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

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WINE HISTORY PROJECT PAVILION
SAUSILITO CANYON VINYARD, SAN LUIS OBISPO
~ SUCCULENT PAVILION ~

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

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STRUCTURAL CALCULATION PACKET
SENIOR PROJECT SUBMITTAL
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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.
Objective: Design, Analyze, and Construct a Pavilion that 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 one of the projects I was able to be a part 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
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. The assignment called for us to look into biomimicry. Where we discovered the organism known as the fenestraria. The fenestraria can filter 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.
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 pattern around the outside. I thought this would allow an ease of design when it came to structural stability design. I thought this would be a good starting 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 fenestaria, 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
STRUCTURAL CALCULATIONS
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Below are different forms 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, AND LIVE LOADING PER ASD LOAD COMBOS [ASCE 7.2.4.1]
Team 3a. Overview

- Roof Beam:
  - 2x6
- Brace #2:
  - 2x2
- Brace #1:
  - 2x
- "Fin"
- 5" Plywood 3/4"
- 2 (1/2" Ø Bolts w/ Washer

Summary of Design
1 Bracket

- 3 separate structures
- All self-supporting
  > essentially furniture
- Triangular panels for roof
  - Aluminum - sheet w/ holes
  - Acrylic for aesthetics
- Triangular panels span between roof beams
  - Connected to either w/ screws

- 6 roof panels
- 6 brackets
- 3 rings

Approximate Plan view of Roof Deck
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 for "L" Brace to Beam
9. Slits for Plywood
10. Aluminum Beam for Roof Material
11. Screws Roof to Roof Beam 4'
12. Plywood Rings
13. Shelf (Ply?) to Fin Bracket Connections
## Hand Calculations

### Dead Load take off - Per 1 Structure

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Source Calculation</th>
<th>Total Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>2&quot; x 6 Pressure Treated Red Wood</td>
<td>Engineering Tool Box Pressure</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>2&quot; x 10 Pressure Treated Red Wood</td>
<td>Treated 4 4/1 = 0.3</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2&quot; x 2 Pressure Treated Redwood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3/4&quot; Plywood Ring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Acrylic Panels (3/8&quot;)</td>
<td>Mosaic Corp &amp; Acrylic Weight</td>
<td>2.7 psf</td>
</tr>
<tr>
<td>6</td>
<td>Aluminum Panels (%)</td>
<td>Mosaic Corp &amp; Acrylic Weight</td>
<td>1.8 psf</td>
</tr>
<tr>
<td></td>
<td>Connections (MISC)</td>
<td>+</td>
<td>4 psf</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>23 psf</strong></td>
<td></td>
</tr>
</tbody>
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### Live Load - use 10 psf for ASCE-7 + 4.2-1

Uninhabitable attic space w/ no storage
Wind Loading

See ASEE Determination Figure
1. Region Central California Coast 92 mph
2. Risk Category II
   Exposure C

Ch. 29 Wind Loads on Buildings, Appurtenances, Other Structures
Building Open 26.2
Each wall is at least 80% open
My build has no walls, very open
\[ A_0 = A_g^{0.8} \]

Structure - takes across loading (structure is open structure/Frame)
in accordance with 29.1 User Note

3. \( K_d \) - wind directionality factor \( T \). 26.6.6-1
   \( K_d = 0.95 \) Trussed Towers/all other \( x \)-sections

- Exposure : C
- \( K_{za} \) - topographic factor
  \( K_{za} = (1 + K_1 K_2 K_3)^2 \)
  \( K_1 = 1.43 \quad \left( \frac{H}{L} = 5 \right) \)
  \( K_2 = 0.75 \quad \left( \frac{H}{L_d} = 1 \right) \)
  \( K_3 = \left( \frac{2}{L_1 - 1.9} \right)^2 = 0.29 \)
  \( K_{za} = (1 + (1.43)(0.75)(0.29))^2 = 1.2 \)

\[ K_{za} = 1.2 \]
Wind continued
3. * Ke Ground Elevation Factor 20.9

\[ \text{Sea level Altitude} = 285.4 \text{ ft above S.L.} \]
\[ h = 0, \quad ka = 1.00 \]

