

THE CROSSES OF LIGHT

Glorious Cross, Cross of Crusifixion & Cross of Redemption



AUGUST 5, 2026
CREO
Phoenix Arizona, US

Table of Contents

Project, The Crosses at Conyers:	4
Design Considerations:	4
Points of Interest:	4
Background:	5
Structural Design/Conditions:	11
IBC:	11
Soil Bearing/Loading:	13
Foundation Cross of the Redemption:	14
Quadrilateral/Square Foundation:	14
Circular Foundation:	16
ASCE 7, Design Classification:	20
Environmental Loading Summary at Conyers:	26
Cross of Redemption:	26
CFD Loadings on The Cross of Redemption:	26
Cross of Redemption Loading Summary:	29
Transient Analysis of the Cross of Redemption:	30
Structural Embedment of the Cross of Redemption:	35
Footing Design.....	35
Site Design:	36
The Cross of the Crucifixion:	36
Crude Corpus Envelope:	37
CFD, Cross, Envelope & Hill:	39
CFD, Cross & Envelope:	41
CFD System Study of Cross & Envelope:	42
Wind Force/s:	44
Beam Stress at Foundation:	45
Transient Analysis of the Cross of Crucifixion:	46
Refined CFD/FEA Model:	48
Area Projection of the Cross of Crucifixion:	48
MIRACULOUS MEDAL STATUE:	63

Structural Embedment of the Cross of Crucifixion:	72
Footing Design:.....	72
Site Design:.....	73
Roof/Cover for the Cross of Crucifixion:	74
Embedment – Footing Design	82
Texture & Color:	85
Color of Sides:	93
Surface Finish: Glorious Cross & Cross of Redemption	93
The Glorious Cross:	95
Design considerations:	95
Location:	95
Structural Design/Conditions w/r Eurocode 8:	96
Geology of France:	97
Damping Ratio for Beam Model:	98
Conclusion of Damping Ratio Model/s:	100
Summary of Eurocode 8 w/r Seismic:	100
Eurocode 1: Actions on Structures.....	100
Snow & Ice:	101
Wind in/near Dozule, France:	101
Wind w/r Altitude:	103
Wind w/r Orography Effect:	104
Wind: Velocity Profile with Upwind Slope/Hill	113
Wind – Velocity Equation for Dozulé:.....	114
Summary of Eurocode 1 Acting Forces:.....	115
CFD of Glorious Cross:	115
Full Cross – Steady State:	116
Angle of Attack, 0[deg]:	116
Angle of Attack, 45[deg]:	119
Angle of Attack, 90[deg]:	121
Full Model – Transient:.....	122
Vortex Shedding:.....	122

Infinite Profile Vortex Shedding:	123
Full Cross, Transient Study:.....	125
Full Cross, FEA Static Study:	135
Full Cross, Combining CFD & FEA:	136
Static Loading Magnitude, Angle of Attack:	139
Loading Moments at Base:	139
Simple Base-beam Array:	142
Panel Rivet Plan:.....	145
Thin Plate to Membrane:	146
Panel, Square, Deformation & Stress	149
Panel (x9) Array, 48[in] (47.986[in]) Std:	150
Shear Flow:	151
Panel, STD, Blind Rivet:	152
Panel, Radii Flow Field:	154
System Frequency:.....	158
Arm Study:.....	160
Arm Support:	160
Arm Structure:	165

Preface: I apologize for the brevity of this “quick” report. Many of the calculations are within the Excel file “EngTools 20251030.xlsm;” it does contain macros (very nice tools). FEA and CFD calculations are contained within original files; which are very large and were not provided. The summary of the calculations are here-in. The original FEA and CFD files may be recovered, upon request only.

Project, The Crosses at Conyers:

The project in Conyers GA contains two crosses:

- A) Project name is the “Cross of the Crucifixion” (see Figure 1)
 - a. Replace the wooden Cross on the holy hill with a corpus cross
 - b. The Cross will support a figure of a crucified body
 - c. Material: Casting Aluminum T3xx, S_y (σ_y) minimum is 22,000[psi]
 - i. Aluminum 356 is acceptable.
 - ii. Aluminum 380/383 are acceptable.
 - d. Repair the stone-cross altar (uncut stone/s)
 - e. Add Mother Mary’s Miraculous Medal statue
 - f. ***The Cross, the uncut stone alter and the Miraculous Medal statue duplicate assembly will be used as a shrine at the Dozule site (see prints)
- B) Project name is the “Cross of Redemption” (see Figure 6 & Figure 7)
 - a. Place a (1/90)th scaled version of the Glorious Cross just north of the Cross of Rosary Hill
 - b. The height will be 8.2[m] (26.9[ft]) with a square base of 0.205[m] (8.07[in])
 - c. East & West sides (only) will be anodized light-blue
 - a. Aluminum 7075-T6; S_y (s_y) minimum is 73,000[psi] is acceptable
 - b. Aluminum 6061-T6; S_y (s_y) minimum is 40,000[psi] is acceptable
 - d. For The Glorious Cross details see, page 95

Design Considerations:

The factors affecting the design are weather, seismic activity and soil conditions. The Crosses will be built to last 500[y]. The main factor with respect to mechanical longevity is the wind. The soil conditions affect the base/foundation construction. Worst-case conditions will be applied wherever applicable.

Points of Interest:

- A) The “Farm:”
 - a. Address of The Farm is 2324 White Rd NE, Conyers, GA 30012, see Figure 6
 - b. 33°42'16"N 83°57'15"W (33.704528, -83.954285)
 - c. Third party ownership
 - d. The Cross of Rosary Hill is NW of the Farm, named Cross of the Redemption
- B) The location of the Cross of Rosary Hill, see Figure 6 thru Figure 9
 - a. Existing cross at 33°42'20"N 83°57'18"W (32.7056, -83.955)
 - b. The Cross of Redemption is located to the north of the current Cross of Rosary Hill
 - i. Its arms will be East -to- West
 - ii. East & West sides will be anodized blue-green, see page 92

- C) The location of the Cross of the Crucifixion ref: Figure 1 thru Figure 4
- 33°42'02"N 83°57'4"W (32.70056, -83.95111), just south-east of the Cross of the Rosary Hill
 - Behind the home at 2900 Hwy 138 NE, Conyers GA, 30013-1110

Background:

The Cross of the Crucifixion, on the Holy Hill, was built on private property. Currently (2025), George Collings owns the original property owned by Nancy Fowler: At 2900 Hwy 138 NE, Conyers GA, 30013-1110. The stone altar is to remain. Repair to the stone altar, as required, should be completed with respect to longevity; without altering its current form/shape. The Wooden Cross is to be replaced with the aluminum corpus cross.



Figure 1: Cross of the Crucifixion on Holy Hill



Figure 2: Cross of the Crucifixion, on the Holy Hill

Note: The cross (approximately) faces to the Southeast.



Figure 3: Base of Cross of the Crucifixion, on the Holy Hill

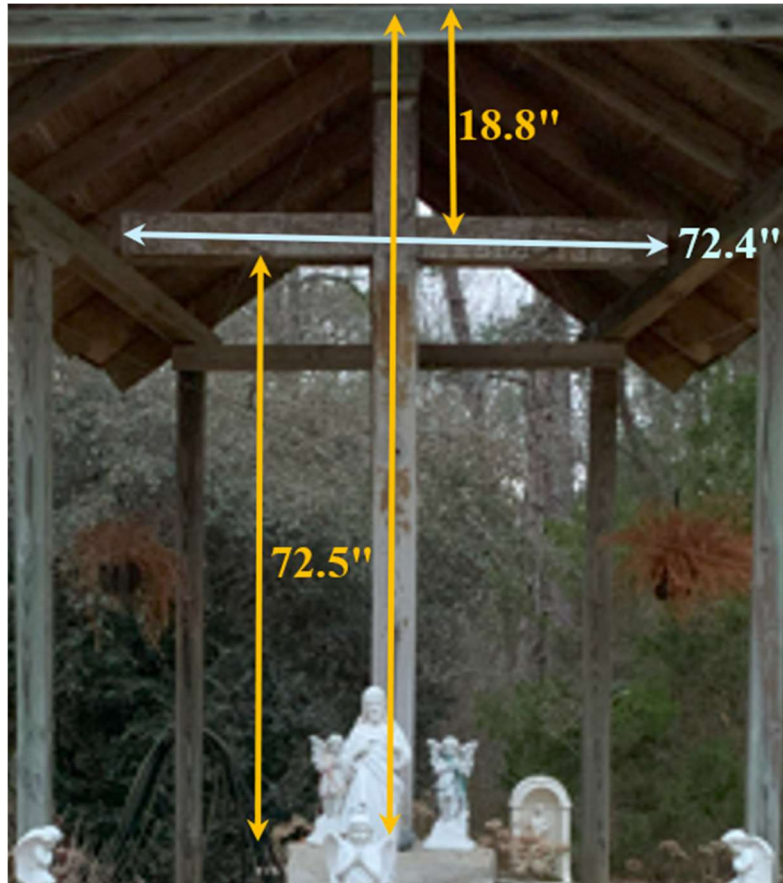


Figure 4: Wooden Cross Dimensions

The Cross of the Crucifixion has an overall height of about 94[in] (above the Stone-Altar) with an arm width of about 72.4[in]. The arm-center(s) are about 18.8[in] from the top, giving a height to arm-location ratio of 0.2[-]. The height of the stone altar, nearest the cross is about 25[in]. The afore mentioned dimensions are approximate. The replacement cross will differ slightly and support a corpus.

The Cross of the Redemption, the $(1/90)^{\text{th}}$ scaled copy of the Glorious Cross, is just north of the Cross of the Rosary Hill. The arms are directly east and west. The body/face/flat has a north and south orientation. This orientation will yield about a 30.6 degree offset from the orientation of the Cross of the Rosary Hill; see Figure 8.

Copies of the Glorious Cross do exist, as in ss. The Cross of the Redemption will be placed about 7[m] behind the current Cross of the Rosary Hill; see Figure 9.

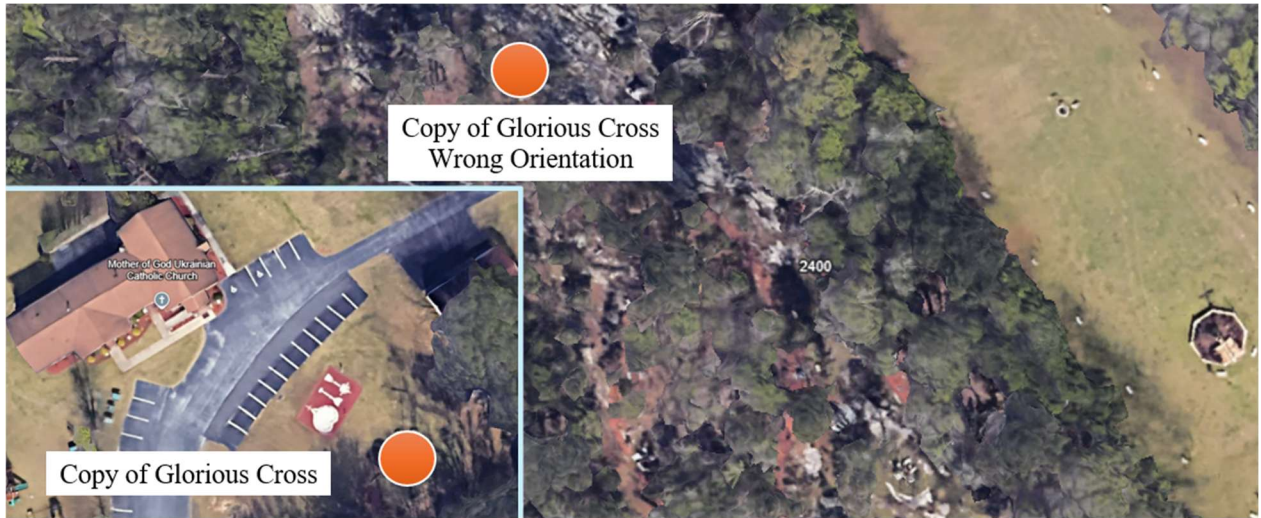


Figure 5: Current Copies of Scaled Glorious Cross

The Cross of Redemption is located on a third-party site. Two copies of the Glorious Cross exist near this site. One copy is NW of the Cross of the Rosary Hill and the other is near the Mother of God Ukrainian Catholic Church.

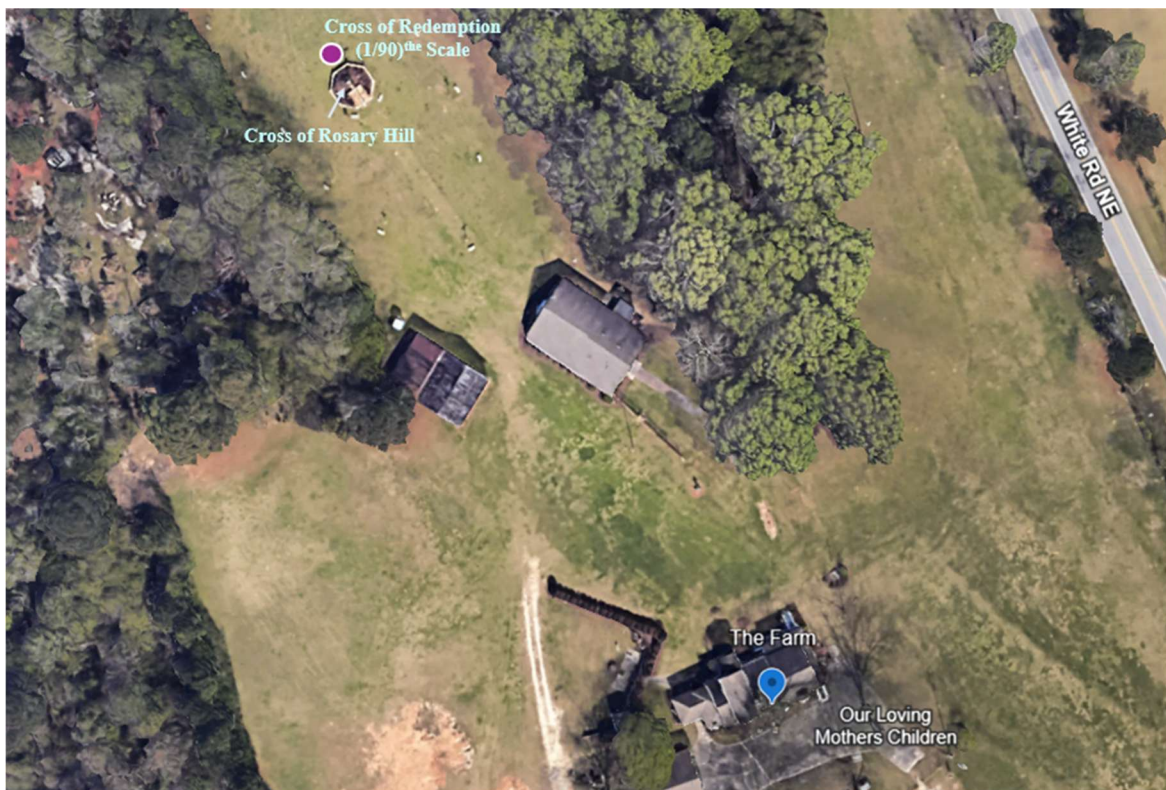


Figure 6: The Farm, 2324 White Rd NE Conyers, GA 30012⁽⁰³⁾



Figure 7: Cross of the Redemption, (1/90)th Scale, Elevation 263[m]⁽⁰⁶⁾



Figure 8: Orientation ~30.6[deg], Facing North & South



Figure 9: Current Corpse Cross of the Rosary Hill



Figure 10: Topography Elevation, 266[m]⁽⁰⁵⁾

The topography varies slightly from one source to the next. In this instance, the values from Google-earth will be applied, because many of the measurements were taken from Google-earth.

From the extensive weight-loss studies conducted around the world on aluminum corrosion rates of 0.03 to 4[$\mu\text{m}/\text{year}$] have been reported.⁽⁰¹⁾ In industrial locations, the corrosion rates average 0.8–2.8[$\mu\text{m}/\text{year}$].⁽⁰¹⁾ In rural area's atmosphere, the corrosion rate averages 0.03 $\mu\text{m}/\text{year}$ (0.001 mils/year).⁽⁰¹⁾ Because the location is rural, over 500[y] the reduction in tensile strength from environmental affects would be less than 0.02[mm]. The surface finish will be specified not to exceed a roughness of 2000[μin] (51[μm]). Surface corrosion, finish, decorative and/or other surface deformations not to exceed 0.01[in] (0.254[mm]).

Structural Design/Conditions:

IBC:

Following the IBC (International Building Code), section 302.1, the occupancy and use designation 10 as a tower. This designation can be utilized for both structures. IBC Table 1604.5 defines an applicable risk category of I. The risk category was defined per the rural/farmland geological designation and visitations to the Farm in Conyers, GA.

Soil Type at Conyers GA:

The Georgia state has mapped the various types of soil around the area of concern; see Figure 11. The main constituent of the soil seems to be clay.



The Cross of the Crucifixion is within a PfC2 – type soil

Pfc2 — Pacolet sandy clay loam, 2 to 10 percent slopes, eroded⁽⁰⁷⁾

- Wedowee and similar soils: 100 percent
- Typical Profile:
 - H1 - 0 to 3 inches: sandy clay loam
 - H2 - 3 to 19 inches: clay
 - H3 - 19 to 39 inches: sandy clay loam
 - H4 - 39 to 60 inches: sandy loam

The Cross of the Redemption is within PaB-type soil

PaB — Pacolet sandy loam, 2 to 6 percent slopes⁽⁰⁷⁾

- Pacolet and similar soils: 100 percent
- Typical Profile:

- H1 - 0 to 4 inches: sandy loam
- H2 - 4 to 20 inches: sandy clay
- H3 - 20 to 33 inches: sandy clay loam
- H4 - 33 to 60 inches: sandy loam

The Georgia Geological site designates all areas within Figure 11 as farmland. The soils are deep, well-drained. Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr).

Table 1 Soil, Site Classification from ASCE/SEI 7-16

Site class	V_s	N_{ch}	S_u
A. Hard rock	>5000 ft/s	NA	NA
B. Rock	2500–5000 ft/s	NA	NA
C. Very dense soil and soft rock	1200–2500 ft/s	>50 blows/ft	>2000 lb/ft ²
D. Stiff soil	600–1200 ft/s	15–50 blows/ft	1000–2000 lb/ft ²
E. Soft clay soil	<600 ft/s	<15 blows/ft	<1000 lb/ft ²
F. Soils requiring site response analysis	Very high plastic soils, soils vulnerable to potential failure, peat and organic clays		

Soil Bearing/Loading:

The soil bearing capacity will be limited to a worst-case by utilizing IBC 1806.2 “Presumptive Load-bearing Values” (see Table 2). These values will be utilized to design the foundation.

Table 2: IBC Table 1806.2, Presumptive Load-bearing Values

CLASS OF MATERIALS	VERTICAL FOUNDATION PRESSURE (psf)	LATERAL BEARING PRESSURE (psf/ft below natural grade)	LATERAL SLIDING RESISTANCE	
			Coefficient of friction ^a	Cohesion (psf) ^b
1. Crystalline bedrock	12,000	1,200	0.70	—
2. Sedimentary and foliated rock	4,000	400	0.35	—
3. Sandy gravel and gravel (GW and GP)	3,000	200	0.35	—
4. Sand, silty sand, clayey sand, silty gravel and clayey gravel (SW, SP, SM, SC, GM and GC)	2,000	150	0.25	—
5. Clay, sandy clay, silty clay, clayey silt, silt and sandy silt (CL, ML, MH and CH)	1,500	100	—	130

For SI: 1 pound per square foot = 0.0479kPa, 1 pound per square foot per foot = 0.157 kPa/m.

a. Coefficient to be multiplied by the dead load.

b. Cohesion value to be multiplied by the contact area, as limited by Section 1806.3.2.

Using the lowest class soil #5, the vertical loading will be limited to 1,500[psf]. The lateral loading will be limited to 100[psf/ft-below-grade].

Foundation Cross of the Redemption:

A solid (1/90)th scale copy of the Glorious Cross made from 7075-T6 (density 0.1[Lb/in³]) would weigh less than 2,800[Lbf]. This would require a minimum diameter foundation of 1.54[ft]. As seen in Figure 12, the front/back of the cross is on the x – axis, the arms (West/East) are on the y – axis and the z – axis is up/down.

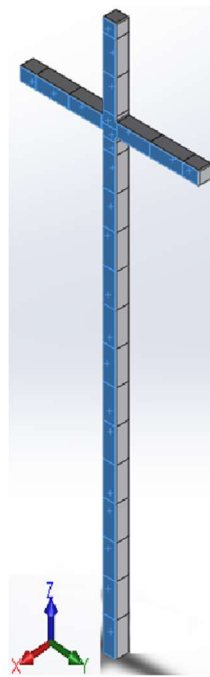


Figure 12: Coordinates of Cross of the Redemption

Quadrilateral/Square Foundation:

A rectangular/square foundation, as depicted in Figure 13, will resist moments with a lateral load (Force on $dx(x)dy$).

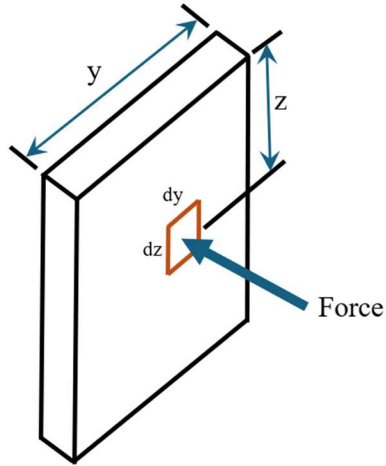


Figure 13: Square Foundation Wall, Fore-aft

Equation 1: Hydrostatic Force

$$F = \int p dA$$

Equation 2: Force Resistant to Moment, General

$$F_{Resist} = \int (P_a + P_{soil}) dA = \int (P_a + 100z) dA = \iint (P_a + 100z) dy dz$$

Since the atmospheric pressure is negligible:

Equation 3: Force Resistant to Moment w/r Depth

$$F_{Resist} = 100 * width \int (z) dz$$

Ref: IBC Table 1806.2, class 5 soil.

Table 3: IBC Soil Load Bearing Values

TABLE 1806.2 PRESUMPTIVE LOAD-BEARING VALUES

CLASS OF MATERIALS	VERTICAL FOUNDATION PRESSURE (psf)	LATERAL BEARING PRESSURE (psf/ft below natural grade)	LATERAL SLIDING RESISTANCE	
			Coefficient of friction ^a	Cohesion (psf) ^b
1. Crystalline bedrock	12,000	1,200	0.70	—
2. Sedimentary and foliated rock	4,000	400	0.35	—
3. Sandy gravel and gravel (GW and GP)	3,000	200	0.35	—
4. Sand, silty sand, clayey sand, silty gravel and clayey gravel (SW, SP, SM, SC, GM and GC)	2,000	150	0.25	—
5. Clay, sandy clay, silty clay, clayey silt, silt and sandy silt (CL, ML, MH and CH)	1,500	100	—	130

For SI: 1 pound per square foot = 0.0479kPa, 1 pound per square foot per foot = 0.157 kPa/m.

a. Coefficient to be multiplied by the dead load.

b. Cohesion value to be multiplied by the contact area, as limited by Section 1806.3.2.

Equation 4: Force on Saure Wall @ 100[psf/ft-depth]

$$F_{Resist_Wall} = 50 \left[\frac{Lbf}{ft^3} \right] wz^2 = (50wz^2)|_{-h}^0 = F_x$$

Where:

[w] = [ft]

[z] = [ft]

“h” is the total height/depth

Circular Foundation:

A circular foundation, as depicted in Figure 14:

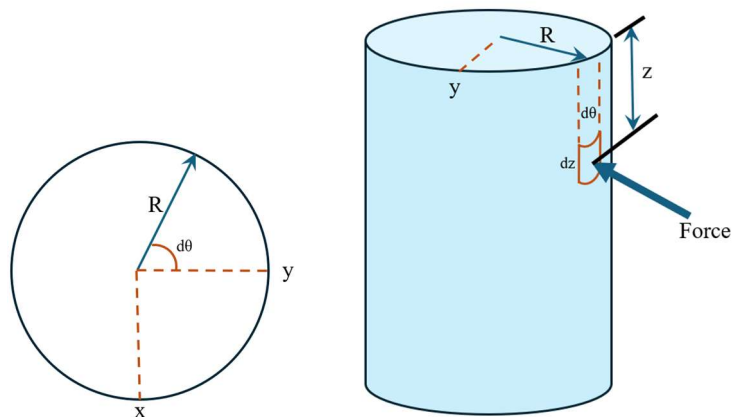


Figure 14: Cylindrical Foundation w/ Applied Force

Equation 5: Resultant on Cylinder

$$F_{Resist} = \sqrt{F_x^2 + F_y^2}$$

Note: Ignore Atmospheric Pressure

Equation 6: Force in "x" direction

$$F_{Resist_x} = \int (100z \sin(\theta)) dA$$

Equation 7: Force in "y" direction

$$F_{Resist_y} = \int (100z \cos(\theta)) dA$$

The force perpendicular to the line of action has no effect, therefore, $F_y = 0$ for M_y (as the coordinate system is defined in Figure 12).

Equation 8: General Cylindrical Resistive

$$F_{Resist} = \iint 100Rz \sin(\theta) d\theta dz$$

Equation 9: General Cylindrical for Theta Range of 0 - 180[deg], Half-Circle

$$F_{Resist} = 100R \int_{z=-h}^{z=0} \int_{\theta=0}^{\theta=\pi} z \sin(\theta) d\theta dz$$

Equation 10: Resistive Force for Cylinder

$$F_{Resist_Cyl} = \left(50 \left[\frac{Lbf}{ft^3} \right] D z^2 \right) \Big|_{-h}^0 = F_x$$

Where:
 [D=Diameter] = [ft]
 [z] = [ft]
 "h" is the total height/depth

It is interesting to note that Equation 4 and Equation 10 are equivalent when the width of the wall is same as the diameter (with similar depths).

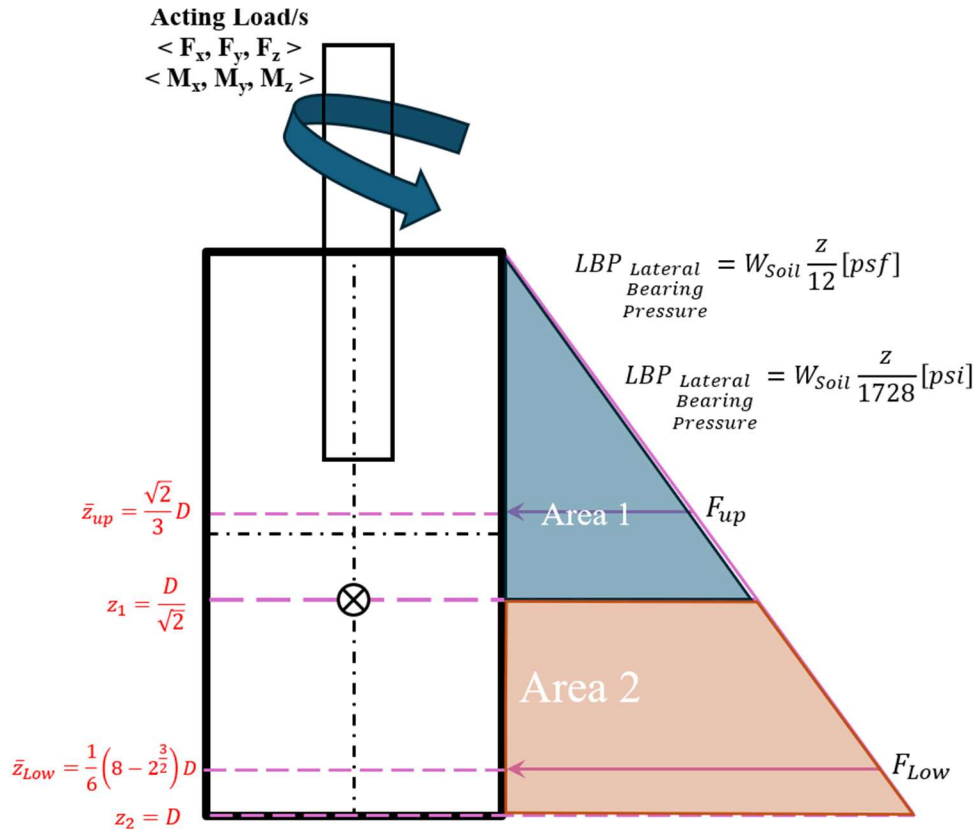


Figure 15: Lateral Acting Loads on Column/Post Foundation

Where:
 (Area 1) = (Area 2)
 "D" is the Depth of Concrete
 [z] = [in]

Considering the lateral loads on a foundation, the neutral plane is at about 0.707(Depth). The line of action of the upper force is at 0.4714(Depth) and the line of action of the lower force is at 0.8619(Depth).

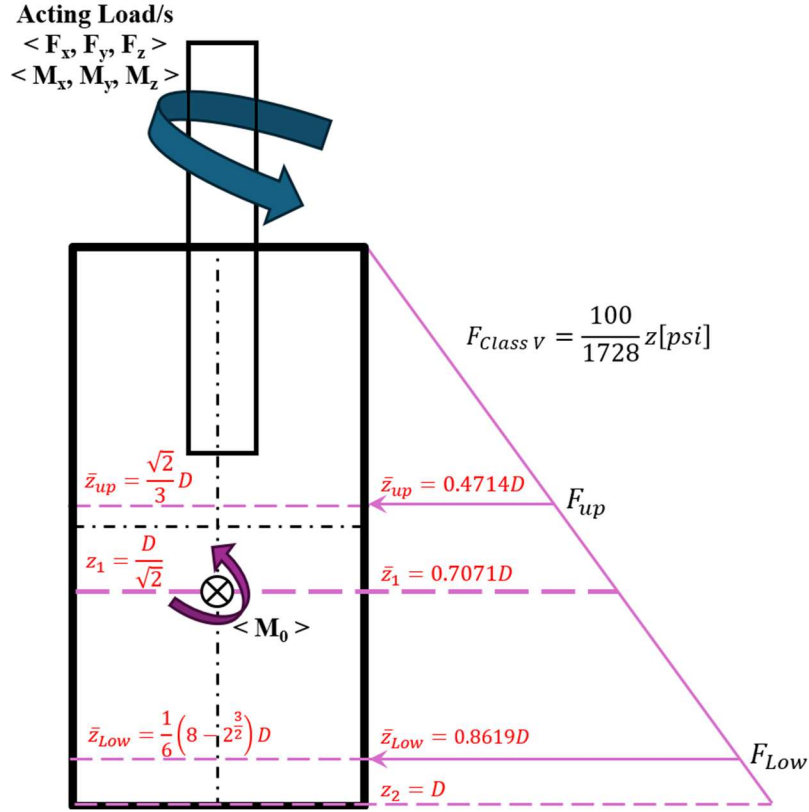


Figure 16: Lateral Load Concrete Embedment

Where:
 (Area 1) = (Area 2)
 “D” is the Depth of Concrete
 [z] = [in]

The simplified model depicted in Figure 15 and Figure 16 show a moment about M_o , where the “moment-areas” are equal. This model does not include the weight or tip-moments incurred. It also utilizes the weakest class of soil (class V); with 100[psf/ft].

Equation 11: Upper Resistant Load (Figure 16)

$$F_{Up_Soil} = \frac{A}{\sqrt{2}} \int_0^{z_1} \frac{100}{1728} z dz = \frac{50}{1728} \frac{A}{\sqrt{2}} z_1^2 = \frac{25A}{1728\sqrt{2}} Depth^2 = 0.01023A Depth^2 [Lbf]$$

Where:
 [LBS (Lateral Bearing Pressure)] = 100[psf/ft]
 Force is acting at (0.4714)Depth
 “A” is the total-projected area in [in²]
 [Depth] = [in]

Equation 12: Lower Resistant Load (Figure 16)

$$F_{Low_Soil} = \left(\frac{2 - \sqrt{2}}{2} \right) A \int_{z_1}^{z_2} \frac{100}{1728} z dz = (2 - \sqrt{2}) \frac{12.5A}{1728} Depth^2 = 0.004237A Depth^2 [Lbf]$$

Where:
 LBS (Lateral Bearing Pressure) is 100[psf/ft]
 Force is acting at (0.8619)Depth

“A” is the total-projected area in [in²]
[Depth] = [in]

Equation 13: Total Lateral Soil Resistive Load

$$F_{Lat_Soil_Total} = A \int_0^{De} \frac{100}{1728} z \, dz = \frac{50}{1728} A Depth^2 [Lbf]$$

Where:
[LBS (Lateral Bearing Pressure)] = 100[psf/ft]
Force is acting at (0.6667)Depth
“A” is the total-projected area in [in²]
[Depth] = [in]

Equation 14: IBC Non-constrained Depth per 1807.3.2.1 eq 18-1

$$depth = 0.5 \left(\frac{2.34P}{S_1 b} \right) \left(1 + \left(1 + \frac{4.36hbS_1}{2.34P} \right)^{\frac{1}{2}} \right) [ft]$$

Where:
[depth] = [ft]
b is the diameter or diagonal of the post [ft]
P is the applied lateral force [Lbf]
h is the distance to applied force, from ground [ft]
S₁ is Class 5 Soil per 1806.2 (Table 3) [psf]
depth is the depth less than 12[ft] with units in [ft]

Since the soil is clay a lateral bearing pressure of 100[Lbf/ft²/ft] will be used to determine the minimum depth of the embedment/s. Calculations utilizing Equation 14 show depths greater than 12[ft], therefore, Equation 11, Equation 12 and Equation 13 will be utilized for foundation calculations; with respect to Table 3: IBC Soil Load Bearing Values.

ASCE 7, Design Classification:

The structural design specifications from ASCE 7 consider wind, snow, ice and seismic conditions for a site of interest. From ASCE 7, the site soil class may be classified as “C.” For the purposes of a worst-case, this analysis utilizes class “D” for the soil. A class D soil has a shear strength between 1,000[psf] and 2,000[psf]; with a penetration resistance between 15 and 20[N-value] (ASTM D1586/D1586M).

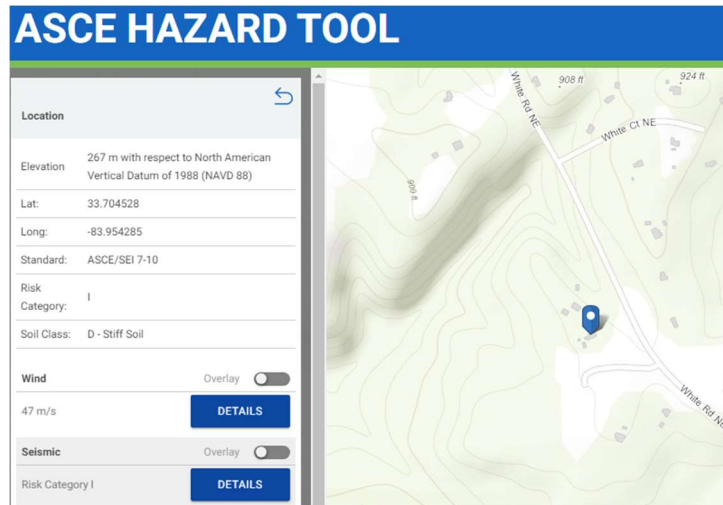


Figure 17: ASCE 7-10 Website Layout⁽⁰²⁾

REPORT SUMMARY	
Wind	
Wind Speed	47 m/s
10-year MRI	34 m/s
25-year MRI	38 m/s
50-year MRI	40 m/s
100-year MRI	43 m/s
Seismic	
S_S	0.182
S_1	0.089
F_a	1.6
F_v	2.4
S_{MS}	0.291
S_{M1}	0.213
S_{DS}	0.194
S_{D1}	0.142
T_L	12
PGA	0.082
PGA_M	0.131
F_{PGA}	1.6
I_e	1
Seismic Design Category	C

Figure 18: ASCE 7-10⁽⁰²⁾ Summary for Cross of the Redemption (Near The Farm)

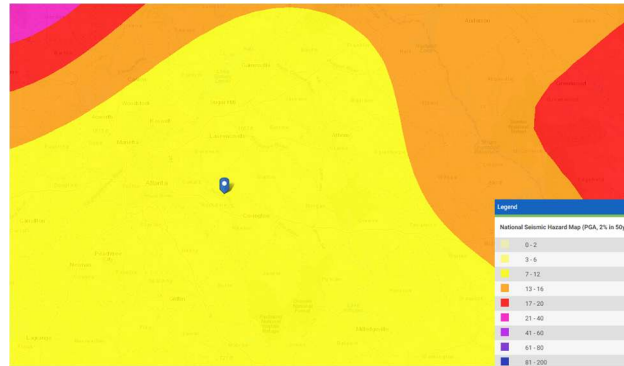


Figure 19: ASCE-tool, Seismic Map for 2% in 50[y]

Utilizing the ASCE hazard tool (Figure 17),⁽⁰²⁾ Figure 18 defines the seismic category as C. The seismic map (Figure 19) shows the relative strength of the seismic activity in the area.

Seismic Criteria/Specifications:

- ASCE 7-16 is an updated version of ASCE 7-10 with wind and seismic changes
- ASCE 7-22 is an updated version of ASCE 7-16 with tornado resistant designs
- ASCE 41-17/23 are used to analyze existing buildings

Note: Tornadoes are not considered for Risk Category I

ASCE 7-10 yields a windspeed of 47[m/s] while ASCE 7-16 specifies a windspeed of 44[m/s]. ASCE 7-22 specifies a windspeed of 44[m/s]. Wind speeds of 47[m/s] or 105[mpg] will be applied to the applicable model/s.

REPORT SUMMARY	
Wind	
Wind Speed	44 m/s
10-year MRI	33 m/s
25-year MRI	35 m/s
50-year MRI	38 m/s
100-year MRI	41 m/s
Seismic	
S_S	0.179
S_1	0.083
F_a	1.6
F_v	2.4
S_{MS}	0.286
S_{M1}	0.199
S_{DS}	0.191
S_{D1}	0.133
T_L	12
PGA	0.089
PGA_M	0.142
F_{PGA}	1.6
I_e	1
C_v	0.7
Seismic Design Category	B
Ice	
Thickness	38 mm
Concurrent Temperature	-9 C
Gust Speed	13 mm/s
Snow	
Ground Snow Load, p_g	0.24 kN/m ²
Mapped Elevation	267.4 m

Figure 20: ASCE 7-16⁽⁰²⁾

Site Information		REPORT SUMMARY	
Elevation:	267 m (NAVD 88)	Ice	
Lat:	33.704528		
Long:	-83.954285		
Standard:	ASCE/SEI 7-22		
Risk Category:	I		
Soil Class:	D - Stiff Soil	Snow	
Wind			
Wind Speed	44 m/s		
10-year MRI	32 m/s		
25-year MRI	35 m/s		
50-year MRI	38 m/s	Tornado	
100-year MRI	40 m/s		
300-year MRI	44 m/s		
700-year MRI	47 m/s		
1,700-year MRI	51 m/s		
3,000-year MRI	53 m/s	Seismic Data	
10,000-year MRI	57 m/s		
100,000-year MRI	65 m/s		
1,000,000-year MRI	73 m/s		
		S_S	0.24
		S_1	0.092
		S_{MS}	0.31
		S_{M1}	0.19
		S_{DS}	0.2
		S_{D1}	0.13
		T_L	12
		PGA_M	0.12
		V_{S30}	260
		Seismic Design Category	B
		Ice	
		Snow	
		Tornado	

Figure 21: ASCE 7-22⁽⁰²⁾

Table 4: ASCE 7-10/16 & 22 Example Comparison Calculations

Standard Seismic Load Calculation	ASCE 7 10	ASCE 7 16	ASCE 7 22
Specified Wind Speed: [m/s]	47	44	44
[mph]	105	98.4	98.4
Soil class	D	D	D
Mapped Spectral Response Acceleration Parameter at Short Periods: S_s [-]	0.182	0.179	0.240
Mapped Spectral Response Acceleration Parameter at Periods of 1[s]: S_1 [-]	0.089	0.083	0.092
Site Coefficient (w/r S_s): F_a [-]	1.600	1.600	1.292
Site Coefficient (w/r S_1): F_v [-]	2.400	2.400	2.174
Risk Category	1.00	1.00	1.00
Importance Factor	1.00	1.00	1.00
Response Modification Coefficient for Ordinary Cantilever Column	1.25	1.25	1.25
S_{ms}	0.291	0.286	0.310
S_{m1}	0.214	0.199	0.200
S_{ds} [-]	0.194	0.191	0.207
S_{d1} [-]	0.142	0.133	0.133
Seismic Response Coefficient: C_s [-]	0.194	0.191	0.207
Vertical Load: [Lbf]	10,000	10,000	10,000
Seismic Base Shear: [Lbf]	1,941	1,909	2,067

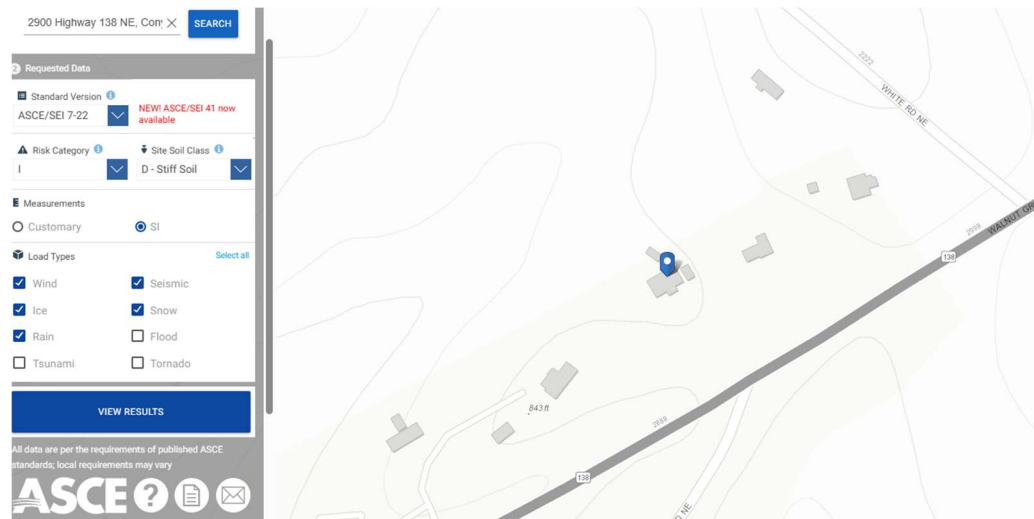


Figure 22: ASCE 7-22 for the Cross of the Crucifixion

Site Information		Ice	
Address:	2900 Highway 138 NE, Conyers, Georgia, 30013	Thickness	14 mm
Elevation:	253 m (NAVD 88)	Concurrent	-9 C
Lat:	33.700367	Temperature	-9 C
Long:	-83.950822	3-s Gust Speed	15 mm/s
Standard:	ASCE/SEI 7-22	Snow	
Risk Category:	I	Ground Snow	0.53 kN/m ²
Soil Class:	D - Stiff Soil	Load, p _g	0.53 kN/m ²
Wind		20-year MRI	0.18 kN/m ²
Wind Speed	44 m/s	Value, p _g	0.18 kN/m ²
10-year MRI	32 m/s	Winter Wind	0.35
25-year MRI	35 m/s	Parameter, W ₂	0.35
50-year MRI	38 m/s	Mapped	234.7 m
100-year MRI	40 m/s	Elevation	234.7 m
300-year MRI	44 m/s	Ground Snow	0.4 kN/m ²
700-year MRI	47 m/s	Loads for IRC	0.4 kN/m ²
1,700-year MRI	51 m/s	only, P _{g(assd)}	0.4 kN/m ²
3,000-year MRI	53 m/s	Rain	
10,000-year MRI	57 m/s	15-Minute	172.21 mm/h
100,000-year MRI	65 m/s	Rainfall Intensity	172.21 mm/h
1,000,000-year MRI	73 m/s	60-Minute	80.77 mm/h
		Rainfall Intensity	80.77 mm/h

Figure 23: Seismic for 2900 Hwy 138, Conyers GA⁽⁰²⁾

As seen in Table 4, the lateral accelerations calculated w/r ASCE 7-22 are about 8.2[%] greater than those in ASCE 7-16. As a side note: The soil class “C” would reduce the shear force by more than 20%, with respect to ASCE 7-22. The seismic coefficient for the Cross of the Crucifixion is 0.200[-]. Overall, the lateral acceleration factor of 0.207[-] will be applied to both locations.

