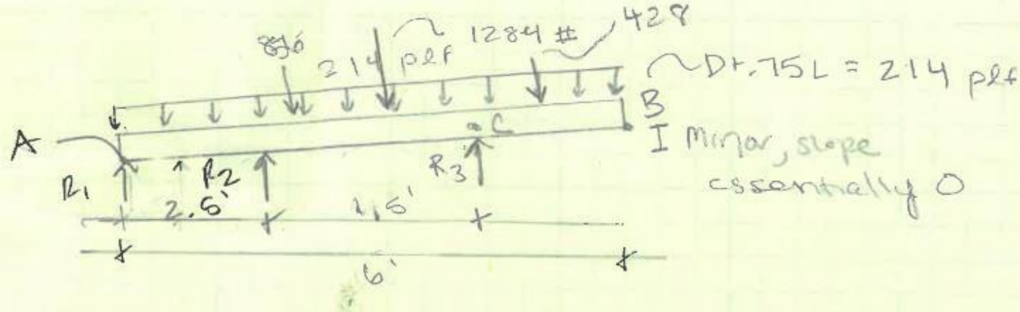
Load combos - ASD 2.4.1 ASCE

1. D + L = 23 psf + 10 psf = 33 psf
2. D + .6W = 23 psf + .6(11) = 29.6 psf
3. D + .75L + .6W = 23 + .75(10) + .6(11) = 37.1
4. (Uplift) .6D + .6W = .6(23) + .6(11) = 20.4 psf

Use 37.1 psf
Use 20.4 psf for uplift

Beam Design

1 - Standard Roof Beam



$D + .75L = 7'[23 + .75(10)] = 214$ plf

trib area

$\circlearrowleft \Sigma M_A = 0 = -1284(3') + R_3(4') + R_2(2.5')$

$R_3 = \dfrac{3852 - 2.4R}{4}$

$R_3 = 963 - .625R_2$

$\circlearrowleft \Sigma M_C = 0 = 856(2) - 428(1) - R_2(1.5') - R_1(4)$

$1284 = R_2 1.5 + 4R_1$

$R_1 = (1284 - 1.5R_2)/4$

$R_1 = 321 - .375R_2$

$\Sigma F_y = -1284 + R_1 + R_2 + R_3$

$0 = -1284 + (321 - .375R_2) + R_2 + (963 - .625R_2)$

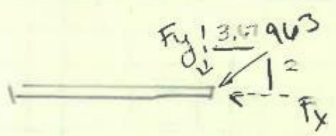
$1284 - 321 - 963 = R_2(-.375 + 1 - .625R_2)$

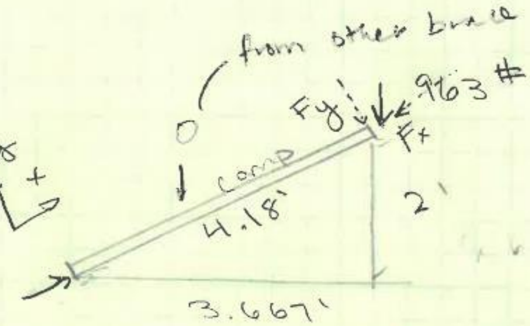
$0 = R_2(0) \qquad R_2 = 0.$

3a

Brace Design

Rotate for calcs:





$F_y = (2/4.18)\,963 = 460.7$ $\quad F_x \left(\frac{3.67}{4.18}\right) 963$

$F_y = 460.7$ # $\quad F_x = 844.8$

area =

(trial size $1.5" \times 1.5"$) $= 2.25\ in^2$

$F_{c_{||}} = 375.$ psi

[see C values previous pages]

Design Values

NDS – Table 4A Redwood

$F_c = 900$ psi (No. 1)

Table 4.3.1

$F_c' = F_c * C_D * C_M * C_i$

$F_c'\ 900(1.6)(.8) \times .80$

$\uparrow$ Fc – CM

$F_c' = 921$ psi $\quad > F_{c_{||}}$ Design 375.47

2×2 for gravity

OK 2×2 for Brace 2

with gravity loading

3a

Adjustment Factors - C's
(NDS - Ch. 4) (NDS Supp Tables)
Sawn Lumber C_D C_M $\cancel{C_t}$ C_L C_F C_{fu}
C_i $\cancel{C}$ $\cancel{C_P}$ $\cancel{C_T}$ $\cancel{C_b}$

$C_D = 1.6$ wind is controlling load

C_M = F_b F_t F_v F_{cv} F_c E E (NDS 4.1.4 5.1.4)
.85 1 .97 .67 .8 .9 .9
Since outdoor structure - assume at some point MC > 19% - C_M < 5x Sawn

F_c → when $F_c C_F \leq 750$ → $C_M = 1.0$

F_b → when $F_b C_F \leq 1{,}150$ psi → $C_M = 1.0$

C_F - 2x 1.5, 1.5, 1.15 1.1, 1.1, 1 Size factor (4.3.6)
No. 1 2x2 2x10 (F_b, F_t, F_c)

C_F 1.5, 1.5, 1.15 1.2, 1.2, 1.05 2x6 → 1.3, 1.3, 1.1
No. 1 2x4 2x8

- C_{fu} = 1.0 (2x2) 1.1 (2x4) 1.15 (2x6) 1.15 (2x8) 1.2 (2x10)

(4.3.7, 5.3.7)

C_{fu} flat use (

C_i Incising factor (4.3.8) - pressure treated lumber being used (preservatives)

C_i = .80 (F_b, F_t, F_v, F_c) 1.0 (F_{cT}) .95 (E, E_{min})

C_L = 1.0 (next pages)

3a

C's continued Adjustment factor [NDS - 3.3.3]

2x6 - Redwood No.1 4.4.1.2b 5.5/1.5 ≈ 3.7
2x8 " "
2x10 " "

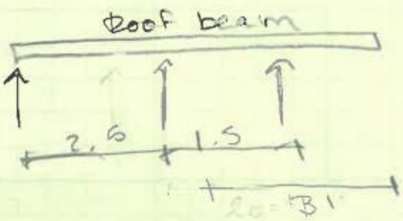
4.4.1.2c 7.5/1.5 = 5

$d \le b$ Id 2" 4.4.1.2e 9.5/1.5 = 6.3

b

[4.4.1 NDS b/d ratios]

2x4 4.4.1.2 → 3.5/1.5 = 2.33



1.5/1.5 = 1.00
↳ no lateral required

E_{min} = 400,000
(NDS Supp T4A)

$l_u = 2.5/2 = 1.25$

$l_e = 1.33(2.5) = 1.66'$

2x6

$l_e = 1.66$
$d = 2$
$b = 6$

$$R_B = \sqrt{\frac{1.66(1.5)}{(5.5)^2}}$$

R_B = .2869 < 50
ok ✓

$$F_{bE} = \frac{1.20(400,000)}{(.2869)^2} = 5831498$$

$F_b^* = F_b(C_D)(C_M)(C_t)(C_i)$

F_b = 775
NDS Supp 4A Redwood

$F_{bE} = 583149.8$

$F_b^* = 775(1.6)(.85)(1.3)(.80)$
$F_b^* = 109616$

2.34

$$C_L = \frac{1+(5831498/109616)}{1.9} - \sqrt{\left[\frac{1+(583149.8/109616)}{1.9}\right]^2 - \frac{(583149.8/109616)}{.95}}$$

$C_L(2\times6) = .999 \approx 1.0$

3a

C_L Adjustment Continued

$C_L(2\times8)$

$l_e = 1.66$
$d = 2$
$b = 8$

$$R_B = \sqrt{\frac{1.66(1.5)}{(7.5)^2}} = .210$$

$F_b^* = 775(1.6)(.85)(1.2)(.8)$

$F_b^* = 1011.84$

$$F_{bE} = \frac{1.20(40000)}{.21^2}$$

$F_{bE} = 1088439 3.7$

$$C_L = \frac{1 + (10884393.7/1011.84)}{1.9} - \sqrt{\left[\;''\;\right]^2 - \frac{\left(\frac{10884393.7}{1011.84}\right)}{.95}}$$

$C_L(2\times8) = .999 \approx 1.0$

$C_L(2\times10)$

$$R_B = \sqrt{\frac{1.66(1.5)}{(9.5)^2}} = .166$$

$l_e = 1.66'$
$d = 2$
$b = 10$

$F_b^* = 927.52$

$$F_{BE} = \frac{1.20(400000)}{.166^2} = 17419073.89$$

$$C_L = \frac{1 + \frac{17419073.89}{927.52}}{1.9} - \sqrt{\left[\;''\;''\;\right]^2 + \frac{\left(\frac{17419073.89}{927.52}\right)}{.95}}$$