* Dust Effect Factor G 20.11
\[ C_d = 0.85 \quad \text{for rigid building or structure} \]

4. Velocity Pressure exposure coefficient \( \Gamma 20.10-1 \)

\[ \text{Height above ground level} = 15 \quad \text{C Exp. 0.85} \]

\[ \frac{v_2}{v_1} = 0.85 \]

5. Velocity pressure \( q_2 = 9h \) \( \text{Eq. 20.10-1} \)

\[ q_2 = 0.0025 \times k_2 \times k_4 \times 1.0 \times V^2 \left( \frac{161}{92}\right) \]
\[ q_2 = 0.0025 \times 0.85 \times 1.2 \times 1.15 \times 1.0 \times 0.85 \]
\[ q_2 = 20.99 = 21 \text{ psi} \]

6. \( C_p \) - face coefficient \( \text{Fig. 28.4.3 Trussed Tower} \)

\[ C_p \]

Notes for towers with rounded members...

* fill \( 0.518^2 + 0.57 \) but not \( > 1.0 \)

* Ratio of solid area to gross area of

\[ \text{solid tower face} \]
\[ \text{Gross} 848 \text{ ft}^2 \]
\[ \text{Solid} 713 \]
\[ 13/48 = 0.27 \]
\[ 51(0.27)^2 + 0.57 = 0.61 \quad \text{psi} \]

7. Wind Force/Pressure \( \text{Eq. 29.4.1} \)

\[ f = q_2 GC \]
\[ \text{Pressure} \]
\[ q_2 GC = 21 \times (0.85) \times (0.61) = 10.84 \]

\[ \text{wind pressure} = 11 \text{ psi} \]

\[ 29.4 \text{ AEP} \]
Load Combsos - ASD 2.4.1 ASCE

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

Use 37.1 psf
Use 20.4 psf for uplift
Beam design

1 - Standard Roof Beam

\[ D + .75L = \frac{N}{2} \left[ 23 + .75(10) \right] = 214 \text{ ft}^2 \]

Area

\[ C_{\text{MA}} = 0 - 1284(3') + R_3(4') + R_2(2.5') \]

\[ R_3 = \frac{3852 - 2.44}{4} \]

\[ R_3 = 913 - 0.625R_2 \]

\[ C_{\text{Mc}} = 0 = 350(7') - 427(1') - R_2(15') - R_1(4') \]

\[ 1284 = R_2(15) + 4R_1 \]

\[ R_1 = \frac{(1284 - 15R_2)}{4} \]

\[ F_y = -1284 + R_1 + R_2 + R_3 \]

\[ 0 = -1284 + (321 - .375R_2) + R_2 + (913 - .625R_2) \]

\[ 1284 - 321 - 963 = R_2(-.375 + 1 - .625R_2) \]

\[ 0 = R_2 \text{ (1)} \]

\[ R_2 = 0 \]
Brace Design

Rotate for loads.

\[ \begin{align*}
F_y &= \left(\frac{3/4 \times 112}{453}\right) \times 963 = 460.7 \\
F_x &= \left(\frac{3.67}{4.18}\right) \times 963 \\
F_y &= 460.7 \\
F_x &= 844.8
\end{align*} \]

Area:

(trial size 1.5\(^2\) x 1.5\(''\)) = 2.25 in\(^2\)

\[ F_{c_{11}} = 3.75 \text{ psi} \]

SEE C VALUES ON PREVIOUS PAGES

Design Values

NDS - Table 4.4: Redwood

\[ F_{c} = 900 \text{ psf} \]

\[ F_{c} = 900 \times 1.6 \times 0.8 \times 0.8 \\
= 375.47 \text{ psi} \]

\[ F_{c} = 921 \text{ psi} \]

\[ \text{OK 2\times2 for brace 2 with gravity loading} \]
Hand Calculations

Adjustment Factors - C's

(NDS - Ch. 4) (NDS Support Tables)