The weather in Conyers, GA, will determine the air density utilized in the CFD. The average low is 2[C] (or 36[F]), the average high is 32[C] (or 90[F]).⁽¹⁸⁾ The record low was -3[C] (or 27[F]) the record high was 34[C] (or 93[F]).⁽¹⁸⁾ Taking the mean value of the high and low temperatures with the record temperatures,

the “hot” air density is 1.106[kg/m³] and the “cold” air density is 1.253[kg/m³] (at an altitude of 263[m], with 50[%] RH).

Weighing the air densities by 2/3rds towards cold temperature, the calculated air density is 1.230[kg/m³]. It has been recognized that this value is greater than that of the European suggested air density of 1.225[kg/m³]. The air density of 1.230[kg/m³] (or 0.076786[Lb/ft³]) is similar to air at 4.5[C] (or 40[F]) with an RH of 55[%]; at an altitude of 263[m].

Environmental Loading Summary at Conyers:

ASCE 7 was utilized to generate the various minimum loading conditions on the structures. Though they are surrounded by tall trees, the simulations will place them on a flat plane without trees.

Seismic Lateral Load:	0.207[-] (to be multiplied by the deadweight)
Wind:	105[mph] or 47[m/s]
Snow & Ice:	0.0952[psi] or 656[Pa]
(Snow:	0.077[psi] or 530[N/m ²])
(Ice:	0.02[psi] or 126[N/m ²])
Air Density:	1.230[kg/m ³] or 0.076786[Lb/ft ³]

Cross of Redemption:

The (1/90)th scale model of the Glorious Cross (in Dozule France) is located at the highest location near the farm of Nancy Fowler. Due to its size, no aircraft warning lights, or other special considerations are required.

CFD Loadings on The Cross of Redemption:

A CFD was performed on the Cross of the Redemption at 47[m/s], with an air density of 1.230[kg/m³]. This analysis was performed with a high skin roughness of 61[μm]. Since this is an external flow, the roughness will affect turbulence. SolidWorks uses the boundary layer profile proposed by Van Driest (1956,

Equation 15: Boundary Layer Profile by Van Driest

$$u^+ = \int_0^{y^+} \frac{2}{1 + \sqrt{1 + 4\kappa^2 \eta^2 \left(1 - e^{\left(-\frac{\eta}{A_v}\right)^2}\right)^2}} d\eta$$

Where:
 κ (Karman constant) = 0.4054
 A_v (Driest coefficient)=26

Equation 16: Roughness w/r Van Driest Equation

$$\varepsilon = \frac{C_\mu^{\frac{3}{4}} k^{\frac{3}{2}}}{\kappa y} \quad \& \quad \frac{dk}{dy} = 0$$

Basically, the boundary layer velocity will be slightly higher than the “unbounded” or free-stream velocity. This effect will occur where the flow does not stagnate. The Van Driest equation allows for a small boundary layer to exist at stagnation cells/points.

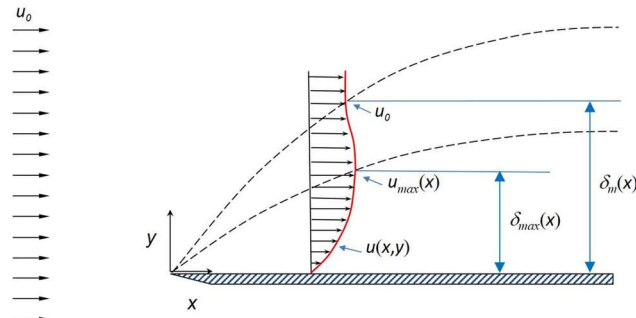


Figure 24: Boundary Layer U_{max} w/Roughness

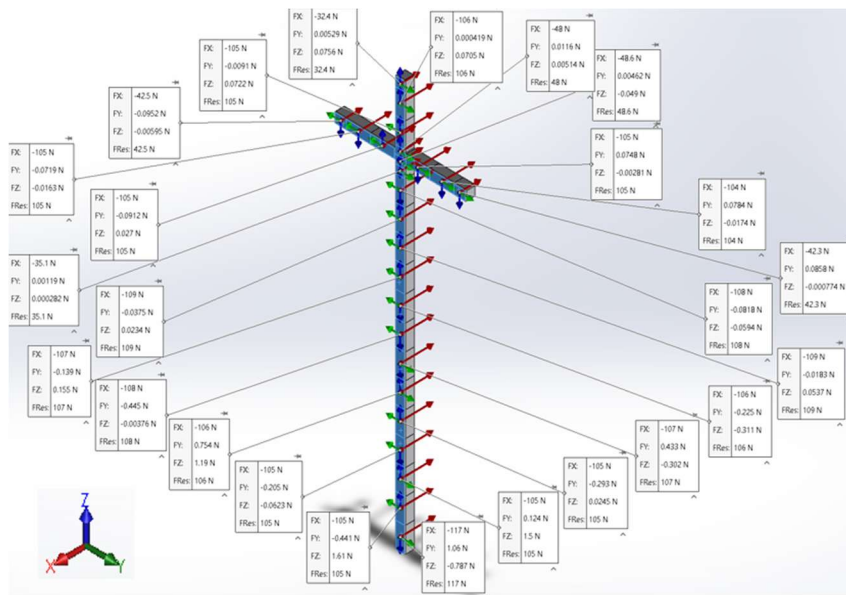


Figure 25: Cross of Redemption @ 47[m/s], Front-face/s

Table 5: Cross of the Redemption, Base Loads @ 47[m/s]

	[N]	[Lbf]
Fx	3,475	781
Fy	-0.9	-0.2
Fz	-0.9	-0.2

	[N-m]	[Lbf-ft]
Mx	-4.4	-3.3
My	16,485	12,159
Mz	-4.1	-3.0

CL	4.744	[m]
	15.564	[ft]

Equation 17: Soderberg Line

$$\frac{1}{FS} = \frac{\sigma_m}{\sigma_y} + \frac{\sigma_a}{\sigma_e}$$

Where:
 σ_m is the mean cycle stress
 σ_y is the tensile yield strength
 σ_a is the amplitude of the stress
 σ_e is the endurance limit at constant strength

Equation 18: Basquin SN Curve⁽²⁴⁾

$$\text{Log}(N) = m_w \text{Log}(\sigma_a) + b$$

$$m_w = \frac{\log_{10} \left(\frac{2(10)^6}{N_{\sigma_y}} \right)}{\log_{10} \left(\frac{0.9\sigma_y}{\sigma_{f6}} \right)}$$

$$N_{\sigma_y} = 400 \left(\frac{\sigma_y}{\sigma_u} \right)^{-10}$$

Where:
 σ_u is the ultimate tensile stress
 σ_{f6} is the strength at $2(10)^6$ cycles

However, Lee & Taylor proposed ss for aluminum alloys and stresses up to 336[MPa] (48,700[psi]).

Equation 19: Lee & Taylor⁽²⁴⁾

$$\sigma_e = 0.4\sigma_u$$

Cross of Redemption Loading Summary:

- 1) The CL (center of loading) is at 15.56[ft] from the base, yielding a moment about < Y > of 12,159[Lbf-ft].
- 2) A seismic event with a solid cross would impart a lateral load of 580[Lbf]
- 3) Snow/Ice loading would add about 82[Lbf] in the vertical (< Z >).
- 4) Soderberg Line: Where $V_{\text{mean}} = 10[\text{mph}]$ (or 4.47[m/s]) @ 90[%] period⁽²³⁾
 - a. 500[y] period
 - b. Less than 10 cycles at 47[m/s]
 - c. $\sigma_m = 101.5[\text{psi}]$ (over 500[y], average wind 12[mph] or 5.35[m/s], per Figure 23)
 - i. The maximum wind speed is 10[mph] for a nominal year
 - ii. The average wind for a year was taken at 10[mph]
 - iii. This value is high, providing a “worst-case”
 - d. $\sigma_y = 22,000[\text{psi}]$
 - e. $\sigma_a = 19,457[\text{psi}]$, with HSS 8 x 1/4“
 - f. $\sigma_e = 0.4(45,000) = 18,000[\text{psi}]$

The loads on the Cross of Redemption would require an 8[in] square beam with a minimum thickness of 0.196[in] (FS = 1). To endure over a 500[y] period, the minimum thickness of an 8[in] HSS beam would be 0.306[in]; yielding a system FS (FS_e) of 1.5[-].

The foundation for the Cross of Redemption would require a circular foundation with diameter of 73.5[in] and a depth of 9[ft]. A square foundation requires a side length of 66[in] and a depth of 9[ft]: The square foundation is recommended.

Transient Analysis of the Cross of Redemption:

A transient analysis was performed with a high-resolution mesh, with over 2[mil] cells. The roughness was and other factors remained the same as in the steady-state analysis. The analysis showed that there is no vortex-shedding.

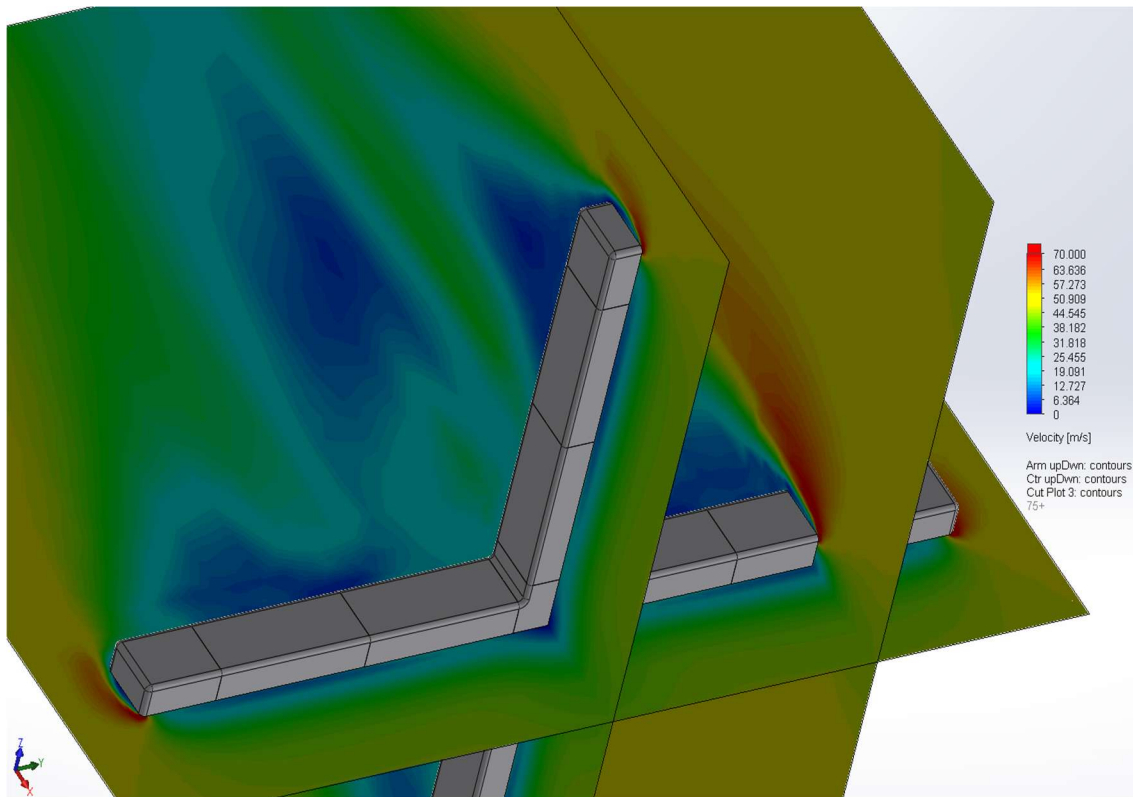


Figure 26: Upper Segment, Transient Analysis

The boundary layer fluid cells were multi-layered and the maximum dt was about 0.001[s]. After about 0.7[s] the velocities and low-pressure zones remain steady. The steady-state condition is depicted in Figure 26.

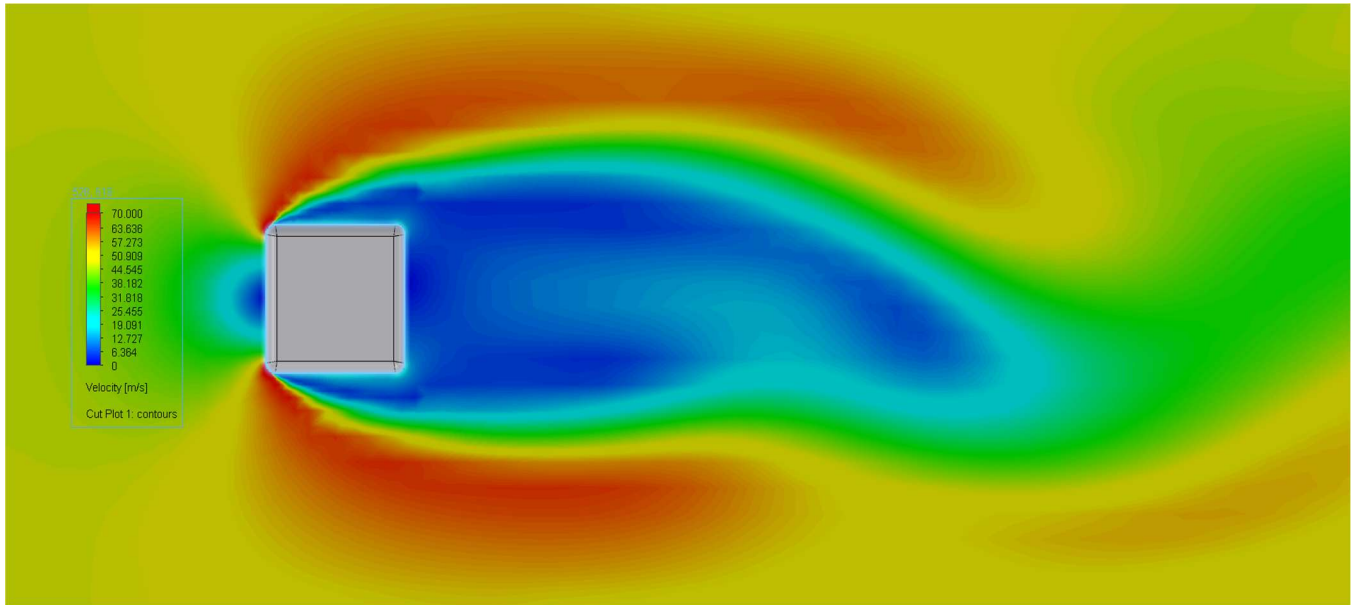


Figure 27: *Fine Mesh, Transient*

A 2D analysis was performed with a much finer mesh. Figure 27 depicts the high point, to which the low-pressure wave would wiggle/wave. The low-pressure zone would move up and down, while remaining intact. The cycle time for the wave is about 0.03[s]. Since no vortex shedding occurs, harmonic resonance is not a factor. If vortex shedding did occur, it would be around (x)10 less than the 1st harmonic (Figure 30), which voids any concerns with respect to vortex shedding.

Figure 29 represents the initiation of a strong wind at 47[m/s] acting on the cross. This shows that under sustained wind conditions, F_z over the 2-D segment remains less than 0.1[N] or 0.022[Lbf] (0.36[oz]). The low-pressure zone trails the object by a factor of five; or 5 body widths. For future applications, no more than (x)10 dimeters (widths) will be required for the CFD domain box (downstream of the object, see Figure 28).

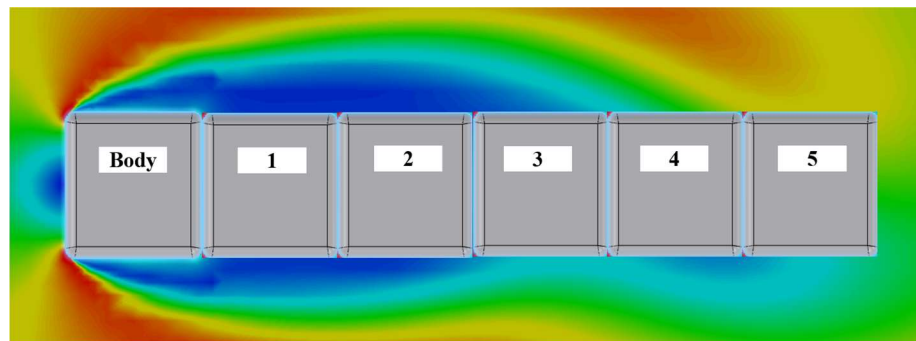


Figure 28: *CFD Domain Minimum (x)5 Diameters/Widths*

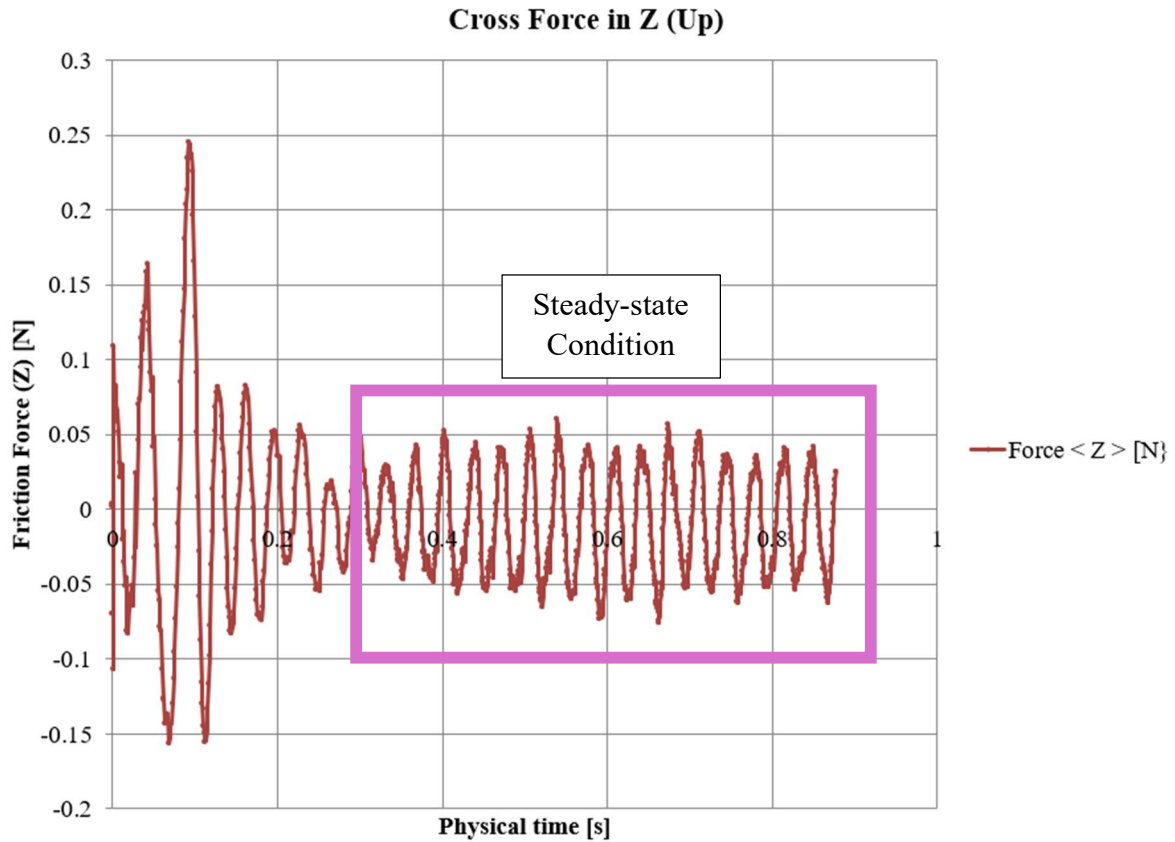


Figure 29: 47[m/s] Wind-wave Acting on Cross-body

Though harmonics are of no concern, a frequency study was conducted for informative purposes. This study will be considered for the design of the Glorious Cross (in Dozule, France).

A frequency study was conducted: ½" thick walls with T6061-T6 Aluminum

- 1) 1st harmonic frequency: 2.507[Hz], cycling every 0.399[s]
 - a. Fore-aft motion of the entire cross
- 2) 2nd harmonic frequency: 12.59[Hz], cycling every 0.079[s]
 - a. Wiggle, torque; left-right motion
- 3) 3rd harmonic frequency: 17.63[Hz], cycling every 0.057[s]
 - a. Wiggle, torque; left-right motion (the 2nd frequency of the 2nd motion)
- 4) 4th harmonic frequency: 19.86[Hz], cycling every 0.05[s]
 - a. Fore-aft motion (the 2nd frequency of the 1st motion)
- 5) 5th harmonic frequency: 42.14[Hz], cycling every 0.024[s]
 - a. Bending Left/Right in < Y, Z >

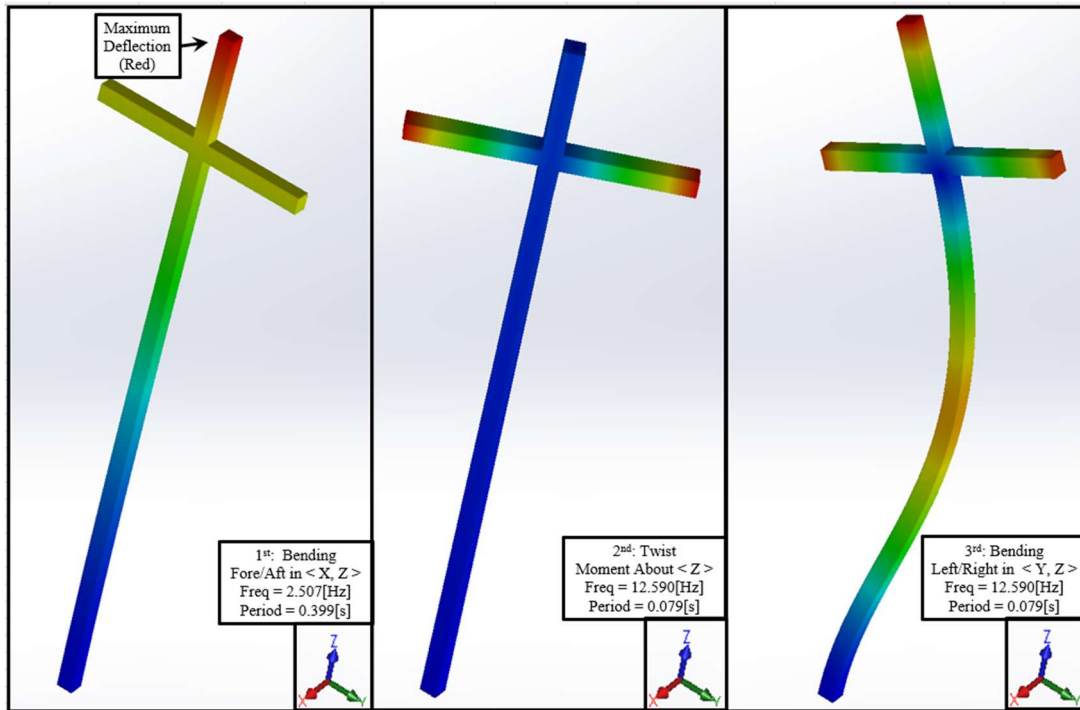


Figure 30: 1st, 2nd & 3rd Harmonic Frequencies

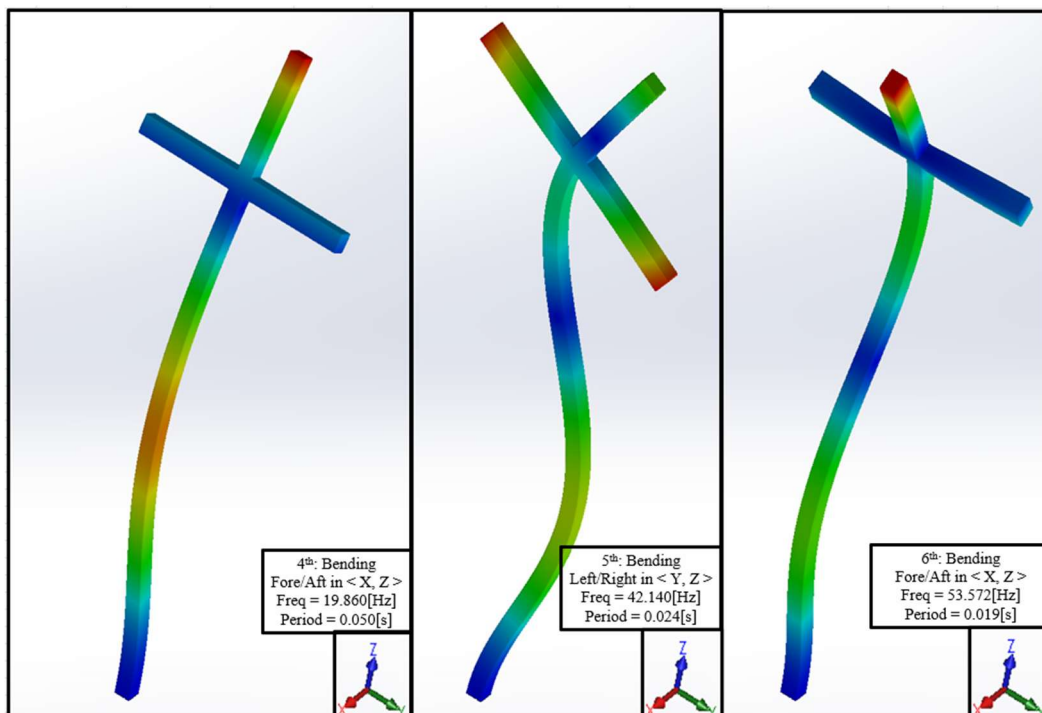


Figure 31: 4th, 5th & 6th Harmonic Frequencies

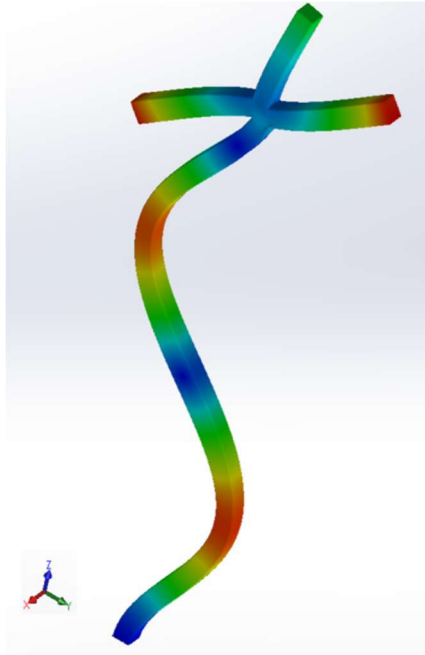


Figure 32: 7th Harmonic Frequency

The 7th harmonic frequency (depicted in Figure 32) bends the arms at a frequency of 82.09[Hz], or 0.012[s]. This frequency is much lower than the period of the wave, in Figure 27; therefore, the structure is stable under very windy conditions. The standing wave produced by the various wind conditions will not induce harmonics.

The first and second harmonics are rather intuitive. Though harmonics are not a concern with the (1/90)th scale cross, the Glorious Cross of Dozule will employ extra stiffening about arm intersection zone to resist loads produced by the arms swaying/moving up/down & left/right.

A (1/90)th scale version of the Glorious Cross will have a height of 322.8[in] and an overall width of 107.6[in]; with an outer square dimension of 8.07[in]. A cross made with Al T6061-T6, HSS 8 x ½[in] will weigh less than 670[Lbf]. Considering loads, the Von-Mises stress will be less than 11,000[psi]; representing an FS (FS_e) of 2.28[-].

Structural Embedment of the Cross of Redemption:

Footing Design

Taking the various loadings into account, the mounting plate will be at least 31[in] square with $\frac{3}{4}$ " mounting bolts at 14[in] from center; as seen in Figure 33. The plate will be 1.5[in] thick with a top and bottom weld, to the main structure, of 0.5[in].

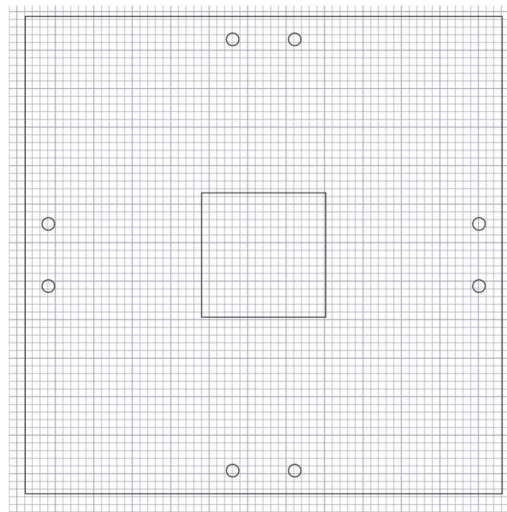


Figure 33: Mounting Plate for Cross of Redemption

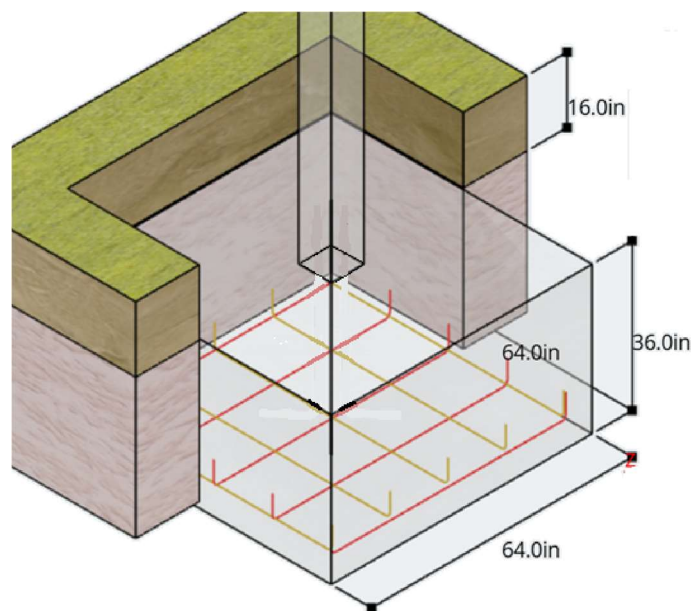


Figure 34: Cross of Redemption, Rough Depiction of Concrete Base⁽²⁶⁾

The mounting plate will rest upon a concrete slab, then 3/8” reinforcement bars will be placed per design. After the reinforcement is installed, the main concrete slab will be poured. The simulated concrete slab was 64[in] square with a depth of at least 3[ft] (below topsoil).

Site Design:

The final design of the foundation was based upon the soil loading capabilities. The diameter of the foundation will be 36[in] (min) at a depth of 4[ft] below topsoil. The reinforcement members shall be placed in a hexagonal orientation around the base.

The Cross of the Crucifixion:

The Cross of the Crucifixion lay atop a rather insignificant hill: In the backyard of residential property. Its location is near trees and well shielded from wind. The cross-casting contains a cross and a corpse. The casting is one piece, where the flow in the base is vertical; in the $\langle Z \rangle$ direction. The CFD model is oversized and contains a very high roughness in an effort to maximize the forces/moments.

The cast body (final design) will have a body height of about 6” – 2” with an estimated flesh-weight of 170[Lbf]. The approved casting materials are Aluminum A3xx. An aluminum casting material with tensile strength (s_y) is greater than 22,000[psi] with a density less than (or equal to) 0.10[Lb/in³].

A 6’ – 2” flesh body, weighing 220[Lb], will have a volume of no more than 26[gal] or 6,050[in³l] ^{(20),(21)}. The cast body will have solid arms, calves and feet. A solid body made with Aluminum A380.0-T5, Casting Alloy, will weigh less than 610[Lbf] (this value is for reference only).

Crude Corpus Envelope:

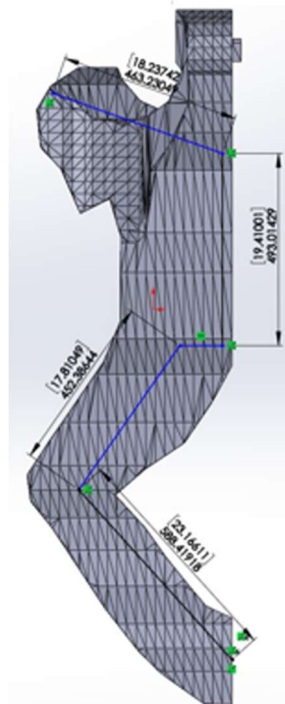


Figure 35: CFD Model/Envelope Body, 6' - 6" (1997[mm])

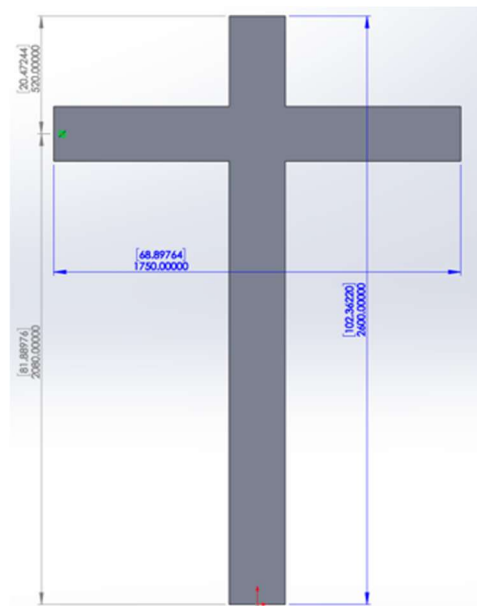


Figure 36: CFD Cross for Body of 6' - 6"

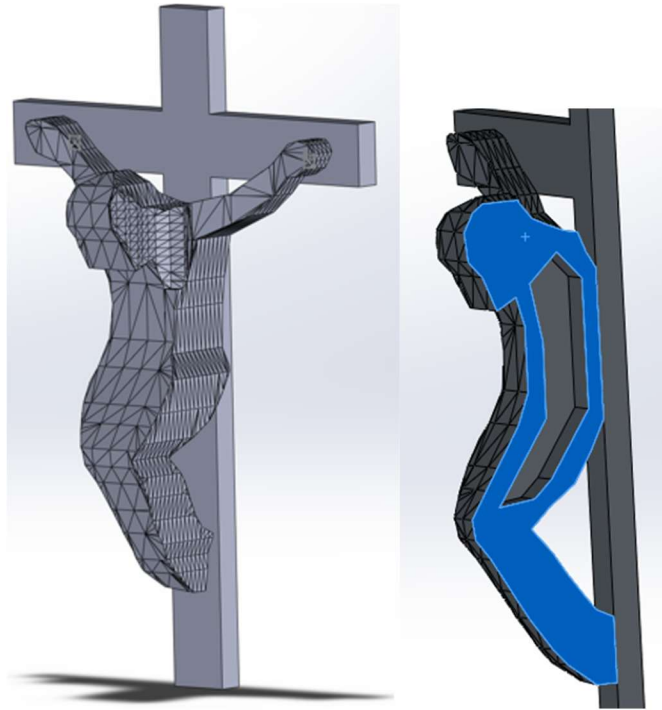


Figure 37: CFD Model Hollow Body & Cross

As seen in Figure 35, Figure 36 and Figure 37 the CFD model for the Cross of the Crucifixion is larger than the final model. The beam width is 0.241[m] (9.5[in]) with a thickness of 0.1[m] (4.0[in]). Also as seen, Figure 35, the CFD model is crude: The envelope surrounding the corpse is also crude.

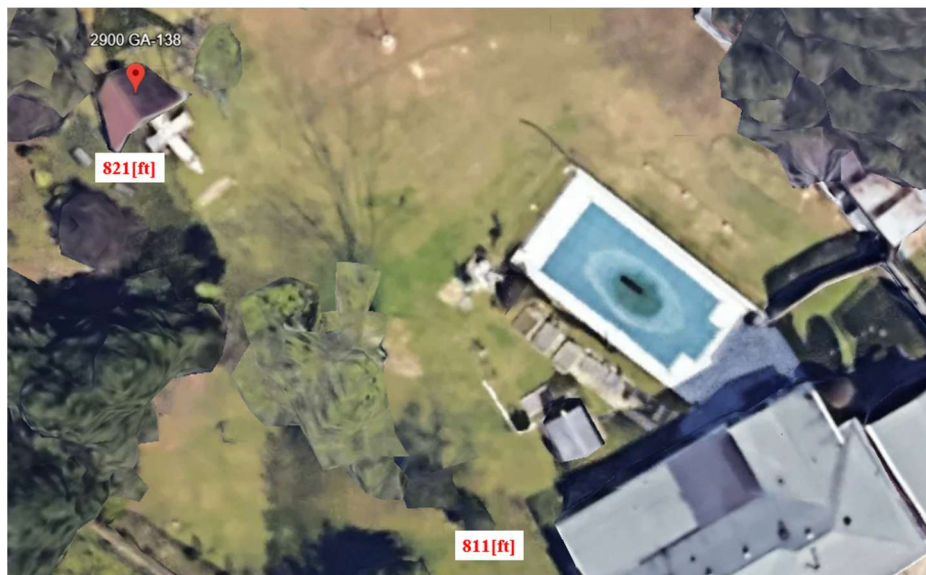


Figure 38: Altitude Variance of 10[ft]

As seen in Figure 38, there is a slope prior south of the Cross of the Crucifixion of about 10[ft]. In order to simulate a worst-case scenario, the cross will be placed in clear terrain. The distance between the two points is about 150[ft]. The simulation mound will have a height of 10[ft] with a radius of 100[ft]; yielding an angle of about 6[deg]. The basic structure is depicted in Figure 39.

CFD, Cross, Envelope & Hill:

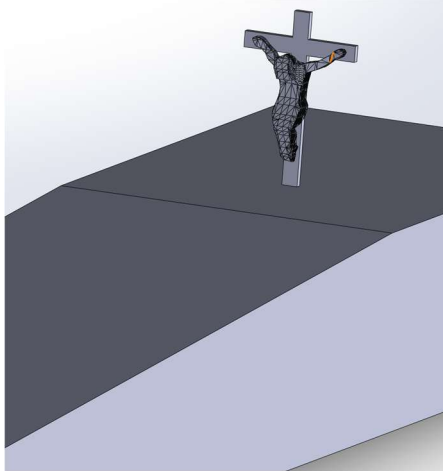


Figure 39: Basic CFD Structure for Cross of the Crucifixion

- The model casting material is Aluminum A383
 - The cross weight is 265 [kg] or 585[Lb]
 - The body-casing weight is 367 [kg] or 809[Lbf]
 - A total weight of 633[kg] or 1,394[Lbf]

The roughness of the model was set to 13[mm] (13,000[μm]). The standard atmospheric pressure was set to 821[ft] or 98,355[Pa]: With an air density of 1.230[kg/m³]. The nominal velocity was set to 47[m/s].

To refine the model further, a short study was conducted to eliminate the hill. The first CFD study was performed with the hill and the cross. The second CFD study was performed without the hill.