$C_L(2\times10) = .999 \approx 1.0$

3a

Beam Design Continued

$R_2 = 0$ zero force member

$R_1 = 321 - .375(0)$ $\quad R_1 = 321$ #

$R_3 = 963 - .625(0)$ $\quad R_3 = 963$ #

Reaction Check

$\Sigma F_y = -1284\# + 0 + 963\# + 321\# = 0$

$0 = 0$ ✓

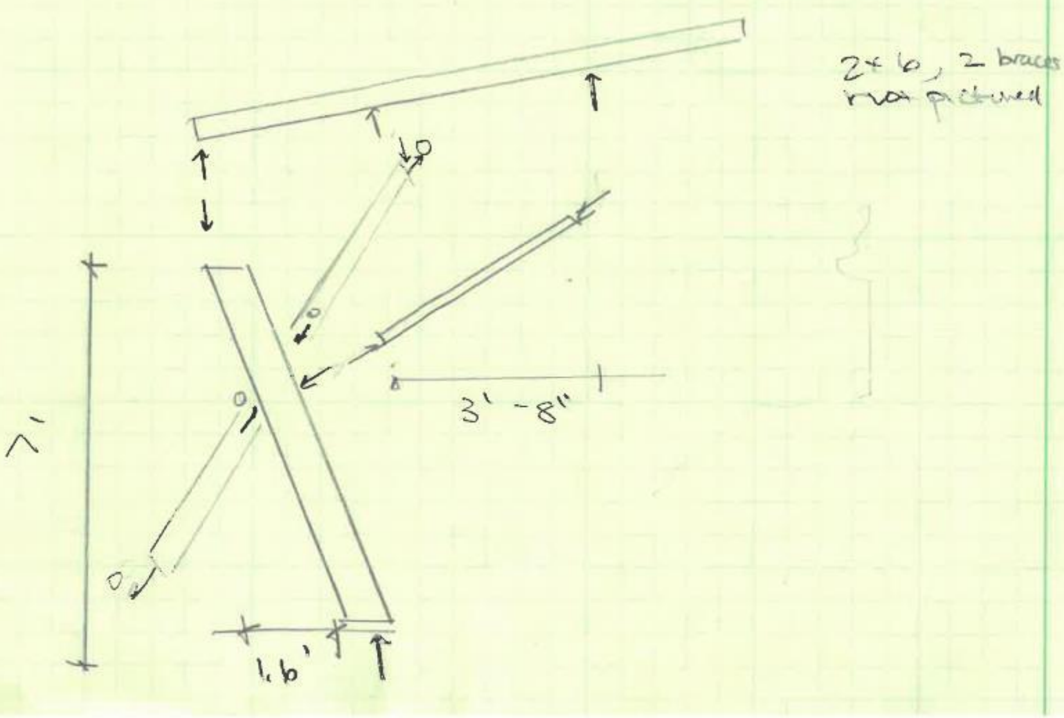
$\circlearrowleft \Sigma_A M = 0 = R_2(0) - 1284(3) + (4')(963)$

$0 = 0$ ✓

$R_1 = 321$ # $\quad R_2 = 0 \quad R_3 = 963$ #

(2×10) $\quad$ (2×6) $\quad$ (2×2)

in gravity



3a

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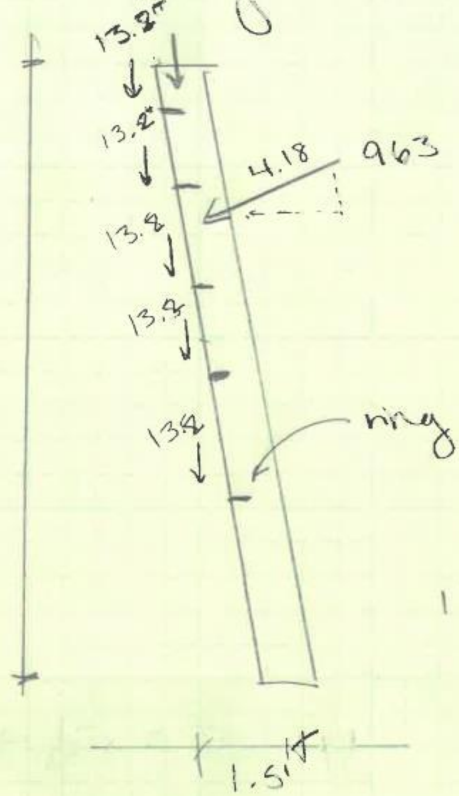
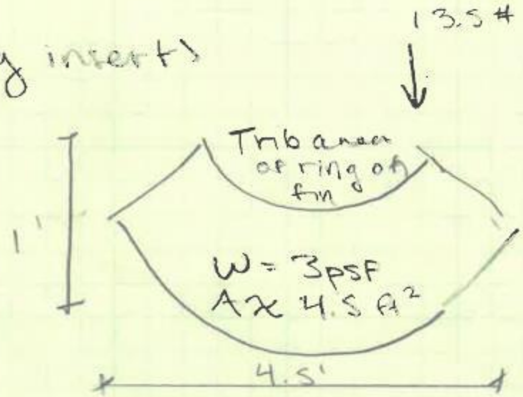
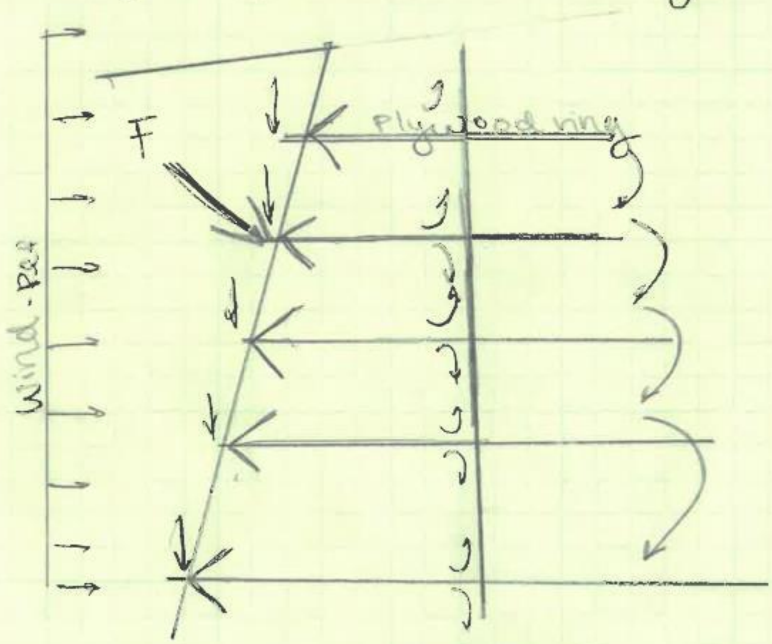
Fin Design



Next page for gravity calcs



Page. ___ → Wind loading Distribution



Wind Diagram - Primary

3a

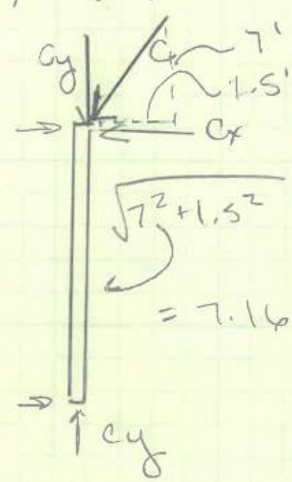
14

Fin Design

$B1 = 0\#\ (R_2)$

$B2 = (F_3\ x\text{-comp}) = 844.8\ \#$

$C = R1 = 321$



Rotate to find C comps

$Cy = \frac{7}{7.16}(321)$

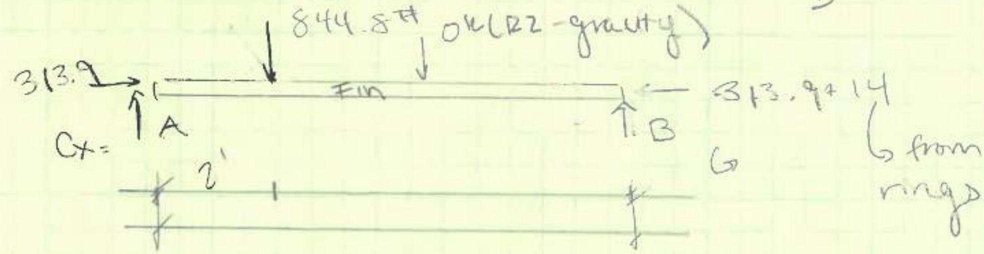
$Cy(\text{axial}) = 313.9$

$Cx =$

$\Sigma F_x = 844.8 - 67.3 - B$

B

Free Body Diagram



Must Check : Bending (per gravity loads)