Sawn Lumber: C_d C_m C_c C_l C_f C_u

C_d = 1.6

C_m = \frac{F_o}{F_c} \frac{F_u}{F_o} \frac{E}{E'}

C_c = 0.85 \frac{1.97}{67} \frac{8}{9} \frac{9}{1.1}

Since outdoor structure - assume at same point \( M_e > 19\% \) - C_m < 5 x Sawm

F_c = when F_c F_c \leq 750 \Rightarrow C_m = 1.0

F_d = when F_d F_c \leq 1,150 PSI \Rightarrow C_m = 1.0

C_f = 1.5, 1.5, 1.5, 1.2, 1.2, 1.05

No. 1 2 x 4 2 x 8

C_u = 1.0, 1.1, 1.18, 1.16, 1.2

2 x 2 2 x 4 2 x 6

C_i incising factor - pressure treated lumber being used (preservative)

C_i = 0.80 \frac{F_o}{F_c} \frac{F_u}{F_o} F_c \frac{E}{E'}

C_f = 1.0 (next pages)
Hand Calculations

C's continued Adjustment Factor

\[ N_D = 3.3:3 \]

2x6 Redwood No.1
2x8
2x10
\[ d = \frac{b}{2} \]
\[ d = \frac{b}{2} \]

1.4.1.2 6.5
1.5
2.3
1.4.1.2 7.5/15 = 5
1.4.1.2 19.5/15 = 6.3

2x4
4.4.1.2
\[ 2.3 \]
\[ 1.5 \]

1.6
\[ \frac{1.5}{1.5} = 1.00 \]

Error = 400,000
(NDS Supp 74A)

\[ L = 1.33 (2.5) = 1.66 \]

\[ \frac{2x6}{2x6} \]

\[ \frac{2.6}{2.6} \]

\[ \frac{1.5}{2} \]

\[ d = \frac{b}{2} \]

\[ b = 6 \]

\[ N_D = 3.3:3 \]

\[ F_L = \frac{1.20 (40,000)}{(3809)^2} \]

\[ F_D = \frac{3.144}{109616} \]

\[ F_B^* = \frac{F_D (C_5) (C_m) (C_e) (C_i)}{F_D} \]

\[ F_B = 775 \]

\[ N_D = 3.3:3 \]

\[ F_B^* = 775 (1.6)(0.5)(1.3)(0.95) \]

\[ F_B^* = 104616 \]

\[ C_L = 1 + \left( \frac{0.3144}{109616} \right) \]

\[ \left\{ 1 + \left[ \frac{0.3144}{109616} \right] \right\} ^{0.95} \]

\[ C_L(2x6) = 0.99 \times 1.0 \]
Hand Calculations

CL Adjustment Continued

\[ CL (2 \times 8) \]
\[ \Delta L = 1.66 \]
\[ \Delta T = 2 \]
\[ b = 8 \]
\[ \sqrt{7.5^2} \]
\[ F_{B} = 1.44(1.5) \]
\[ F_{E} = \frac{1.20}{40000} \]
\[ F_{BE} = 105.84353.7 \]
\[ C_{L} = \frac{1}{40000} \]
\[ 2 \pm \sqrt{9.9^2} \]
\[ C_{L} (2 \times 8) = 0.999 \approx 1.0 \]

\[ CL (2 \times 10) \]
\[ \Delta L = 1.46 \]
\[ \Delta T = 2 \]
\[ b = 10 \]
\[ \sqrt{9.5^2} \]
\[ F_{B} = 927.52 \]
\[ F_{BE} = \frac{1.20}{40000} \]
\[ 174.19073.89 \]
\[ C_{L} = 0.999 \approx 1.0 \]
Beam Design Continued

\[ R_2 = 0 \text{ zero force number} \]
\[ R_1 = 321 - 0.375(0) \quad R_1 = 321 \text{ #} \]
\[ R_3 = 963 - 0.625(0) \quad R_3 = 963 \text{ #} \]