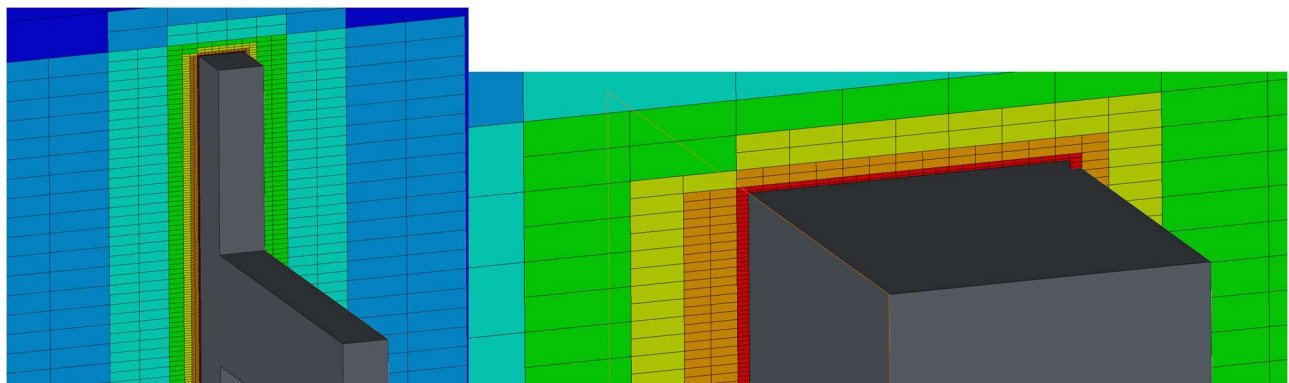


Figure 40: Mesh of Cross with Hill, with Boundary Layer Mesh

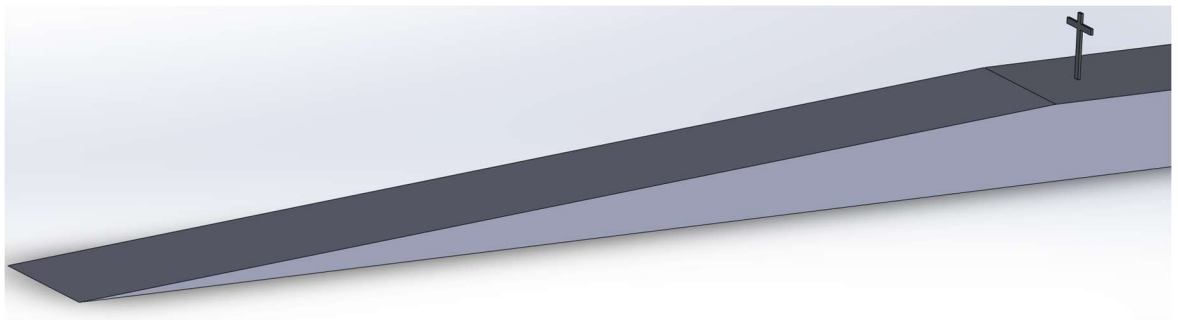


Figure 41: Cross with Hill

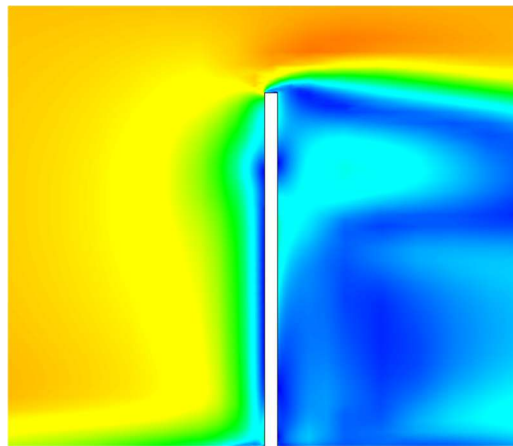


Figure 42: CFD 1st Study, with Cross & Hill

Table 6: Force Vectors with Cross & Hill

X	-1,726	[N]
Y	-2	[N]
Z	10	[N]
Magnitude	1,726	[N]

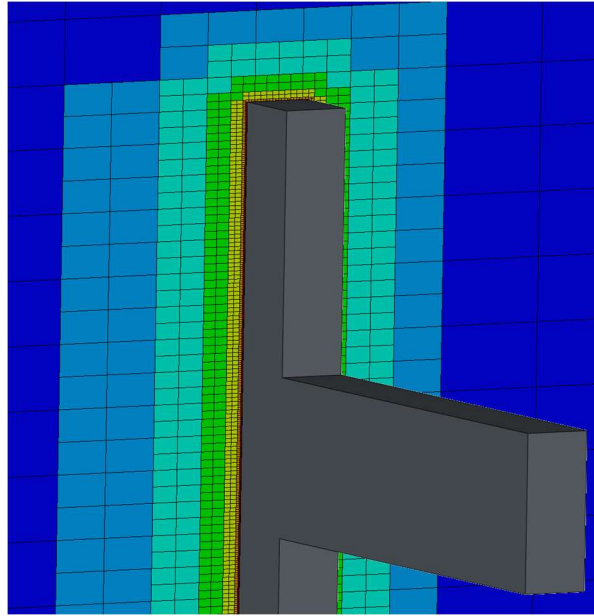


Figure 43: Mesh of Cross (Alone), with Boundary Layer Mesh

CFD, Cross & Envelope:

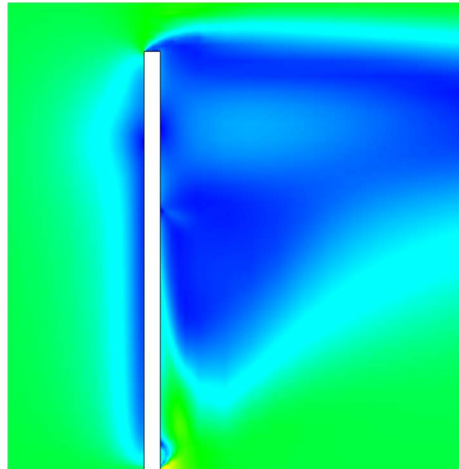


Figure 44: CFD 2nd Study, with Cross (Alone)

Table 7: Force Vectors with Cross (Alone)

X	-1,989	[N]
Y	-2	[N]
Z	21	[N]
Magnitude	1,989	[N]

The wind loading/s with the cross (by itself) are about 15[%] higher, as compared to those with the hill. The 2nd study contains better/symmetrical elements, and it is a bit finer. Due to the rather large difference between the two studies, the gentle hill will be ignored.

CFD System Study of Cross & Envelope:

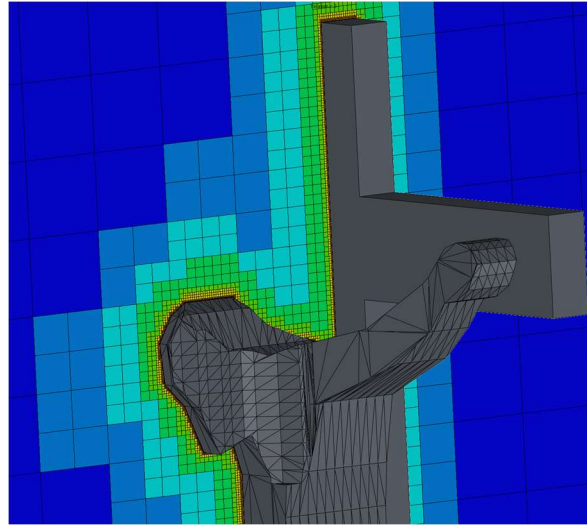


Figure 45: Mesh of Cross & Body, $V[m/s] = \langle V_x, V_y, 0 \rangle$

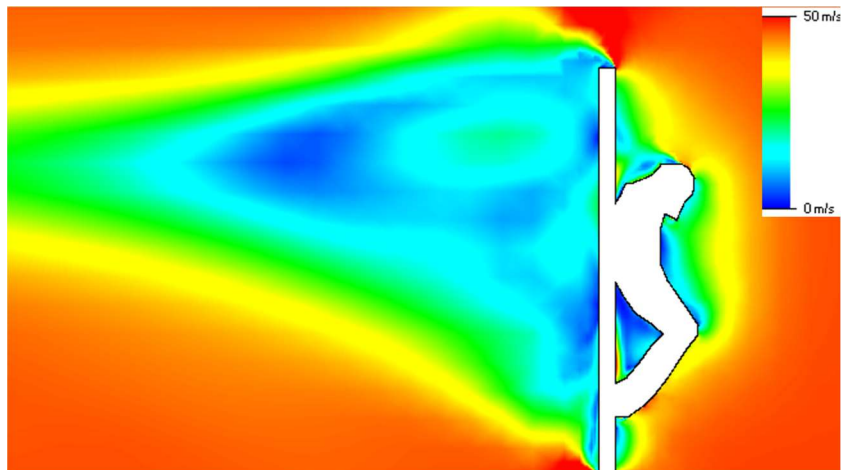


Figure 46: CFD Steady State, $V_x = -47[m/s]$

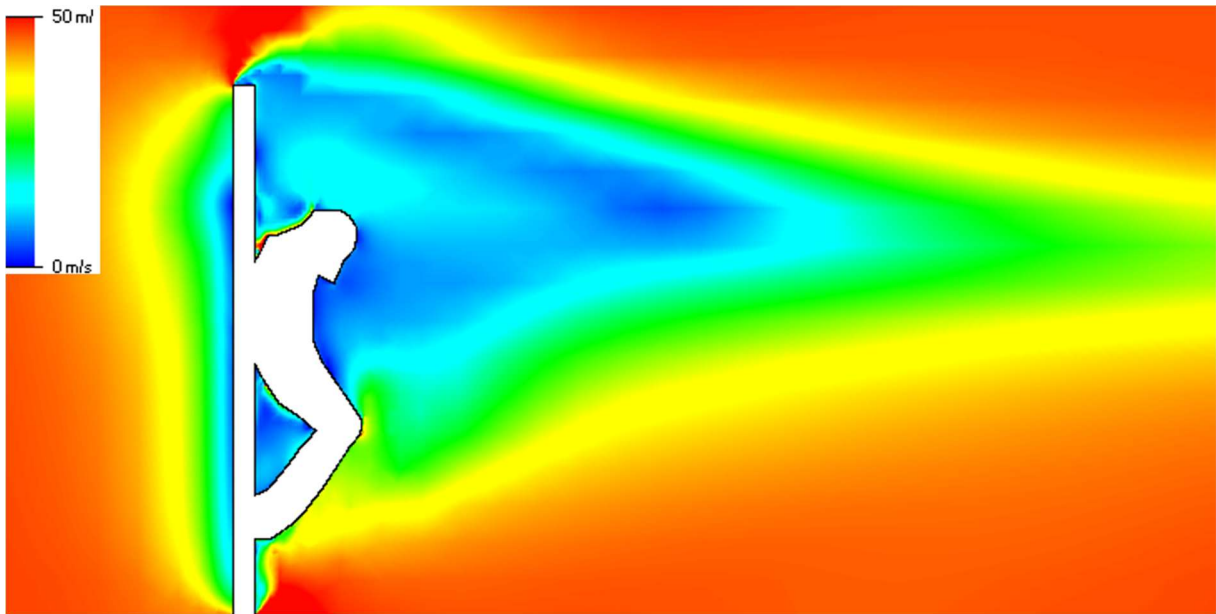


Figure 47: CFD Steady State, $V_x = 47[m/s]$

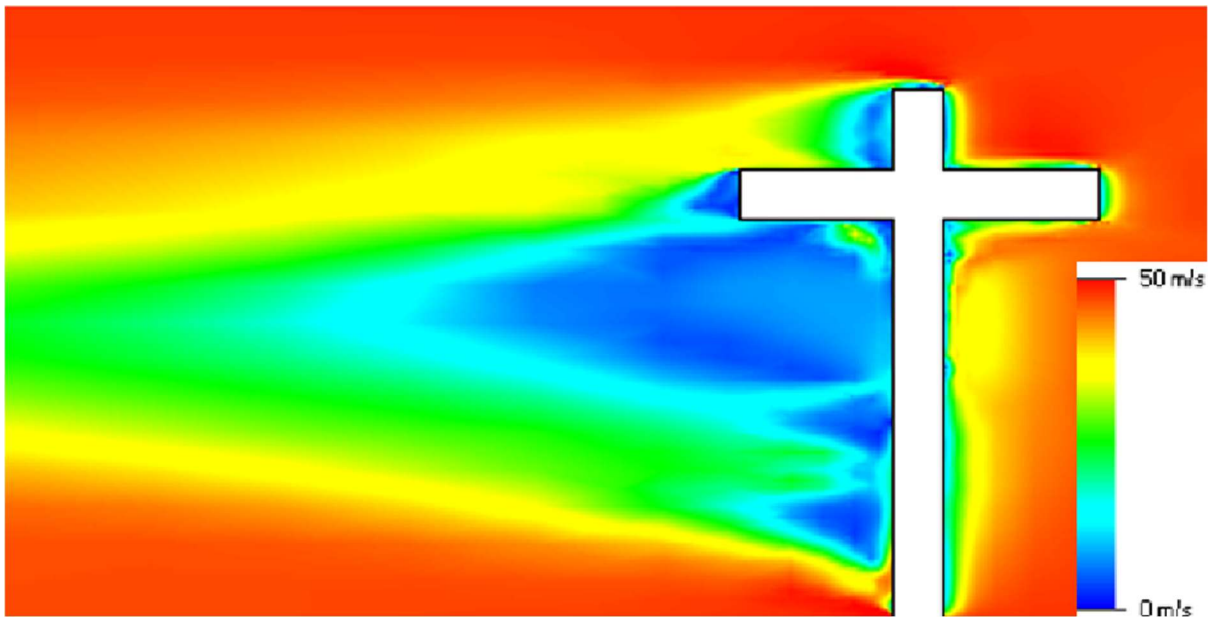


Figure 48: CFD Steady State, Y-Z Plane, $V_y = -47[m/s]$,

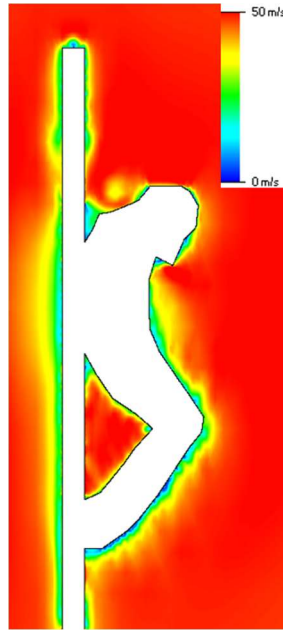


Figure 49: CFD Steady State, X-Z Plane, $V_y = -47[m/s]$

Wind Force/s:

Table 8: CFD of Cross of the Crucifixion where $V_x = -47[m/s]$

Force	[N]	[Lbf]
< X >	-1,205	-271
< Y >	12	3
< Z >	8	2
F	1,205	271

Table 9: CFD of Cross of the Crucifixion where $V_x = 47[m/s]$

Force	[N]	[Lbf]
< X >	1,820	409
< Y >	-13	-3
< Z >	45	10
F	1,821	409

Table 10: CFD of Cross of the Crucifixion where $V_y = -47[m/s]$

Force	[N]	[Lbf]
< X >	-186	-42
< Y >	-386	-87
< Z >	2	0
F	429	96

The largest loading upon the casting/model occurred where $V_x = 47[m/s]$; with a resultant force of 409[Lbf] (1,821[N]). Adding in the system weight of the bodies and the snow/ice, the maximum force acting on the cross will be no more than 413[Lbf] or 1,837[N]; as seen in Table 11.

Table 11: Cross of the Crucifixion Maximum Loading

Force	[N]	[Lbf]
< X >	1,820	409
< Y >	-13	-3
< Z >	1,775	399
F	2,542	572

Where:
 F_x acts fore-aft
 F_y acts side-side
 F_z acts up-down

Beam Stress at Foundation:

The next procedure obtained the loadings on the base of the structure, thereby defining the stresses at the base of the cross. Because there is no actual model of the corpus at this time, the oversized CFD model will be utilized. This has a lever-arm from the base of about 10[in]: The moment induced by the body will be less than 690[Lbf-ft] (931 [Nm]). The combined loading will be applied to the mathematical model, defining the stresses.

The overriding model used is the cantilever beam with a concentrated load:

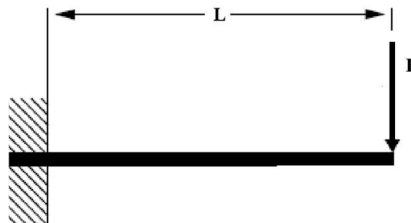


Figure 50: Cantilever Beam w/ Concentrated Load

Equation 20: Simple Beam Moment

$$M_{max} = FL$$

Equation 21: Beam Stress

$$\sigma_{max} = \frac{M_{max}c}{I_c}$$

Where:
“c” is the furthest from the line of action
“I_c” is the inertia w/r “c”

Considering the hollow envelope:

A ratio of 5:1 was placed on the beam width to its thickness: This value comes from the Fatima visitation (Figure 51). Utilizing the CFD and model mechanical values, a minimum base dimension of 6” x 1.2” was determined. To fit the painting from Fatima more accurately, the cross-base dimensions will be nearer 14.6[in] x 2.92[in]. The value of 2.92[in] was taken from biblical measurements as a “handbreadth distance.”

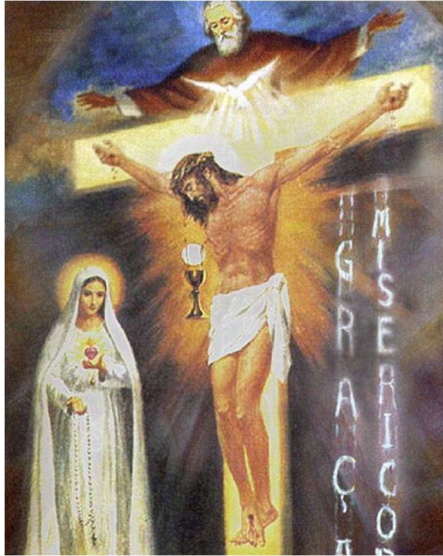


Figure 51: Fatima Cross for Beam Ratio 5:1

Though the analysis is a bit rough, the final design may be manufactured with respect to the afore mentioned design criteria. A similar construction as analyzed above, with a base of 14.6[in] x 2.92[in] will have an FS of more than 5[-].

Transient Analysis of the Cross of Crucifixion:

The following transient analysis was performed on a 14.6[in] x 2.92[in] beam with a wind velocity of 47[m/s], the roughness coefficient was set to zero. This was done because the roughness on this scale as very little affect on the forces of interest.

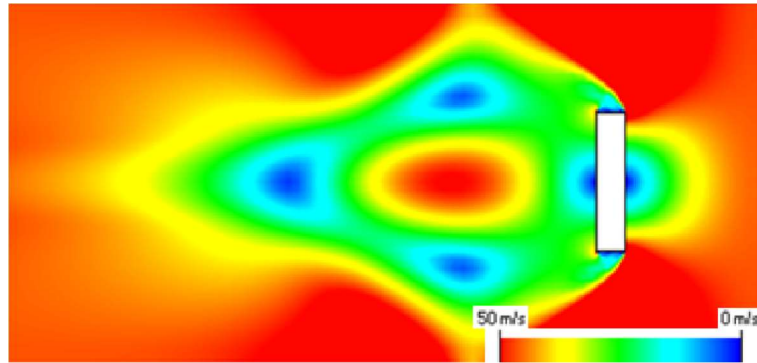


Figure 52: CFD, Transient, Initial Shape/Contour

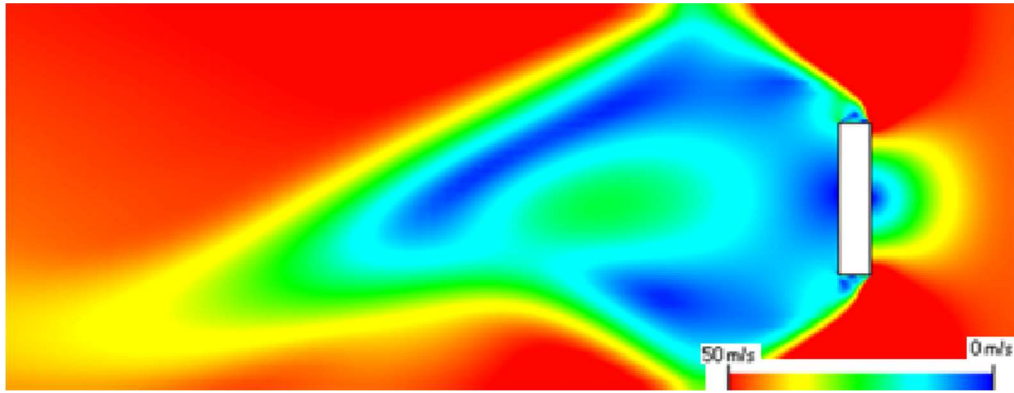


Figure 53: CFD, Transient, Trailing Wave < -Z >

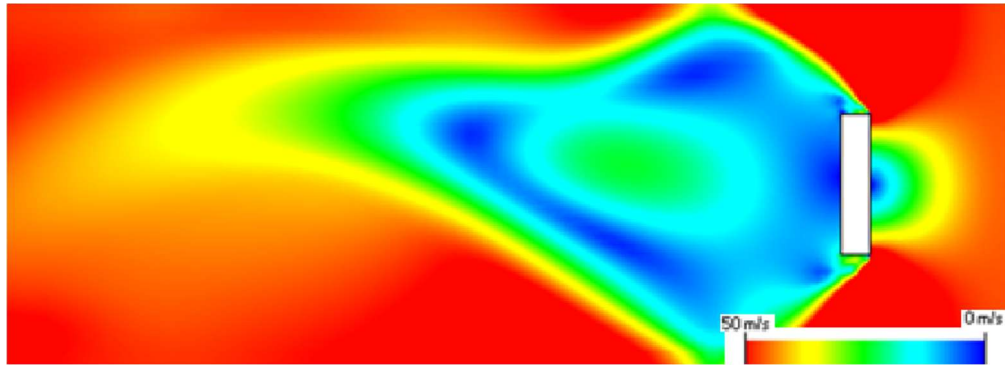


Figure 54: CFD, Transient, Trailing Wave < Z >]

The downward wave has an average dt of 0.851[s], with an average force of -0.014[Lbf] or -0.06[N].
The upward wave has an average dt of 0.943[s], with an average force of 0.009[Lbf] or 0.04[N].

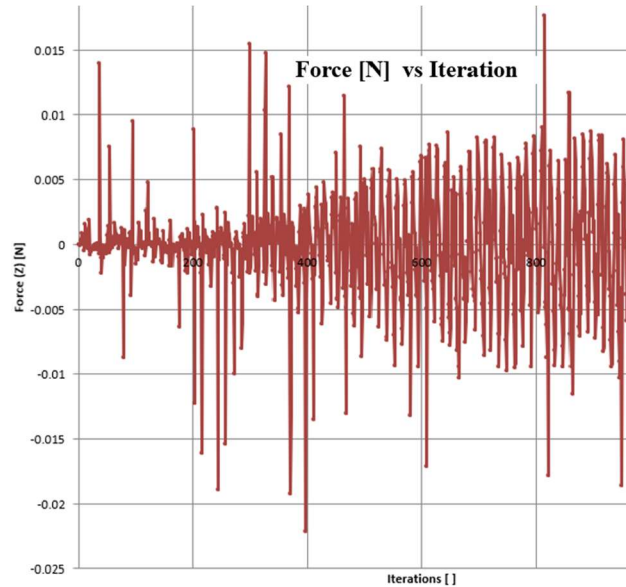


Figure 55: CFD, Transient, Force $\langle Z \rangle$ vs Iteration

After examining the transient data for the 14.6" x 2.92" beam, it was found that there is no vortex shedding. Since there is no vortex shedding, harmonics will be ignored.

Refined CFD/FEA Model:

The overall (above ground) height is 3.26[m] or 10[ft] – 9[in]; with a span of 1.6[m] or 5[ft] – 3[in]. The corpse “straight” height is about 6[ft] or 1.8[m]. The origin of the model ($\langle 0, 0, 0 \rangle$) is at the center of the base of the cross.

Area Projection of the Cross of Crucifixion:

For the purposes of this minor study, 0[deg] is Northwest (about 43[deg] from north). The actual orientation is as shown in Figure 2 and Figure 4: See drawings for construction details.



Figure 56: Approximate Orientation NW

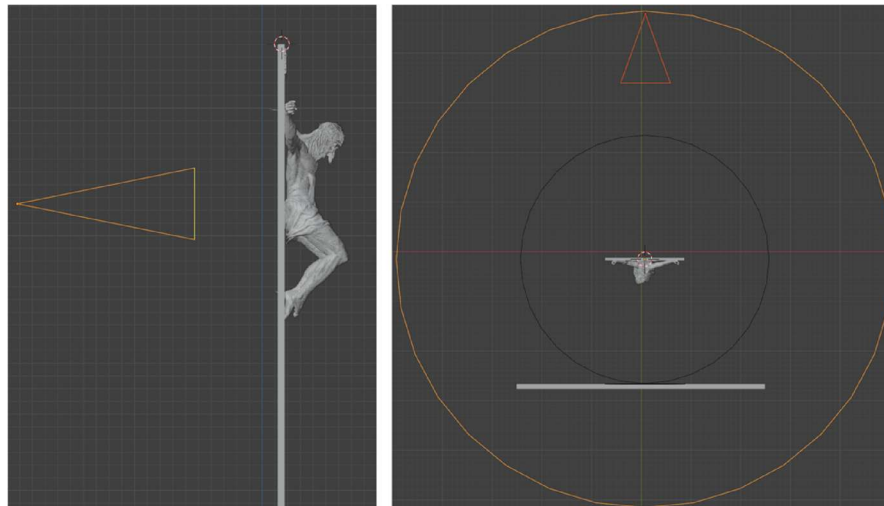


Figure 57: 0[deg] Camera Orientation

The “camera” is at a Radius of 5[m] with the respective angle (0[deg] is shown in Figure 57). The radius of plane for projection is 2.5[m] (the gray rectangle in Figure 57).

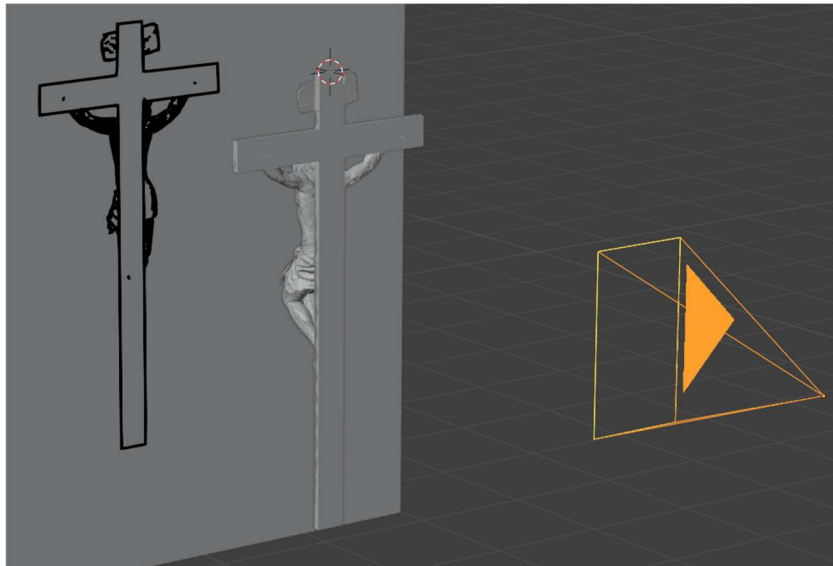


Figure 58: 0[deg] Projection "Grease Ink"

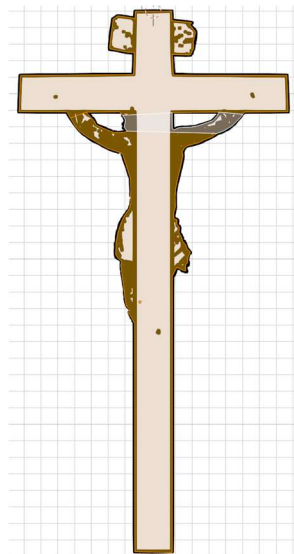


Figure 59: Profile of the Cross of Crucifixion at 0[deg]

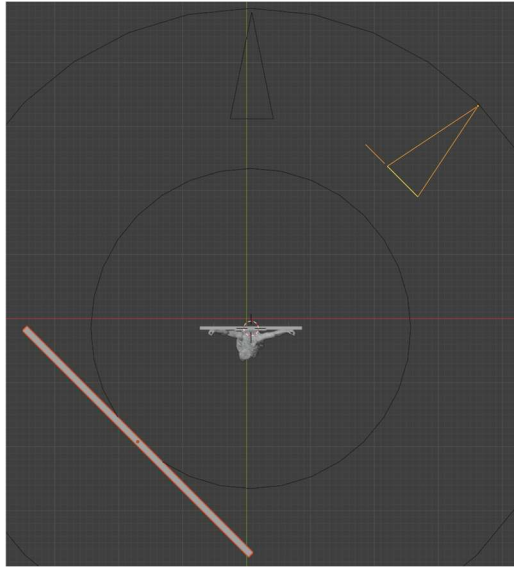


Figure 60: 45[deg] Projection

The file/data utilized may be found in “Combined model 20.blend” within CrossBody Decimate model 20.7z.” Moving in a clockwise direction, projections were taken at 15[deg], 30[deg], 45[deg], 60[deg] and 90[deg].

Table 12: Area of Projection w/r Angle

[deg]	From North	[m2]	[ft2]	[%] from 10.8°
0	317	1.277	13.750	0.1
10.8	327.8	1.279	13.769	---
15	332	1.278	13.758	0.1
30	347	1.262	13.580	1.4
45	2	1.016	10.933	20.6
60	17	1.003	10.796	21.6
90	47	0.614	6.612	52.0

Note: Table 12 references the Cross of Crucifixion.

The interpolated angle of 10.8[deg] from the horizontal contains the greatest profile area. The greatest profile areas are at angles of 10.8[deg] WNW (327.8° from N), 169.2[deg] SSW (212.2° from N), 190.8[deg] SW (233.8° from N) and 349.2[deg] NW (306.2° from N).

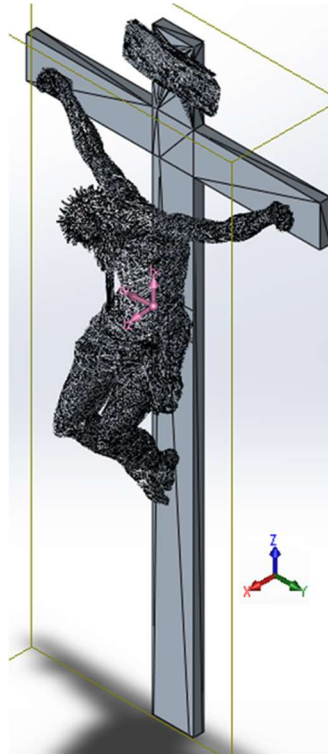


Figure 61: CFD/FEA Solid-body Model for Cross w/ Corpse

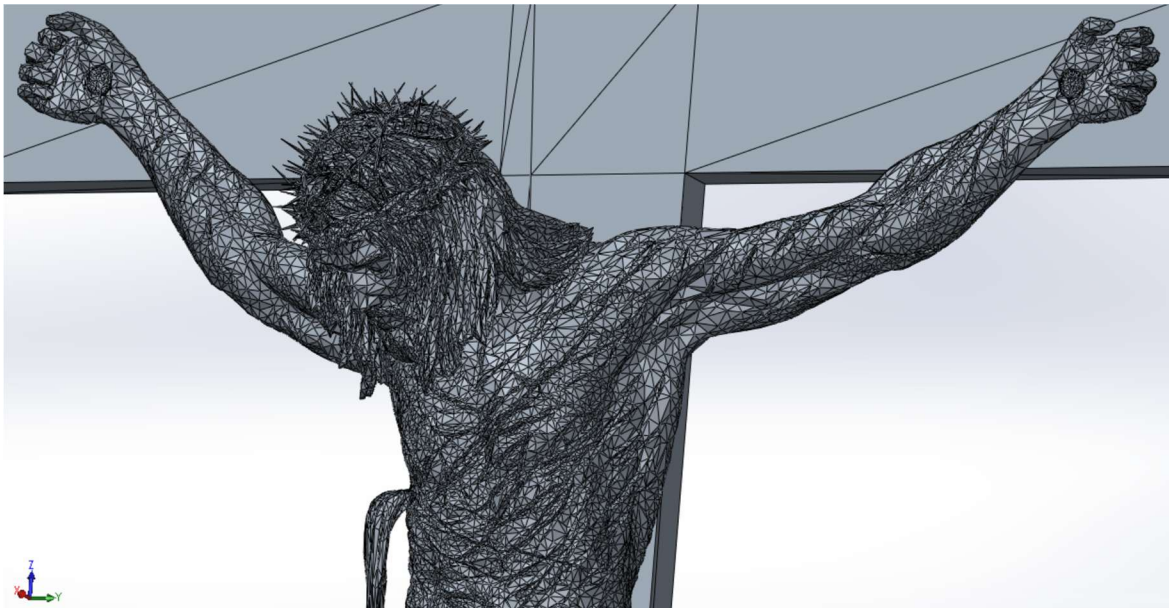


Figure 62: Close-up of 2[%] Decimated CFD/FEA Model

The CFD/FEA model has about 90,000 faces; whereas the detailed model has over 4 million. The actual model was decimated to 2[%] of the original surfaces. The model for the calculations may be found in “CrosBodyASM dec 2per A FEA.7z.”

The base of the cross is 8.76[in] x 2.19[in] (222.5[mm] x 55.63[mm]) with an overall height of 127.32[in] (3234.0441[mm]) and a maximum width of 62.99[in] (1600.001[mm]).

Table 12 shows that the variance of the profiles varies less than 2[%], between the angles of 0[deg] and 30[deg]. Also, the base of the cross has a width/thickness ratio of about 4[-], this generates a bending moment that will be (x)16 greater about < Y >: Therefore, the wind will parallel to the < X > axis (no angle will be applied).

Table 13: CFD/FEA Model Weight & Volume w/ Solid-body

	Mass [kg]	Mass [Lbf]	Volume [m3]	Volume [ft3]
Body	213.9	471.60	0.0798	2.818
Cross	157.2	346.66	0.0587	2.073
Assembly	371.2	818.26	0.1385	4.891

Table 14: CFD/FEA Model Inertia about the Origin

	Ix	Iy	Iz
Assembly [kg-m2]	186	177	23
Assembly [Lb-ft2]	4,415	4,189	541

Table 15: CFD/FEA Model Center of Gravity

Assembly	Cg [m]	Cg [ft]	Cg [in]
< X >	0.123	0.4033	4.839
< Y >	-0.012	-0.0398	-0.4771
< Z >	2.019	6.625	79.498

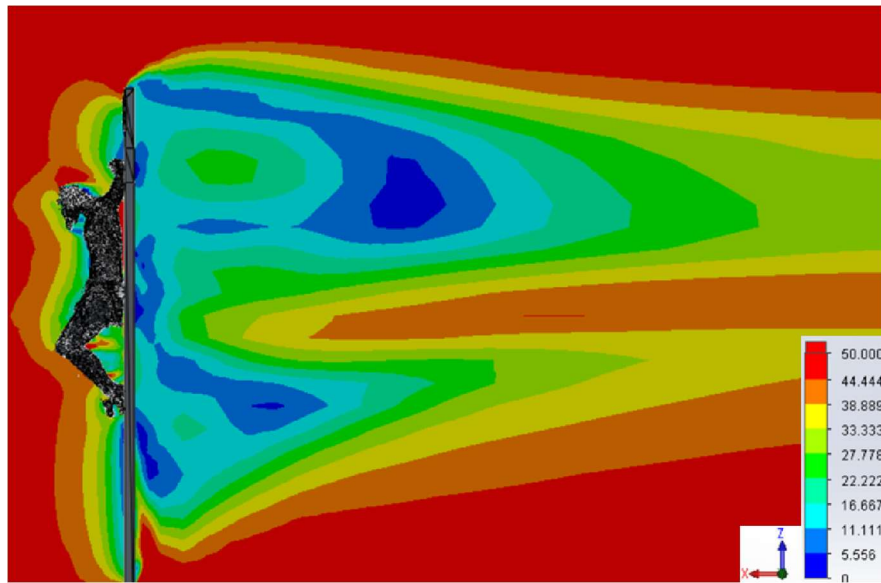


Figure 63: Velocity $\langle -47, 0, 0 \rangle$ [m/s]

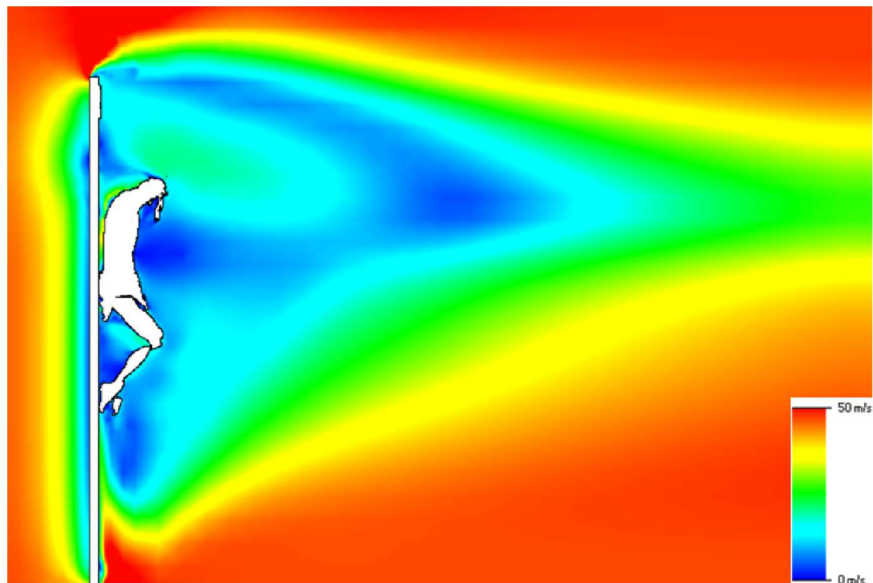


Figure 64: Velocity $\langle 47, 0, 0 \rangle$ [m/s]

Table 16: Forces w/r 47[m/s] & -47[m/s]

47[m/s]	[N]	[Lbf]
Fx1	2,763	621
Fy1	-36	-8
Fz1	-42	-9
-47[m/s]	[N]	[Lbf]
Fx2	-2,894	-651
Fy2	-186	-42
Fz2	-67	-15
Fx1/Fx2	4.5%	

As expected, the largest loadings are when the wind is from the northerly direction (-47[m/s]). The torque about $\langle Y \rangle$ or M_y , was calculated to be -5,881[Nm] or 4,338[Lbf-ft]; with a lever-arm of 2.03[m] or 6.67[ft]. The magnitude of the skin friction was less than 8[N] or 1.8[Lbf].

With a base of 8.7[in] x 2.19[in] and an ultimate stress of 47,000[psi] (for cast aluminum 383), the maximum stress due to the wind, seismic and snow is less than 8,100[psi]; yielding a FS (FS_e) of 2.2[-]. The drawings will show a minimum thickness of 2.5[in] in the chest area, increasing the FS; due to less bending.

The square foundation for the Cross of the Crucifixion requires a side length of 48[in] and a depth of 5[ft].

The graphics data to be cast/molded is located

For Solidworks: Cross Body ASM 1.zip and Cross Body ASM 1 Part 1 sldprt.zip

Iges file: Cross Body ASM 1 IGS.7z

PLY file: Cross Body ASM 1 PLY.zip

Individual parts: body 18 mm obj ply.zip

Blender and Other: Full ASM C n B model 20.zip

The data for the molded part within “Cross Body ASM...” has much more detail as seen in ss, as compared to the CFD model in ss.