Comp

Combination F_b, F_c

Cross section : $\overset{(2\times 6)}{1.5\times 5.5} = 8.25\,in^2$

$F_c = 313.9 \big/ 1.5 \times 5.5 = 38$

3a

15

Fin Design Continued

$F_b = F_{b\text{-max}} \quad \frac{M}{S} = \frac{M_{below}}{bh^2/6} = \frac{4694.8 \text{ \#ft}}{\frac{(1.5)(5.5)^2}{6}}\left(\frac{12\text{in}}{1\text{ft}}\right)$

See below

$F_{b\,design} = 7354.3$ k-ft

Design loads

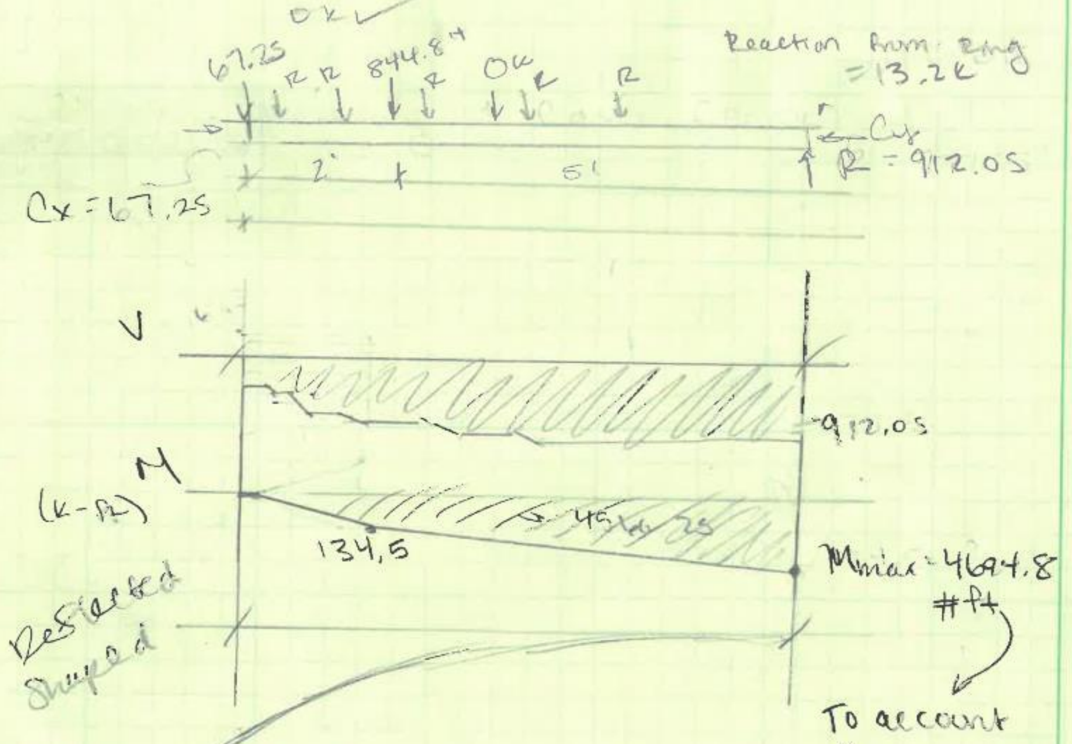
$F_c' = F_c(C_D)(C_M)(C_F)(C_i)$ $\quad F_b' = F_b(C_D)(C_M)(C_F)(C_{Fu})(C_i)$

$F_c' = 900(1.6)(.8)(1.1)(.8)$ $\quad F_b' = 725(1.6)(.85)(1.3)(1.15)(.8)$

$F_c' = 1013.76$ psi $\quad F_b' = 1179.3$

$F_{c\,design} = 11.4$ psi < 1013.8 $\quad F_{b\,design} \Rightarrow$ not ok

OK



To account for add

$M = 13.2(5)(1')$

66 kft

$\Sigma F_y = +844.8 - 67.25 + R = 0$

$R = 912.05$

$M_{max} = 4694.8 + 66$ kft

$M_{max} = 4760.8$

3a

16

Fin Design Continued

Combined Loading Continued

$$R_B = \sqrt{\frac{l_e d}{b^2}} = \sqrt{\frac{14''(11.5)}{2.5^2}} = 5.08$$

$$F_{BE} = \frac{1.20 E_{min}}{(5.08)^2} = \frac{1.20(400000)}{5.08} = 18633.5 \text{ psi}$$

$f_{b1} = 1036.8$ psi $<$ 18633.5 F_{BE} ok

$f_{b2} = 0$ (none when gravity loaded)

b/c $f_{b2} = 0$

$$\left[\frac{11.4}{921.6}\right]^2 + \frac{1036.8}{1526.3\left[1 - 11.4/616.3\right]} + 0 \leq 1 ?$$

.012 + .692 + 0 ≤ 1

.704 ≤ 1 ✓ ok

$F_c' = 921.6$ psi $> f_c = 11.4$ psi

$F_B' =$ $> f_b = 1036.8$ psi

Combined

$$\left[f_c/F_c'\right]^2 + \left[\frac{f_{b1}}{F_{b1}'\left[1-(f_c/F_{cE1})\right]}\right] + \left[\frac{f_{b2}}{F_{b2}'\left[1-(f_c/F_{cE})-(f_{b1}/F_{bE})^2\right]}\right] \leq 1$$

.704 ≤ 1 ok ✓

Use 3x12 No.1 Redwood for fin for gravity

3a 17

Fin Design Continued

Try 2×12 cross section = 1.5 × 11.5 = 17.25 in²

S = 33.06 in³ M = 4694.8 #-ft

↳ 56337.6 =

$F_b = \frac{M}{S} = \frac{56337.6}{33.06} = 1704.1$

not OK

Try 3×

3"×12" ⤳ for fin

$C_F = 1.5\ (F_b)$ × section = 28.75

$C_F = 1.15\ (F_c)$

$F_b = \frac{4760.8 \times 12}{\frac{(2.5)(11.5)^2}{6}} = 1036.8$ $F_c = \frac{328}{11.5(2.5)} = 11.4$

3×12

$F_b' = 725(1.6)(.8)(1.5)(1.2)(.84) = 1026.3$

$F_c' = 900(1.6)(.8)(1.0)(.8) = 921.6$ psi

Check Combined

$F_{cE1} = \frac{.822 E_{min}'}{(l_{e1}/d_1)^2}$ $l_{e1} = 7' \times 12 = 84"$ $d_1 = 12 in = 11.5"$

$l_{e2} = 14"$ $d_2 = 3 in = 2.5"$

$F_{cE1} = \frac{.822(400000)}{(84/11.5)^2} = 616.3 > f_c = 11.4$ psi

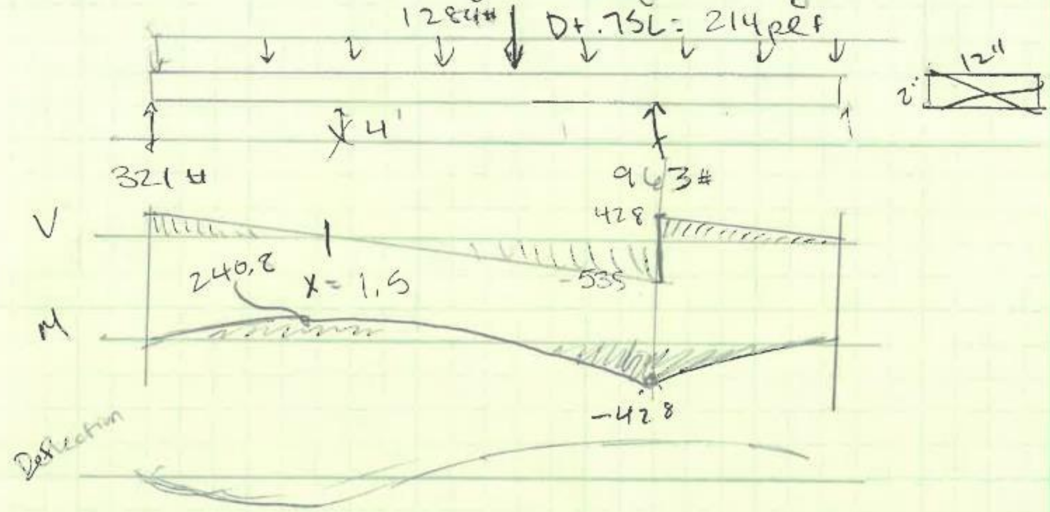
OK

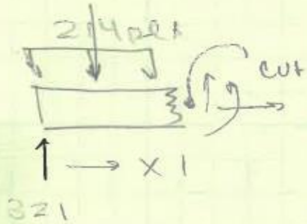
$F_{cE2} = \frac{.822(400000)}{(14/2.5)^2} = 1048.46 > 11.4 = f_c$