Reaction Check
\[ \sum F_y = -284 + 0 + 963 + 321 = 0 \quad \sum F_y = 0 \]

\[ \sum M = 0 = R_2(0) - 1284(3) + (4')(963) \quad \sum M = 0 \]
\[ R_1 = 321 \text{ #} \quad \therefore R_2 = 0 \quad R_3 = 963 \text{ #} \]

in gravity

2 x 6, 2 beams not pictured
Hand Calculations

Fi Design

13.2
13.2
13.2
963
13.8
13.8
13.8

Next page for gravity cases

13.5 #
13.5 #

2.8
(Ring) 7/36

W = 3 psf
A x 4.5 ft^2

Page: Wind loading distribution

Wind Diagram - Primary

Wind Load: 2 #
Hand Calculations

Fin Design

\[ B_1 = 0 \# (R_2) \]
\[ B_2 = (F_3 \times \text{comp}) = 844.8 \# \]
\[ C = R_1 = 321 \]

Rotate to find C comps

\[ C_y = \frac{7}{4146} (321) \]
\[ C_y(\text{Actual}) = 313.9 \]

Free Body diagram

\[ 844.8 \# \text{ out (R2-gravity)} \]
\[ 313.2 \]
\[ C_x = \]

MUST check: Bending (per gravity loads)

Comp

Combination \( F_0, F_c \)

Cross section: \( 1.5 \times 8.5 = 8.25 \text{ in}^2 \)

\[ F_c = \frac{8 \times 3.9}{1.5 \times 8.5} = B_k \]
Hand Calculations

Load Path Exploration

Design Loads

\[ F_{c} = 1013.76 \text{ psi} \]

\[ F_{c}^{'prime} = 1179.3 \]

\[ F_{c}^{'prime} < 1013.76 \quad \text{Fb design is not OK} \]

\[ M_{\text{Max}} = 4694.8 \quad \text{lb-ft} \]

\[ M_{\text{Max}} = 4746.8 \]

\[ \sum F_y = 134.9 \quad \text{lb} \]

\[ \sum F_y = 134.9 - 67.25 + 12 = 0 \]

\[ 12 = 912.05 \]

\[ 134.9 - 67.25 = 67.65 \]
Fin Design Continued
Combined Loading Continued

\[ \frac{R_b}{b^2} = \sqrt{\frac{400}{b^2}} = \sqrt{\frac{148}{115}} = 5.08 \]

\[ \frac{F_{bc}}{b} = \frac{1.20 \times 5.08}{5.08} = 1.20 \times 0.0005 = 1843.3 \text{ psi} \]

\( f_b = 1036.8 \text{ psi} < 1843.3 \text{ psi } \text{ OK} \)

\( f_c = 0 \) (since when gravity loaded)

\[ \begin{align*}
\left[ \frac{11.4}{921.3} \right]^2 + \frac{1036.8}{1626.3} - 11.4 & \leq 1 \\
0.012 & \leq 0
\end{align*} \]

\( 0.012 \leq 0 \leq 1 \)

\( 0.04 \leq 1 \text{ OK} \)

\( F_c' = 921.6 \text{ psi} > f_c = 11.4 \text{ psi} \)

\( F_b' = 1036.8 \text{ psi} \)

Combined

\[ \frac{f_b'}{F_c'} + \left[ \frac{f_c'}{1 - 1.4 f_b'} \right] + \left[ \frac{f_b'}{F_c'} \left[ 1 - \left( \frac{f_b'}{F_c'} \right) \left( \frac{f_c'}{F_c'} \right) \right] \right] \leq 1 \]

\( 0.04 \leq 1 \text{ OK} \)

Use 3x12 No. 1 redwood per fin for gravity
Hand Calculations

Fin Design Continued

Try 8 2 x 12 Cross Section = 1.5 x 11.5 = 17.25 in²
S = 33.06 in² M = 4,694.8 lbs
L = 56,337.6 lbs

\[ F_b = \frac{M}{S} = \frac{56,337.6}{33.06} = 1,704.1 \text{ lbs} \]

Not OK

Try 3 x 12” 3 x 12” U’ for fin

\[ C_F = 1.5 \ (F_b) \quad \text{X section} = 23.75 \]

\[ F_b = \frac{4740.8 \times 2.7036}{17.5 \times 11.5^2} \quad \text{F_c} = \frac{1328}{11.5(2.5)} = 11.4 \]

\[ 3 \times 12 \]

\[ F_b = 72.5 \ (1.5) \ (11.5)(1.2)(.8) = 1,624.3 \]

\[ F_c = 900 \ (1.5)(.8)(1.0)(6.8) = 921.6 \text{ psi} \]