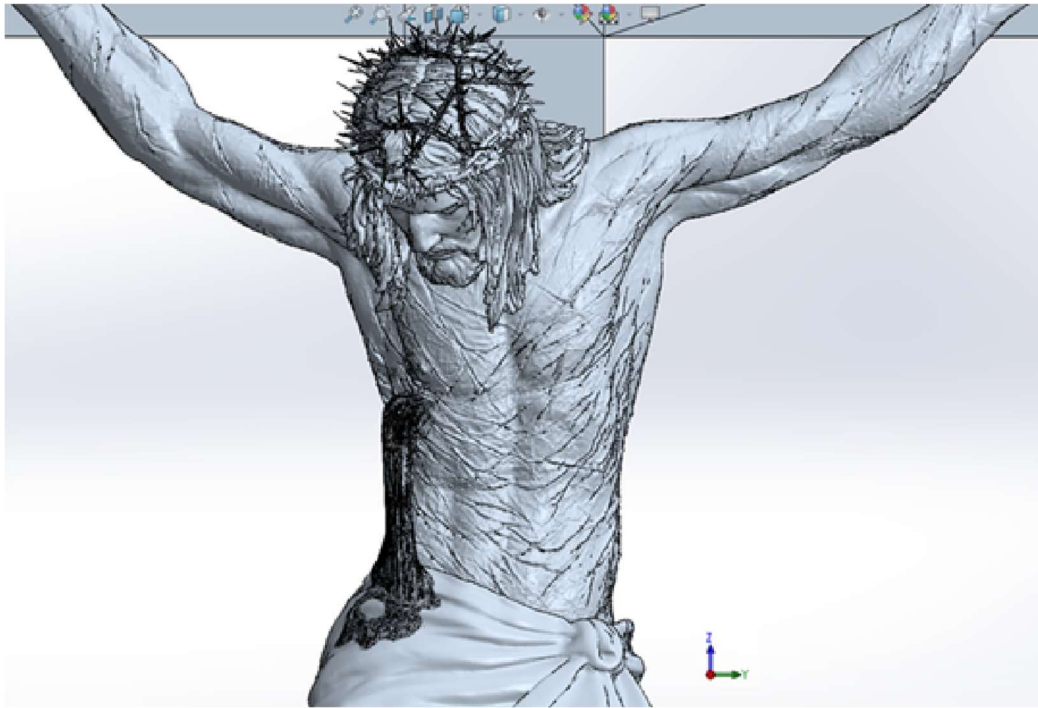


Figure 65: Detailed Molded Assembly

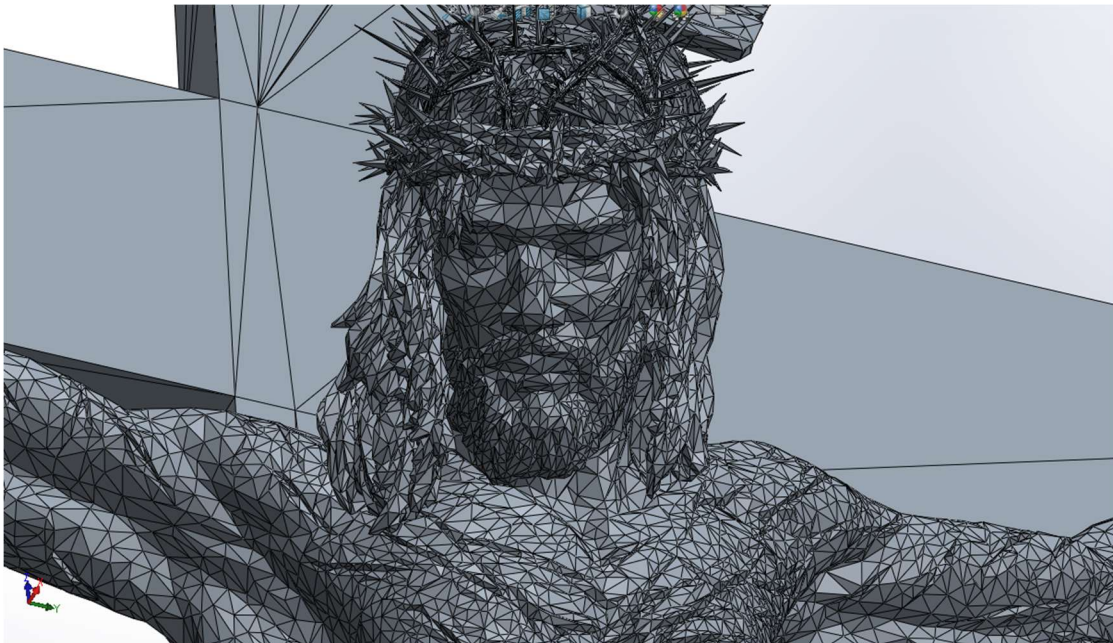


Figure 66: Coarse CFD Model

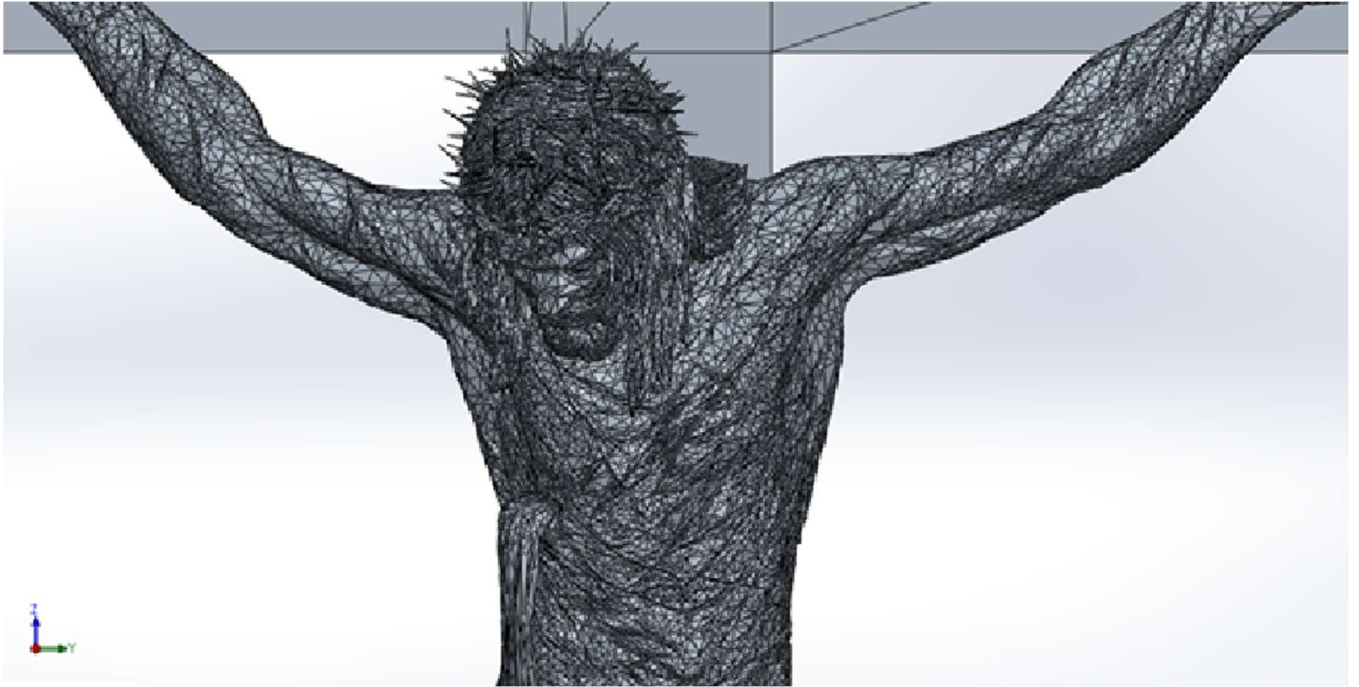


Figure 67: Coarse CFD Model – Middle Section



Figure 68: Coarse Model – Upper Section

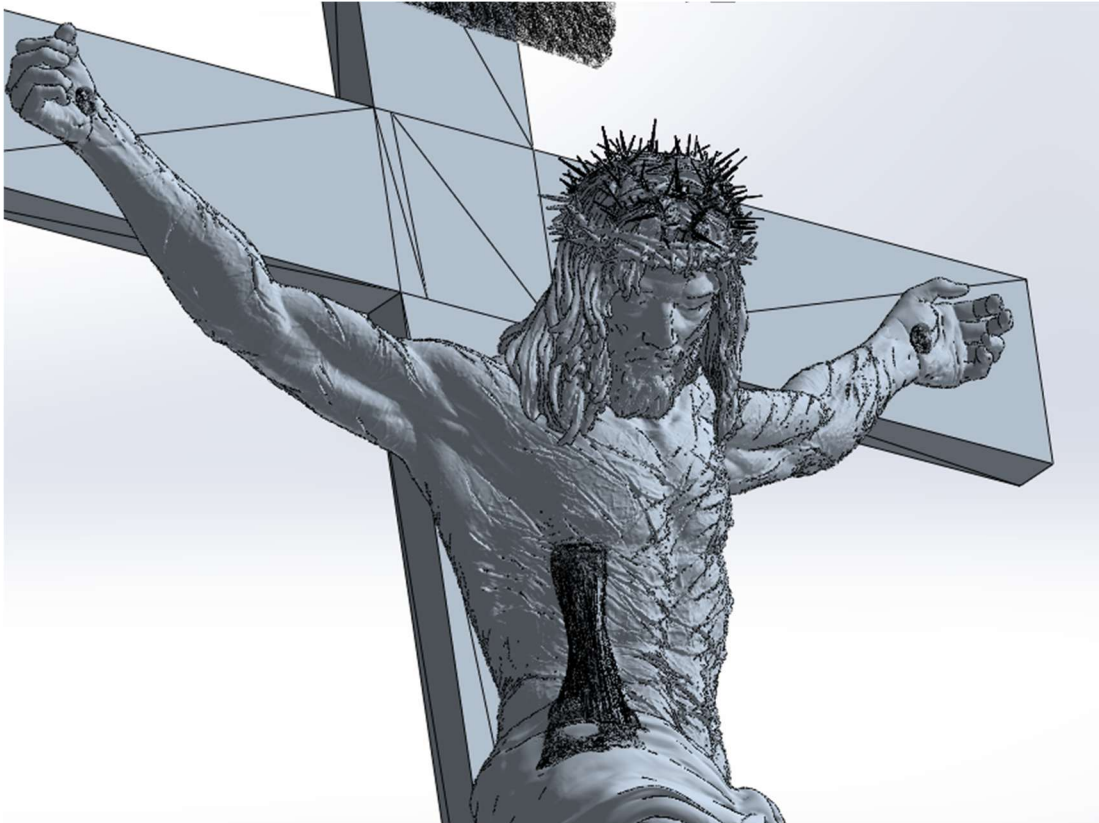


Figure 69: Detailed Model – Blood/Water from Wound



Figure 70: Detailed Model – Cloth and Legs

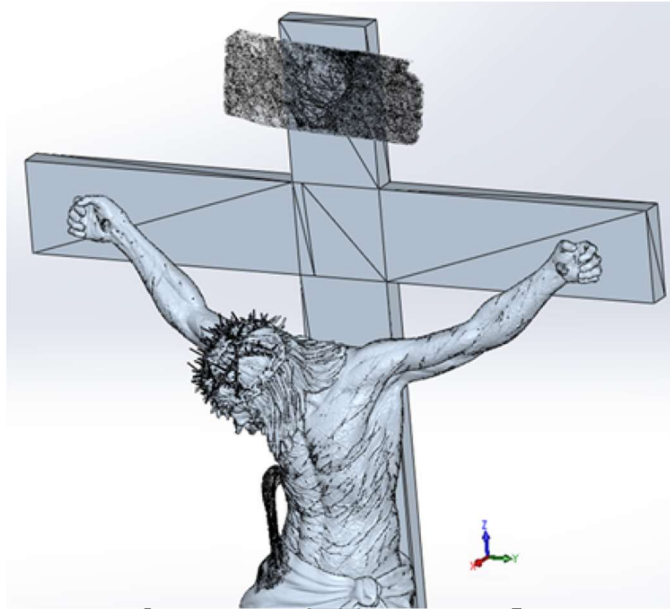


Figure 71: Detailed Model – Upper Segment

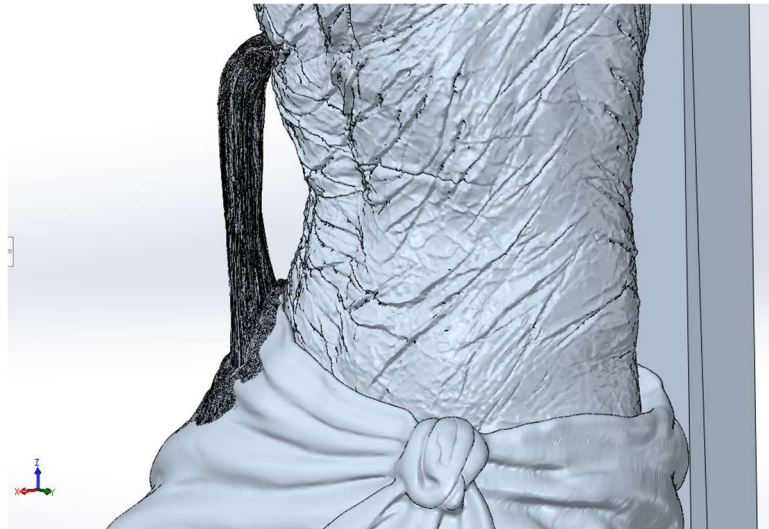


Figure 72: Detailed Model – Mid-segment

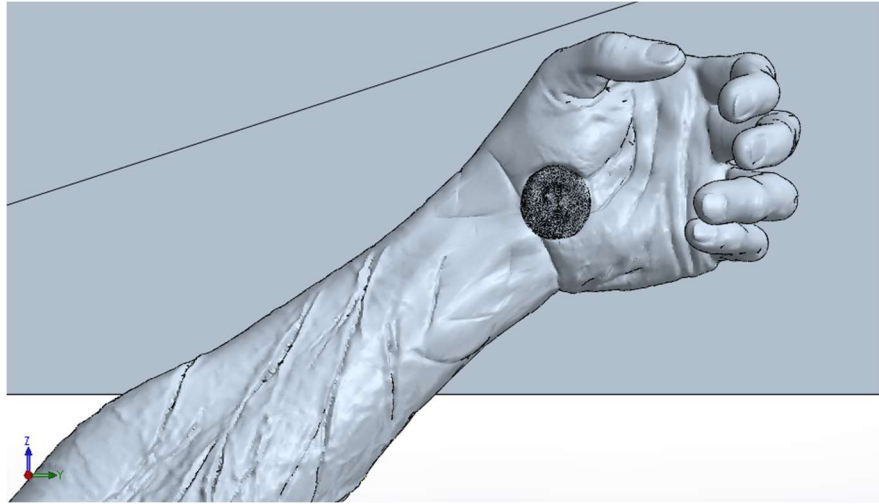


Figure 73: Detailed Model – Left Hand



Figure 74: Detailed Model – Crown of Thorns

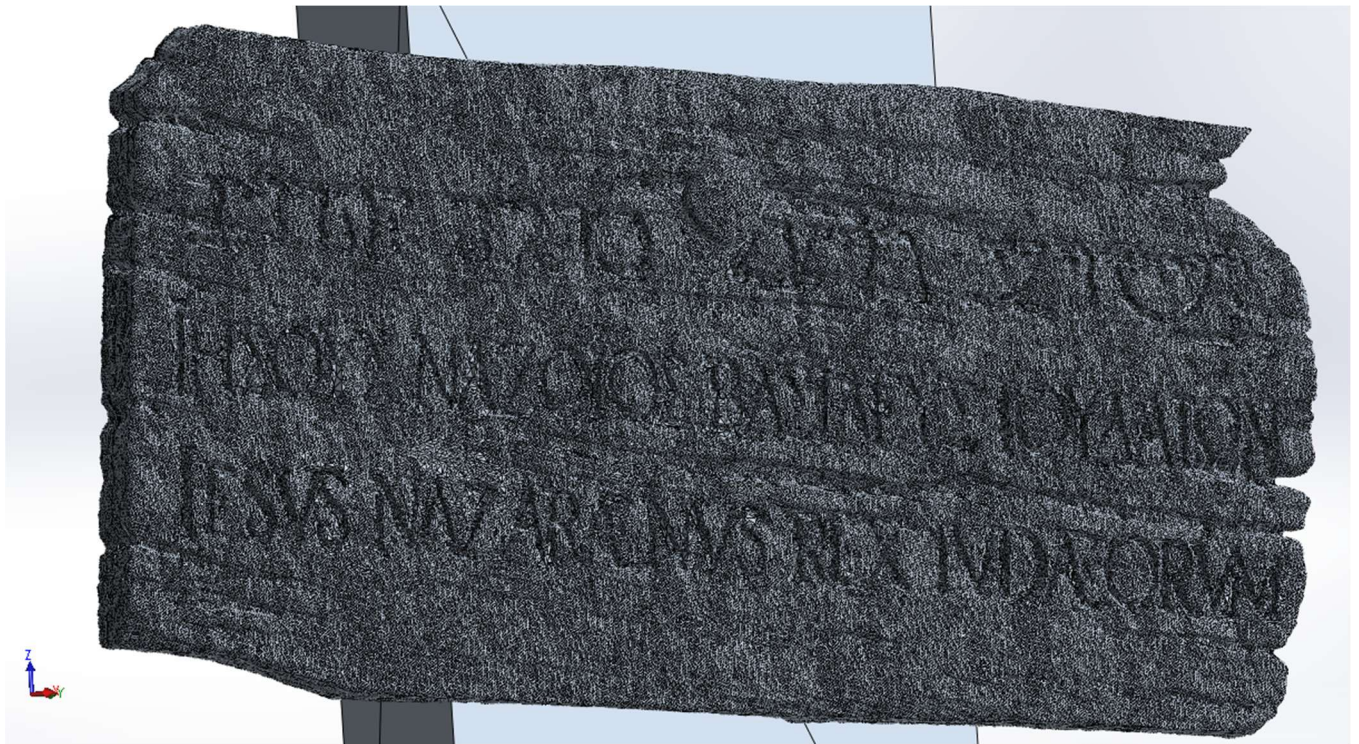


Figure 75: Detailed Model – Full Sign

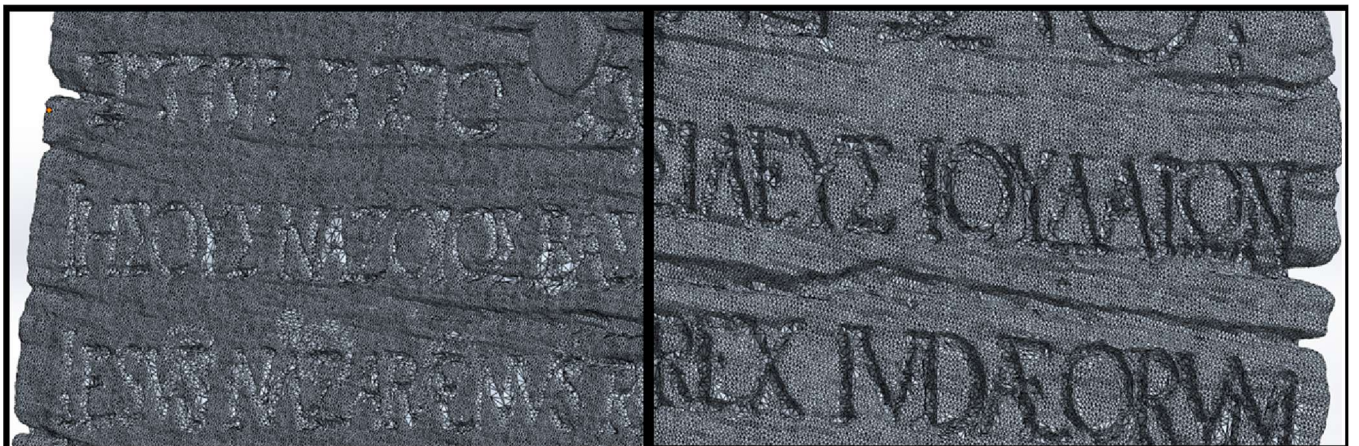


Figure 76: Detailed Model – Sign, Close-up



Figure 77: Detailed Model - Left & Right-Side Views

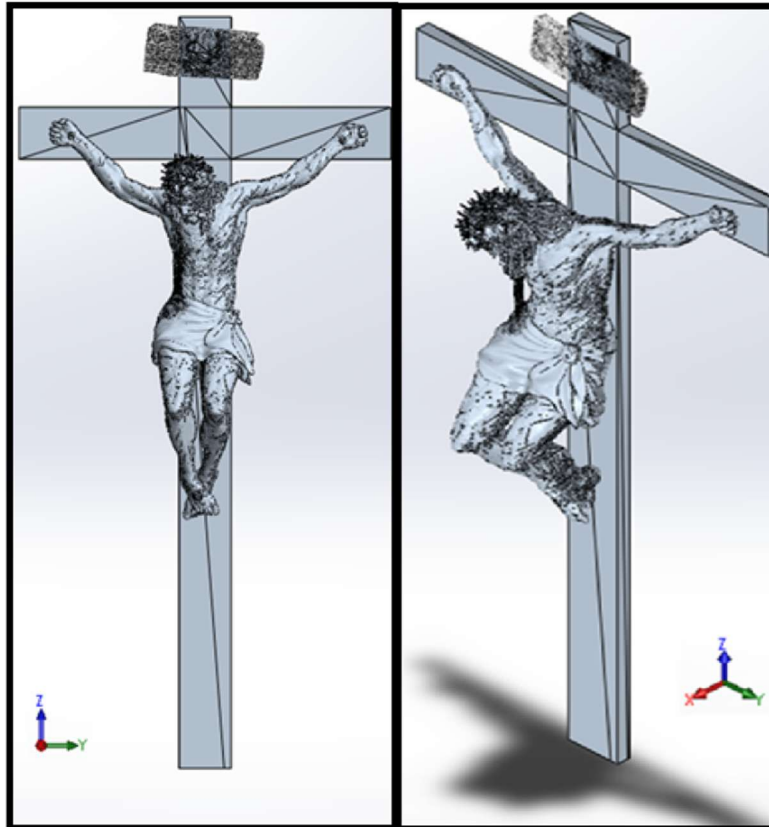


Figure 78: Detailed Model – Above Ground View 1

The components of the model include:

- 1) The Cross
- 2) The Body
- 3) Crown of Thorns
- 4) The Blood & Water
- 5) The Cloth
- 6) The Nails

The detailed model is used for production, while the rough model is utilized for calculations. See the final prints for construction details.

MIRACULOUS MEDAL STATUE:

The Miraculous Medal statue is placed at the foot of the altar. It is a depiction of Mother Mary's Miraculous Medal visitation/s.

The Miraculous Medal Model Face:

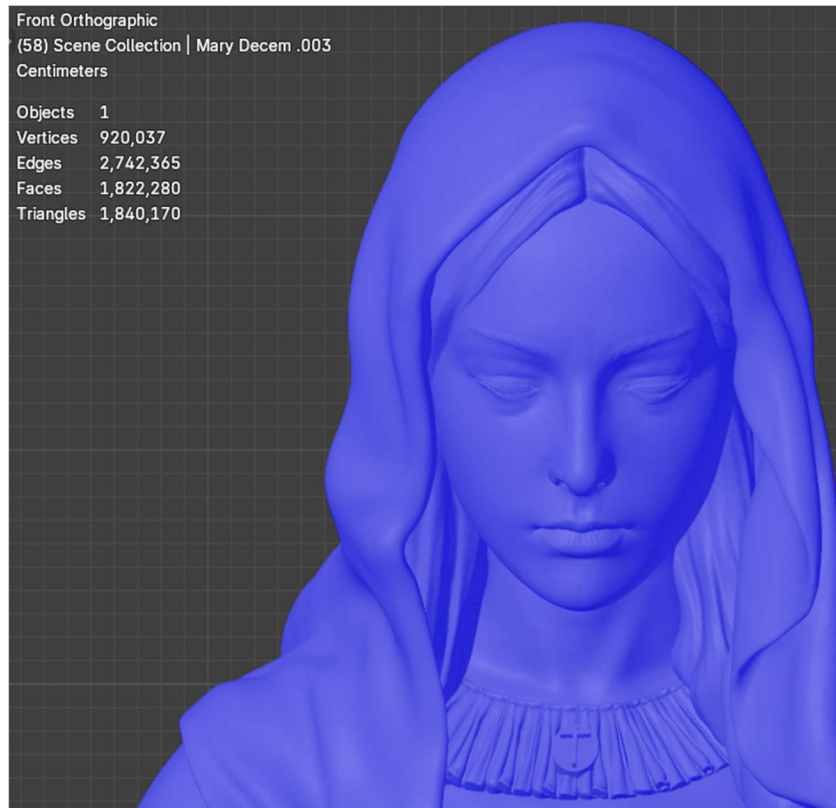


Figure 79: Mother Mary, Detailed Model (in Blender)



Figure 80: Mother Mary, Detailed Model (for Production)



Figure 81: Miraculous Medal, Front View

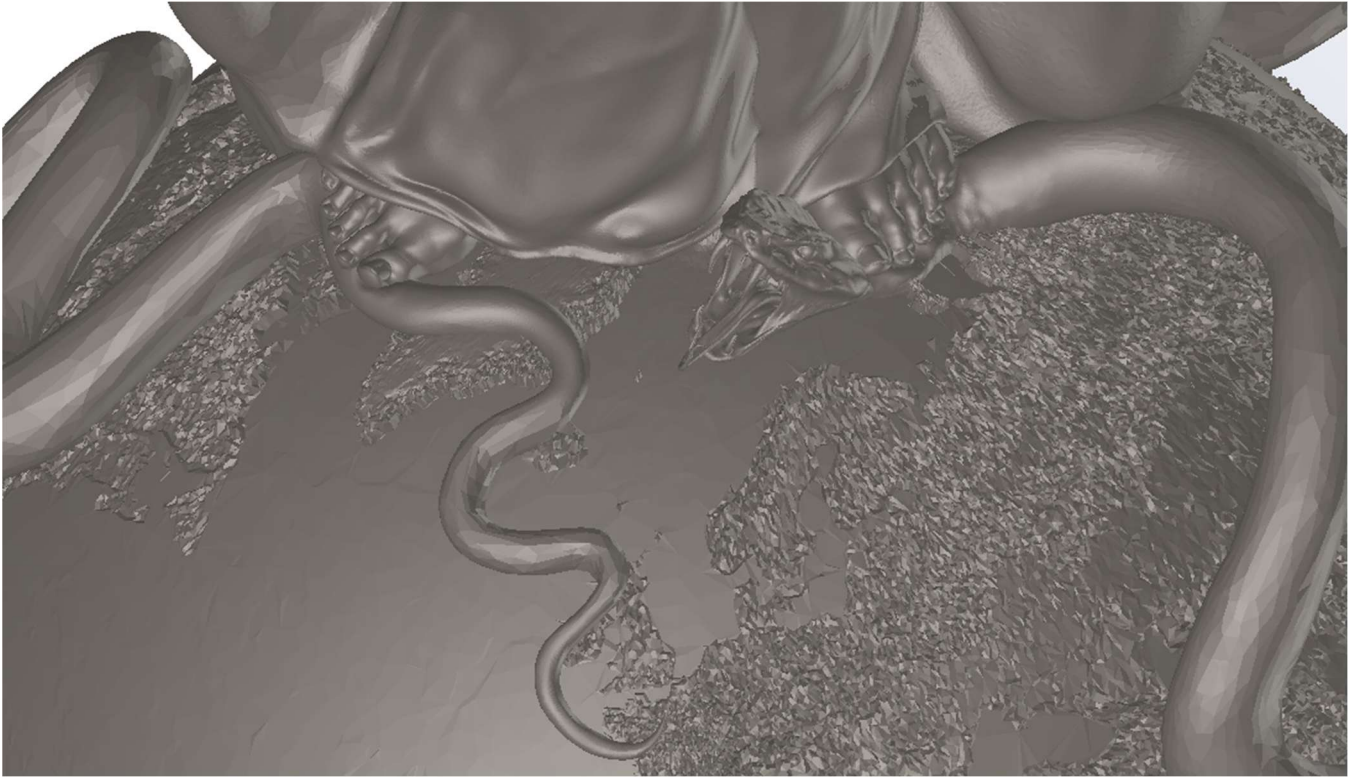


Figure 82: Miraculous Medal, Earth and France

Note: The model points to France, as in the visitation notes.



Figure 83: Miraculous Medal w/8-Pointed-Stars, Side II of Medal



Figure 84: Miraculous Medal, Overall View I



Figure 85: Miraculous Medal, Overall View II

Table 17: Miraculous Medal Full Volume & Weight

Volume in Blender	595,680,128.001	mm3
	0.596	m3
	21.036	ft3
	36,350.632	in3
density	0.097	Lb/in3
	3,526.011	Lbf
	1,599.371	kg

Note: Above information is without cavities.

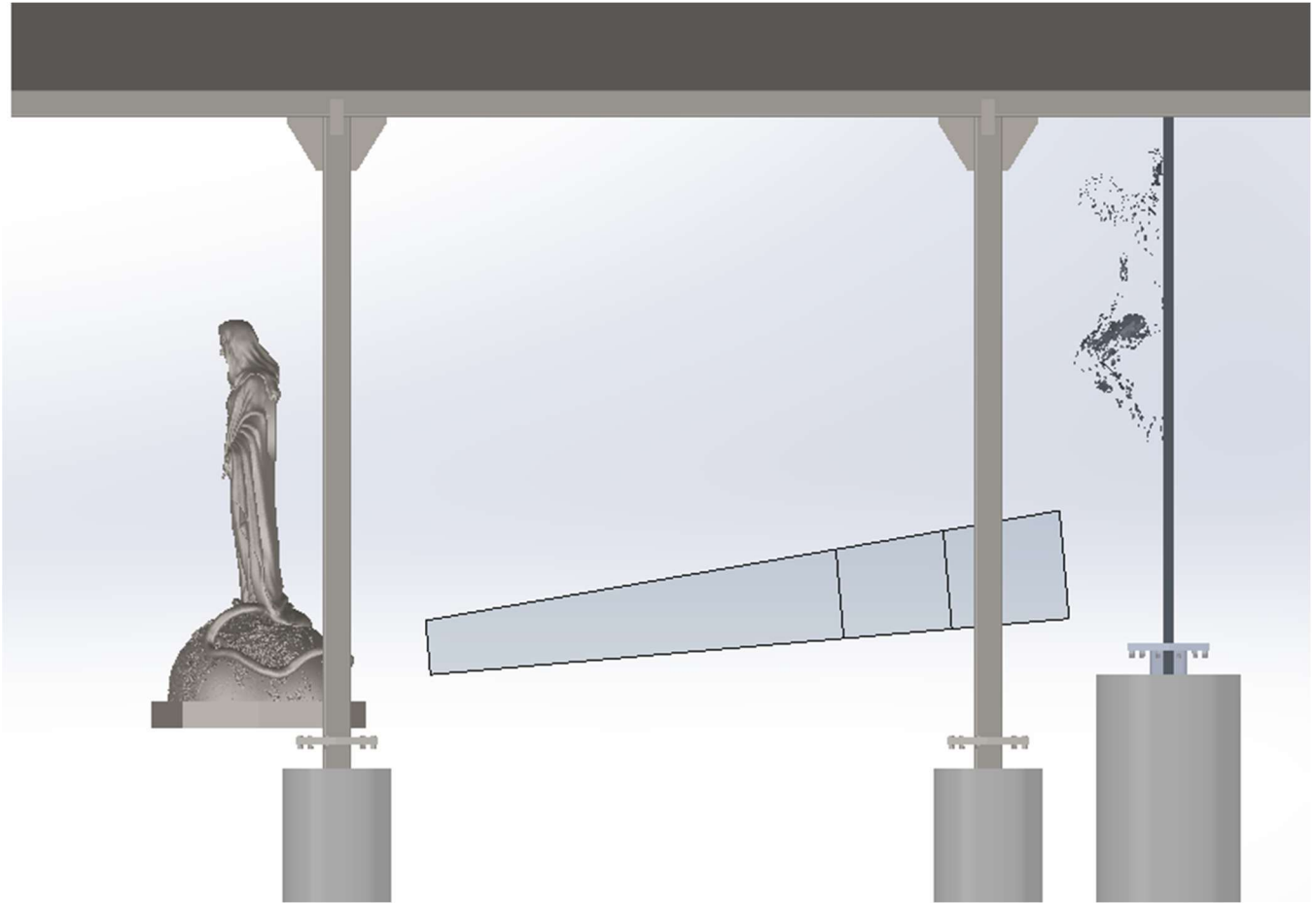


Figure 86: Corpus Cross, Miraculous Medal, Stone Alter & Roof (View I)

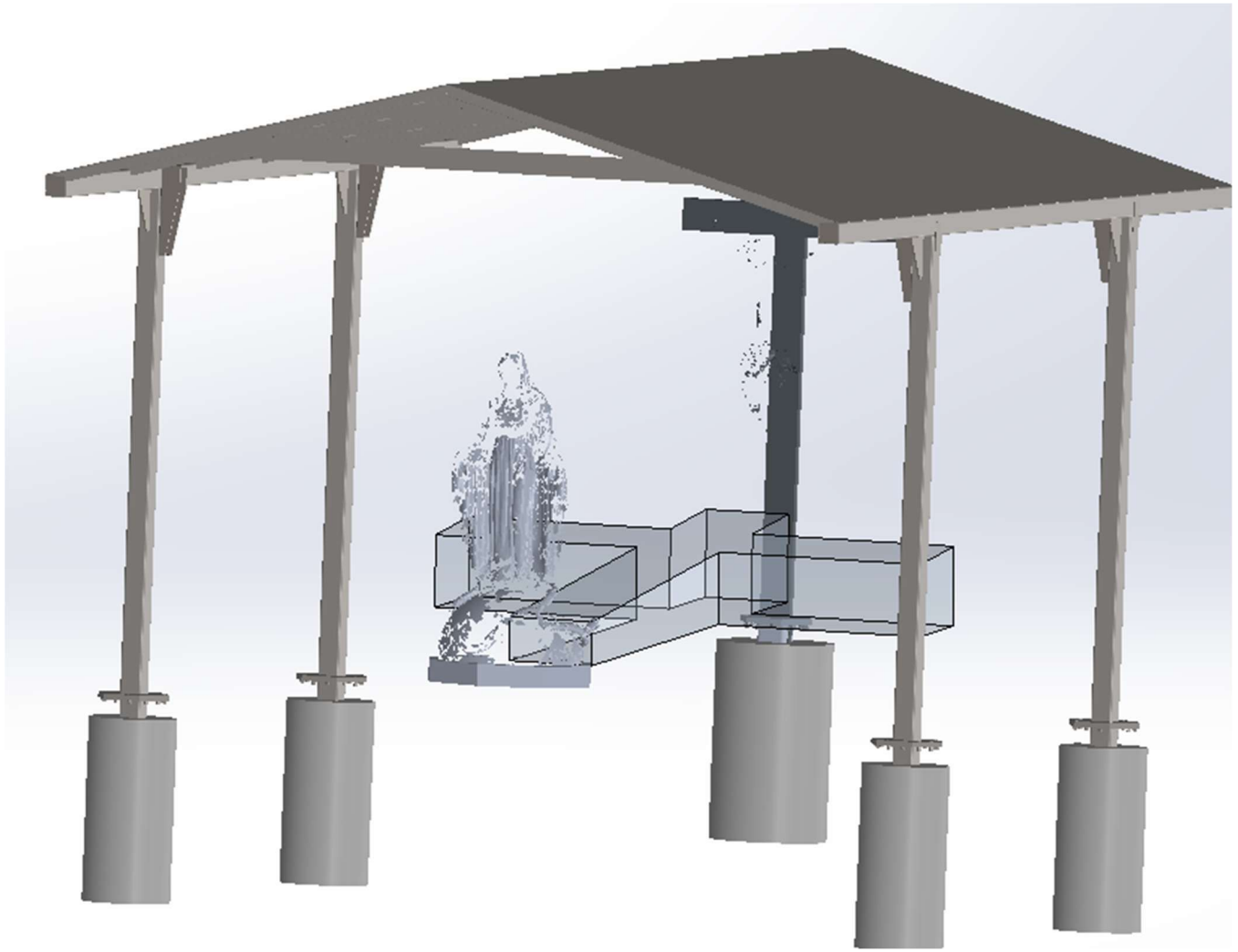


Figure 87: Corpus Cross, Miraculous Medal, Stone Alter & Roof (View II)

The assembly of the shrine, containing the Corpus Cross, the Miraculous Medal and the stone alter will be used at Conyers, GA and Dozule, France. The alter is made with uncut stones, which is present at Conyers, GA. A duplicate stone-cross alter is to be made at the shrine site, in Dozule. The shrine in Dozule will be located somewhere between the Glorious Cross and the pool (for the washing of the feet).

Structural Embedment of the Cross of Crucifixion:

Footing Design:

Taking the various loadings into account, the mounting plate will be at least 25[in] square with ½" mounting bolts at 11[in] from center; as seen in Figure 33. The plate will be 1[in] thick with a top and bottom weld, to the main structure, of 0.3[in].

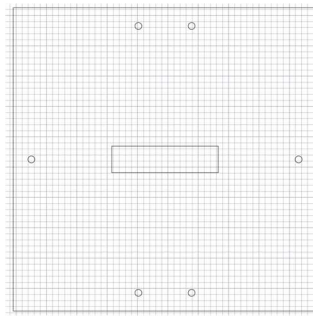


Figure 88: Mounting Plate for Cross of Crucifixion

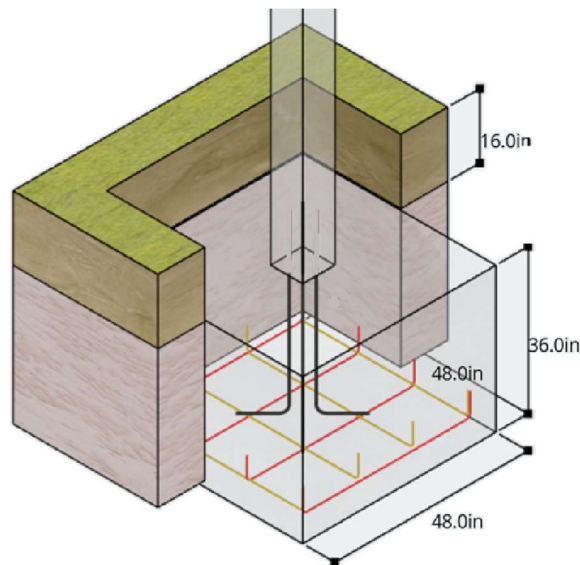


Figure 89: Cross of Crucifixion, Rough Depiction of Concrete Base⁽²⁶⁾

The mounting plate will rest upon a concrete slab, then $\frac{3}{8}$ " reinforcement bars will be placed per design. After the reinforcement is installed, the main concrete slab will be poured. The main concrete slab will be 48[in] square with a depth of at least 3[ft] (below topsoil).

Site Design:

The final design of the foundation was based upon the soil loading capabilities. The diameter of the foundation will be 24[in] (min) at a depth of 4[ft] below topsoil. The reinforcement members shall be placed in a hexagonal orientation around the base.

Roof/Cover for the Cross of Crucifixion:

The Cross of Crucifixion will have a roof to protect it from falling (random) debris. This cover will also protect the Altar; the cross built into the side of the hill (from rain). It will be a simple structure made from stainless steel, lasting about 500[y].

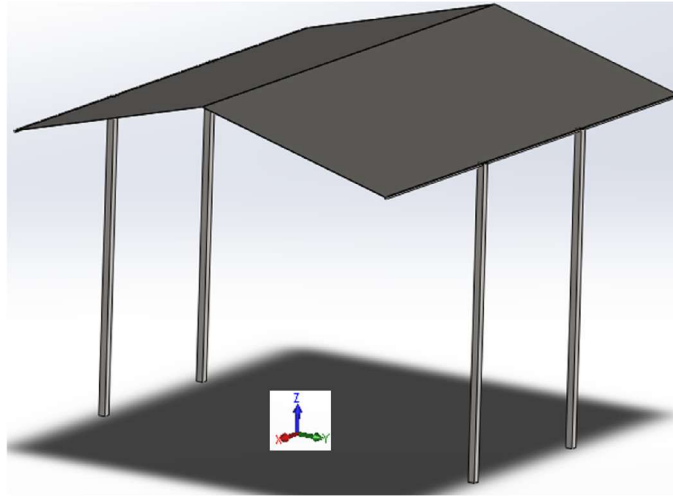


Figure 90: Roof/Shelter for The Holy Hill Altar & Cross

The roof, or shelter, has an angle of 15[deg] and is about 20[ft] wide by 25[ft] long. A CFD analysis was performed in the $\langle X \rangle$ direction with a velocity vector of 47[m/s] at 6[deg] up: $\langle -46.743, 4.913, 0 \rangle$ [m/s]. Then a lateral loading analysis was performed with a velocity vector of 0[deg]: $\langle 0, -47, 0 \rangle$ [m/s]. The values represented in Table 18 and Table 19 contain a 15[%] FS and are applied only to the roof (not the supporting beams).

Table 18: Roof/Shelter Axial $\langle X \rangle$ Loading

Wind @ 6[deg] $\langle -46.743, 4.913, 0 \rangle$ [m/s]	[N]	[Lbf]
F _x	-322	-72
F _y	0	0
F _z	11,446	2,573
F	11,450	2,574

Table 19: Roof/Shelter Lateral < Y > Loading

Wind @ 0[deg] < 0, -47, 0 >[m/s]	[N]	[Lbf]
F _x	3	1
F _y	-7,458	-1,677
F _z	21,657	4,869
F	22,906	5,149

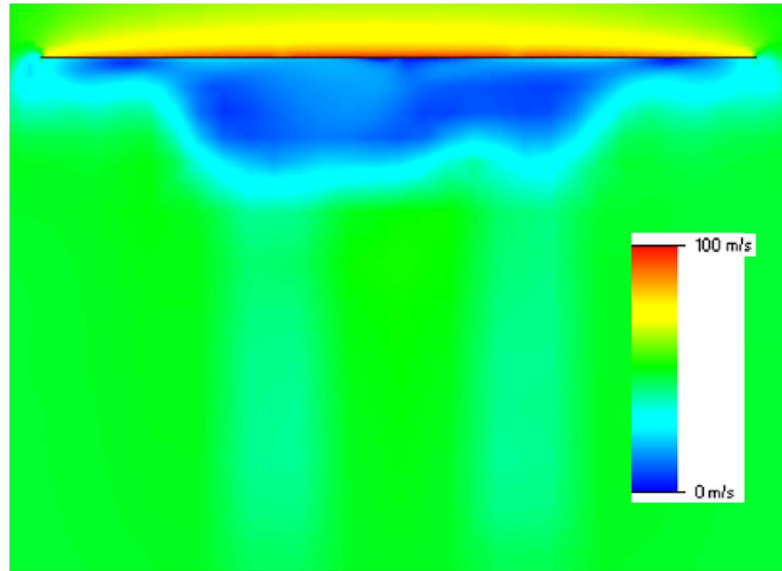


Figure 91: Lateral Velocity Profile at Mid-section

If the wind does travel up the hill at 6[deg], a lifting force of about 2,600[Lbf] would be applied to the structure. The lateral wind produces a low-pressure zone producing a lifting force of about 4,900[Lbf] and a lateral load of about 1,700[Lbf].

From the ground to the top of the Cross of Crucifixion is 127.32[in] (10.6[ft]) (per design); with a maximum width of about 63[in]. The minimum beam height is about 130[in]. The slope of the hill requires slightly longer beams; to be verified in the field. The maximum length of the beam, above ground, is 187[in]. The elevations came from Google Earth at the old home of Nancy Fowler: 2900 Hwy 138 NE, Conyers GA, 30013-1110.⁽⁰³⁾

In various publications, the AISI endurance strength of 304ss is 240[MPa]⁽³⁵⁾ or 34[ksi]. There are other equations such as those proposed by Argonne National Laboratory (ANL).⁽³⁶⁾

Equation 22: Modified Langer Equation

$$\ln(N) = A - B \ln(\varepsilon_a - C)$$

Where:
A & B model coefficients from data
 ε_a is the applied strain amplitude

Equation 23: ANL Fatigue/Endurance for 304ss & 316ss

$$\ln(N) = 6.703 - 2.030\ln(\varepsilon_a - 0.126)$$

Where:
N ≥ 10,000[-]

Over a 500[y] period, there would be around 60 events of high wind conditions, over 30[m/s]. If 10,000 such events were to occur, the strain amplitude would be 0.4167[-]. Similar to stress amplitude ($\sigma_a = \frac{1}{2}(\sigma_{\max} - \sigma_{\min})$), the strain amplitude is defined as in Equation 24. This equation states that the stress amplitude may be as high as 41,000[psi]; which is about 56[%] of the ultimate strength, $\sigma_{ut} = 73,200$ [psi]. Since remaining within the elastic regime is a goal for this project, the maximum stress for 304[ss], over 10,000[cycles] will be 30[%] of the Se (34,809[psi]), 24,366[psi].

Equation 24: Strain Amplitude (Elastic Regime)

$$\varepsilon_a = \frac{1}{2}(\varepsilon_{\max} - \varepsilon_{\min}) = \frac{\sigma_a}{E}$$

Where:
 ε_a is the strain amplitude
 $\varepsilon_{\max}$ is the maximum strain
 $\varepsilon_{\min}$ is the minimum strain
 σ_a is the Stress amplitude
E is the elastic modulus

The maximum pressure on the roof of 0.269[psi] was utilized the maximum verses minimum pressures across the assembly and snow/ice loadings. The loading requires (x)4 beams that are 6[in] square with ¼[in] thickness. The beams will be evenly placed, each supporting ¼ of the loading. The maximum stress in the beam is not expected to exceed 10,000[psi]; with the ability to last over 1[mil] cycles.

The roof panels were modeled with the SolidWorks FEA modules. The roof sheet metal was 0.0625[in] thick with a 24[in] width and a 24[in] length. The ribs were modeled with 0.125[in] thickness and a height of 1.5[in]. The model was symmetrically defined, so it will cover a 48[in] x 48[in] span.