OK

3a

Roof Beam Design for gravity





ΣM_{cut}:

x

$321x - 214(x/2) - V(x) = 0$

$V(x) = 321x - 107x$

$V(x) = -214x + 321$

$0 = -214x + 321$

$-321 = -214x$

$x = 1.5$

M_{up} $321(.5)(1.5) = 240.75$

$M_{up} - 428(2)(.5) = 428$

$M_{down} = 2.5(.5)535 = -428$

$M_{max} = 428$ ~~#ft~~

$f_b = \frac{428 \times 12}{\left(\frac{11.5(2.5)^2}{6}\right)} = 428.7$ psi <

Try 3×12

gravity: use 3×12 for roof beam

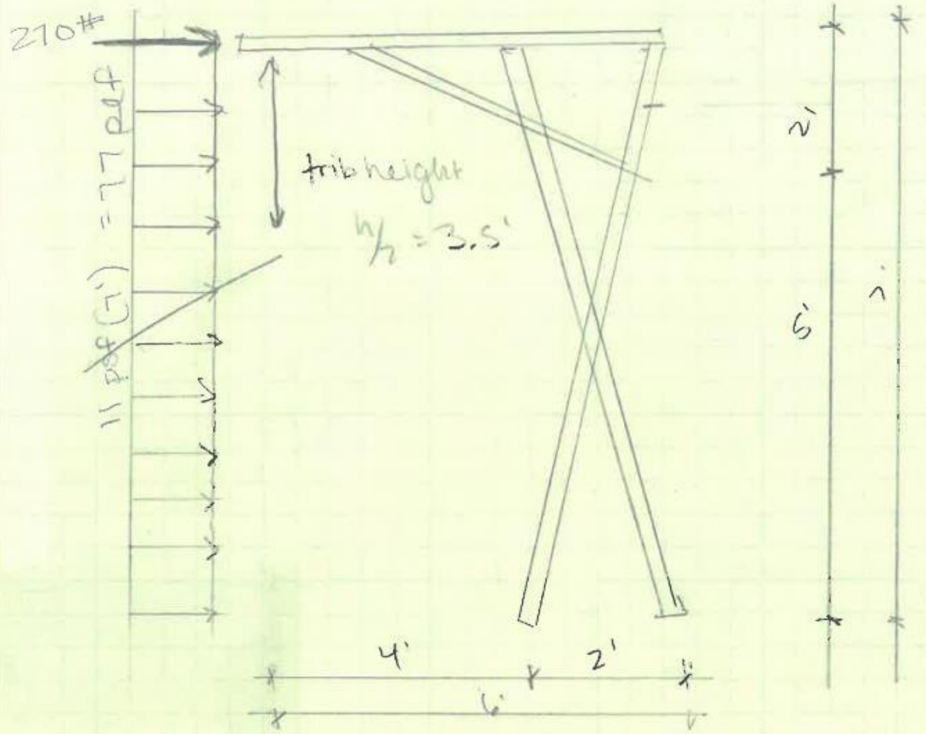
1(2×12)

$F_b = 775(1.6)(.85)(1.0)(1.2)(.8) = 1011.84$

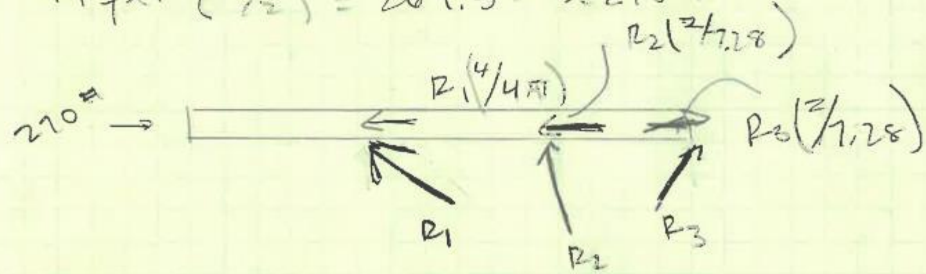
$f_b < F_b = 1011.84$

3a 19

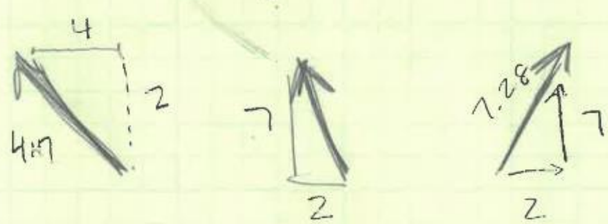
Check wind members



77 plf (7/2) = 269.5# ≈ 270 #



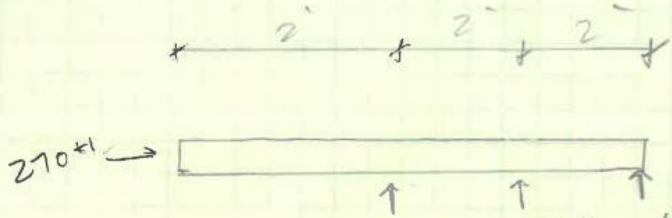
Force Geometry



$R_1 =$

3a

Wind



$R_1(2/4.47)$ $R_2(7/7.28)$ $R_3(7/7.28)$

$$\Sigma F_y = 0 = .447R_1 + .961R_2 + .961R_3$$

$$\circlearrowright \Sigma M_{R_3} = 0 = -4(.447)R_1 - 2(.961)R_2$$

$$1.788R_1 = -1.923R_2$$

$$R_1 = -1.076R_2$$

$$\circlearrowright \Sigma M_{R_1} = 0 = 2(.961R_2) + 4(.961R_3)$$

$$R_3 = -.5R_2$$

$$\Sigma F_y = [.447(-1.076R_2)] + .961R_2 + [.961(-.5)R_2]$$

$$\cancel{.447(-1.0 + .961R_2 + .481R_2}$$

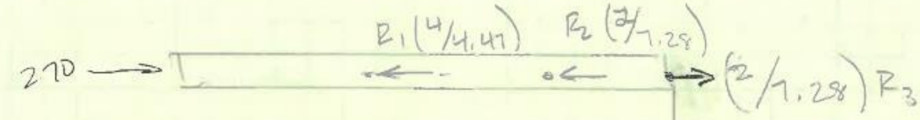
$$\cancel{0 = R_2}$$

All vertical reactions will be 0

only horizontal component of Reactions will go into bracing

21

Wind continued



Take M about G

7'

Ground

$$\circlearrowleft \Sigma M_G = 0 = -270(7) + R_1(.895)(7) + R_2(.275)(7) - .275R_2(7)$$

$$1890 + 1.925R_3 = 6.265R_1 + 1.925R_2$$

$$270 + .275R_3 = .895R_1 + .275R_2$$

$$.275R_3 = .895R_1 + .275R_2 - 270$$

$$R_3 = 3.255R_1 - R_2 - 981.8$$

$$R_3 - R_2 = 3.255R_1 - 981.8$$

$$1890 - 6.265R_1 = -1.925R_3 + 1.925R_2$$

$$-981.8 + 3.255R_1 = R_3 - R_2$$

$$3.255R_1 - 981.8 = -981.8 + 3.225R_1$$

$$R_1 = 0$$

$$R_3 - R_2 = 3.225(0) - 9.81.8$$

$$R_3 - R_2 = -9.81.8$$

$$R_3 = -981.8 + R_2$$

$$\Sigma F_x = 0 = 270 + \overset{R_3}{(-981.8\ R_2)} - .275R_2$$

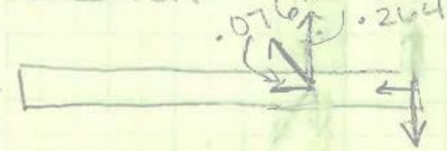
$$-270 = R_2(-981.8 - .275) \rightarrow R_2$$