Check Combined

\[ F_c e_1 = 822 \text{ ksi} \]

\[ (e_c / d_1) \]

\[ L_e_1 = 7.1 \times 12 = 84” \]

\[ L_e_2 = 14” \]

\[ d_1 = 12” \quad d_2 = 3” \]

\[ F_c e_1 = \frac{822 \times 1000000}{(84/11.5)^2} = 616.3 > F_c = 11.4 \text{ psi} \]

OK

\[ F_c e_2 = \frac{822 \times 1000000}{(14/2.5)^2} = 1045.4 \text{ psi} > 11.4 = F_c \]

OK
Hand Calculations

Roof Beam Design for Gravity

12 ft 7.5 L: 214.8 ft

V

M

Load Path Exploration

\[ \text{Max} \]

\[ \text{Try} 3 \times 12 \]

\[ f_b = \frac{42.8 \times 12}{11.425} \]

\[ f_b = \frac{42.8 \times 12}{11.425} \]

\[ f_b = 778 \times (1.0) \times (0.85) \times (1.0) \times (1.2) \times (1.8) = 1011.84 \]

\[ f_b < F_b = 1011.84 \]
Hand Calculations

Check Wind Members

 trib height
\( \frac{h_2}{2} = 3.5' \)

\[ \text{Load Path} = 770 \, \text{lb} \]

\[ \text{H1 (wind)} = 209.6 \, \text{lb} \times 770 \, \text{lb} \]

\[ R_1 (\frac{h_1}{2}) \]

\[ R_2 (\frac{h_2}{2}) \]

\[ R_3 (A, 2v) \]

Force Diagram

\[ R_1 = \]

\[ 7.28 \]
Hand Calculations

\[ \mathbf{F}_y = 0 = 0.447R_1 + 0.961R_2 + 0.961R_3 \]
\[ GEM_{R_3} = 0 = -4(0.447)R_1 - 2(0.961)R_2 \]
\[ 1.785R_1 = -1.923R_2 \]
\[ R_1 = -1.074R_2 \]
\[ GEM_{R_2} = 0 = 2(0.961R_2) + 4(0.961R_3) \]
\[ R_3 = -0.5R_2 \]
\[ \mathbf{F}_y = \left[ 0.447\left( -1.074R_2 \right) \right] + 0.961R_2 + 0.961\left[ -0.5R_2 \right] \]
\[ 0 = R_2 \]

All vertical reactions will be 0

Only horizontal component of reactions will go into bracing
Weld continued

\[ R_1 \left( \frac{4}{3}, 0 \right) \quad R_2 \left( \frac{3}{2}, 0 \right) \]

\[ \text{Take W about } C \]

\[ \sum M_C = 0 = -270 \left( \frac{3}{2} \right) R_1 \left( \frac{4}{3}, 0 \right) + \left( \frac{3}{2} \right) R_2 \left( \frac{3}{2}, 0 \right) \]

\[ \sum R_0 + 1.925 R_2 = 6.25 R_2 + 1.925 R_2 \]

\[ 270 + 1.275 R_2 = 0.895 R_1 + 1.275 R_2 \]

\[ 0.275 R_2 = 0.895 R_1 - 270 \]

\[ R_2 = 3.255 R_1 - R_2 - 9.81 \text{ Y} \]

\[ R_2 = 3.255 R_1 - 9.81 \text{ Y} \]

\[ 1890 - 6.275 R_1 = -1.925 R_3 + 1.925 R_2 \]

\[ -9.81 + 3.255 R_1 = R_3 - R_2 \]

\[ 3.255 R_1 - 9.81 \text{ Y} = -981.8 + 3.275 \text{ Y} \]

\[ R_1 = 0 \]

\[ R_3 - R_2 = 3.225 (0) - 9.81 \text{ Y} \]

\[ R_2 = -9.81 \text{ Y} \]

\[ R_3 = 9.81 \text{ Y} + R_2 \]