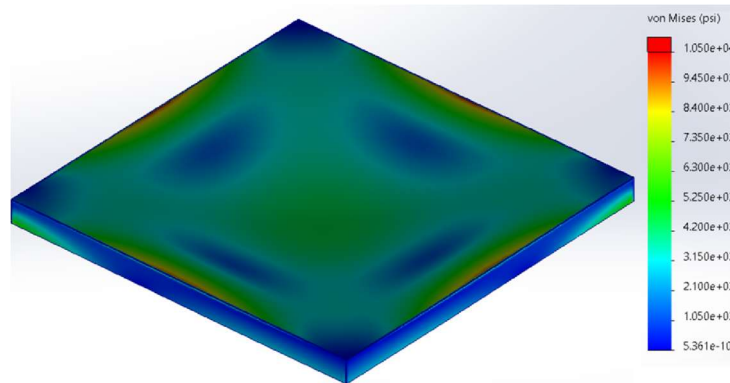


Figure 92: Maximum Panel Stress @ 0.27[psi] Pressure

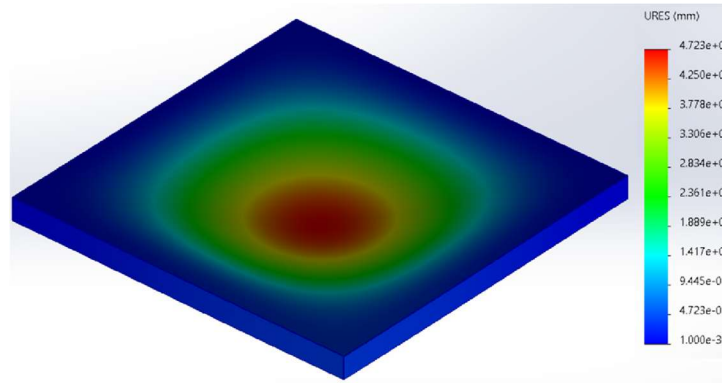


Figure 93: Deflection of Panel @ 0.27[psi] Pressure

The FEA shows that under the wind and snow conditions, the maximum deflection will be under 0.2[in] or 5[mm], with a maximum stress under 11,000[psi] or 75.8[MPa].

To ensure a person can walk on the roof, a pressure of 0.52[psi] was applied to the model; with respect to a 300[Lb] person. A maximum stress of 28,000[psi] was realized, with a maximum deflection of about 0.36[in] or 9[mm].

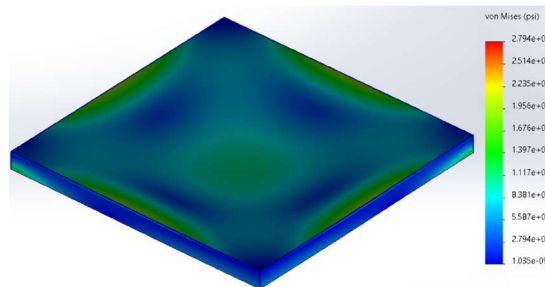


Figure 94: Maximum Panel Stress @ 0.52[psi] Pressure

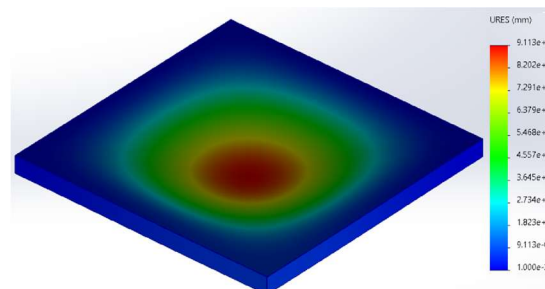


Figure 95: Deflection of Panel @ 0.52[psi] Pressure

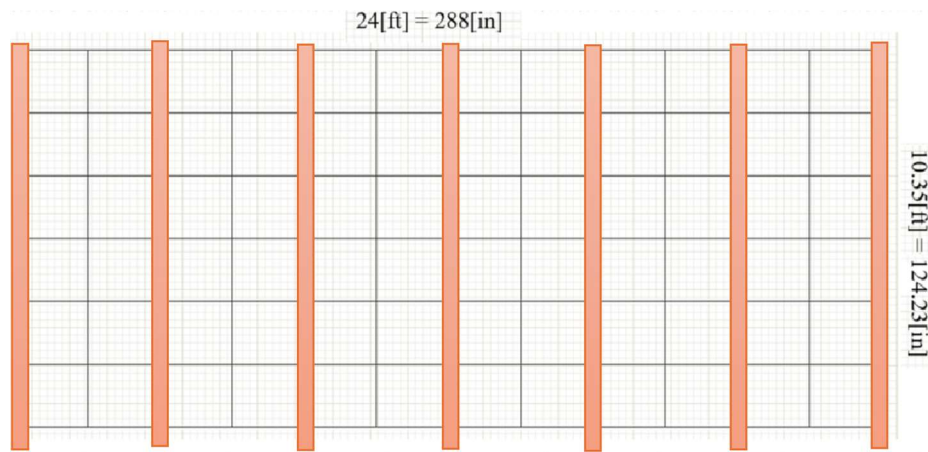


Figure 96: Roof/Shelter Panel Support

The main panel support consists of 4[in] square beams with a thickness of 0.12[in]. The ribbing structure between the supports consists of 1.5[in] x 0.125[in] bars (minimum). The maximum stress in this assembly is less than 16,000[psi]. The main crossbeams will be 8[in] square, with a thickness of ¼[in]. In an effort to commonize the beams, the vertical support beams will be the same as the horizontal crossbeams.

Because 300[Lbf] people will not be traversing the roof, the 4[in] beams are reduced to 3[in] and the intermediate supports are reduced in number.

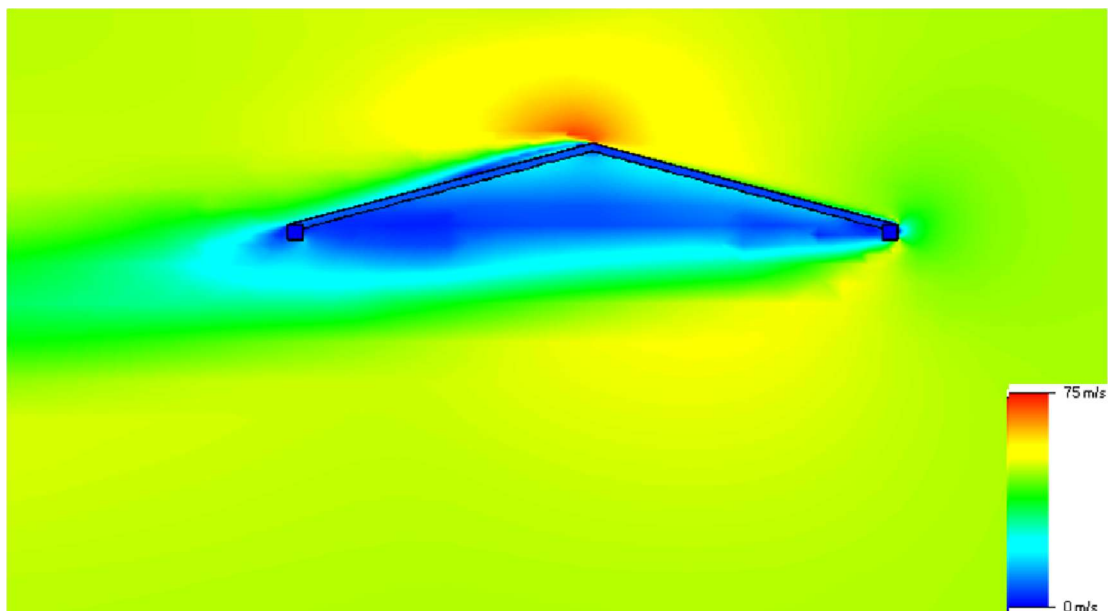


Figure 97: Roof with 47[m/s] Wind and 3[in] & 6[in] Beams

The average lateral loading on the structure in Figure 97 was 967[Lbf] or 4,300[N]. Without ribbing, the maximum deflection is close to 2[in]; as seen in Figure 98. Stresses near 30[ksi] are seen only where

deflections approach or exceed 1.5[in]. It is interesting to note that the highest deformations occur on the leeward side of the roof.

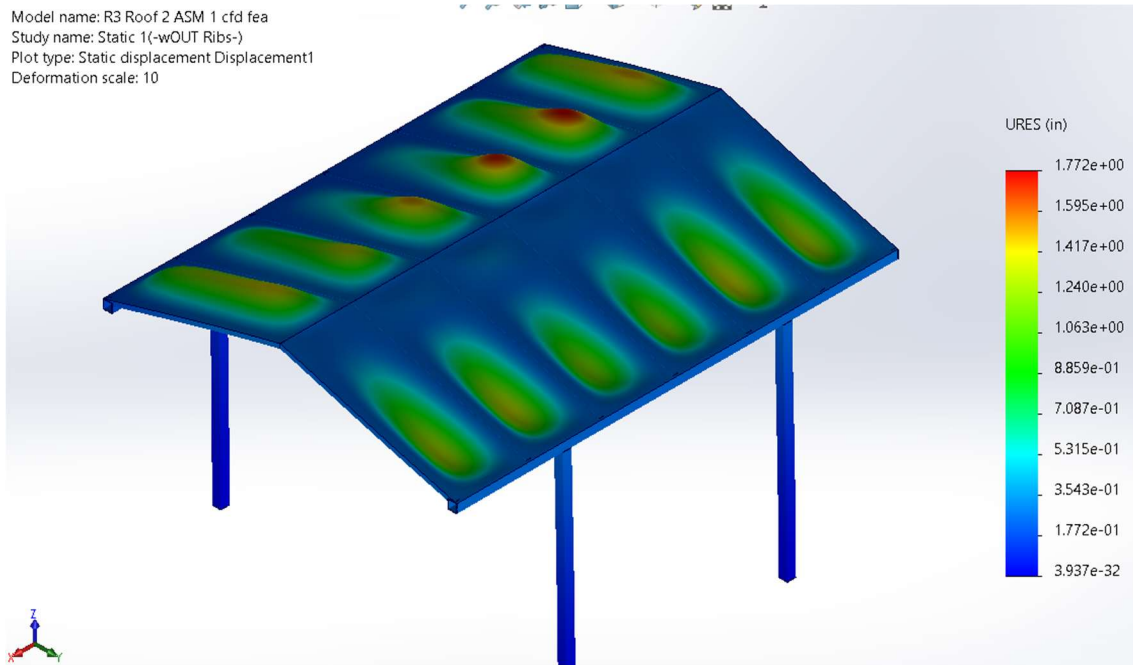


Figure 98: Roof without Cross-Ribbing

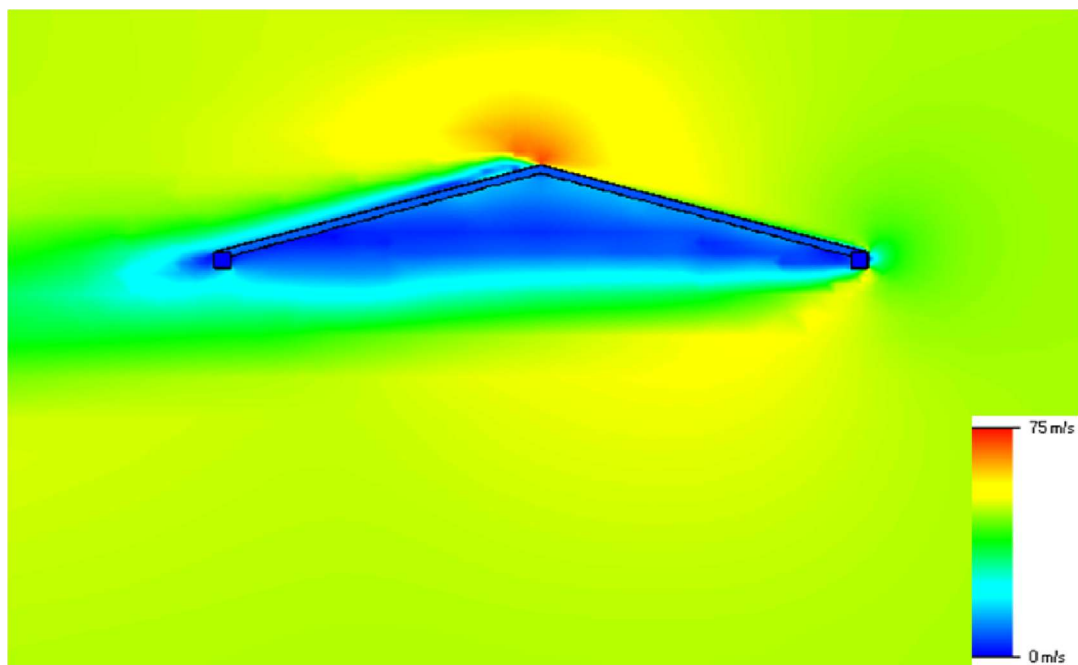


Figure 99: $V_y = -47$ [m/s] with 6[in] & 3[in] Support Beams w/inner Ribbing of 1.5[in]

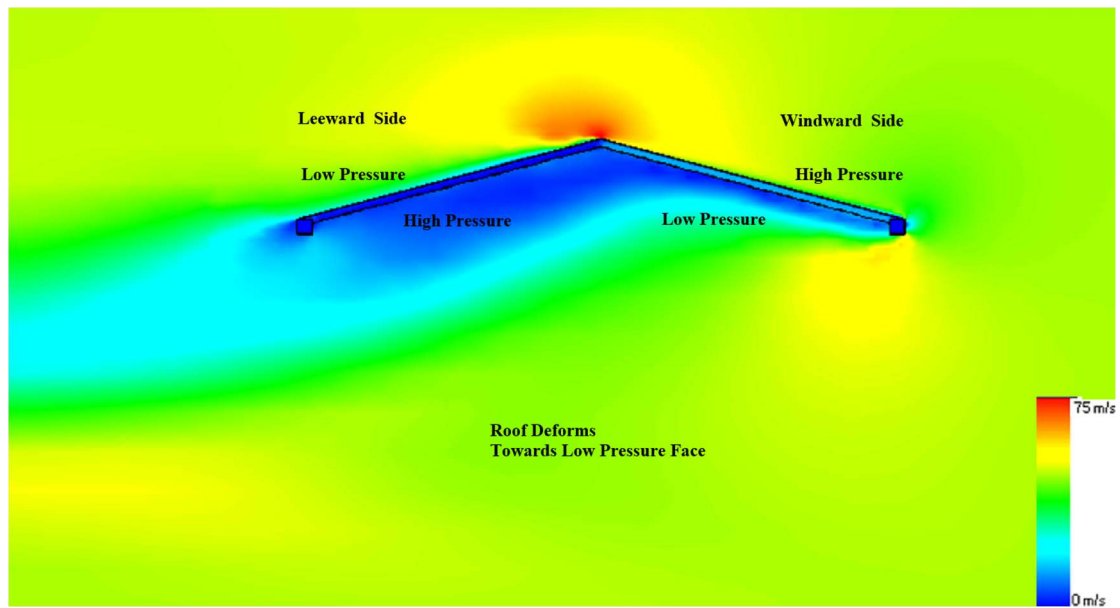


Figure 100: Wind/Leeward Side Roof Deformation Pressure Zones

The highest deformation is seen near the top of the roof, on the leeward side. The next greatest deformation is found on the windward side, near the top of the roof.

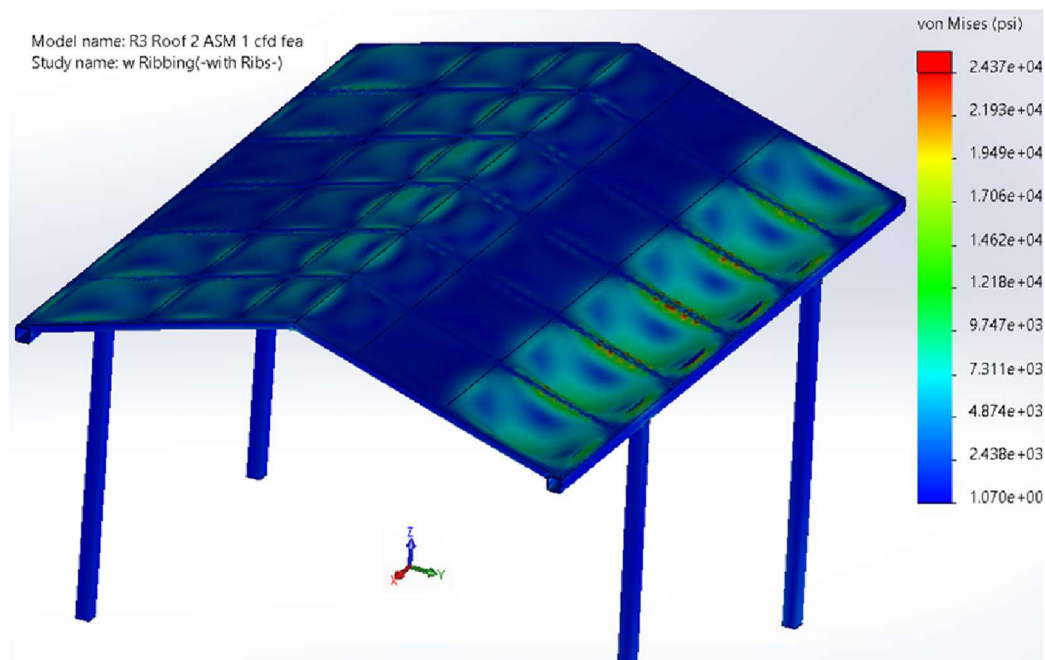


Figure 101: Roof Panel Stress w/2-Ribbs

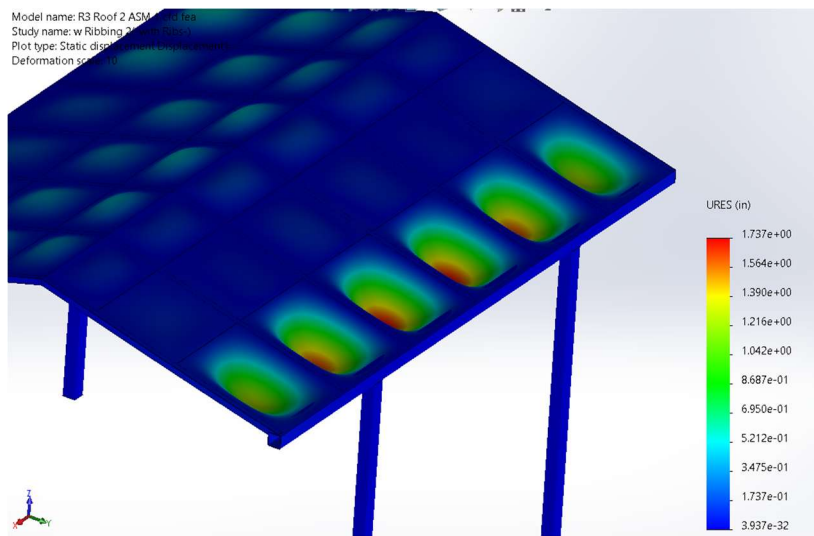


Figure 102: Roof Panel Deformation w/2-Ribbs

After several iterations, the minimal roof spacing was found, as seen in Figure 101. The target stress is surpassed on the windward side; with an average stress of about 28,000[psi]. The maximum deflection is about 1.74[in] or 44.1[mm]. Though the stress is about 12[%] larger than the target stress of 24,366[psi], it is less than the AISI fatigue stress (34[ksi]): Therefore, it is an acceptable design. However, in an effort to nominalize the panel stresses during high wind conditions, the final design will add ribs within the high stress zones.

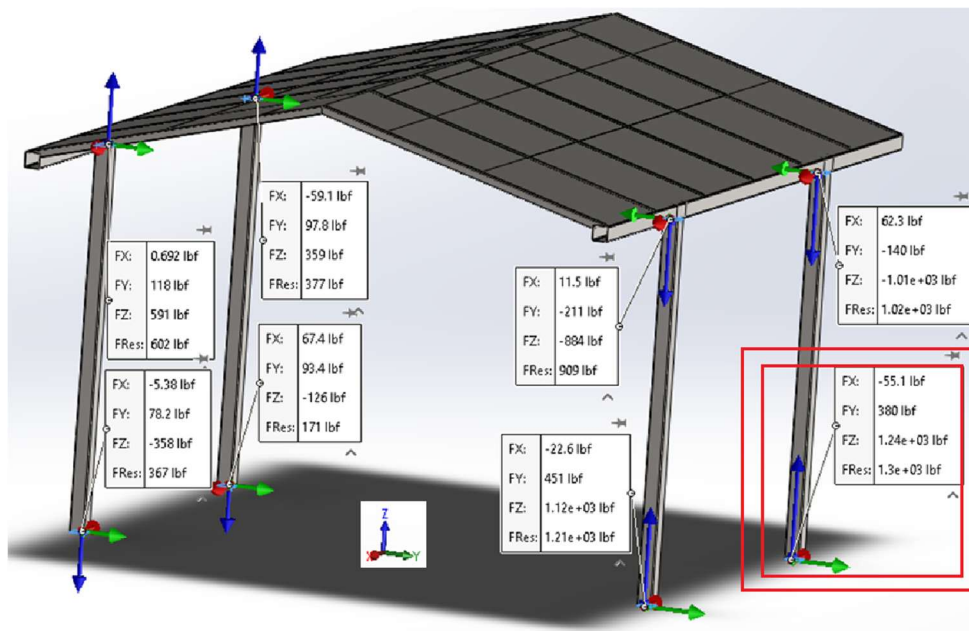


Figure 103: Support Post Loads

The supporting structure, the (x)4 – 6[in] x ¼[in] beams, have stresses less than 1,000[psi] at their base: The cross-beams have stresses near 8,000[psi]. The wind load produces a torque about $\langle X \rangle$, or $\langle T_x \rangle$, with an F_y of about -950[Lbf] and a lever-arm of about 5.2[ft], or 1.6[m], from ground level. The free-body moment of the rear-right support beam ($\langle -X, Y, 0 \rangle$), about its ground-center, is $\langle M_c \rangle = \langle -2200, -560, 60 \rangle$ [Lbf-ft], or $\langle -3,000, -760, 85 \rangle$ [Nm].

Embedment – Footing Design

The design envelope of the footings will be simulated using IBC's load-bearing values from 1806.2, Table 3. The embedment depicted in Figure 104 shows the main embedment with a common 8[in] thick concrete base. The soil was modeled with a yield strength of 0.7[psi]; a very weak shell, see Figure 105.

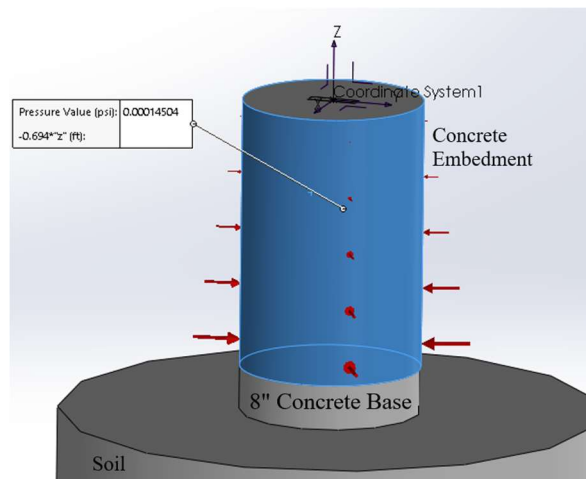


Figure 104: Embedment w/Soil Bearing Pressure

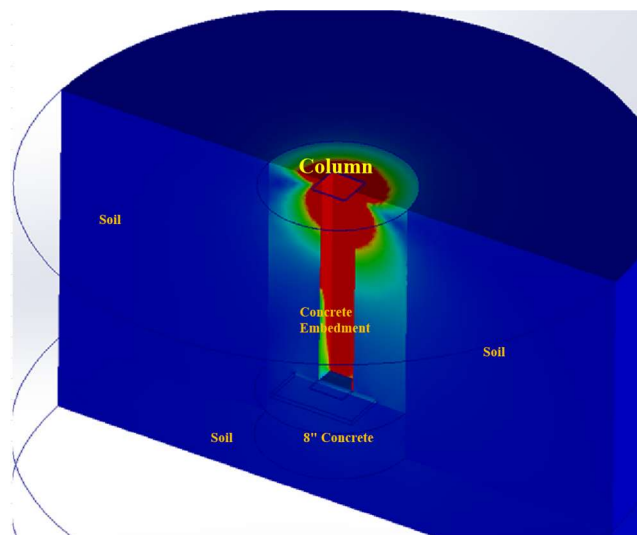


Figure 105: Post/Pole Embedment Model

The 6[in] structural beam was modeled with a footing/concrete diameter of 24[in] at a depth of 32[in]. The depth of 32[in] is based on $\frac{1}{3}$ rd the height, to prevent tip-over. The maximum loading, represented in Table 20, contains snow/ice and seismic loading for the structure; applied to the beam under the greatest loading.

Table 20: 6[in] Roof Support Maximum Loading

	[Lbf]	[N]
F _x	-67	-296
F _y	459	2,040
F _z	1,240	5,515
F	1,324	5,888

	[Lbf-in]	[Nm]
M _x	-26,396	-2,982
M _y	-6,724	-760
M _z	904	102
M	27,254	3,079

Table 21: Embedment Loading for Cross of Crucifixion

	[Lbf]	[N]
F _x	-845	-3,758
F _y	-51	-225
F _z	834	3,710
F	1,188	5,286

	[Lbf-in]	[Nm]
M _x	3,059	346
M _y	-56,013	-6,329
M _z	-629	-71
M	56,100	6,338

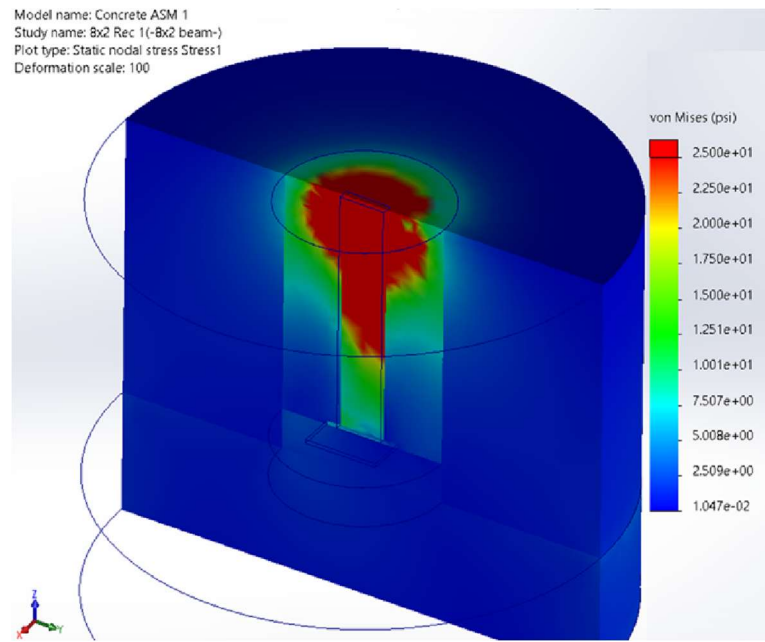


Figure 106: 8[in]x3[in] Post/Pole, Surrounding Soil Pressure

The pressure exerted on the surrounding soil is less than 25[psi] and its movement is very small. Therefore, the Cross of Crucifixion will stand with 32[in] diameter embedment's that are 48[in] in depth.

The 8[in] structural beam was modeled with a footing/concrete diameter of 36[in] at a depth of 10[ft]. The depth of 10[ft] is based on $\frac{1}{3}$ rd the height, to prevent tip-over. The maximum loading, represented in Table 22Table 20, contains snow/ice and seismic loading for the structure; applied to the beam under the greatest loading.

Table 22: 8[in] Cross of Redemption Maximum Loading

	[Lbf]	[N]
Fx	1,361	6,052
Fy	-580	-2,579
Fz	-82	-365
F	1,481	6,589

	[Lbf-in]	[Nm]
Mx	-9,024	-1,020
My	21,177	2,393
Mz	-1,940	-219
M	23,101	2,610

Table 23: Post/Pole Embedment Dimensions

Structure	Pole/Post	Diameter [in]	Depth [in]
Roof	6[in] Beams	24	48
Cross of Crucifixion	8[in]x3[in]	32	52
Cross of Redemption	8[in] Beam	48	64

The embedment's need to last 500[y] and maintain a minimum factor of safety of (x)6. The depths and diameters of the embedment's will be as simulated, as represented in

Table 23. The "Depth" is defined as the length of the submerged structural member.

Texture & Color:

The Cross of Redemption and the Glorious Cross of Dozule will have the same color and texture. The texture will not be scaled by a factor of 90. These two crosses will have blue-green side panels, a turquoise color. This color approximates the morning sky of August 2548, during the eclipse.

The tilma depicting Our Lady of Guadalupe has been photographed and copied many times. The actual image of the Virgin Mary is in the Basilica of Our Lady of Guadalupe in Mexico City. Utilizing photographs, a mathematical correlation between the color of Our Lady's cloak and the color of the sky, during an eclipse, was found. The final color, Figure 116, is a mathematical representation based off the tilma of Juan Diego depicting Our Lady of Guadalupe and the expected average color (outside the corona of the sun) in August of 2548.

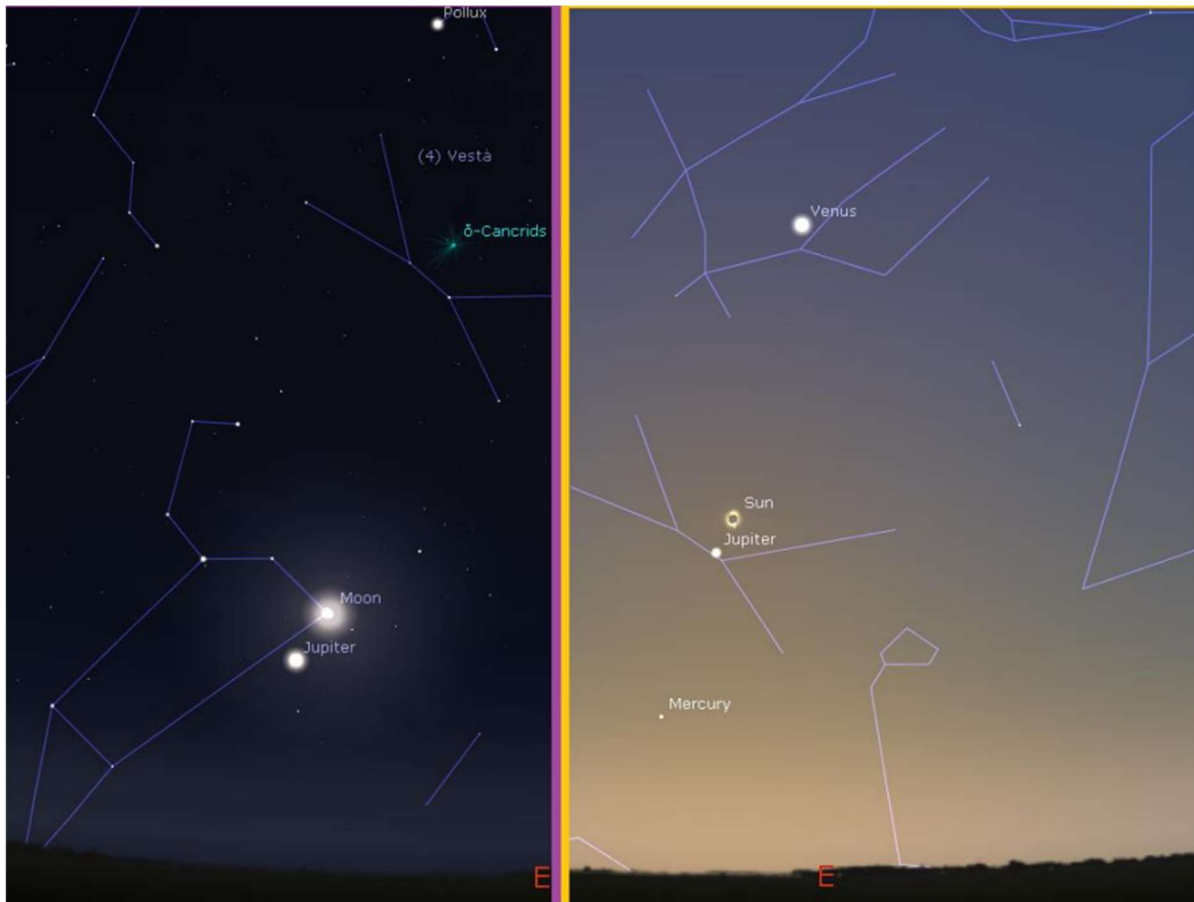


Figure 107: Left is 2BC, Birth of Christ, Eclipse of Regulus || Right is 2548AD, Eclipse of Sun

Note: Courtesy of the Stellarium Astronomy Software⁽²⁵⁾

Figure 107 depicts two eclipses, **over Bethlehem Israel:**

- 1) Left side, Regulus is eclipsed in the evening hours
 - a. Near 7[pm] or 19:00[hr] of the year of 2[BC]
 - i. Note: there is no “year zero”
 - ii. Star-map calculations contain a “year zero”
 - b. Constellation of Leo
 - c. Regulus is within the Star of David and is known as the “King-maker”
 - d. The conception of Jesus was in April of 3[BC]
 - i. The date of conception is when life is given
 - ii. The actual date of birth
- 2) Right side, the sun is eclipsed by the moon in the morning hours of 5-Aug-2548
 - a. The total eclipse occurs about 7:52[am]
 - b. Mother Mary arrives for the wedding, near the time of the eclipse
 - c. Jesus arrives during the 9th hour
 - d. The Bride and Father of the bride tarry
 - i. For no one knows the day or hour (Matthew 24:36 & Mark 13:32)
 - ii. The bride is the New Jerusalem

iii. Isaiah 62:4, Hephzi-Bah (הֶפְצִי-בָּהּ)

1. "... I delight in her"⁽²⁷⁾
 - a. Ref: [Isaiah 62:4](#)
 - b. <https://www.sefaria.org/Isaiah.62.4?lang=bi>
 - c. "Because YHWH delights in you"
2. "... My pleasure in her ... "⁽²⁸⁾
 - a. Ref: [Isaiah 62 DRB](#)
 - b. <https://biblehub.com/drb/isaiah/62.htm>
3. "... My heart is there ..."
 - a. A rough translation
 - b. Parsing words/phrases thru translation tools

3) See the report, "Circular Events" for further details (only available thru the Creo Designs website)

The important item in the above is the color of the sky during an eclipse. The following result is an average of various datums.



Figure 108: Evening Eclipse & Morning Eclipse

Courtesy of Gettyimages, with credit to K. Campos: The photographs in Figure 108 are actual representations of the sky and its change in hue; from an eclipse. The images show that color values must be taken outside of the sun's corona.



Figure 109: Our Lady of Guadalupe on the Tilma of Juan Diego

A picture/photo of Our Lady of Guadalupe in natural sunlight is not forthcoming: A high-quality interior picture of the tilma of Juan Diego with Our Lady of Guadalupe is represented in Figure 109. The actual color of the tilma is blue-green (turquoise). The artificial light causes a yellow-shift in the hue of the tilma.



Figure 110: Tilma of Our Lady of Guadalupe in a Fiesta with Natural Lighting

Note: Pilgrims may touch the approved copy of the tilma⁽²⁹⁾



Figure 111: Solar Eclipse, Gettyimages, Credit: D. Buffington

In terms of lighting, the eclipse depicted in Figure 111 is close to the light of the morning sky over Israel in August of 2548. Though not very accurate, it yields a mathematical basis for RGB differentiation.



Figure 112: Solar Eclipse

Note: Unreferenced Author/Name⁽³⁰⁾

The color of the mantle of Our Lady of Guadalupe resembles the upper right corner/section of Figure 112. The HTML color code is 437C8B or (using the gimp program) RGB of 26.4, 48.7 and 54.6.



Figure 113: Dark Turquoise Color 437C8B Averaged from Figure 110



Figure 114: Evening Solar Eclipse, iStock, Credit: Mario Guti



Figure 115: Morning Sky, Ohio US

The HTML color code represented in Figure 113 were taken using the tool “gimp”.⁽³²⁾

- 1) Average RGB (Red-Green-Blue) of the cloak in sunlight: 26.4, 48.7, 54.6
 - a. 13 random points were taken from Figure 110
 - b. The values averaged to a dark turquoise color
 - c. HTML color code of 437C8B
- 2) RGB average of a daytime solar eclipse: 23.9, 42.0, 54.9
 - a. Points outside of corona
 - b. Matches well with Figure 110
 - c. Interesting to note that these values match well with Figure 110
- 3) Gimp gave the HTML color code of 437C8B
 - a. Online color identifiers differ in RGB values
 - b. HTML Color Codes⁽³³⁾
 - i. RGB 67, 124, 139
 - c. Rapid Tables⁽³⁴⁾
 - i. RGB 67, 124, 139
- 4) Evening & Morning Eclipses from Figure 108
 - a. The closer to the sun, the value of color Red goes up
 - b. 13 points taken from the Evening eclipse gave
 - i. An RGB (gimp): 11.8, 40.7, 54.5
 - ii. HTML/HEX code: 1E688B
 - c. 13 points taken from the Morning eclipse gave
 - i. An RGB (gimp): 9.7, 60.6, 82.1
 - ii. HTML/HEX code: 199BD1
- 5) The eclipses in Figure 112 and Figure 114
 - a. Match well with the tilma color and evening eclipses
 - b. High red value
 - c. Low green value
 - d. Low blue value
- 6) Morning Eclipse estimation for August of 2548
 - a. The mornings shown in Figure 108 and Figure 115
 - i. Ratio of Blue/Green is about 1.4
 - ii. An eclipse decreases Red by about 68[%]
 - iii. An eclipse increases Green by about 24[%]
 - b. The “gimp” weighted RGB average is 16.6, 57.7, 74.8
 - i. HTML/HEX: 2A93BF
 - ii. General RGB code: 42, 147, 191

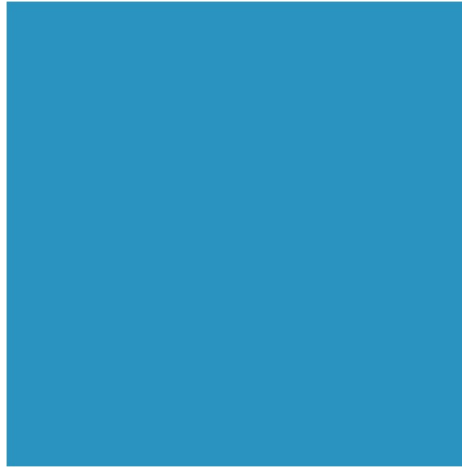


Figure 116: Side Panel Color Code, HTML/HEX: 2A93BF

The RGB values were weighted with respect to the effect of the eclipse, outside the sun's corona. The red-value of the eclipse (68[%]) and 76[%] of the green-value (of the eclipse) were averaged with the morning sky (Figure 115). The final color for the morning sky of August 2548, is (HTML/HEX) 2A93BF (per GIMP). This is the color of the sides of the Glorious Cross and the Cross of Redemption (Conyers, GA).

Color of Sides:

As defined by Mrs. Madeleine Aumont of Dozule France, the arms of the cross stretch East and west; with the faces of the cross, North and South. The East and West or side-panels (to include the top) are blueish. Therefore, the Glorious Cross of Dozule and the Cross of Redemption (in Conyers, GA) will have side panels with the Color Code, HTML/HEX#: 2A93BF (RGB of 42, 147, 191).

The process for the side-panels will be by an anodic coating. All aluminum surfaces designation NASF/AA-M12-C32. The side-panels add an anodized layer, with the designation: NASF/AA-M12-C32-A44.

Surface Finish: Glorious Cross & Cross of Redemption

Sides & Top: East and West

NASF/AA-M12-C32-A44-P w/: (HTML/HEX#) 2A93BF (RGB of 42, 147, 191)

Front & Back: North and South

NASF/AA-M12-C32-P

Where:

NASF – National Association for Surface Finishing

AA – The Aluminum Association

M12 – Mechanical finish, Sandblast or other per RA & RMS values

*Mechanical finish may be replaced with chemical finish

*Non-specular

*Deburred

*No defects such as scratches greater than 2,300[μin] (58[μm]), bruising and other structural defects

C32 – Diffuse bright

*Where: $R_a = 120[\mu\text{in}] = 3.05[\mu\text{m}]$ (CLA(ISO) = 120) with an RMS of $132[\mu\text{in}] = 3.35[\mu\text{m}]$

For “East – West,” side/top-panels only: This does not include the radiused panels

A44 – Architectural Class I, 0.7[mil] (0.0007[in] {17.78[μm]}) thick (minimum), electrolytically deposited color, color definition/code: (HTML/HEX#) 2A93BF (RGB of 42, 147, 191)

*Color to be verified in natural light near noon local time

Where:

AA – Aluminum Association

AAMC – American Architectural Manufacturers Association

Analysis/Method/Definition per: ANSI/ASME B46.1

NAAMM – National Association of Architectural Metal Manufacturers (NOMMA)

The color must be verified in natural sunlight, around noon. This verification must be approved. The Glorious Cross and site at Conyers, GA are related by object and color.

The Glorious Cross:

The project contains two structures:

- A) Construct the Glorious Cross
 - a. Height 738[m]
 - b. Base width $(1/40^{\text{th}})H$, 18.45[m]
 - c. Overall length of (x1) arm, from center, 123[m]: 246[m] overall width
 - d. Material: Aluminum 7075-T6; $S_y(\text{min})$ is 73,000[psi]
- B) Construction of a Sanctuary
 - a. The “Cross of the Crucifixion,” the Corpus Cross
 - b. The Miraculous Medal, Mother Mary

Design considerations:

The factors affecting the design are weather, seismic activity and soil conditions. The Cross will be built to last 500[y]. The main factor with respect to weather is the wind: Snow and ice will be included. The soil conditions affect the base/foundation construction. Worst-case conditions will be applied: Full wind/snow/ice-loadings and maximum seismic acceleration/s.

Location:

The location has no address: it is located on les buttes of Dozule, France. The current Cross is at 49.222612 N, -0.052249 W (49°13'21.4"N 0°03'08.1"W). The sanctuary will be located near the Cross.