$R_2 = .275\#$ $\qquad$ $R_3 = -981.5\#$

3a

Wind continued

Check Reaction



$R_1 = 0$ $\quad R_2 = 2/7.28(.275)$ $\quad R_3 = 2/7.28(-981.5)$

$R_{2x} \approx 0.076\#$ $\quad R_{3x} = -269$

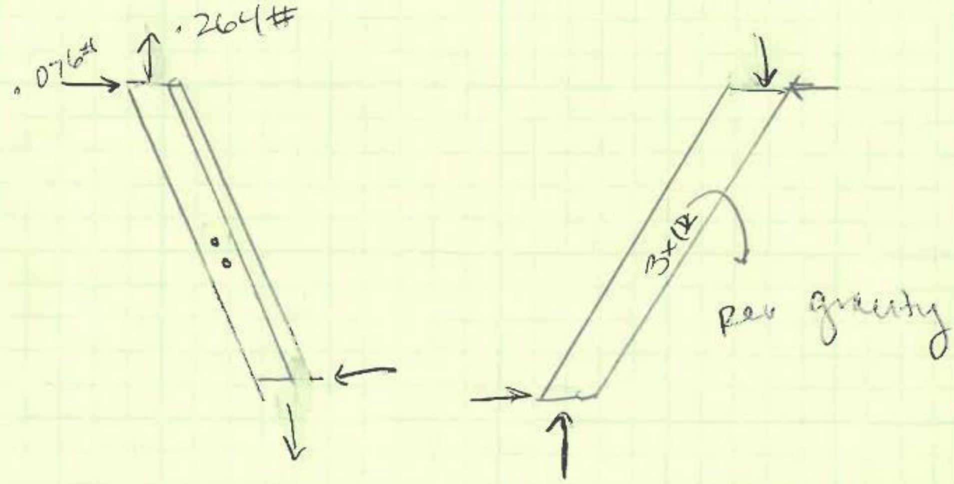
$R_{2y} = 7/7.28(.275)$ $\quad R_{3y} = 7/7.28(-981.5)$

$R_{2y} = .264\#$ $\quad R_{3y} = -943.75$

$\Sigma F_x = 270 - .016 - 269.64$

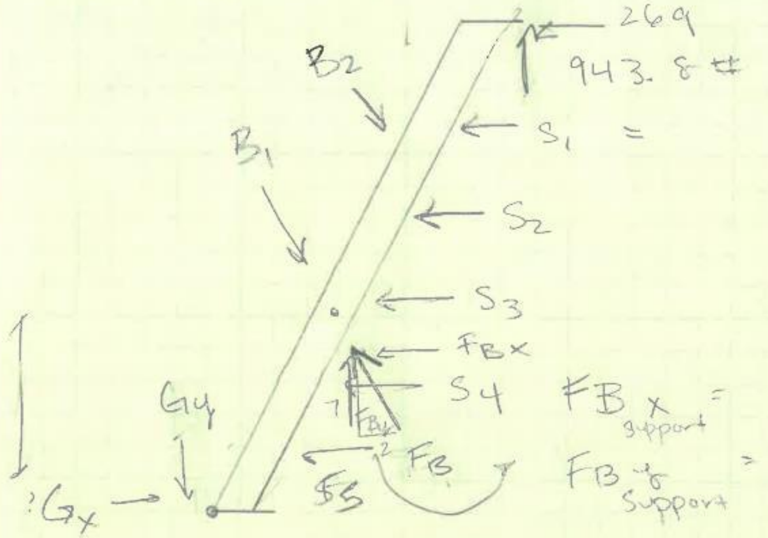
$0 \approx 0$ ✓

Because 2x6 Double Braces are carry essentially 0 load - 2x6 should be and okay size for this bracing arrangement



3a

Wind continued



will neglect B_1 because load from this Brace and B_2 which corresponds to $R_1 = 0$ is essentially 0

$$\Sigma M_G = 0 \quad F_{Bx}(2.5) + 269(7) + 943(1.5) + S_5(2) + S_4(3.2) + S_3(4.4) + S_2(5.6) + S(6.8)$$

Assume $S_1 = S_2 = S_3 = S_4 = S_5$

$$F_{Bx} = .076(2.5) + 269(7) + 943(1.5)$$
$$S_1(2 + 3.2 + 4.4 + 5.6 + 6.8)$$

$S_1 = -171.3$ #

The plywood rings are in compression
- transferring load into other fins in same structure

$G_x = 1125.6$ #

3a

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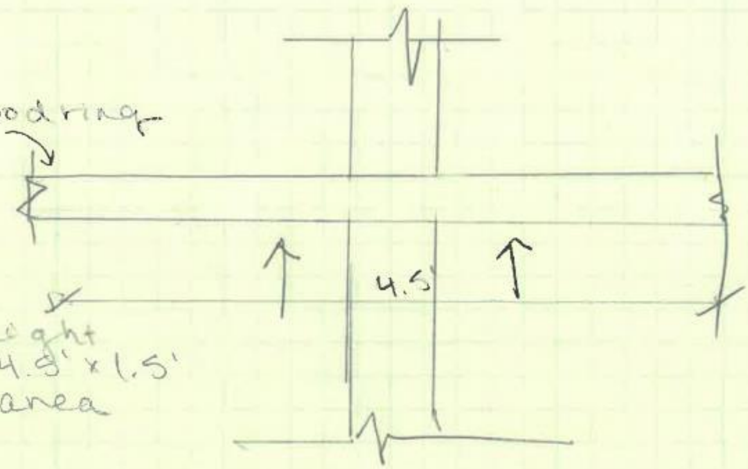
Connections - Calcs

Shelves

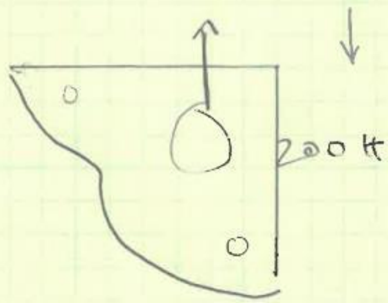


Unit weight
3psf × 4.5' × 1.5'
trib area

20.25 # _ max load at 1 slit of 1 fin intersecting with 1 plywood shelving ring

* There will be support on either side

Connection; Bracket/shelving - Stainless steel
Capacity 200 # each APEX BLACK



$20.25/2 = 10.13$ #

$200 > 10.13$ #

more than ok

Connections Continued - Bolts

NDS Ch12 T12F

Double Shear

Main Member thick 2.5"

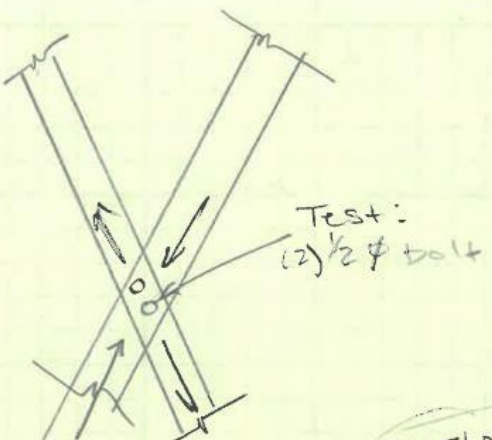
Side member thick 1.5"

Bolt Diameter = 1/2"