\[ \sum F_x = 0 = 270 \left( -981.8 + R_2 \right) - 275 R_2 \]

\[ -270 = R_2 \left( -981.8 - 275 \right) - R_2 \]

\[ R_2 = 0.275 \text{ Y} \]

\[ R_2 = -981.5 \text{ Y} \]
Hand Calculations

Wind Load

Check Reaction

\[ R_1 = 0 \]
\[ R_x = \frac{270 \times 31.25}{275} = 31.24 \text{ kips} \]
\[ R_y = \frac{270 \times 21.25}{275} = 21.23 \text{ kips} \]
\[ R_x = 0.314 \text{ kips} \]
\[ R_y = 0.212 \text{ kips} \]

\[ S \cdot F_x = 270 - 0.16 - 269.64 = 0 = 0 \]

\[ R \]

Because 2x6 double braces are carrying essentially 0 load, 2x6 should be an okay size for this bracing arrangement.
Wind continued.

will neglect \( B_1 \) because load from this brace and \( B_2 \) which corresponds to \( R_1 = 0 \) is essentially 0.

\[
\begin{align*}
\mathcal{L} \mathcal{M}_{y_3} &= 0 \\
FB_x (2.5) + 269 (7) + 943 (1.5) + S_3 (2) + S_4 (3.2) + S_5 (4.4) \\
&+ S_2 (5.4) + S (16.8)
\end{align*}
\]

Assume \( S_1 = S_2 = S_3 = S_4 = S_5 \)

\[
\begin{align*}
FB_x &= .07(6)(2.5) + 269 (7) + 943 (1.5) \\
S_1 (2 + 3.2 + 4.4 + 5.6 + 6.8) \\
S_1 &= -171.3 \# \\
\end{align*}
\]

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

\( G_x = 1126.6 \# \)
Connections - Calc

Shelves

1 plywood ring

Unit weight
3 psf x 4.5" x 1.5"
in plus 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 ft

200 > 10.13 ft

More than OK
Connections Continued - Bolts

NDS CH12 T12

Double Shear

Main Member thick 2.5"

Side member thick 1.5"

Bolt Diameter = 1/2"

Red Wood G = 37

211 = 1080 #
Z_k1 = 640
Z_k2 = 610

Each bolt has capacity of 1080 #
In this connection capacity = 2160 #
more than enough for shear and axial in both members

(2) 2 x 6 - (1) 3 x 16

small brace

also more than enough to call 1080 #

CAPE 6/1

bolt

large brace

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

From analysis:

Uplift load
20.4 ksf =

81.6 #

Thin area of footing:

\[ 2 \times 2' \times 6 \]

= 4 ft

Uplift worst case:

81.6 #

Lok good for all bolts in assembly.

\[ \sigma = \frac{P}{A} \]

F bearing max psi = 80

Ft of fin (max axial) = 9.43 tension

For Wind Analysis:

2.5 \times 11.5

28.75

= 9.43 ksi for Comp for

Gravity governing

1000 bearing = \[ \frac{9.43}{A} \] #

A required = 9.43 ft

16" x 16" Board for foundation

> 16" x .94" OK
Hand Calculations

NDS T.4

Plates - 2 (see)

1/2" Ø Bolts
with - L plate

2 - (1/2" Ø)
Bolts

Check $F_{ct}$ = 1.0

$F_{ct} = \frac{F_{ct}}{C_{t}} = 0.67 (425 \text{ psi}) = 284.75$

$F_{ct} = \frac{F_{ct}}{A} = \frac{10400}{(2.5 \times 11.5)} = 33.5 \text{ psi}$

Table 4A NDS Supp / $C_{w} = 4.14$ NOS

$f_{ct} = 33.5$

Check $F_{ct}$ =

1) See above
Bolts in Z plate steel - double shear

T12 NDS Double shear $Z_{L} = 810 \# \times 2$

(2) 1/4" side plates

1020# capacity

2) Bolts on foundation lumber through steel plate

T12B NOS Single shear 1/4" side 3# x 10# Steel side plate

$Z_{L} = 300 \# \times 8 = 2400 \#$

$963 \# < 2400 \#$ Capacity transfer
Footing to ground

American Earth Anchors - 14" Penetrator

Using (4) - 1 at each corner of footing

14" Penetrator

Double

Single Shear

8) 1/2 ø bolts

Plywood

Plan of foundation 16" x 16"

14" Penetrator (4) per footing

Soil 1 max strength 2.5 k - 4
Soil 3 min strength .6 lb/s x 4

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

Material Technical Data
PEIH-STD - specs per American Earth Anchors.com

1/2" 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.