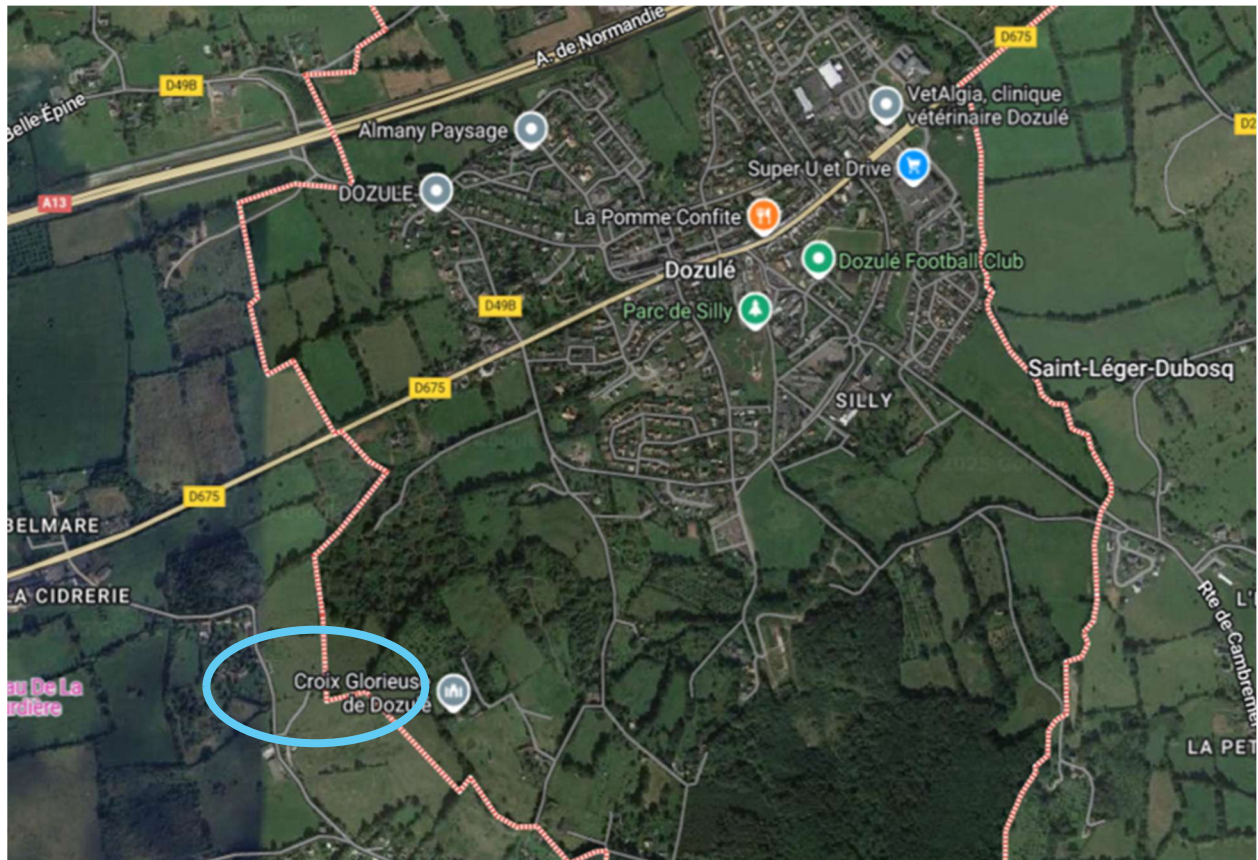


Figure 117: Location of the Glorious Cross⁽⁰³⁾

Structural Design/Conditions w/r Eurocode 8:

Eurocode 8 EN1998: Design of Structures for Earthquake Resistance. This code may be calculated at the Eurocode website Ref(10).

Eurocode 8 Input Requirements:

- 1) Shape of the response spectrum is taken as Type 1
 - a. Type 1 spectra correspond to typical high seismicity hazard. Low seismicity
 - b. Type 2 spectra are recommended when the earthquakes that contribute most to the seismic hazard have a surface-wave magnitude
- 2) Direction of the seismic component is taken as Horizontal
- 3) Reference peak ground acceleration on type A ground (rock) is $0.4[m/s]$
 - a. From Dlubal.com⁽¹¹⁾
 - i. Location $49.223^{\circ} N, -0.052^{\circ} W$
 - ii. Seismic Zone 1 with $a_{g,r} = 0.4[m/s^2]$
 - iii. Fundamental Wind velocity, $V_{b,0}$ of $24[m/s]$
 - iv. Basic Wind Velocity Pressure, q_b of $0.35[kN/m^2]$ (Air density $1.215[kg/m^3]$)

- 4) Importance factor of 1
- 5) Viscous damping ratio of the structure as 0.4 from reference⁽⁰⁸⁾

Geology of France:

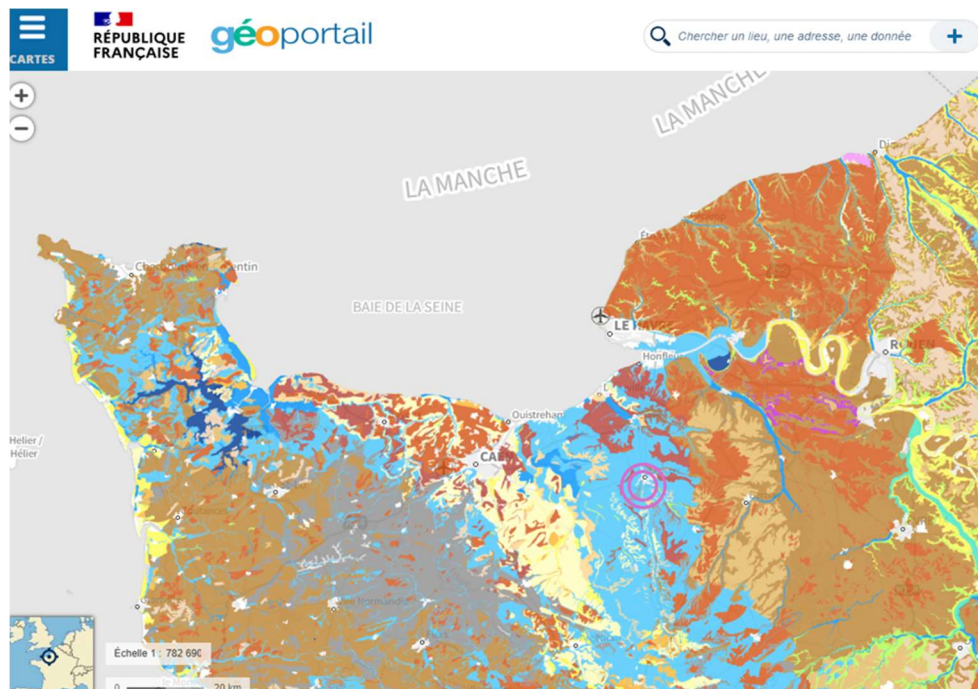


Figure 118: France Soil, Near the Bay of Seine⁽¹²⁾

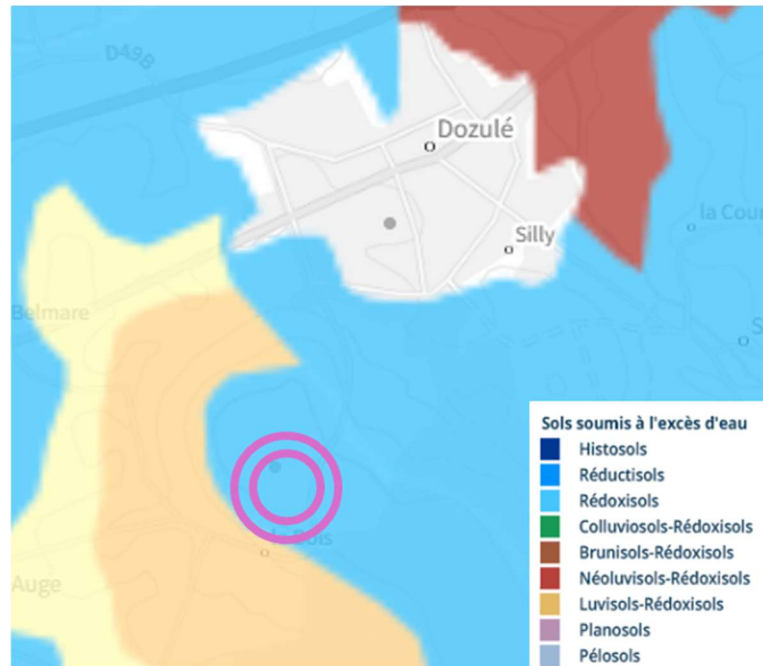


Figure 119: Red Clay Soil

The soil make-up was taken from the GeoPortail.⁽¹²⁾ This is from the government of France. Dominant soil type: REDOXISOL 63[%] of fairly shallow hydromorphic soil from flint clay of heterogeneous topographic position and slope.

UCS name: Thin hydromorphic soils of heterogeneous topographic position and slope, mainly resting on Meso-Cenozoic flint clays from the Entre Plaine de Caen and Bessin, Pré-Bocage, Cinglais and Pays d'Auge.

There are five base classes of soil, ranging from Rock – A, to E; no special classes are considered for this analysis because the soil is typical. The classification under Eurocode 8 is estimated as a class “C” for “dense sand or gravel or stiff clay.” Because of its location, it may be considered a class “B” or “very dense.”

Damping Ratio for Beam Model:

The structure is supported by W-beams.

Governing equations for a cantilever beam:

Equation 25: Basic Dynamic Spring

$$m\ddot{x} + kx = 0$$

Equation 26: Dynamic Frequency

$$\ddot{x} + \omega_n^2 x = 0$$

Where:

Equation 27: Spring Constant

$$k = \frac{3EI}{L^3}$$

Single degree of freedom:

Equation 28: Dynamic Damping

$$m\ddot{x} + c\dot{x} + kx = 0$$

Equation 29: Dampening System Equation

$$\ddot{x} + 2\zeta\omega_n\dot{x} + \omega_n^2 x = 0$$

Where:

"c" is the damping of the System
 "ζ" is the damping factor

Has a solution:

Equation 30: Solution $x(t)$

$$x(t) = \left(x_o \cos(\omega_d t) + \frac{v_o + \zeta\omega_n x_o}{\omega_d} \sin(\omega_d t) \right) e^{-\zeta\omega_n t}$$

Equation 31: Damping Factor

$$\omega_d = \omega_n \sqrt{1 - \zeta^2}$$

A simply supported beam (supported at both ends) with a mid-load/mass has a natural frequency of:

Equation 32: Natural Frequency, Point-load

$$\omega_{n_M} = \frac{1}{2\pi} \sqrt{\frac{48EI}{Mass L^3}}$$

Where (for Imperial):

Equation 33: Imperial Unit Conversion

$$M = M[Lbm] \left[\frac{Lbf s^2}{386.1 Lbm in} \right]$$

A 10[ft] long W14x132 beam would have a weight of 1,320[Lbf], where $M=1,320[Lbm]$.

A simply supported beam (supported at both ends) with a distributed load ($[q]=[mass/Length]$) has a natural frequency of:

Equation 34: Natural Frequency, Distributed-load

$$\omega_{n-q} = \frac{\pi}{2} \sqrt{\frac{EI}{qL^4}}$$

A 10[ft] long W14x132 beam would have a distributed weight of 1,32[Lbf/ft], where $q=132[Lbf/ft]$.

Equation 35: Natural Frequency Variance

$$\frac{\omega_{n-M}}{\omega_{n-q}} = \left(\frac{1}{2\pi} \sqrt{\frac{48EI}{MassL^3}} \right) \left(\frac{2}{\pi} \sqrt{\frac{qL^4}{EI}} \right) = \frac{\sqrt{48}}{\pi^2} \approx 0.7$$

Conclusion of Damping Ratio Model/s:

To avoid a 30% variance in values, it would be best to utilize the distributed-load model.

As seen in Equation 34, the natural frequency is inversely proportional to length to the power of $\sqrt{3}$. Since the main supporting structure is continuous, the natural dampening frequency complies with a continuous metal structure. The dampening ratio of continuous metal structures is less than 0.04; or 4[%].^{(08), (09)}

An array of heavy beams, such as W14x665, support the Glorious Cross. A W14x665 beam, 738[m] in length will have a natural frequency of about 3[ms] (0.003[s]); while a W14x74 beam will have a natural frequency of about 9[ms]. The reduction of mass reduced the frequency by a factor of ($\times 3$). A system with about ($\times 9$) less weight will reduce its response time by a factor of ($\times 3$) (which is the root of 9).

Summary of Eurocode 8 w/r Seismic:

The maximum g-force applied is 1.265[m/s²] with a soil classification of “B.”⁽¹⁰⁾

The maximum g-force applied is 1.212[m/s²] with a soil classification of “C.”⁽¹⁰⁾

The model will utilize lateral acceleration of 1.265[m/s²] or 4.15[ft/s²].

Eurocode 1: Actions on Structures

Snow & Ice:

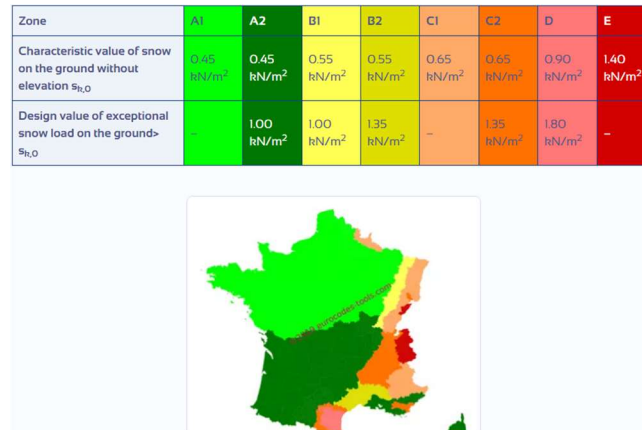


Figure 120: Snow Loading at Dozule

The snow loading is taken from Eurocode 1 (NF EN 1991-1-3/NA). Since the elevation of Dozule is less than 200[m], $S_k = S_{k,0}$. In Dozule, France, the loading is 0.45[kN/m²].

Wind in/near Dozule, France:

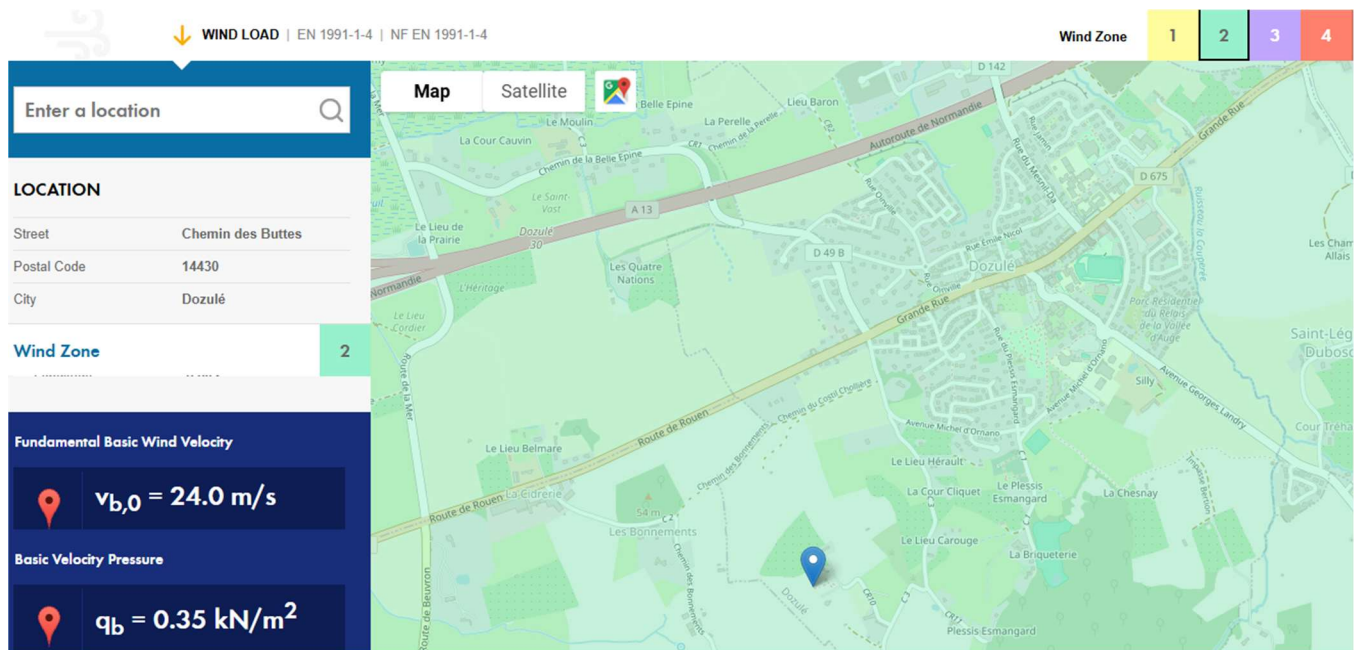


Figure 121: Dozule, Wind Velocity and Pressure⁽¹⁴⁾

The wind zone classification for Dozule, France, is 2. The fundamental wind velocity $V_{b,0} = 24.0$ [m/s] with a base pressure of $q_b = 0.35$ [kN/m²]. The air density with respect to the base velocity (24[m/s]) is 1.215[kg/m³]. Due to the height of the Glorious Cross, the pressure will be calculated based upon the air velocity.

The basic wind velocity is given as $v_b = v_{b,0} \cdot c_{dir} \cdot c_{season}$ where the fundamental value of basic wind velocity $v_{b,0}$ is defined in EN1991-1-4 §4.2(1)P and its value is provided in the National Annex. Altitude correction may also be specified in the National Annex for EN1991-1-4 §4.2(2)P. The directional and seasonal factors are generally $c_{dir} = 1.0$ and $c_{season} = 1.0$. For particular cases values smaller than 1.0 may be specified in the National Annex for EN1991-1-4 §4.2(2)P.

Eurocode 1-4.2 states “The fundamental value of the basic wind velocity, $v_{b,0}$ is the characteristic 10 minutes mean wind velocity, irrespective of wind direction and time of year, at 10[m] above ground” Therefore, v_b , the basic wind velocity, is at an altitude of 10[m].

Equation 36: Basic Wind Velocity

$$v_b = c_{dir} c_{season} v_{b,0} = c_{dir} c_{prob} v_{b,0} = v_{b,0}$$

Where:
 $c_{dir} = 1$ and $c_{prob} = 1$

The Glorious Cross is located atop a large hill with a terrain category of II.⁽¹⁴⁾ This is analogous to the Swiss-data “roughness” class of 1.0 or 1.5; see Table 24. The Eurocode roughness classification is closely related to category II; although, category I is viable (see Table 25).

Table 24: Swiss-Data Roughness/Terrain⁽¹⁵⁾

Roughness class	Roughness length z_0	Land cover types
0	0.0002 m	Water surfaces: seas and Lakes
0.5	0.0024 m	Open terrain with smooth surface, e.g. concrete, airport runways, mown grass etc.
1	0.03 m	Open agricultural land without fences and hedges; maybe some far apart buildings and very gentle hills
1.5	0.055 m	Agricultural land with a few buildings and 8 m high hedges separated by more than 1 km
2	0.1 m	Agricultural land with a few buildings and 8 m high hedges separated by approx. 500 m
2.5	0.2 m	Agricultural land with many trees, bushes and plants, or 8 m high hedges separated by approx. 250 m
3	0.4 m	Towns, villages, agricultural land with many or high hedges, forests and very rough and uneven terrain
3.5	0.6 m	Large towns with high buildings
4	1.6 m	Large cities with high buildings and skyscrapers

Table 25: Eurocode-1 Roughness/Terrain⁽¹⁴⁾

Table 4.1 — Terrain categories and terrain parameters

Terrain category		z_0 m	z_{min} m
0	Sea or coastal area exposed to the open sea	0,003	1
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0,01	1
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0,05	2
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0,3	5
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1,0	10
NOTE: The terrain categories are illustrated in A.1.			

Wind w/r Altitude:

As an example, the Swiss roughness class of 1.5 (roughness value of 0.055[m]) and the Eurocode terrain category II (roughness value of 0.05[m]) will be compared. For this example, the Swiss roughness value of 0.055[m] will be reduced to 0.05[m].

Eurocode 1-4.3.2 defines the terrain factor, k_f , as in Equation 35.

Equation 37: Terrain Factor

$$k_r = 0.19 \left(\frac{z_0}{z_{0,II}} \right)^{0.07} = 0.19 \left(\frac{2[m]}{0.05[m]} \right)^{0.07} = 0.246$$

Where:
 $z_0 = 2[m]$, Table 4.1, Roughness Length
 $z_{0,II} = 0.05[m]$, Table 4.1, Terrain Category II, Base Roughness

Eurocode 1-4.3.1 defines the velocity with respect to height.

Equation 38: Mean Wind Velocity at height “z”

$$v_m(z) = c_r c_0 v_b = c_r v_{b,0} = v_b k_r \ln \left(\frac{z}{z_0} \right) = 5.903 \ln \left(\frac{z}{0.05[m]} \right)$$

Where:
 $2[m] \leq z \leq 200[m]$
 c_0 is the orography effect
Note: $z_{max} = 200[m]$

Equation 39: Swiss Wind Power Data, Velocity

$$v(h) = v_b \frac{\ln\left(\frac{h}{z_{RL}}\right)}{\ln\left(\frac{h_1}{z_{RL}}\right)} = \frac{24 \left[\frac{m}{s}\right]}{\ln\left(\frac{2[m]}{0.05[m]}\right)} \ln\left(\frac{h}{0.05[m]}\right) = 6.506 \ln\left(\frac{h}{0.05[m]}\right)$$

Where:
 z_{RL} , Is the roughness length of 0.055[m]
 $h_1 = 2[m]$, Table 25, Eurocode-1 Table 4.1
 $c_o = 1$
 h , is the height of interest

Equation 40: Swiss-Eurocode Velocity Ratio

$$\frac{v(h)}{v_m(z)} = \frac{6.506 \ln\left(\frac{h}{0.05[m]}\right)}{5.903 \ln\left(\frac{z}{0.05[m]}\right)} = 1.102$$

As seen in Equation 40, the basic Swiss-data/energy equation is about 10[%] greater than the equation represented by Eurocode-1. For calculations without CFD, the Eurocode-1 equation requires terrain adjustments, because the Cross is located on a hill or mount/mound.

Wind w/r Orography Effect:

Eurocode-1 4.3.3, terrain orography (hills, cliffs ect.) is shown by c_0

Equation 41: Orography Effect

$$c_0 = \frac{v_m}{v_{mf}}$$

Where:
 V_m = mean wind velocity at height z above terrain
 V_{mf} = mean wind velocity above flat terrain

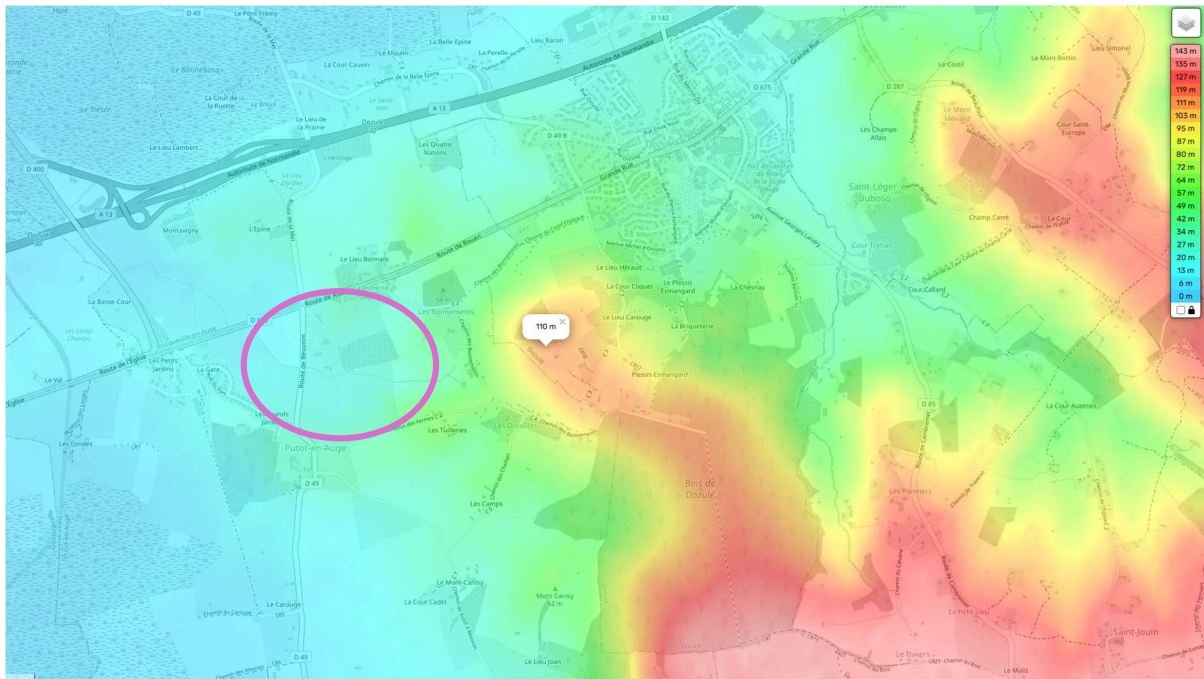


Figure 122: Greatest Slope Near the Glorious Cross⁽⁰⁵⁾

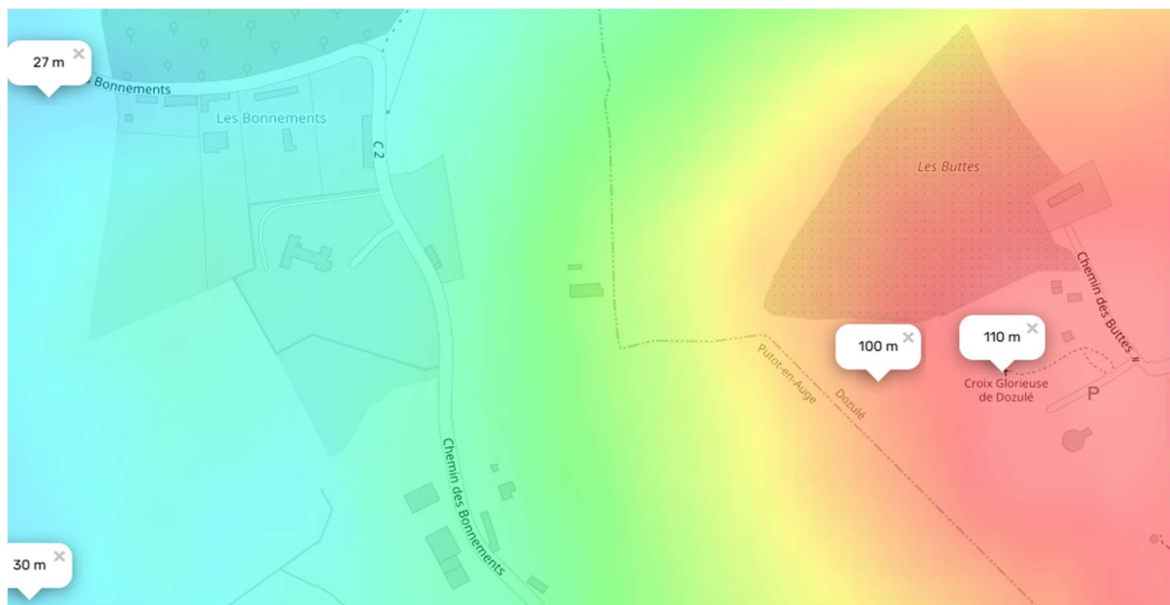


Figure 123: Topography, Valleys near the Cross⁽⁰⁵⁾

The slope of the mount, near the location of the Glorious Cross is less than 10[deg]. Note that google-earth shows an altitude of 113[m].⁽⁰⁶⁾

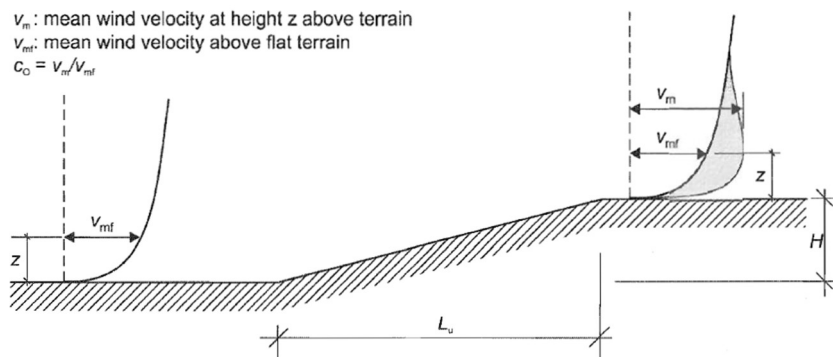


Figure 124: Topography Effect on Velocity

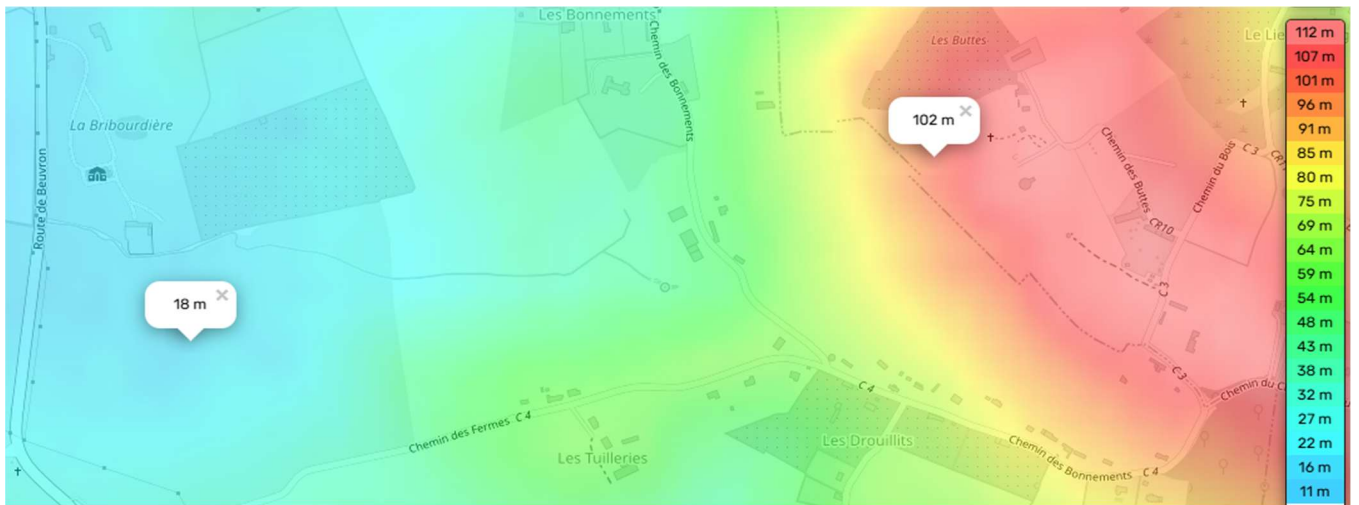


Figure 125: Topography, Lowest Point Near Cross⁽⁰⁵⁾

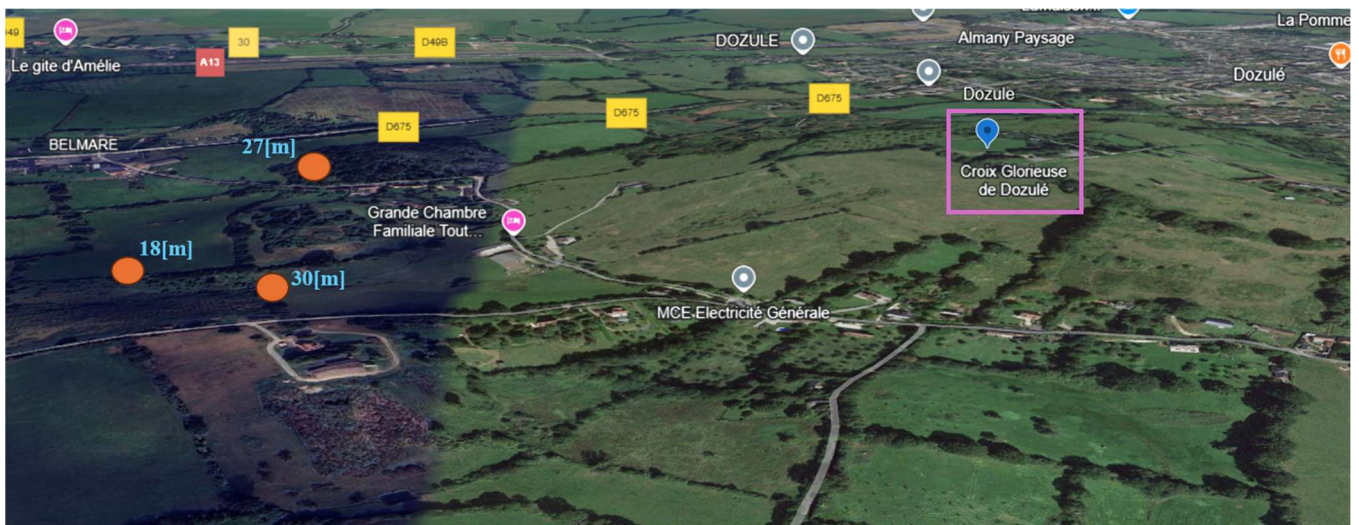


Figure 126: Largest Slope Near the Glorious Cross⁽⁰⁶⁾

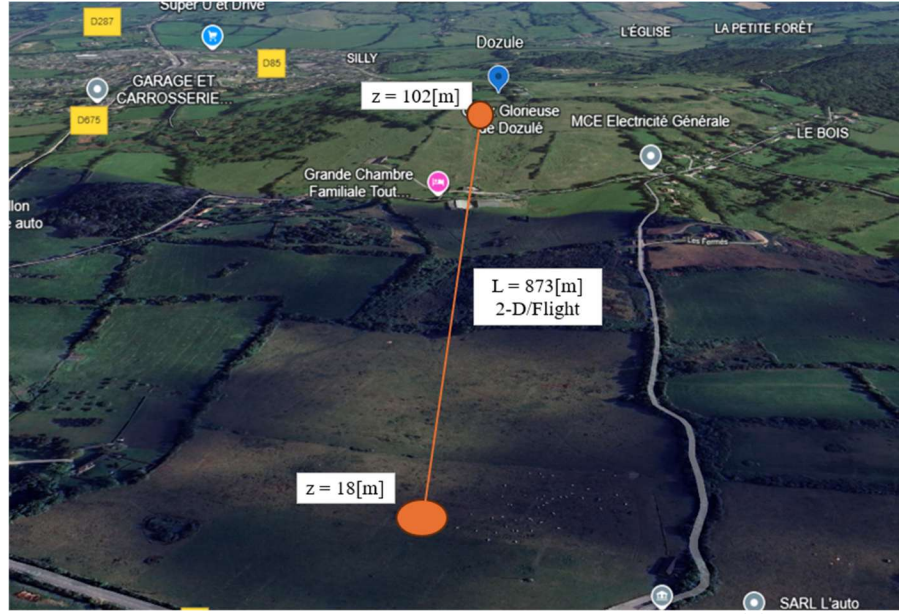


Figure 127: Topography of Hill, Angle of 0.1[rad], 5.5[deg]⁽⁰⁶⁾

The Eurocode-1 specifies the ratio ϕ in Equation 42: The averages of various points (Figure 125 and Figure 127) yield the ratio of 0.123[-].

Equation 42: Site Slope, ϕ

$$\phi = \frac{H}{L_u} = \frac{H}{L_d} = \frac{H}{L_e} = 0.123[-]$$

From the preceding data, the average slope of the mount is about 7[deg]. In an effort to obtain a more accurate view of a worst-case scenario, Google-earth⁽⁰⁶⁾ was utilized with respect to the topography map obtained from reference (05): Focusing on the greatest slope region depicted in Figure 122.

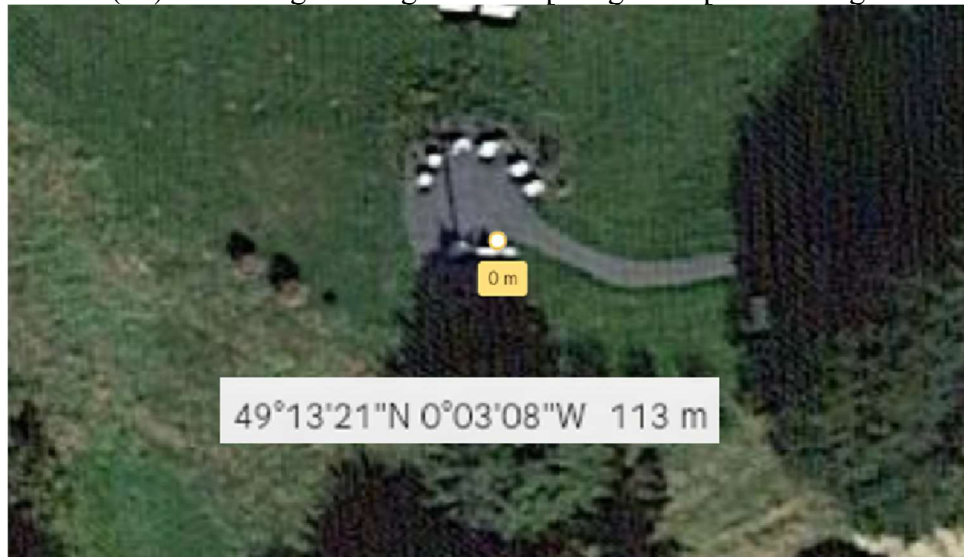


Figure 128: Center Location for the Glorious Cross

The center of the Glorious Cross is at 49°13'21.4"N 0°03'08.1"W (or 49.222611N, -0.052252W). Google-earth as an altitude of 113[m] for this location. All datums were taken with respect to this origin datum.



Figure 129: Two Directions, West and 11[deg] W-SW

Note:
East is taken as 0[deg]
West is taken as 180[deg]

On average, the tolerance of the first set of data (directly west from the origin) is less than 4.0[m] off of the longitude; directly west of the origin. The value of 4.0[m] is from Google-earth measurements where the calculated unit is 111,027[m/deg-Latitude(up/down)]. At Dozule, the meter-per-degree for longitude is 73,145[m/deg-Longitude(West/East)]. The data suggests that the plateau begins about 41[m] from the origin, at an elevation of 107[m]. The average slope at the edge is 20.5[deg].

Table 26: Westerly Slope of Mount, w/r Glorious Cross

dis [m]	elev [m]	N-to-S	W-to-E	w/r Cross [deg]	(i) -to- (i+1) [deg]
0.00	113	49.22	-0.052	0.0	0.0
30.21	110	49.22	-0.053	5.7	5.7
35.36	109	49.22	-0.053	6.5	11.0
37.95	108	49.22	-0.053	7.5	21.1
39.96	107	49.22	-0.053	8.5	26.5
48.11	105	49.22	-0.053	9.4	13.8
97.29	100	49.22	-0.053	7.6	0.0
100.61	100	49.22	-0.054	7.4	5.4
152.65	93	49.22	-0.054	7.5	7.2
166.32	90	49.22	-0.054	7.9	12.4
188.70	85	49.22	-0.055	8.4	12.6
206.64	80	49.22	-0.055	9.1	15.6
233.77	75	49.22	-0.055	9.2	10.4
253.71	70	49.22	-0.056	9.6	14.1
285.40	65	49.22	-0.056	9.5	9.0
306.72	60	49.22	-0.056	9.8	13.2
330.36	55	49.22	-0.057	10.0	11.9
357.58	50	49.22	-0.057	10.0	10.4
387.30	45	49.22	-0.058	10.0	9.5
613.03	40	49.22	-0.061	6.8	1.3
662.29	35	49.22	-0.061	6.7	5.8
696.29	30	49.22	-0.062	6.8	8.4
763.52	25	49.22	-0.063	6.6	4.3
920.29	20	49.22	-0.065	5.8	1.8
1,178.45	15	49.22	-0.068	4.8	1.1

The westerly slope from the origin (w/r Cross) averages 7.97[deg], while the walking slope (i -to- i+1) yields an average slope of 10.10[deg]. The three highlighted rows designate the slope-zone. The first set of data concentrated on elevation changes of 5[m]. The second set of datums kept the distance from the origin similar to the first set of datums: This was done to maintain a consistent radial distance from the origin.

Table 27: 191[deg], West-SW Slope

	from				Slope	Slope
	Data - West				w/r Cross	(i) -to- (i+1)
dis [m]	dis- ini - [m]	elev [m]	N-to-S	W-to-E	[deg]	[deg]
0.000	0.00	113	49.22	-0.052	0.0	0.0
30.27	30.21	109	49.22	-0.053	7.5	7.5
35.37	35.36	108	49.22	-0.053	8.0	11.1
37.69	37.95	107	49.22	-0.053	9.0	23.3
39.28	39.96	106	49.22	-0.053	10.1	32.2
48.15	48.11	104	49.22	-0.053	10.6	12.7
97.24	97.29	100	49.22	-0.053	7.6	4.7
100.04	100.61	100	49.22	-0.053	7.4	0.0
152.62	152.65	90	49.22	-0.054	8.6	10.8
166.03	166.32	88	49.22	-0.054	8.6	8.5
187.87	188.70	83	49.22	-0.055	9.1	12.9
206.26	206.64	80	49.22	-0.055	9.1	9.3
233.98	233.77	74	49.22	-0.055	9.5	12.2
253.25	253.71	70	49.22	-0.056	9.6	11.7
285.10	285.40	62	49.22	-0.056	10.1	14.1
306.20	306.72	58	49.22	-0.056	10.2	10.7
330.77	330.36	55	49.22	-0.057	9.9	7.0
357.55	357.58	51	49.22	-0.057	9.8	8.5
387.40	387.30	48	49.22	-0.057	9.5	5.7
613.77	613.03	34	49.22	-0.060	7.3	3.5
662.60	662.29	29	49.22	-0.061	7.2	5.8
696.36	696.29	25	49.22	-0.061	7.2	6.8
763.94	763.52	24	49.22	-0.062	6.6	0.8
922.03	920.29	19	49.22	-0.064	5.8	1.8
1,104.81	1,178.45	16	49.22	-0.067	5.0	0.9
1,141.38	1,178.45	18	49.22	-0.067	4.8	-3.1

On average, the west-southwesterly set of data is about 191[deg] from east: 11[deg] south of the west-line. This data-set suggests that the plateau begins at about 40[m] from the origin, at an elevation of 106[m]. The average slope at the edge is 22.7[deg]. The west-southwesterly slope from the origin (w/r Cross) averages 8.53[deg], while the walking slope (i -to- i+1) has an average slope of 9.68[deg]. The three highlighted rows designate the slope-zone. Over all datums, the upper-average walking-slope for both sets of data is 12.5[deg]

The distance from the edge of the slope/hill and the Cross is about 40.7[m]: $L_u/2 = 220$ [m] and $\phi < 3.5$, the site falls under Appendix A.3.3.b of Eurocode 1.