Red wood G = .37

Z|| = 1080 # $Z_{s\perp}$ = 640

$Z_{m\perp}$ = 610

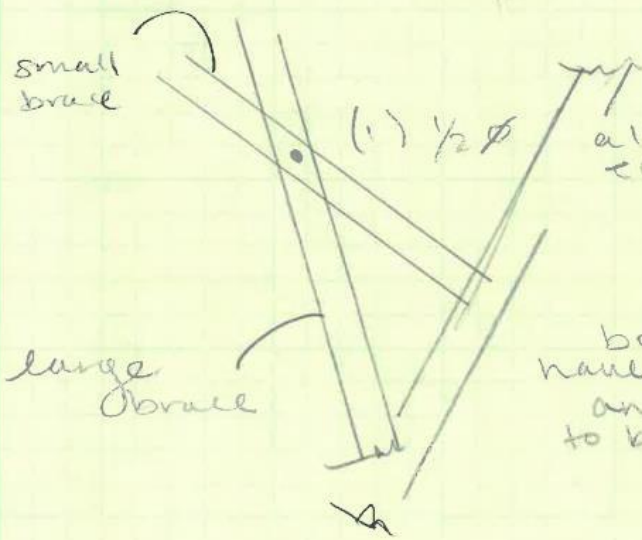


each bolt has capacity of 1080 #

this connection capacity = 2160 #

more than enough for shear and axial in both members

(2) 2x6 - (1) 3x16

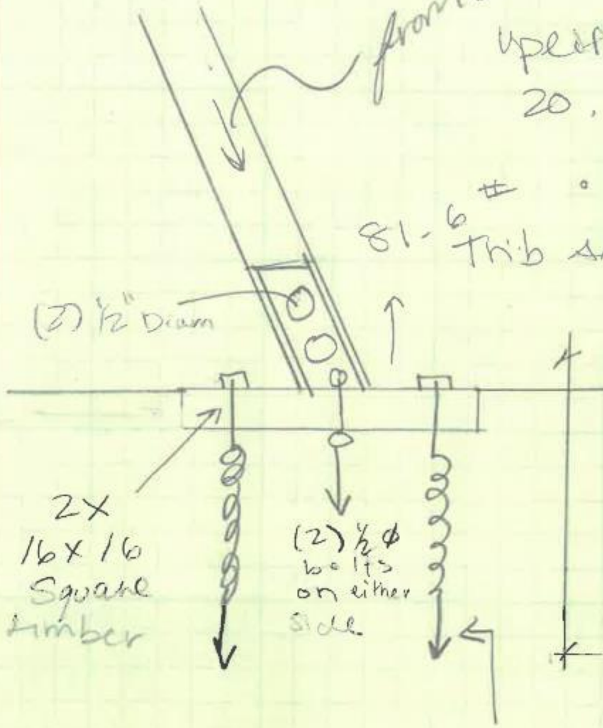


also more than enough to calc 1080 # cap w/ 1 bolt

both these members have very little axial and shear relative to bolt capacity

3a

Foundations



Uplift load

20.4 psf $= .6(23) + .6(11)$

$81.6\#$ Trib area of footing $= 2 \times 2'$ $= 4\ ft^2$

Uplift worst case

$81.6\#$ ↳ good for all bolts in assembly

$\sigma = \frac{P}{A}$ $F_{bearing}$ $1000\ psf = P$

F_c of fin (max axial) ≈ 943 Tension for Wind Analysis

2.5×11.5
28.75

$\underline{963}\#$ Comp for Gravity

governing

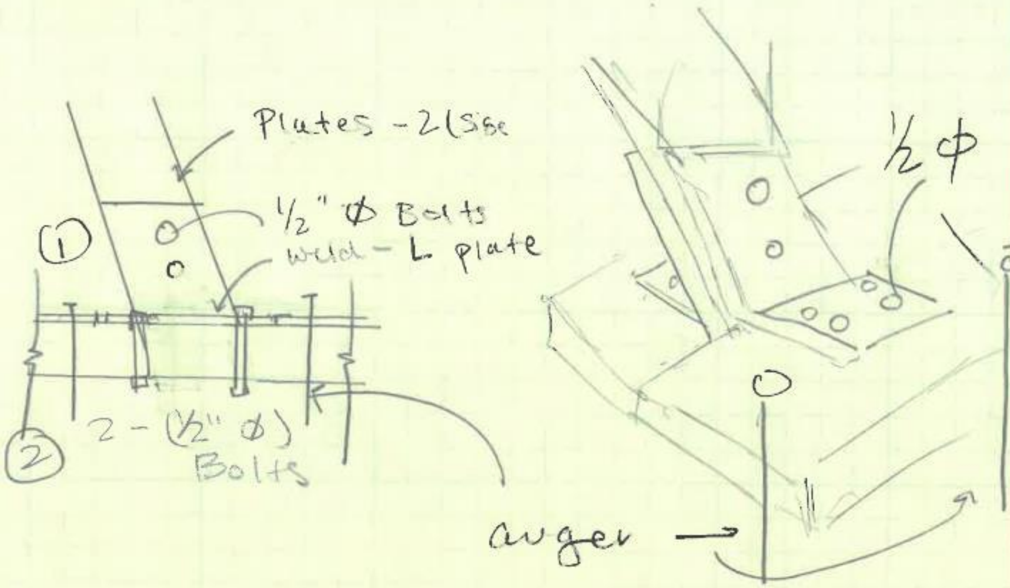
1000 bearing psf $= \frac{963\#}{A}$ A required $= .963\ ft^2$

16" x 16" Board for foundation

$> .96" \times .94"$

ok

NDS T.4



Check $F_{c\perp}$

$F_{c\perp}' = F_{c\perp} \underset{.67}{C_M} \overset{1.0}{C_i} C_b = .67\,(425\text{ psi}) = 284.75$

$f_{c\perp} = \frac{963}{A} = 963\#/(2.5\times 11.5) = 33.5\text{ psi}$

Table 4A NDS Supp / C_M - 4.1.4 NDS

$f_{c\perp} = 33.5$ $\quad$ $F_{c\perp}' =$

1 see above

Bolts in 2 plate steel - double shear

T 12 NDS Double Shear $Z_\perp = 510\# \times 2$
(2) - 1/4" side plates 1020# capacity

2 Bolts on foundation lumber through steel plate

T 12B NDS Single Shear 1/4" side A36 Steel side plate

$Z_\perp = 300\# \times 8 = 2400\#$

963# < 2400# capacity transfer

3a

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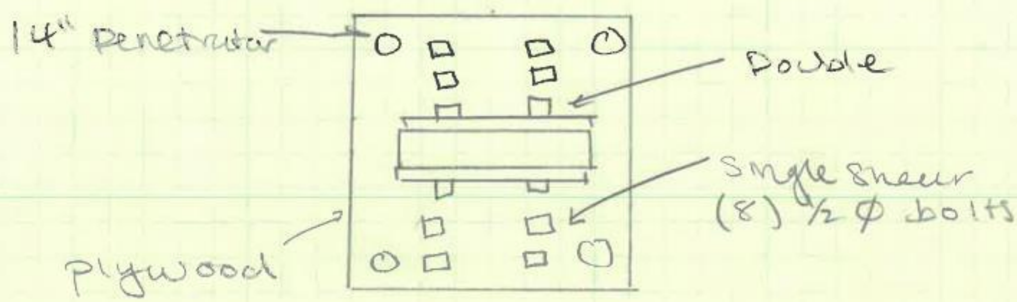
Footing to ground

American Earth Anchors - 14" Penetrator
using (4) - 1 at each corner of footing



Plan of foundation 16" x 16"

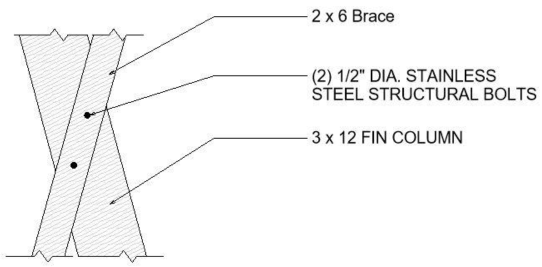
14" penetrator (4) per footing
soil 1 max strength 2.5k x 4
Soil 3 min strength .6 lbs x 4

2.4k - 10k per footing
into ground depending
on site

Material Technical Data
PE14 - STD - Specs per American Earth
Anchors.com

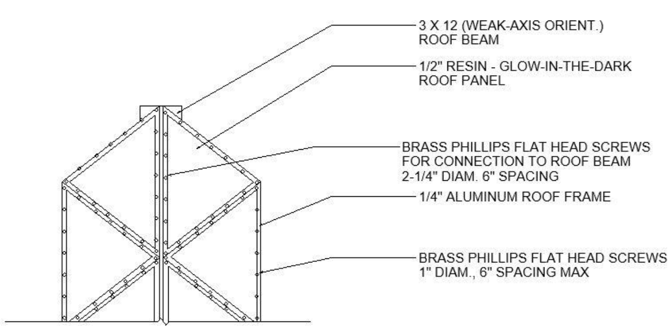
½" square drive installation

Connection Details



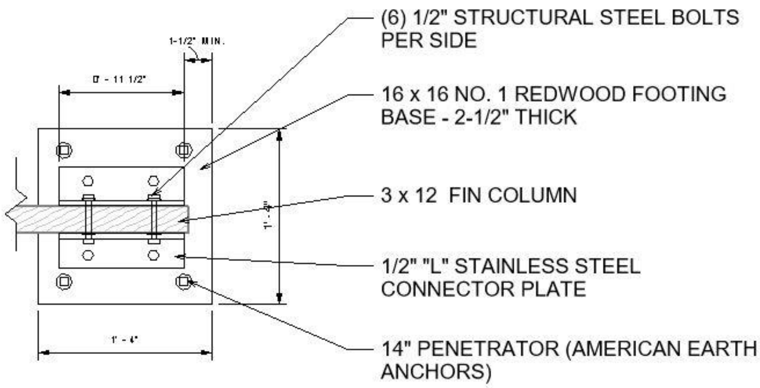
1 FIN TO BRACE CONNECTION
1-1/2" = 1 FT.