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

- 2 x 6 Brace
- (2) 1/2" Dia. Stainless Steel Structural Bolts
- 3 x 12 Fin Column

- 1" Plywood Shelf Bracket
- (2) Stainless Shelf Brackets (Apex Black Steel Shelf Brackets)
- 3 x 12 Pressure Treated No. 1 Redwood Fin Column

- 3 x 12 (Weak-Axis Orient.) Roof Beam
- 1/2" Resin - Glow-In-The-Dark Roof Panel
- Brass Phillips Flat Head Screws for Connection to Roof Beam 2-1/4" Dia., 6" Spacing
- 1/4" Aluminum Roof Frame
- Brass Phillips Flat Head Screws 1" Dia., 6" Spacing Max
Foundation Details

3. Footing Plan View

1-1/2" = 1 FT.

(6) 1/2" Structural Steel Bolts Per Side

16 x 16 No. 1 Redwood Footing Base - 2-1/2" Thick

3 x 12 Fin Column

1/2" "L" Stainless Steel Connector Plate

14" Penetrator (American Earth Anchors)

4. Foundation Elevation

1-1/2" = 1 FT.

3 x 12 No. 1 Redwood Fin Column

(6) 1/2" Diam Stainless Steel Structural Bolts

1/4" Penetrator (American Earth Anchors) See Specs

16 x 16 Plan Dim. 3 x No. 1 Redwood Footing Base

1/2" Thick Stainless Steel "L" Shape Plate Connector
American Earth Anchors

14" Penetrator™
with stud/nut/washer

- Aircraft-quality cast aluminum 356 alloy
- Heat-treated to T6 specification
- Install with ⅜" square drive
- Removable

LOAD CAPACITY
Pullout strength with flight fully embedded

<table>
<thead>
<tr>
<th>Soil Class</th>
<th>Pullout Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardpan Asphalt</td>
<td>2,500 lb 11.1 kN</td>
</tr>
<tr>
<td>Sandy gravel  Very dense sand</td>
<td>1,700 lb 7.56 kN</td>
</tr>
<tr>
<td>Silty/clayey sand  Silty gravel</td>
<td>600 lb 2.67 kN</td>
</tr>
<tr>
<td>Loose/fine sand  loose sands  Fines clays</td>
<td>350 lb 1.56 kN</td>
</tr>
<tr>
<td>Soil Class 4 Loose fine uncompacted sand</td>
<td>200 lb 0.89 kN</td>
</tr>
</tbody>
</table>

Neck diameter 1.4" (36 mm)
1.5" (38 mm) ID pipe fits over

Flight diameter 2¼" (58 mm)

Threaded steel stud (⅜"-13) with nut and washer

Fits ⅜" square drive

Tapped hole
Depth: 1" (25 mm)
Thread: ⅜"-13
For stud, bolt, hook, eye, or other threaded fitting

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

American Earth Anchors
info@americanea.com
americanearthanchors.com

866-520-8511
+1 508-520-8511
**Foundation Specs**

**PE14-STD | Installation**

**Through asphalt**

- Drill PILOT HOLE through asphalt
- **1 ½” (4 cm) diameter hole**

| Asphalt | Soil |

**Installation methods**

- **Impact wrench**
- **T-handle**
- **Optional ratchet**
  - **½” square drive tip**

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CONSTRUCTION:
ASSEMBLY, MATERIALS,
TRANSPORTABILITY

Renders by Ryan Huddlestun
Full Size Detail Model

Constructed by Entire Design Team
Materials Deconstructed

By Alex Beaubien
Typical Fin Detail

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
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.