Equation 43: Site Slope, Φ

$$\varphi = \frac{97.5}{440} = \frac{H}{L_d} = \frac{H}{L_e} = 0.222[-]$$

Equation 44: Orography Factor

$$c_0 = 1 + 2s\varphi$$

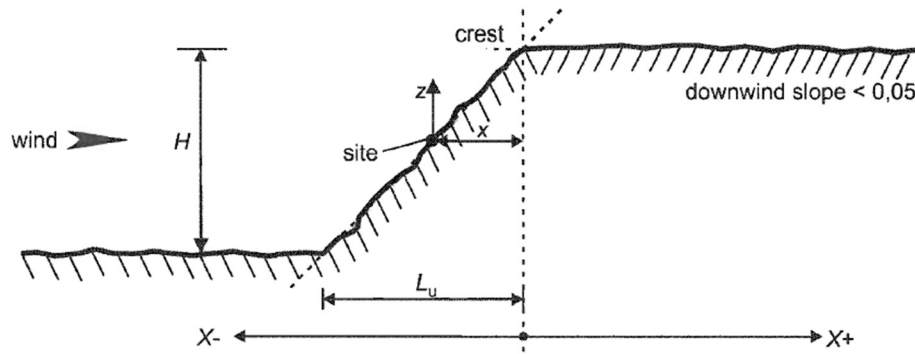


Figure 130: Location w/r Crest⁽¹⁴⁾

Per Figure 130, $x = 126$ [m], $x/L_e = 0.14$ [-]

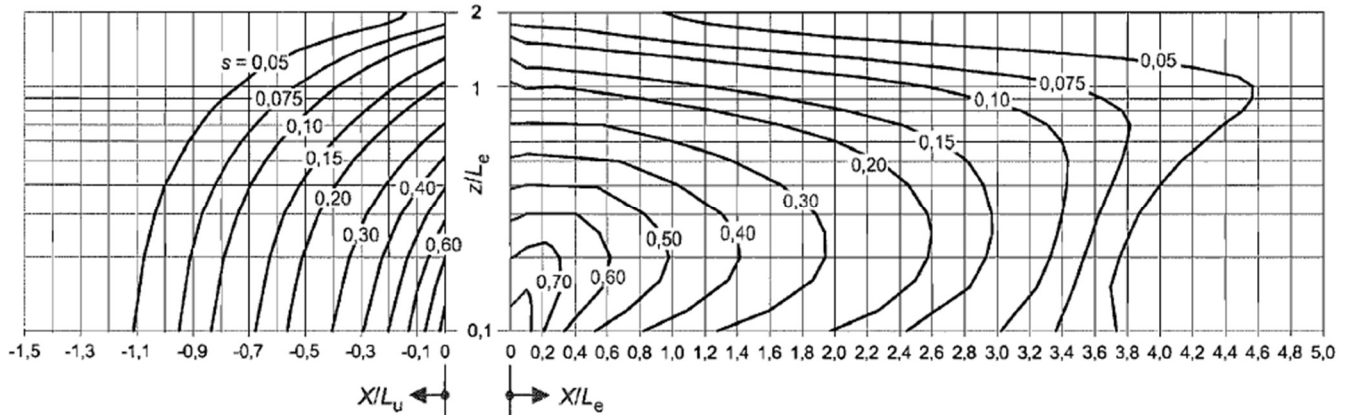


Figure 131: "s" Graph w/r Figure 130: $s > 0.8$ ⁽¹⁴⁾

With respect to the equations and $z_{\max} = 200$ [m], downwind section for cliffs and escarpments (Eurocode-1, Figure A.2) Figure 130: Equation-set "b" is utilized.

$$s = A \left(\log \left(\frac{x}{L_e} \right) \right)^2 + B \log \left(\frac{x}{L_e} \right) + C$$

Where:

$$A = -1.3420 \left(\log \left(\frac{z}{L_e} \right) \right)^3 - 0.8222 \left(\log \left(\frac{z}{L_e} \right) \right)^2 + 0.4609 \log \left(\frac{x}{L_e} \right) - 0.0791$$

$$B = -1.0196 \left(\log \left(\frac{z}{L_e} \right) \right)^3 - 0.8910 \left(\log \left(\frac{z}{L_e} \right) \right)^2 + 0.5343 \log \left(\frac{x}{L_e} \right) - 0.1156$$

$$C = 0.8030 \left(\log \left(\frac{z}{L_e} \right) \right)^3 + 0.4236 \left(\log \left(\frac{z}{L_e} \right) \right)^2 - 0.5738 \log \left(\frac{x}{L_e} \right) + 1.1606$$

$z = z_{\max} = 200[\text{m}]$
 $L_e = 873[\text{m}]$
 $x = 126[\text{m}]$

$$s = 1.63[-]$$

$$c_0 = 1 + 2(1.704)(0.1) = 1.643 = \frac{v_m}{v_{mf}}$$

Equation 45: Mean Wind Velocity Above Flat Terrain

$$v_m = 1.643v_{mf} = 1.643v_m(z)$$

Where:
 $z_{\max} = 200[\text{m}]$
 v_m is from Equation 38

As seen in Equation 45, due to the location of the Cross (with respect to the crest of the hill) the mean wind velocity is increased by 31[%]. Due to the high factor introduced here-in, the CFD model will imitate the mound on which the Cross is built.

In an effort to match the Eurocode equation and the Swiss energy/data, Equation 39, the base values need to change. The Eurocode-1 Equation 38 and the Swiss equation become equivalent when the zone roughness is set to 0.018636[m], with a minimum roughness of 1[m]. Applying this change to the equation, an added 2[%] safety is added to the original Eurocode-1 equation; for a total of 12[%].

$$\frac{V_{z_0,B=0.018636}}{V_{z_0,A=0.05}} = \frac{v_b \ln \left(\frac{h}{0.018636} \right)}{\ln \left(\frac{1}{0.018636} \right)} \frac{\ln \left(\frac{2}{0.05} \right)}{v_b \ln \left(\frac{h}{0.05} \right)} > 1.02$$

Where:
 $h < 850[\text{m}]$

This adjustment, along with the added mound/hill factor of 64.3[%], from Equation 45, yield a velocity profile as seen in Equation 46.

Equation 46: Eurocode Velocity w/Hill Factor, Version 1

$$v_m(z) = 1.643 \left(6.026 \ln \left(\frac{z}{0.018636[m]} \right) \right) = 1.643(6.0262 \ln(z) + 24)$$

Where:
 $1[m] \leq z \leq 200[m]$
 $[z] = [m]$
 $[v_m] = [m/s]$

Equation 47: Eurocode Velocity w/Hill Factor, Version 2

$$v_m(z) = 9.901 \ln(z) + 39.432$$

Where:
 $1[m] \leq z \leq 200[m]$
 $[z] = [m]$
 $[v_m] = [m/s]$

Equation 48: Velocity Profile w/o Hill-Model

$$v_m(z) = 6.0262 \ln(z) + 24$$

Where:
 $[z] = [m]$
 $[v_m] = [m/s]$

Wind: Velocity Profile with Upwind Slope/Hill

The method described in the Eurocode would estimate the loading and is valid to an altitude of 200[m]. This analysis will utilize CFD modeling of the hill/mount, as represented in Figure 132. This CFD model represents a realistic and worst-case scenario.

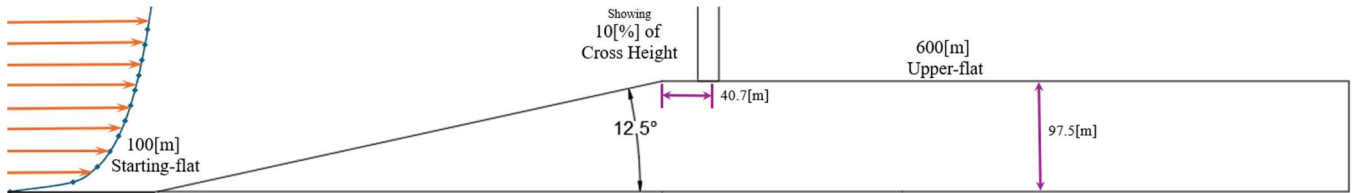


Figure 132: Initial CFD Model

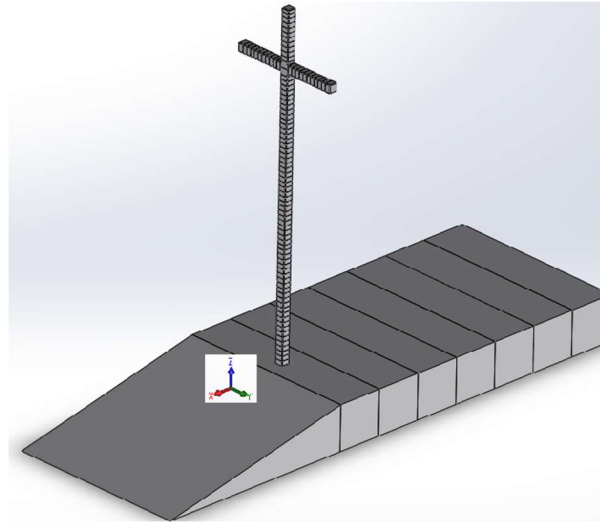


Figure 133: Initial CFD Hill Representation

Due to the data gathering utilizing Google-earth, the difference of 3[m] in altitude of the mount (between reference (05) and reference (06)) the altitude of Google-earth will be maintained. The hill/mount/slope represented in Figure 132, will be the initial CFD model. Changes to the initial model will be realized, should trailing vortices or other anomalies warrant changes.

As seen in the CFD for the Cross of Redemption, the skin friction offered little resistance. Since the boundary layer for the Cross of Redemption and the Glorious Cross of Dozule (France) are much less than the flat-length ($\epsilon/L \ll 1$: Ref,

Equation 15 & Equation 16) the skin friction will be set to zero. As an example, the height of a rivet head is 4.75[mm], where-as the side length is about 15,950[mm]; or about 0.03[%].

Wind – Velocity Equation for Dozulé:

Equation 49: CFD Velocity vs Altitude with Zero-height Adjustment

$$v_m(z) = 6.0262 \ln(z + 0.018637) + 24$$

Where:
[z] = [m]
[v_m] = [m/s]

Because the $\ln(0)$ is undefined ($\ln(0) = \infty$), the CFD model will adjust the velocity profile Equation 48 to Equation 49. This adjustment adds a small amount to the velocity profile. The velocity at 1[m] goes from 24[m/s] to 24.11[m/s]. At the “top” of the hill, the velocity will be around 51.6[m/s]. The velocity at the top of the cross will be about 62[m/s].

The air density for the CFD analysis will be determined by a short analysis of the weather in Dozule. In Dozule, France, The hottest month of the year in Dozulé is July, with an average high of 71°F and the coldest month of the year in Dozulé is January, with an average low of 37°F.⁽¹⁶⁾ The record high for Caen, France, was 40.1[C] (104.2[F]) and its record low was -19.6[C] (-3.3[F]).⁽¹⁷⁾ Taking the mean value of the

high and low temperatures with the record temperatures, the “hot” air density is 1.135[kg/m³] and the “cold” air density is 1.315[kg/m³] (at an altitude of 110[m], with 50[%] RH).

Weighting the air densities by $\frac{2}{3}$ rds towards cold temperature, the calculated air density is 1.286[kg/m³]. Though the suggested air density is 1.225[kg/m³], the weighted air density value will be utilized. This change will add about 5[%] to the pressure exerted on the structure. Thus, at the top of the Cross, a 48[in] square panel will experience a force of about 4,000[N] or 900[Lbf]. The air density of 1.286[kg/m³] would exist in air that has a humidity ratio of 55[%] with a temperature of -2.5[C] or 27.5[F].

Summary of Eurocode 1 Acting Forces:

Eurocodes were utilized to generate the various minimum loading conditions on the structures. The Glorious Cross is on a high hill and the velocities will be adjusted per the Swiss velocity profile; to be discussed later.

Seismic Lateral Load:	1.265[m/s ²] or 4.15[ft/s ²]
Wind, $V_{b,0}$:	24[m/s] or 53.7[mph] @ $Z = 1$ [m]
Snow/Ice:	450[N/m ²] or 0.065[psi]: Applied to upper panels only
Air Density:	1.286[kg/m ³] or 0.08028[Lb/ft ³]
(x30) People:	33,362[N] or 7,500[Lbf]: Applied to beams as an end-point load
Arm Construction:	311,375[N] or 70,000[Lbf]: Applied to beams as an end-point load

CFD of Glorious Cross:

The CFD performed on the entire structure contains initial pressure and density parameters: P_0 of 101325[Pa] and a ρ_0 of 1.286[kg/m³]. The velocity vector is $\langle v_m[Z], 0, 0 \rangle$; as seen in Figure 133 and Equation 50. Note that the base of the cross is at $Z = 0$ and the bottom of the hill is at $Z = -97.5$ [m].

Equation 50: CFD Velocity vs Altitude with Model Adjustment

$$v_m(z) = -6.0262 \ln(z + 0.018637 + 97.5) - 24$$

Where:
 $[z] = [m]$
 $[v_m] = [m/s]$

Full Cross – Steady State:

Angle of Attack, 0[deg]:

The velocity profile represented in Equation 50 was adjusted for the hill height, so that at the bottom of the hill and 1[m] above the flat ground, the velocity was 24.11[m/s]; basically adding 97.5[m] to the maximum altitude of the cross. The angle of attack is defined as zero, for $V = \langle f[z], 0, 0 \rangle$ (note, $V < 0$).

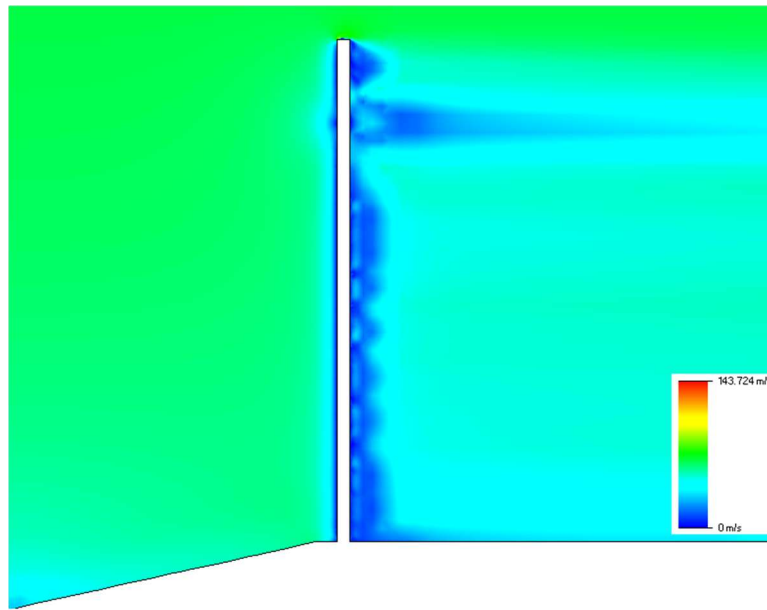


Figure 134: Steady-state, Mid-section, Velocity Contour, $V = \langle f[z], 0, 0 \rangle$, w/V_{max}

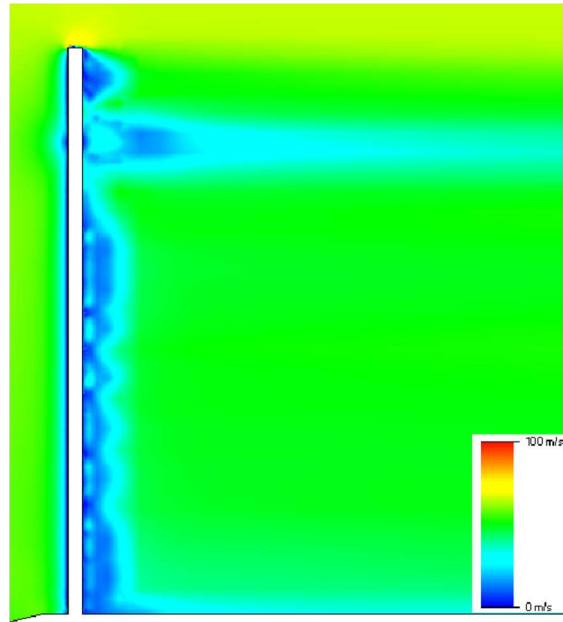


Figure 135: Steady-state, Mid-section, Velocity Contour, $V = \langle f[z], 0, 0 \rangle$

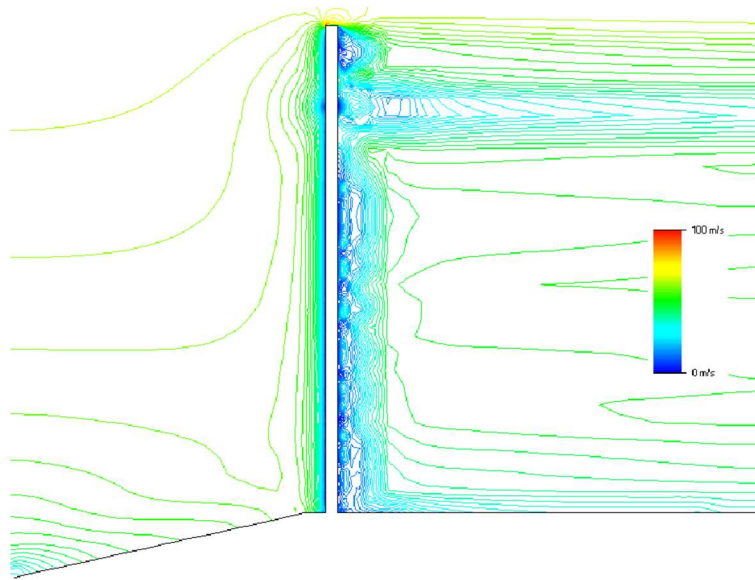


Figure 136: Steady-state, Mid-section, Iso-lines, $V = \langle f[z], 0, 0 \rangle$

The slope of the hill has a minor effect on the velocity profile. There is a slight increase in pressure, to an altitude of about 280[m] (925[ft]); as depicted in Figure 136.

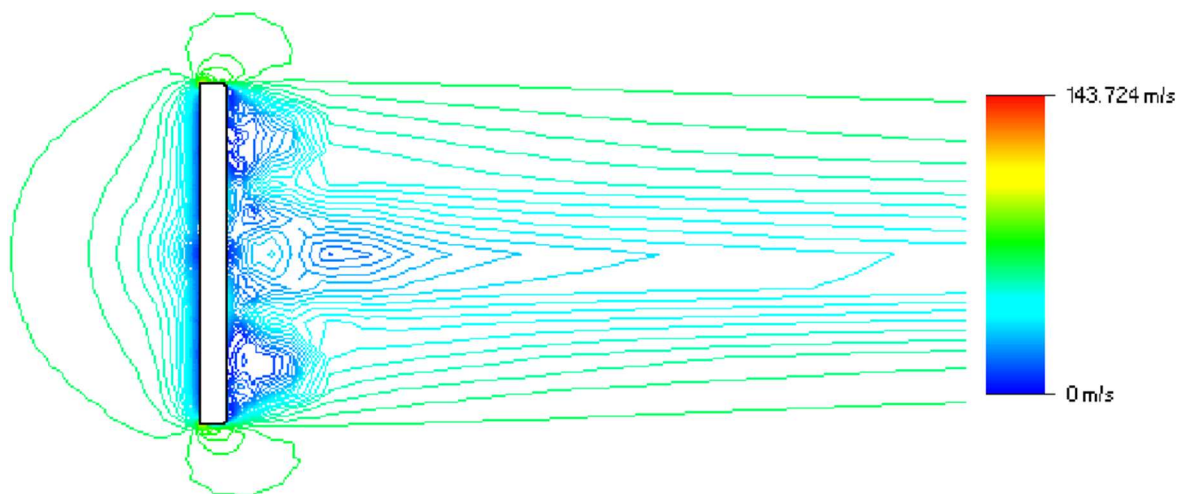


Figure 137: Steady-state, Mid-Arm, $Z = 615[m]$, Iso-lines, $V = \langle f[z], 0, 0 \rangle$

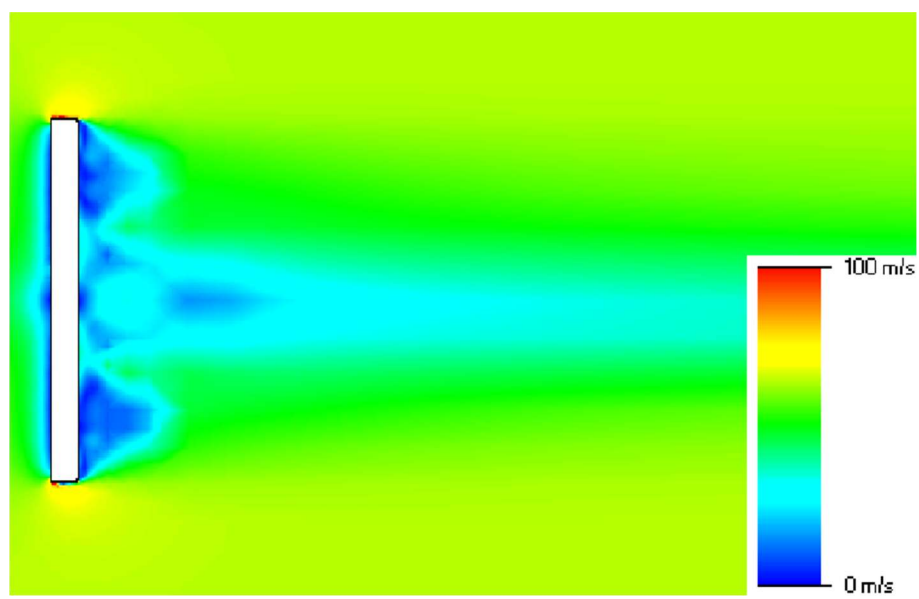


Figure 138: Steady-state, Mid-Arm, $Z = 615[m]$, Velocity Contour, $V = \langle f[z], 0, 0 \rangle$

Table 28: CFD Steady-state, Velocity Contour, $V = \langle f[z], 0, 0 \rangle$

Angle of Attack	0[deg]	
Steady State	[N]	[Lbf]
Fx	39,959,000	8,983,148
Fy	-1,614,900	-363,044
Fz	-1,309,300	-294,343
F	40,013,046	8,995,298
	[Nm]	[Lbf-ft]
Mx	3.207E+08	236,521,623
My	1.733E+10	12,782,700,036
Mz	6.559E+06	4,837,748
M	17,333,967,800	12,784,888,975

Angle of Attack, 45[deg]:

The angle of attack is defined as 45[deg], for $V = f[z] \langle 2^{-0.5}, 2^{-0.5}, 0 \rangle$. The loading, F_y , is the highest of the static analysis and will be utilized in the final loadings.

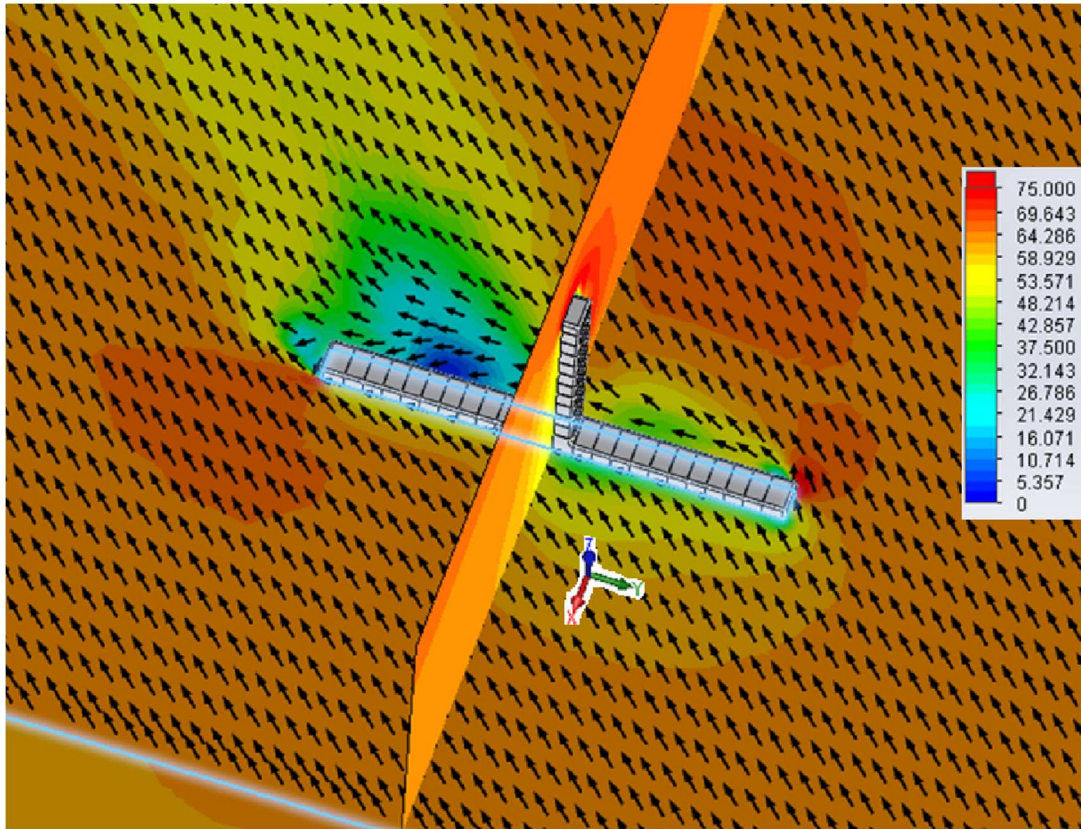


Figure 139: Steady-state, Velocity Contour, $V = f[z] < 2^{-0.5}, 2^{-0.5}, 0 >$

Table 29: CFD Steady-state, Force & Moment for 45[deg]

Angle of Attack	45[deg]	45[deg]
Steady State	[N]	[Lbf]
F_x	-34,550,000	-7,770,000
F_y	-31,710,000	-7,130,000
F_z	1,530,000	340,000
$ F $	46,920,000	10,550,000
	[Nm]	[Lbf-ft]
M_x	12,442,000,000	9,177,000,000
M_y	-14,931,000,000	-11,012,000,000
M_z	208,000,000	154,000,000
$ M $	19,436,000,000	4,369,000,000

Angle of Attack, 90[deg]:

The angle of attack is defined as 90[deg], for $V = \langle 0, 0, f[z] \rangle$.

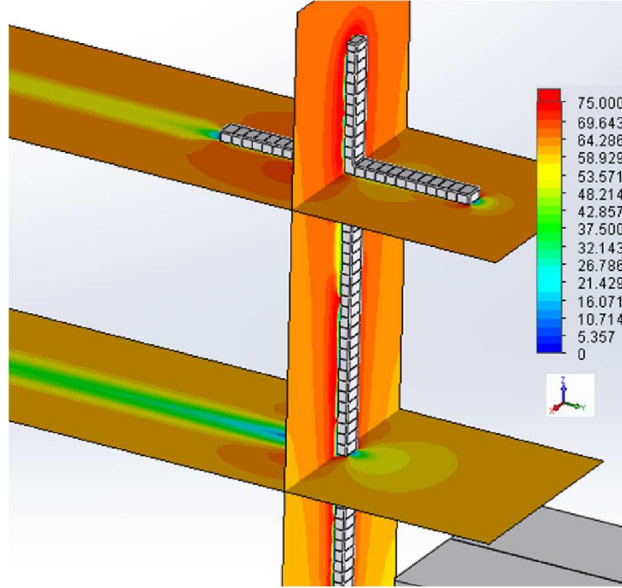


Figure 140: Steady-state, Velocity Contour, $V = \langle 0, 0, f[z] \rangle$

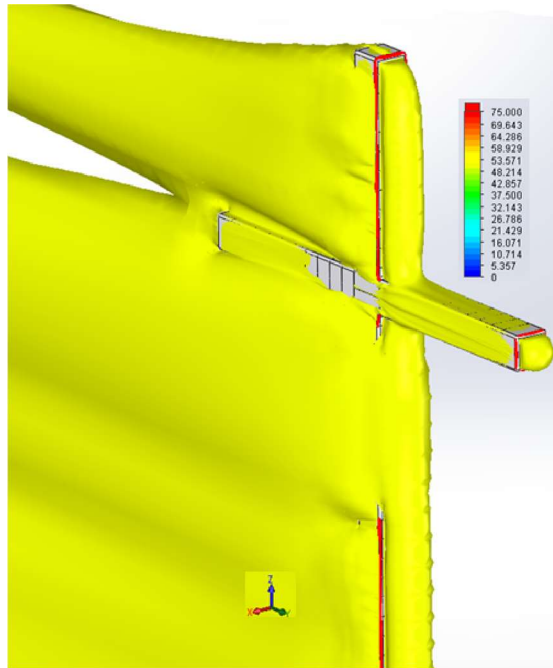


Figure 141: Steady-state, Iso-surface, $V = \langle 0, 0, f[z] \rangle$

Table 30: CFD Steady-state, Force & Moment for 90[deg]

Angle of Attack	90[deg]	90[deg]
Steady State	[N]	[Lbf]
F _x	-1,800,000	-400,000
F _y	-28,700,000	-6,450,000
F _z	640,000	140,000
F	28,760,000	6,470,000
	[Nm]	[Lbf-ft]
M _x	11,341,000,000	8,365,000,000
M _y	-557,000,000	-411,000,000
M _z	5,000,000	4,000,000
M	11,355,000,000	2,553,000,000

Full Model – Transient:

Vortex Shedding:

The generation of vortices may be depicted by the curl of the Navier-Stokes equation. As noted in Equation 51 with the definition of Equation 52, yields Equation 53.

Equation 51: Curl of the Navier-Stokes equation

$$\nabla \left(\frac{\partial u}{\partial t} + u \cdot \nabla u \right) = -\Delta \left(\frac{P}{\rho} + gz \right) + \nu \nabla^2 u$$

Equation 52: Vorticity/Rotation Vector Definition

$$\nabla \times u \equiv \omega$$

Equation 53: Vorticity Equation

$$\frac{d\omega}{dt} = (\omega \cdot \nabla)u + \nu \nabla^2 \omega$$

Equation 53, states that the higher the velocity, the stronger the vorticity. Since the viscosity of air is relatively consistent, the greatest effect on the strength of a vortex is its velocity. Thus, the highest flat portion of the cross will be utilized in a time-dependent study to see if a vorticity shedding occurs.

Infinite Profile Vortex Shedding:

The main cross-sectional profile of the Glorious Cross was analyzed for vortex shedding. The model was as if it were an infinite – filleted square. The data clearly shows that pressure bubbles develop and tear themselves away, with time; see Figure 142 and Figure 143.

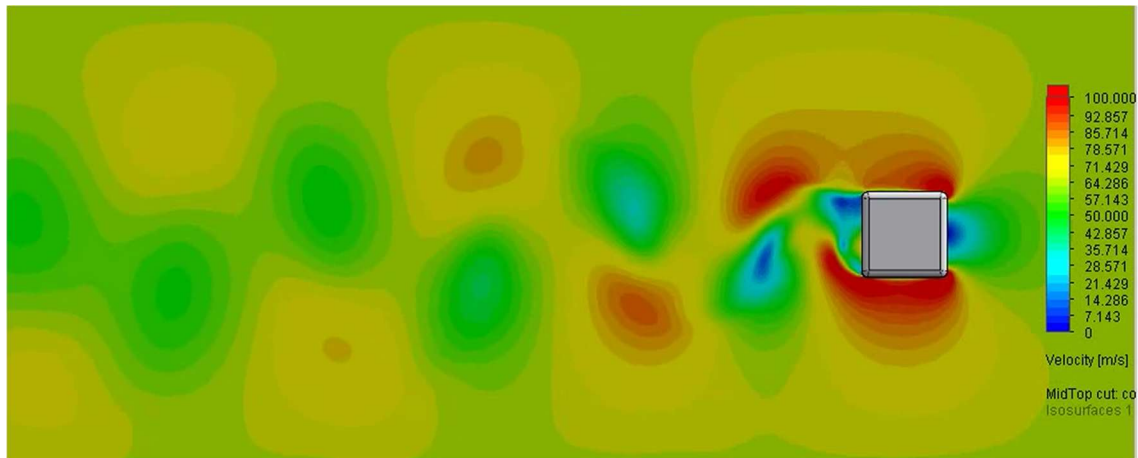


Figure 142: "Upper" Vortex, Pressure Wave Detachment

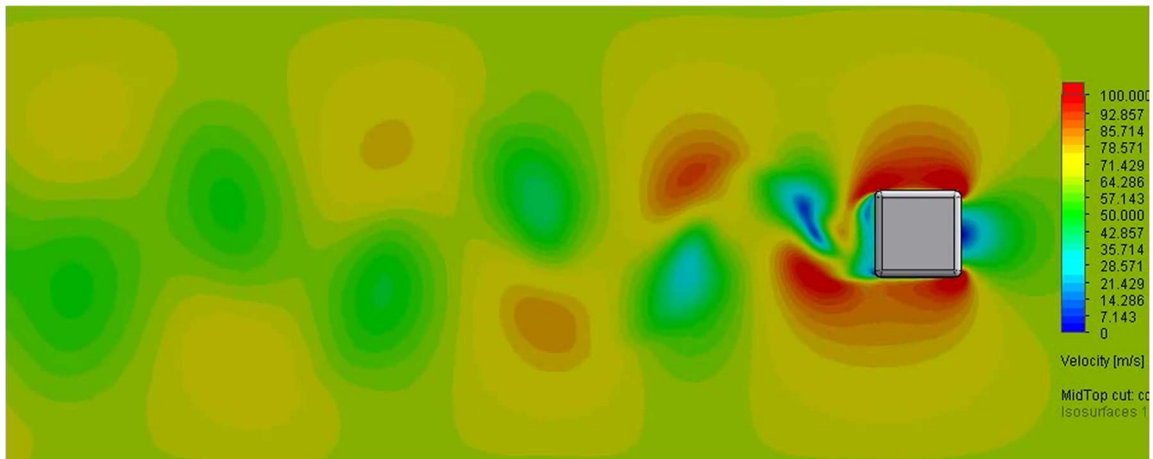


Figure 143: "Lower" Vortex, Pressure Wave Detachment

A pressure-domain is established and detaches themselves from the main body; as seen in Figure 142 and Figure 143. The high pressure-bubbles detach themselves with respect to the moment about $\langle Z \rangle$. The CFD model was configured to be an un-ending cross-section.

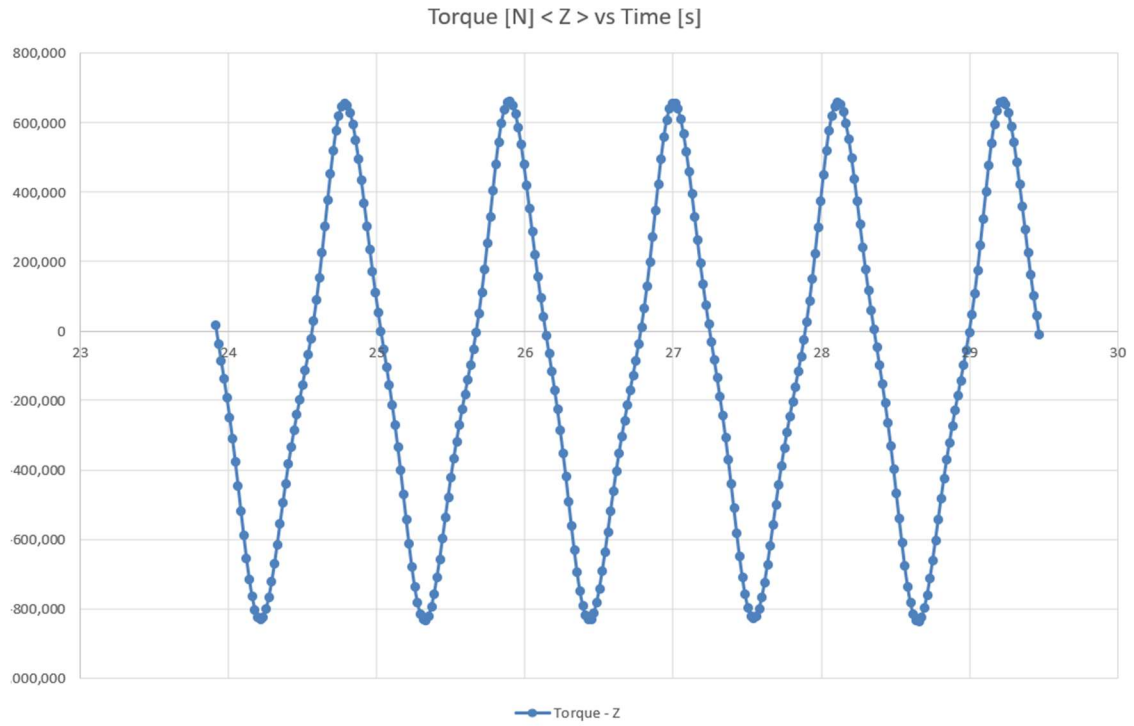


Figure 144: Torque of Shedding

The study showed that, with an infinite segment, the shedding occurred every 1.11[s] with a variance of less than 0.5[%]. The half-period is about 0.556[s]. The average $|M_z|$ should be greater than $2.6(10^6)$ [Lbf-ft] or $11.4(10^6)$ [Nm].

Table 31: Ideal/Infinite Body, Shedding Frequency

T_{shed}	1.11	[s]
f_{shed}	0.90	[Hz]
ω_{n_shed}	5.65	[rad/s]

Table 32: Torque < Z >, Over Top Section Only (6.5232[m])

M_z	Nm/m	Lbf-ft/ft
Max	101,569	22,834
Min	-128,213	-28,823
Ave	-15,440	-3,471
Range	229,782	51,657

Full Cross, Transient Study:

The transient analysis proceeded by subjecting the full model to the maximum wind conditions (per Equation 50) upon a hill. Animation with time-steps of about 0.13[s] do not exhibit vortex shedding. The view depicted in Figure 145 remains consistent throughout the analysis; the high pressure-bubble (red zones) do not display a cyclic behavior (as in Figure 142 and Figure 143).

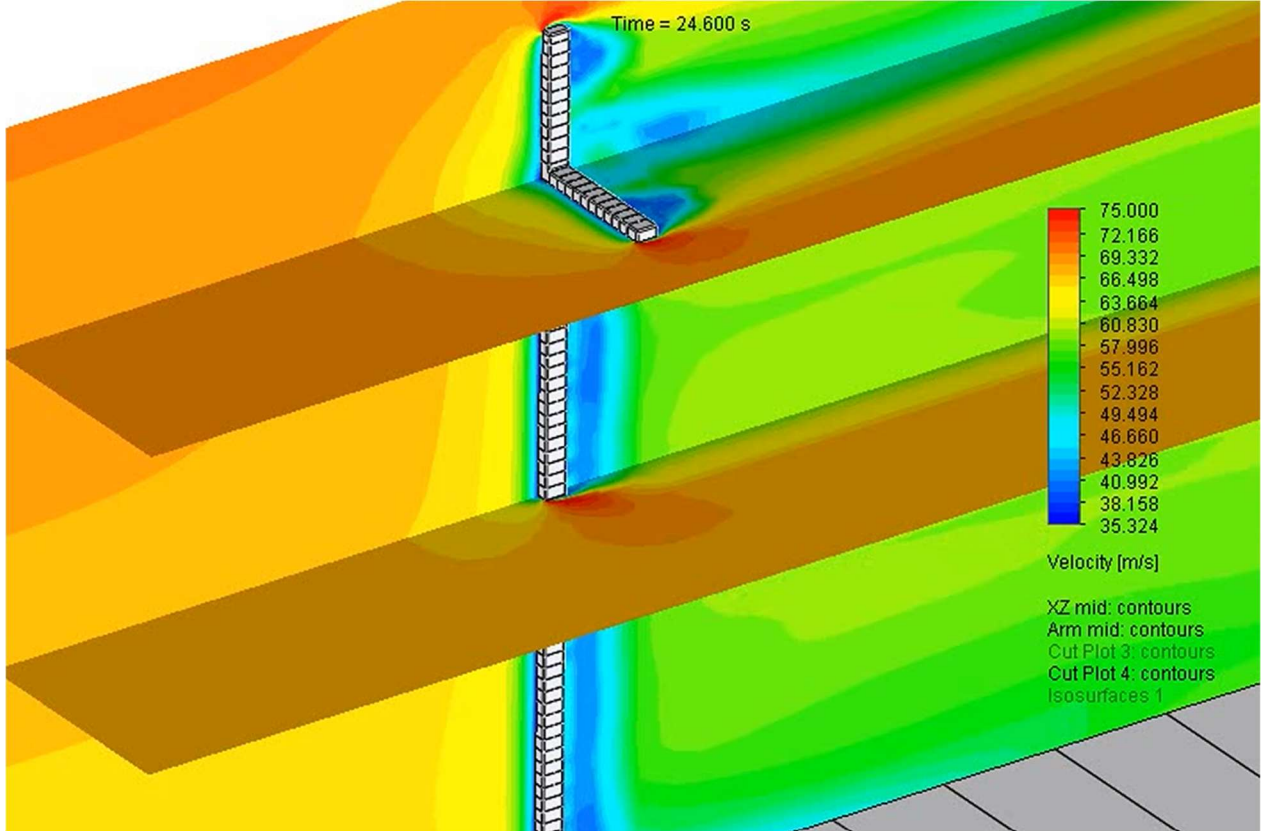


Figure 145: CFD, Transient of Full Model, Velocity $\langle -f[z], 0, 0 \rangle$

The flow cord-center, the point at which the forces are acting, was calculated utilizing vector theorem identities. Equation 54 and Equation 55 were solved for the vector $R = \langle R_X, R_Y, R_Z \rangle$. Equation 55 is valid because the vector “R” is perpendicular to the vector “F.”

Equation 54: Vector Moment Equation

$$(R \times F) = T$$

Equation 55: Vector Orthogonal Identity/Theorem

$$R_X F_X + R_Y F_Y + R_Z F_Z = 0$$

A solution-set may vary, here-in, R_y was derived/defined by Equation 56, the R_x and finally R_z . In any case, the final solution will be identical. Because R_z was the last derivation, it contained two possible solutions. In each case, the “real/plausible” solution was chosen.

Equation 56: R_y , "Y" Length to Cord-center

$$R_y = \frac{(M_x F_z - M_z F_x)}{(F_x^2 + F_y^2 + F_z^2)}$$

Equation 57: R_x , "X" Length to Cord-center

$$R_x = \frac{M_z + R_y F_x}{F_y}$$

Equation 58: R_z (1 & 2), "Z" Length to Cord-center

$$R_{z1} = -\frac{(R_x F_x + R_y F_y)}{F_z}$$

$$R_{z2} = \frac{M_y + R_x F_z}{F_x}$$

The data for the transient analysis for the full model, Velocity $\langle -f[z], 0, 0 \rangle$ was processed, yielding the following:

- The geometric area-center is at $\langle 0, 0, 427 \rangle$ [m]
 - $\langle 0, 0, 1,401 \rangle$ [ft]
 - Solution – set 1 for the average wind-center: $\langle 12.9, -0.230, 444 \rangle$ [m]
 - $\langle 42.2, -0.748, 1,457 \rangle$ [ft]
 - Solution – set 2 for the average wind-center: $\langle 12.9, -0.230, 496 \rangle$ [m]
 - $\langle 42.2, -0.748, 1,627 \rangle$ [ft]
- ✓ The average cord-center ranges from 17[m] (56[ft]) to 69[m] (226[ft]) above the geometric center.