2 PLYWOOD SHELF TO FIN CONNECTION
1-1/2" = 1 FT.



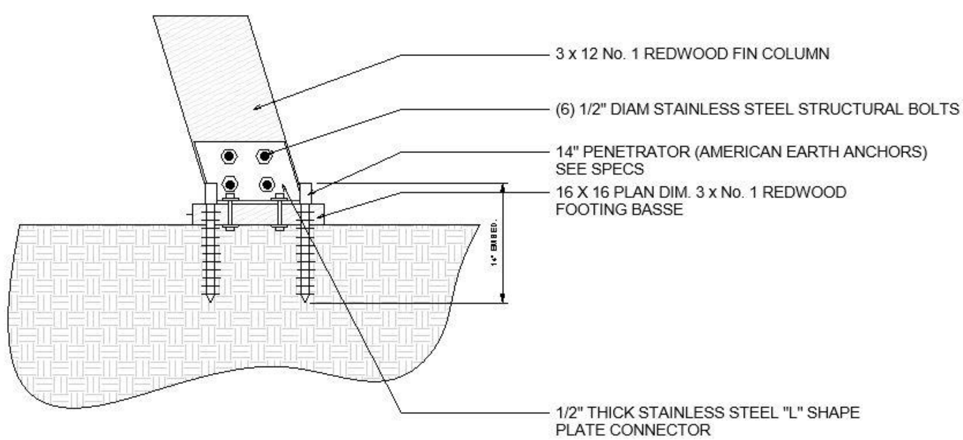
5 ROOF PLAN DETAIL
1-1/2" = 1 FT.

Foundation Details



3 FOOTING PLAN VIEW

1-1/2" = 1 FT.



4 FOUNDATION ELEVATION

1-1/2" = 1 FT.

American Earth Anchors

The best screw you will have in the dirt™

americanearthanchors.com

QUICK REFERENCE

PE14-STD | Specifications

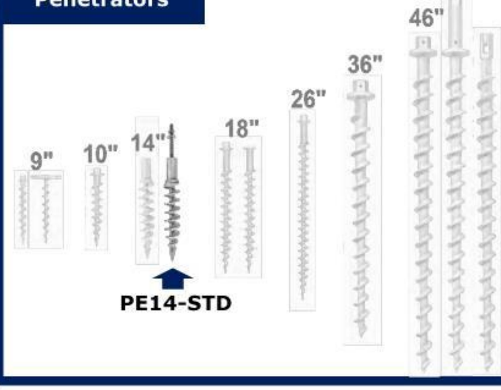
14" Penetrator™

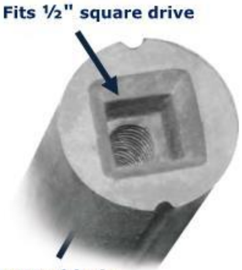
with stud/nut/washer

- **Aircraft-quality cast aluminum 356 alloy**
- **Heat-treated to T6 specification**
- **Install with ½" square drive**
- **Removable**

1.5 lbs (.7 kg)

Penetrators





LOAD CAPACITY

Pullout strength with flight fully embedded

Soil Class 1 Hardpan Asphalt	Soil Class 2 Sandy gravel Very dense sand	Soil Class 3 Silty/clayey sand Silty gravel	Soil Class 4 Loose/med dense sands Loose sands Firm clays	Soil Class 4 Loose fine un-compacted sand
2,500 lb 11.1 kN	1,700 lb 7.56 kN	600 lb 2.67 kN	350 lb 1.56 kN	200 lb 0.89 kN

Soil classification per ASTM D-2487/2488

American Earth Anchors
info@americanea.com
americanearthanchors.com

Contact us for CUSTOM WORK
Size, length, shape, material, prototypes, cable assemblies

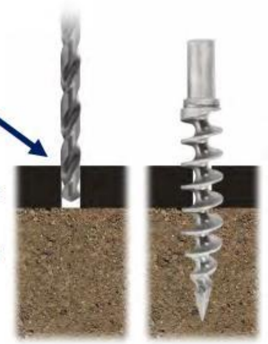
866-520-8511
+1 508-520-8511

PE14-STD | Installation

QUICK REFERENCE

Through asphalt

Drill PILOT HOLE through asphalt



Installation methods

Impact wrench

AEA **T-handle**

American Earth Anchors
info@americanea.com
americanearthanchors.com

866-520-8511
+1 508-520-8511

Renders by Ryan Huddlestun

CONSTRUCTION:

ASSEMBLY, MATERIALS,

TRANSPORTABILITY

Full Size Detail Model

Constructed by Entire Design Team

Detail 1

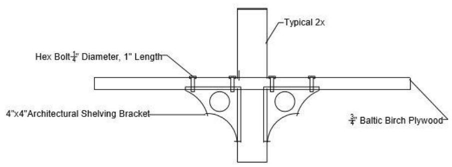
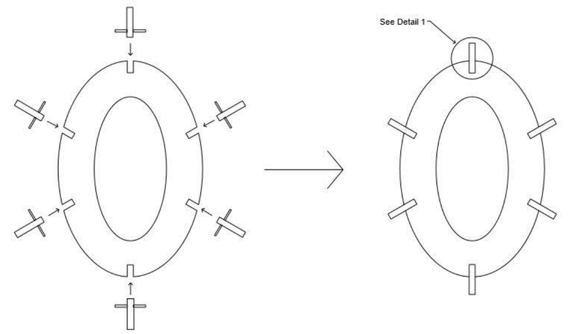
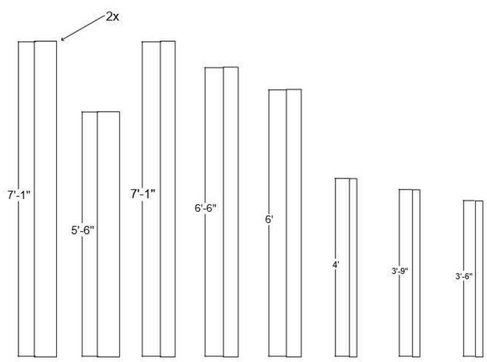
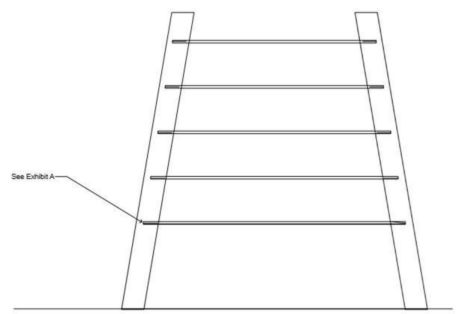
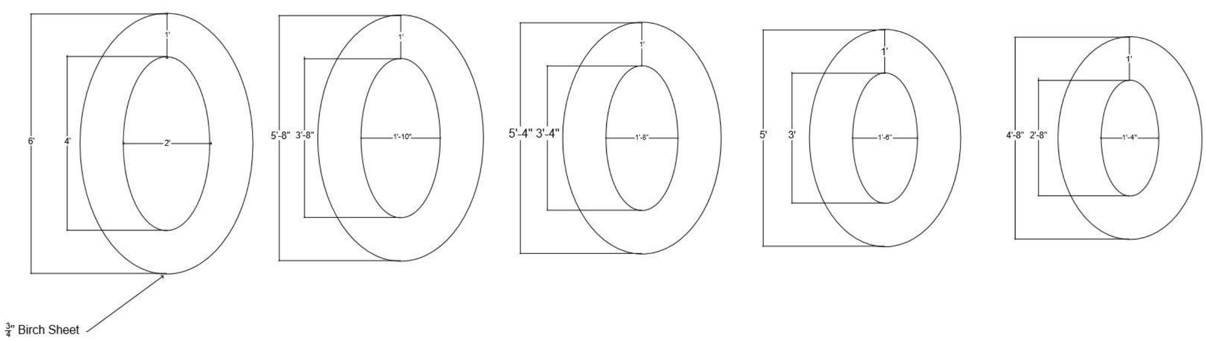


Exhibit A





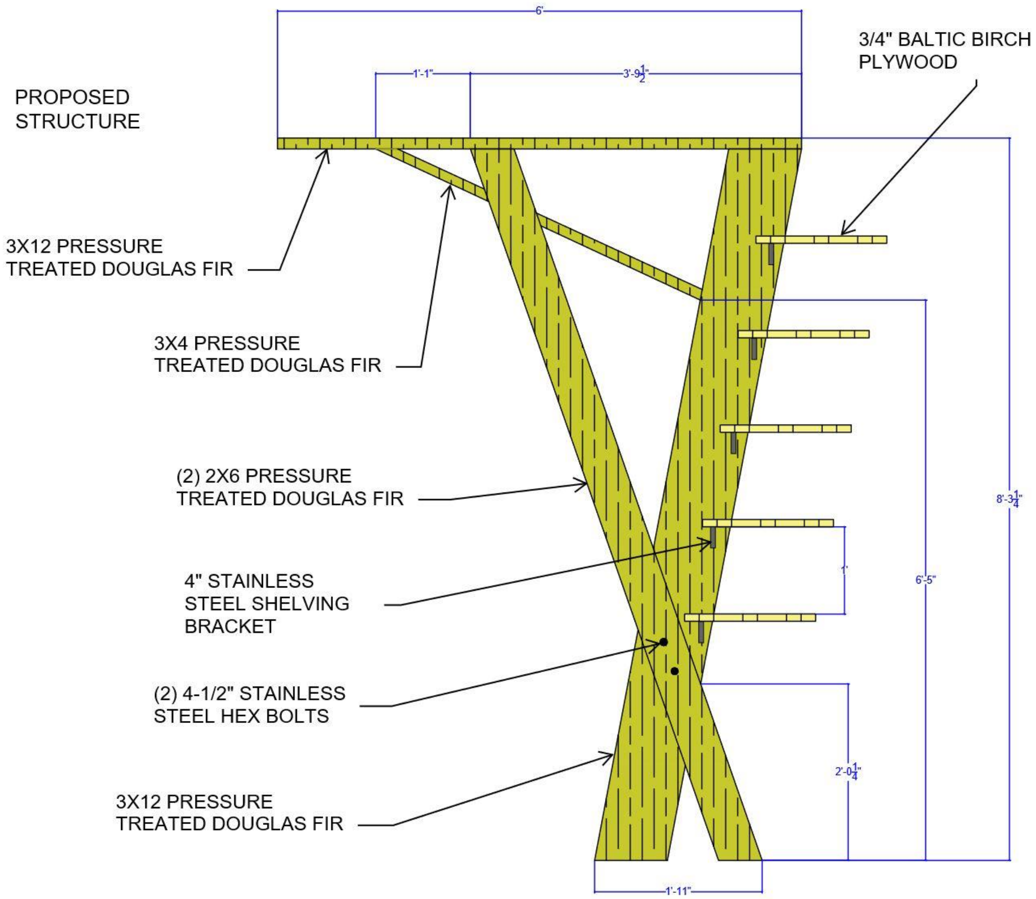




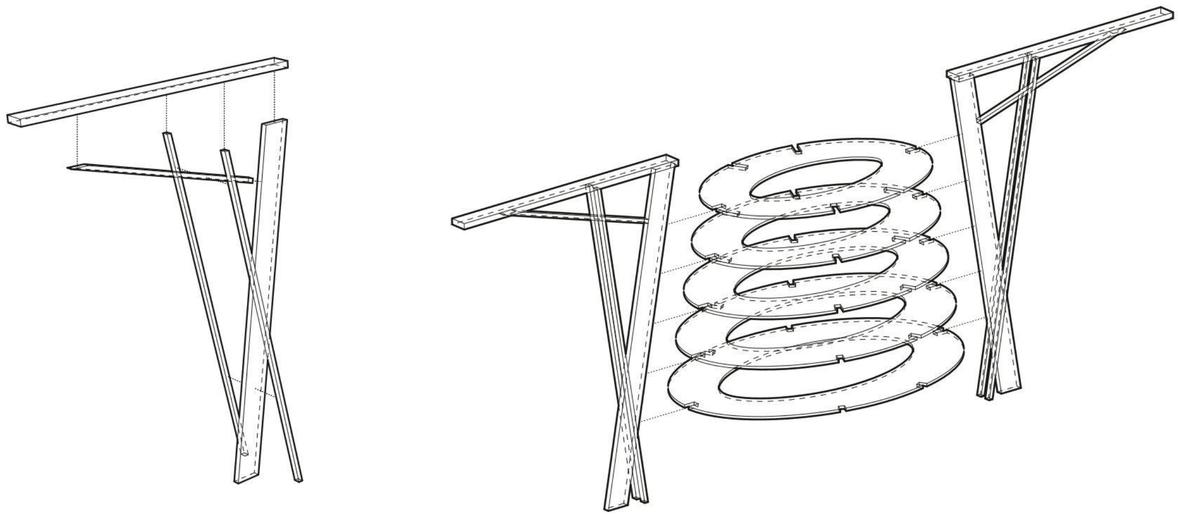
By Alex Beaubien

Typical Fin Detail

By Alex Beaubien



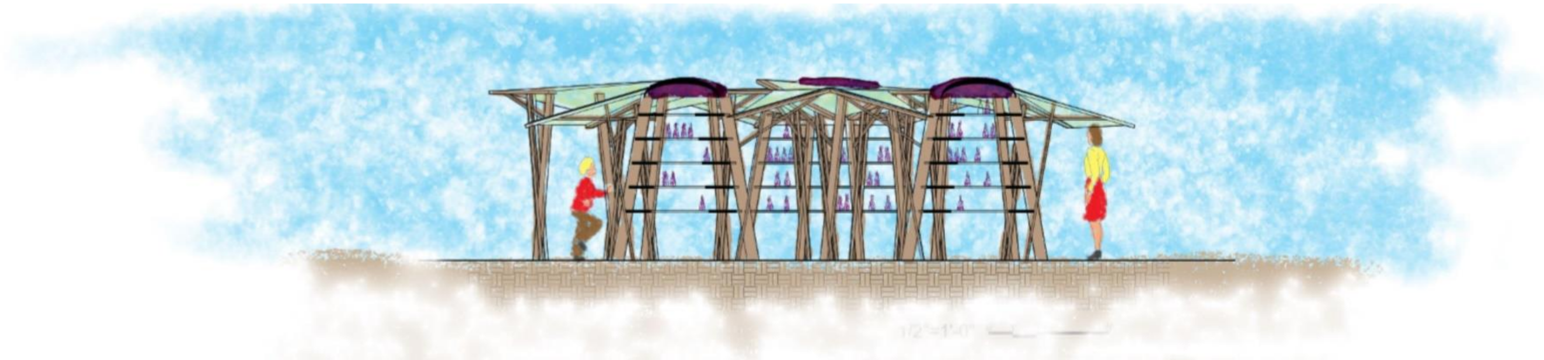
Fin to Rings Deconstructed

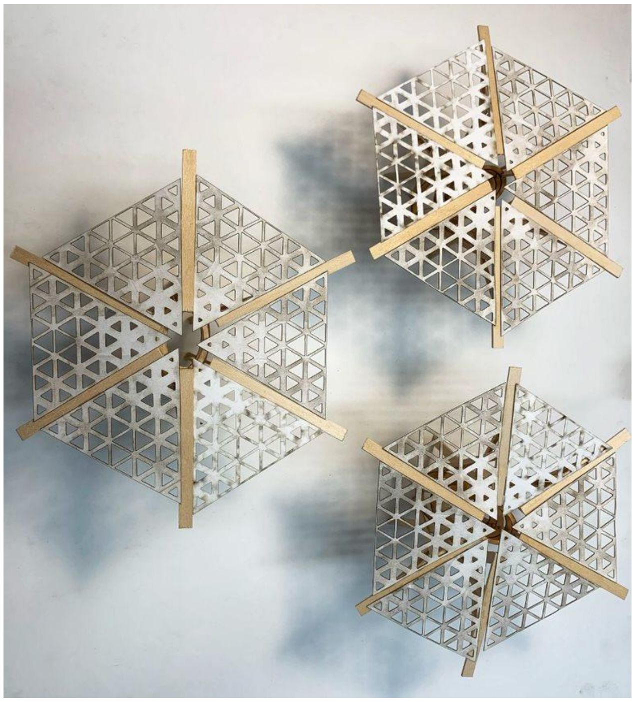


By Alex Beaubien

The overall assembly and deconstruction to transport of this particular structure is relatively straightforward. All the members shall be screwed and bolted and then unscrewed and unbolted when it comes time to move the structure to a new site. Once the Base Rings, Fins and Braces are put together, the roof aluminum and acrylic resin can be installed by screws every 6 inches to for security and shelter. Once deconstructed all the materials should be able to fit in the back of a U-Haul van. All the this can be down with ladders, hand tools, and man power.

Final Project Render and Model





Render and Model by Ryan Huddlestun

REFLECTION

This project, while extremely challenging, taught me a lot about what it's like in the real-world industry. I developed more of an understanding of what it is Architects and Construction Managers values when taking on projects. This Interdisciplinary Project Development (IPD) Method is a clear choice for a project to become a successful product. Having the Engineers and Project Managers, and Estimators in the early stages allows for any mistake to be caught before too much damage has been done.

After this project, I would like to explore the other two disciplines more and become more parallel with these professionals as I am approaching applying for jobs. Having a background that encompasses skills from each of these occupations will be beneficial to my future success and help guide me in any IPD projects that come across my desk down the road.