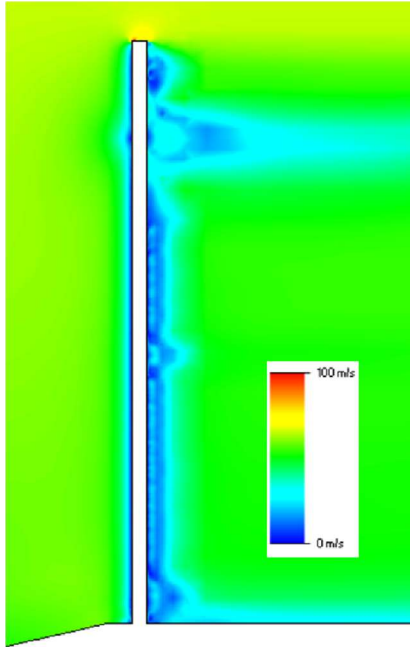


Figure 146: Transient Mid-section, Full Model, Velocity $\langle -f[z], 0, 0 \rangle$

Where:
 $\langle X \rangle$ is to the left
 $\langle Z \rangle$ is up

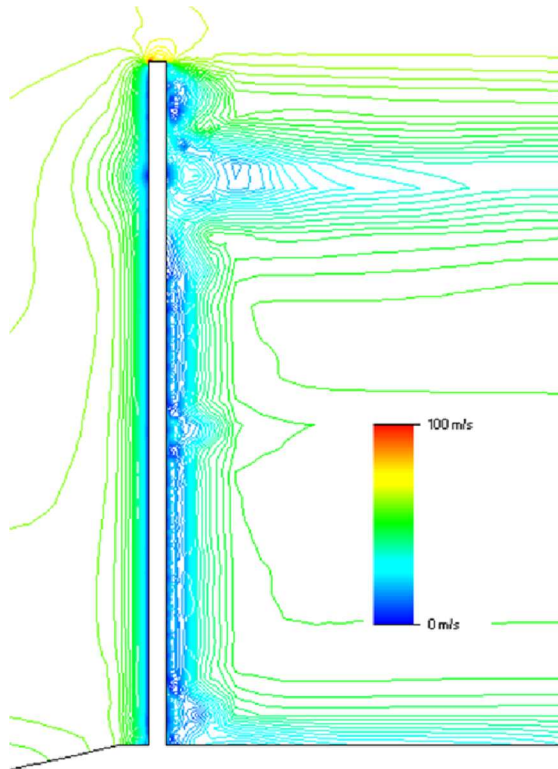


Figure 147: Transient Mid-section, Full Model w/Iso-lines, Velocity $\langle -f[z], 0, 0 \rangle$

Where:
 $\langle X \rangle$ is to the left

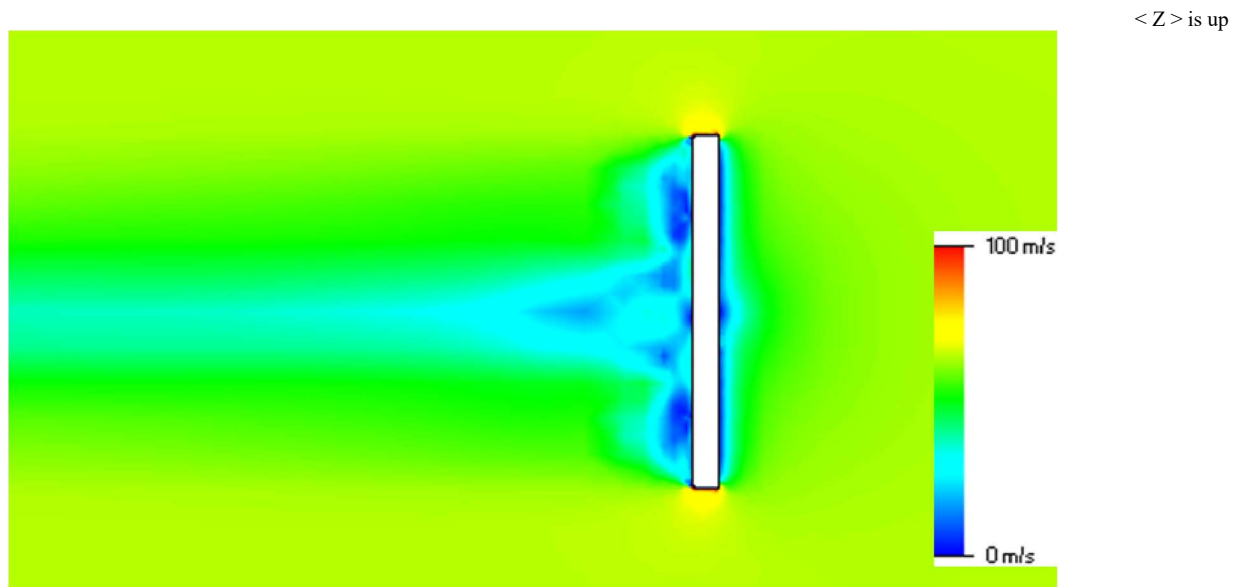


Figure 148: Transient Mid-Arm, Full Model, Velocity $\langle -f[z], 0, 0 \rangle$

Where:
 $\langle X \rangle$ is to the right
 $\langle Y \rangle$ is up

A preliminary analysis shows that the M_x oscillates every 3.0[s] and M_y oscillates every 3.3[s]. The oscillations about $\langle Z \rangle$ are governed by the coupling of the arm/s and the main body; less than 3[s].

The transient graphical velocity contours depicted in Figure 146 and Figure 147, show that the hill/ground effect the cross to an altitude of about 60[m] or 200[ft]. The steady-state condition depicted in Figure 136, is almost (x)5 greater than the transient and is considered the upper limit of the ground/hill affect. It is thought that edge vortices traveling up (away from the ground) disseminate the back pressure, generating the differences between the models.

A preliminary analysis shows that with an M_y (torque about $\langle Y \rangle$) of 17,832[MNm] and an S_y (yield stress, σ_y) of 125[MPa], the minimum area-inertia required is 1,315[m⁴] or 152,100[ft⁴]. The maximum deflection at the cord-center should be no more than 0.307[m] or 1.01[ft] (utilizing the approximation from Equation 63).

Table 33: Full Cross, Transient Analysis, M_x

CFD Transient Data	M_x [Nm]	M_x [Lbf-ft]
Max (Ave + 3SD)	2.778E+08	2.049E+08
Ave	-2.150E+08	-1.586E+08
Min (Ave - 3SD)	-7.078E+08	-5.221E+08
Range	9.856E+08	7.270E+08

Where: SD = "Standard Deviation"

T(ave) - [s]	2.18
T(min) - [s]	1.68
f(ave) - [1/s]	0.46
ω (ave) - [rad/s]	2.89

Data Boundary Variation w/r Max & Min

(Ave + 3SD)/Max	8.46%
(Ave - 3SD)/Min	7.38%

The statistical variance of M_x (Table 33) is less than 9%, with an average period of 2.18[s]. No unusual phenomena occur. The cyclic twisting of 2.18[s] is about (x)2 greater than the cross-sectional period of 1.11[s]. Since the cyclic nature of $M_x > T_{shed}$, no contiguous vortex shedding is expected.

Table 34: Full Cross, Transient Analysis, M_y

CFD Transient Data	M_y [Nm]	M_y [Lbf-ft]
Max (Ave + 3SD)	-1.403E+10	-1.035E+10
Ave	-1.438E+10	-1.061E+10
Min (Ave + 3SD)	-1.473E+10	-1.086E+10
Range	6.982E+08	5.149E+08

Where: SD = "Standard Deviation"

T(ave) - [s]	3.36
T(min) - [s]	2.86
f(ave) - [1/s]	0.30
ω (ave) - [rad/s]	1.87

Data Boundary Variation w/r Max & Min

(Ave + 3SD)/Max	0.305%
(Ave - 3SD)/Min	0.371%

The statistical variance of M_y (Table 34) is less than 0.4[%], with an average period of 3.71[s]. Therefore, no unusual phenomena occur, and it is very consistent/stable. The cyclic twisting of 3.71[s] is about (x)3 greater than the cross-sectional period of 1.11[s]. Since the cyclic nature of $M_y > T_{shed}$, contiguous vortex shedding is expected.

Table 35: Full Cross, Transient Analysis, M_z

CFD Transient Data	M_z [Nm]	M_z [Lbf-ft]
Max (Ave + 3SD)	1.143E+07	8.427E+06
Ave	-1.783E+06	-1.315E+06
Min (Ave - 3SD)	-1.499E+07	-1.106E+07
Range	2.642E+07	1.948E+07

Where: SD = "Standard Deviation"

T(ave) - [s]	2.30
T(min) - [s]	1.80
f(ave) - [1/s]	0.43
ω (ave) - [rad/s]	2.73

Data Boundary Variation w/r Max & Min

(Ave + 3SD)/Max	36.2%
(Ave - 3SD)/Min	3.58%

The statistical variance of M_z (Table 35) is less than 4[%] on the lower boundary and 36[%] on the upper boundary; with an average period of 2.30[s]. Since the transient analysis ran for less than 5[min], a 6 – Sigma value will be applied (i.e. Max (3SD)) where necessary. The cyclic twisting of 2.3[s] is about (x)2 greater than the cross-sectional period of 1.11[s]. Since the cyclic nature of $M_z > T_{shed}$, no contiguous vortex shedding is expected.

Table 36: Full Cross, Transient Analysis, $\langle F_x, F_y, F_z \rangle$

CFD Transient Data	F_x [N]	F_x [Lbf]	F_y [N]	F_y [Lbf]	F_z [N]	F_z [Lbf]
Max ($Ave + 3SD$)	-3.160E+07	-7.104E+06	1.340E+06	3.013E+05	1.640E+06	3.687E+05
Ave	-3.236E+07	-7.276E+06	4.345E+05	9.768E+04	8.410E+05	1.891E+05
Min ($Ave + 3SD$)	-3.313E+07	-7.448E+06	-4.711E+05	-1.059E+05	4.189E+04	9.418E+03
Range	1.533E+06	3.446E+05	1.811E+06	4.072E+05	1.598E+06	3.593E+05

Where: SD = "Standard Deviation"

T(ave) - [s]	4.35	2.24	2.30
T(min) - [s]	3.86	1.74	1.80
f(ave) - [1/s]	0.23	0.45	0.43
ω (ave) - [rad/s]	1.44	2.81	2.73

Data Boundary Variation w/r Max & Min

3SD/Max	0.336%	0.168%	1.05%
3SD/Min	0.271%	30.9%	31.8%

The statistical variance of F_y and F_z are rather high, likely due to the velocity profile and their relatively low values: F_y and F_z are less than 6[%] of F_x . Also, the time of the analysis was less than 5[min], therefore, the statistical (6-Sigma {Standard Deviation, SD}) values will be utilized as necessary.

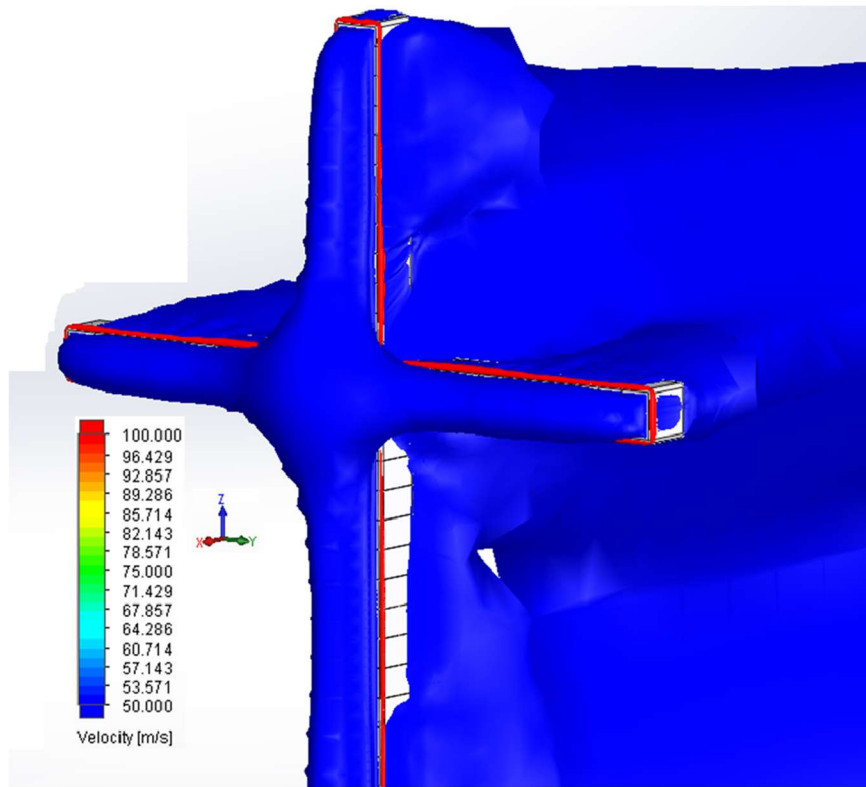


Figure 149: Transient, Full Cross, Iso-surface 50[m/s] to 100⁺[m/s] , Velocity $\langle -f[z], 0, 0 \rangle$

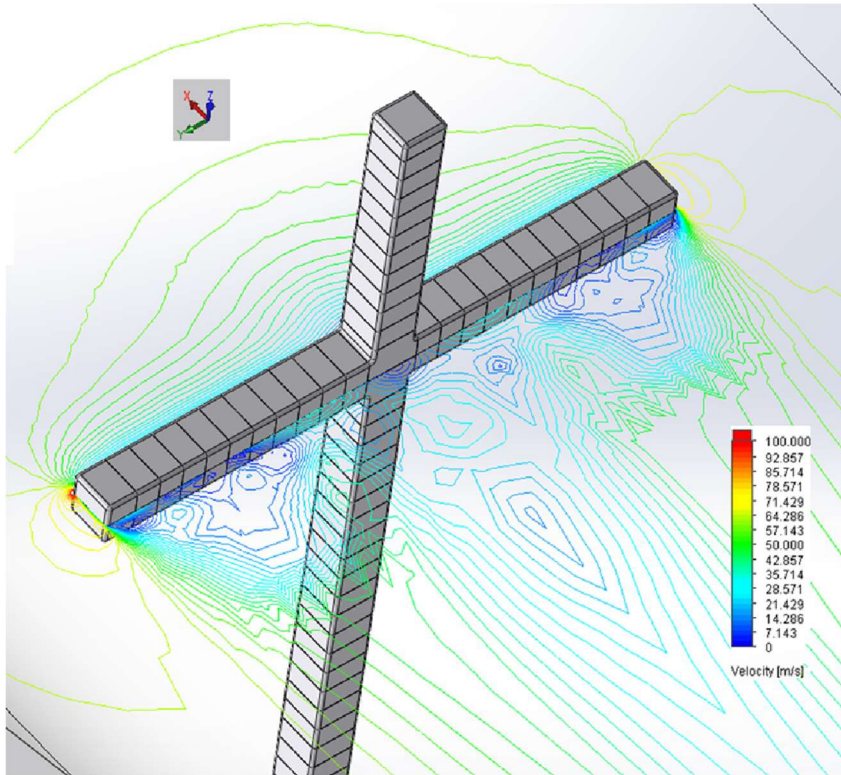


Figure 150: Transient, Full Cross, Iso-lines, Mid-arm, Velocity $\langle -f[z], 0, 0 \rangle$

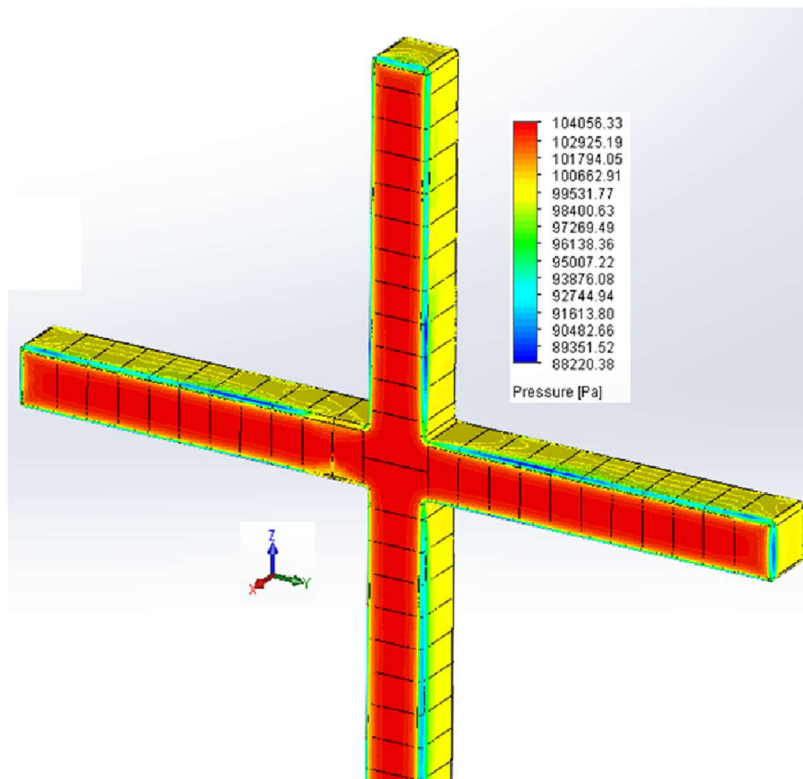


Figure 151: Transient, Full Cross, Frontal Pressure Map, Velocity $\langle -f[z], 0, 0 \rangle$

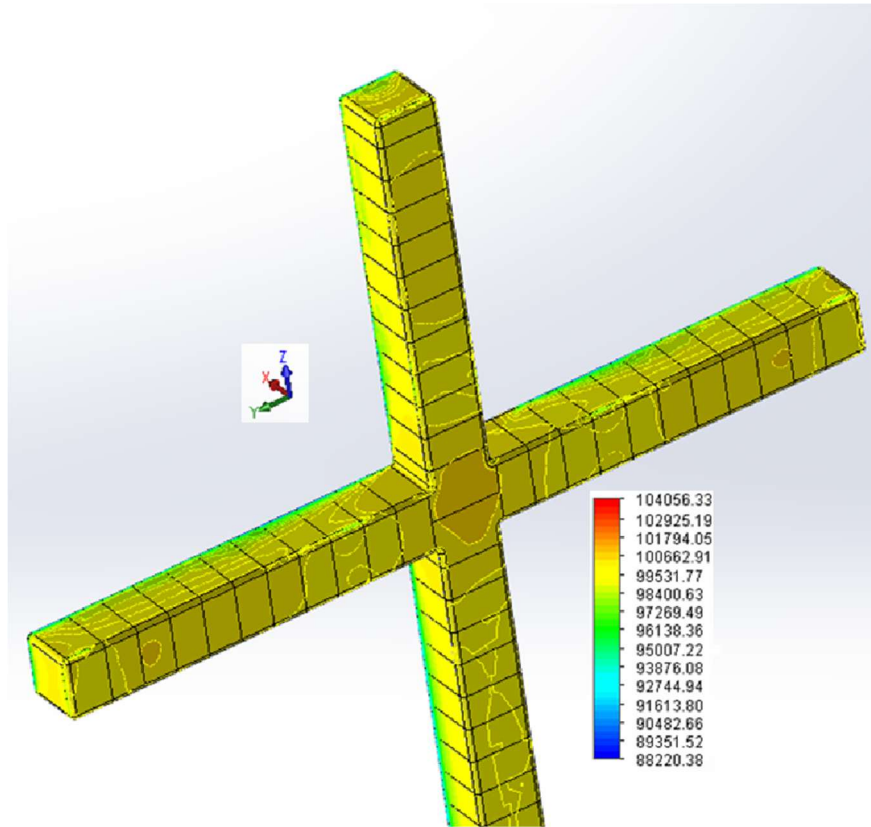


Figure 152: Transient, Full Cross, Rear Pressure Map, Velocity $\langle -f[z], 0, 0 \rangle$

The maximum pressure difference across the cross is well seen in Figure 151 and Figure 152, is 3,464[Pa] or 0.50[psi]. At that elevation (615[m]), the dynamic pressure is 2,737[Pa] or 0.397[psi]. Subtracting these values yields a vacuum of 727[Pa] or 0.106[psi].

Therefore, the maximum flat panel pressure for the study will be defined as $P_{\max} = 2,820[\text{Pa}]$ (0.409[psi]) with a minimum possible pressure of $P_{\min} = -730[\text{Pa}]$ (-0.106[psi]). The cyclic stresses will be obtained, utilizing these values.

Full Cross, FEA Static Study:

The maximum loading condition from the transient CFD analysis was found at 45[deg] angle of attack. The model utilized for the FEA study was at 0[deg] angle of attack. The CFD information was mapped to the FEA model and the F_y information from the 45[deg] analysis was transferred to the 0[deg] analysis.

Table 37: FEA, 0[deg] Static, F_x & M_x

FEA Static Analysis	F_x [N]	F_x [Lbf]
Reaction Load	3.996E+07	8.983E+06
Resultant Load	-3.996E+07	-8.983E+06

FEA Static Analysis	M_x [Nm]	M_x [Lbf-ft]
Reaction Load	3.207E+08	2.365E+08
Resultant Load	-3.207E+08	-2.365E+08

Table 38: FEA, 0[deg] Static, F_y & M_y

FEA Static Analysis	F_y [N]	F_y [Lbf]
Reaction Load	-1.615E+06	-3.630E+05
Resultant Load	1.615E+06	3.630E+05

FEA Static Analysis	M_y [Nm]	M_y [Lbf-ft]
Reaction Load	1.733E+10	1.278E+10
Resultant Load	-1.733E+10	-1.278E+10

Table 39: FEA, 0[deg] Static, F_z & M_z

FEA Static Analysis	F_z [N]	F_z [Lbf]
Reaction Load	-1.309E+06	-2.943E+05
Resultant Load	1.309E+06	2.943E+05

FEA Static Analysis	M_z [Nm]	M_z [Lbf-ft]
Reaction Load	6.559E+06	4.838E+06
Resultant Load	-6.559E+06	-4.838E+06

Full Cross, Combining CFD & FEA:

The data from the transient CFD analysis was performed, then a 6-Sigma (3SD) was applied to the maximum and minimum values. Then the CFD file was utilized for the FEA study and the final maximum loading was determined. The transient analysis showed that M_y is more consistent than M_x or M_z; as seen in Figure 153.

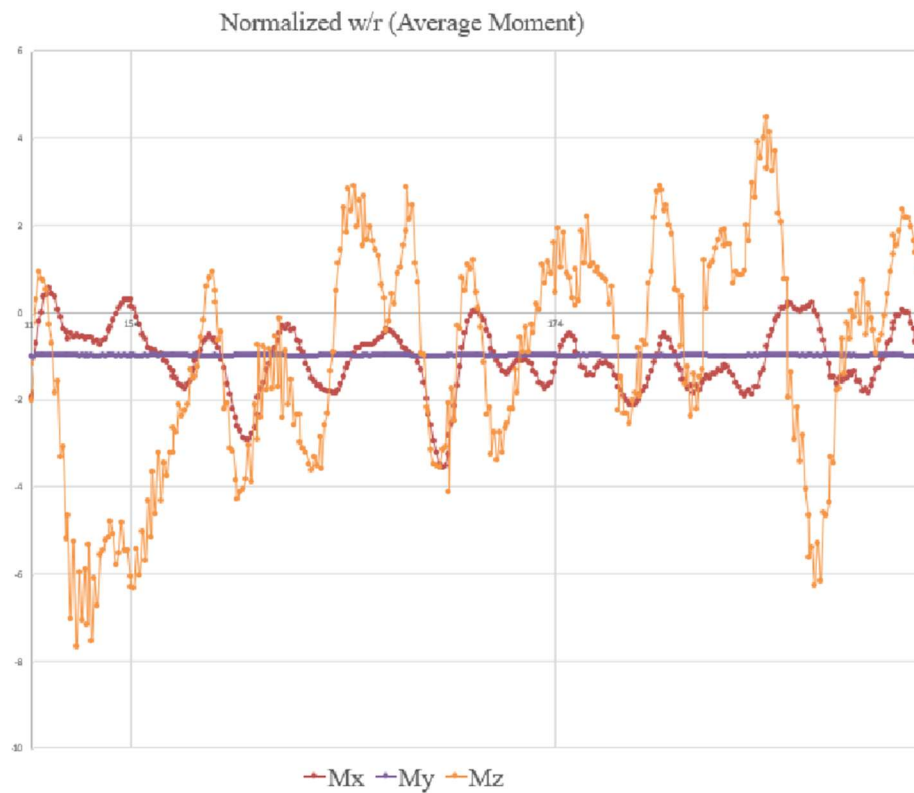


Figure 153: Transient Normalized - Moments $\langle M_x, M_y, M_z \rangle$

Note: Normalized w/r the Average Value

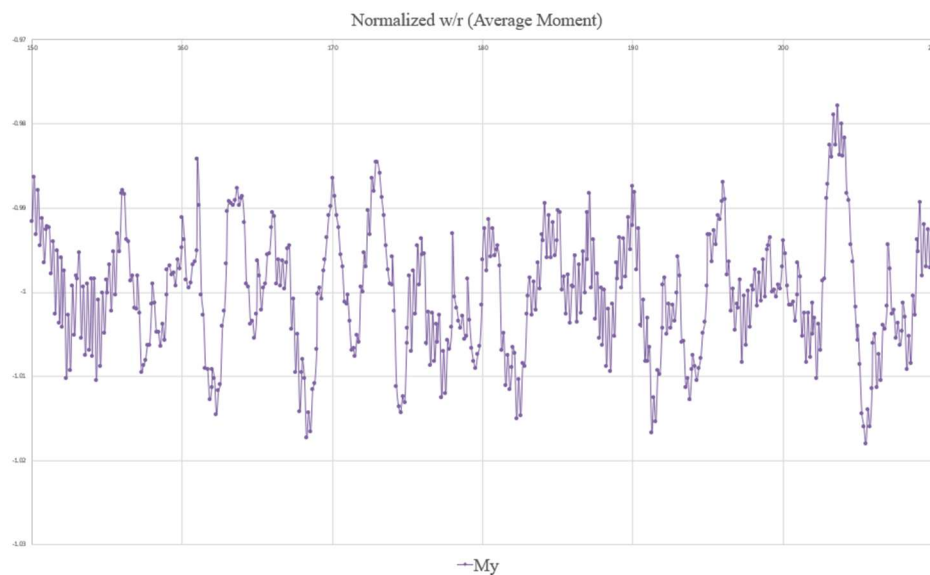


Figure 154: Transient Normalized - Moments $\langle 0, M_y, 0 \rangle$

Note: Normalized w/r the Average Value

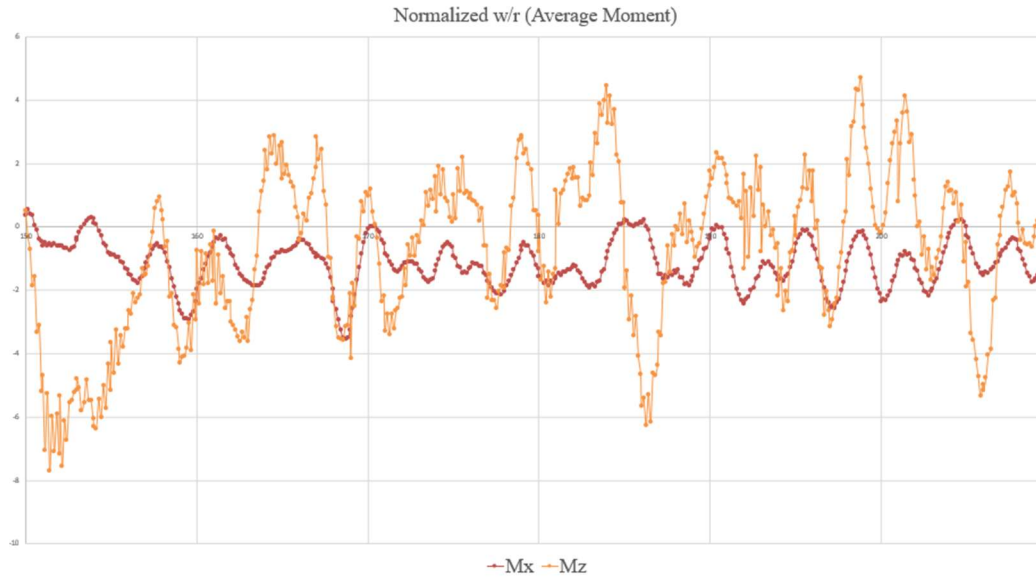


Figure 155: Transient Normalized - Moments $\langle M_x, 0, M_z \rangle$

Note: Normalized w/r the Average Value

From the transient analysis it is noted that M_x follows M_y and M_z is erratic. Utilizing the 6-Sigma boundaries and the erratic behavior of M_z , the maximum loading is represented in Table 40.

Table 40: Maximum Loading at $0[\text{deg}]$, $V_{\max} = \langle V[z], 0, 0 \rangle$

Loading at Base - Center	Maximum Resultant	Average Resultant	Minimum Resultant
Fx - [N]	-40,000,000	-32,400,000	-24,800,000
[Lbf]	-8,990,000	-7,280,000	-5,570,000
Fy	1,620,000	435,000	-746,000
[Lbf]	364,000	97,700	-168,000
Fz	1,650,000	841,000	41,900
[Lbf]	369,000	189,100	9,420
Mx - [Nm]	278,000,000	-216,000,000	-708,000,000
[Lbf-ft]	205,000,000	-159,000,000	-523,000,000
My	-17,400,000,000	-14,400,000,000	-11,500,000,000
[Lbf-ft]	-12,800,000,000	-10,700,000,000	-8,430,000,000
Mz	11,500,000	-1,790,000	-15,000,000
[Lbf-ft]	8,430,000	-1,320,000	-11,100,000

The maximum loading vector, for construction, was taken from Table 40, where M_x follows M_y and M_z was taken to produce the maximum amount of stress at the base of the cross.

Static Loading Magnitude, Angle of Attack:

The highest loading is found at 45[deg] angle of attack, because $F_y(@45[\text{deg}]) \gg F_y(@0[\text{deg}])$. The resultant moments are increased by about 12.2[%].

Table 41: Static Force & Moment w/r Angle of Attack

F [N] @ 0[deg]	40,000,000
F [N] @ 45[deg]	46,900,000
F [N] @ 90[deg]	28,800,000
M [Nm] @ 0[deg]	17,330,000,000
M [Nm] @ 45[deg]	19,440,000,000
M [Nm] @ 90[deg]	11,350,000,000

Loading Moments at Base:

The data which presents the greatest loadings are from Table 40: Added to this loading is the increased loading from the study at the angle of attack of 45[deg].

Table 42: Final Loading for The Glorious Cross

FINAL LOADING FOR GLORIOUS CROSS

Loading at Base - Center	Maximum Resultant	Average Resultant	Minimum Resultant
F _x - [N]	-40,000,000	-32,400,000	-24,800,000
[Lbf]	-8,990,000	-7,280,000	-5,570,000
F _y - [N]	1,620,000	-15,700,000	-32,900,000
[Lbf]	364,000	97,700	-168,000
F _z - [N]	1,650,000	841,000	41,900
[Lbf]	369,000	189,100	9,420
F - [N]	40,100,000	36,100,000	41,300,000
[Lbf]	9,010,000	8,100,000	9,270,000

M _x - [Nm]	13,000,000,000	6,150,000,000	-708,000,000
[Lbf-ft]	205,000,000	-159,000,000	-523,000,000
M _y - [Nm]	-17,400,000,000	-14,400,000,000	-11,500,000,000
[Lbf-ft]	-12,800,000,000	-10,700,000,000	-8,430,000,000
M _z - [Nm]	222,000,000	104,000,000	-15,000,000
[Lbf-ft]	8,430,000	-1,320,000	-11,100,000
M - [Nm]	21,800,000,000	15,700,000,000	11,600,000,000
[Lbf-ft]	16,100,000,000	11,600,000,000	8,500,000,000

Note: The estimated weight is not included.

The final loading, found in Table 42, represents about a 12[%] increase in energy (torque) with respect to the CFD analysis at 45[deg]. The loads, F_y, M_x and M_z were modified to include the CFD analysis at 45[deg].

Table 43: Moment at Base of Cross, High-Loading

High Moment at Base of Cross		
M _{x-H}	[MNm]	13
M _{y-H}	[MNm]	-17.4
M _{z-H}	[MNm]	0.222
M _{base High}	[MNm]	21.7

Note: See Table 42 for [Lbf-ft]

Table 44: Moment at Base of Cross, Low-Loading

Low Moment at Base of Cross		
M_{x-L}	[MNm]	-708
M_{y-L}	[MNm]	-11.5
M_{z-L}	[MNm]	-0.015
$ M_{base\ Low} $	[MNm]	11.5

Note: See Table 42 for [Lbf-ft]

The high moments are found by the cross product of these force and lever-arm vectors:

$$\vec{F} = \langle -40, -32.9, 1.65 \rangle [MPa] : \vec{R} = \langle 395, 435, 135 \rangle [m]$$

$$\vec{F} = \langle -9.0, -7.40, 0.371 \rangle [10^6 Lbf] : \vec{R} = \langle 1,296, 1,427, 441 \rangle [ft]$$

The estimated weight of the cross is a separate vector, with a distributed load/pattern. This weight came from an over estimation of the previous (revision II) design of the Glorious Cross.

$$\overrightarrow{F_{Weight}} = \langle 0, 0, 1.023 \rangle [MPa]$$

$$\overrightarrow{F_{Weight}} = \langle 0, 0, 755 \rangle [10^6 Lbf]$$

The maximum stress limit is found in Table 43 and the low stress limit is found in Table 44. These values will be used to determine the Goodman equivalent stress for 1,000 cycles.

A simple 15x15 beam array/model experiences a high stress of about 51.6[ksi] (Figure 156). The minimum stress encountered during the cyclic action was about 29.9[ksi].

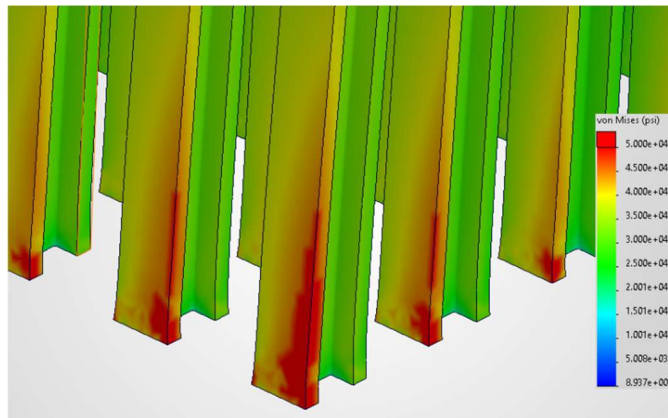


Figure 156: Simple Beam Array/Model w/Maximum Moments

The Weibull S-N Fatigue Strength Curve Analysis for A572 Gr. 50 Steel⁽⁴⁰⁾ paper was utilized to obtain the various values for the Goodman line and A572 structural steel. The Goodman equivalent stress is 26[ksi]; therefore, the design will withstand the cyclic stresses for more than 450,000[cycles].

Equation 59: Goodman Line for Equivalent Stress

$$\sigma_{eq} = \sigma_{alt} + \frac{\sigma_e}{\sigma_{ut}} \sigma_m$$

Where:
 σ_{alt} is $0.5 * (\sigma_{max} - \sigma_{min})$
 σ_e is the endurance stress, 20.2[ksi]
 σ_{ut} is the ultimate stress, 78[ksi]
 σ_m is the average stress

Simple Base-beam Array:

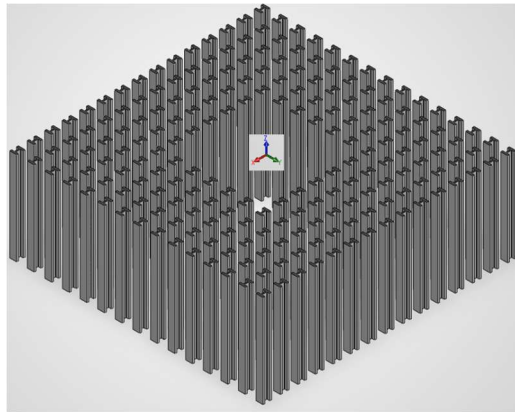


Figure 157: Simple Base Beam 15x15 Array, W14x730

The conclusion with respect to the cyclic stresses on the base-beams is that either grade 50 or 55 may be used, however grade 50 steel will experience minor yielding. It is recommended that an array of 15x15, W14x730 (as seen in Figure 157), be utilized with ASTM A572 grade 65 steel. With further analysis, the beam size and layout may be optimized.

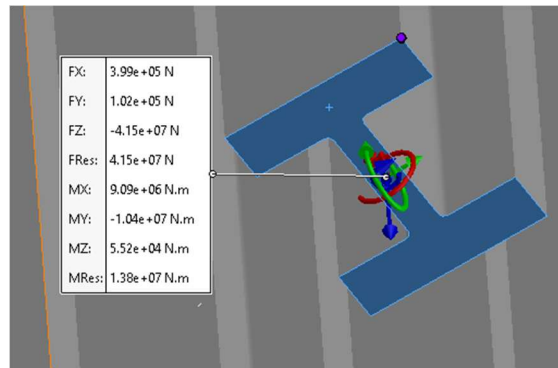


Figure 158: W14x730 Corner Beam at Maximum Stress

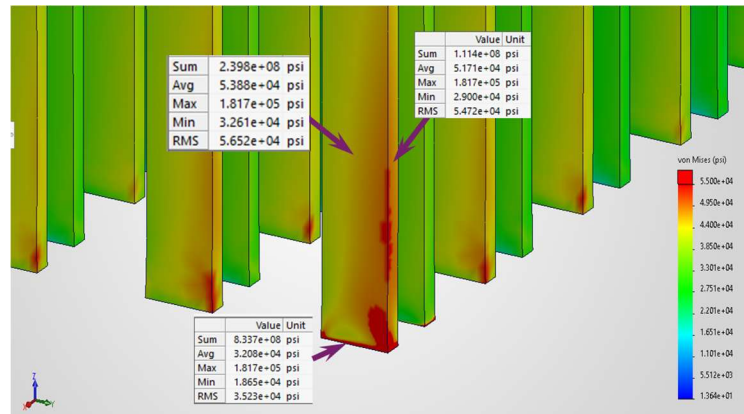


Figure 159: W14x730 Corner Beam Maxima Stress

The corner beam, FEA shows peak stresses in excess of 70[ksi], likely due to corner nodes. The average maximum stress (36[in], {1[m]} from the floor) is about 64[ksi]. About 20[ft] (6[m]) from the floor the beam deflects $\langle -0.392, -0.235, 0.361 \rangle$ [in] ($\langle -9.95, -5.97, 9.17 \rangle$ [mm]): It is stretched almost $\frac{3}{8}$ [in] and twisted about 1.7[deg].

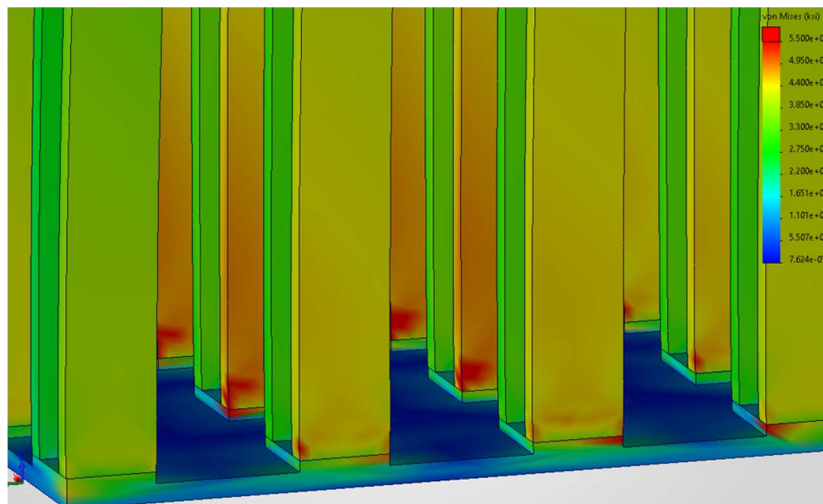


Figure 160: W14x730 Maximum Stress Distribution

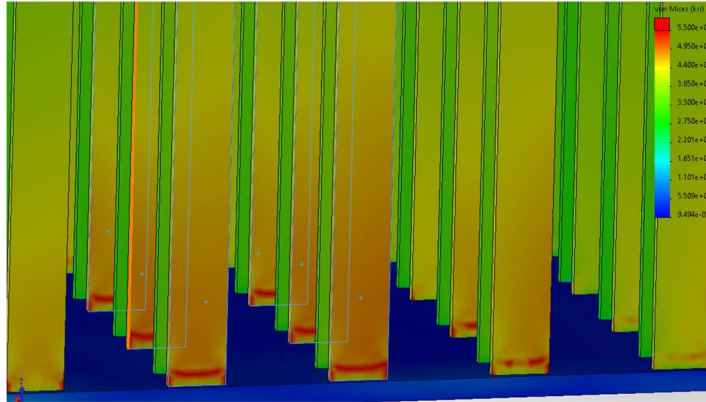


Figure 161: W14x370 Maximum Stress Distribution

As seen in Figure 159, Figure 160 and Figure 161 the maximum stress distribution changes depending on weight and torsion applied to the model. The corner (x)4 beams are the critical, high stress, beams.

Table 45: Beam Weight Distribution w/r Altitude (Height)

W14 - Beam	Z - Altitude [m]	Maximum Stress [ksi]	Maximum Stress [MPa]	Beam Plate Thickness	Transverse Plate Thickness
730	0	62	430	2.500	1.500
665	50	60	420	2.500	1.500
605	80	55	380	2.500	1.500
550	110	54	380	2.250	1.500
500	140	54	380	2.250	1.500
455	170	55	380	2.000	1.250
426	200	52	360	2.000	1.250
370	230	62	430	1.750	1.250
257	350	62	430	1.500	1.000
193	450	59	410	0.750	0.500
193 Outer Row Only	650	35	250	0.750	0.500

Table 46: Z0 Beam Maximum Lift & Down Loading

Maximum Lift Force	41,522,000	N
	9,334,525	Lbf
Maximum Down Force	-40,781,000	N
	-9,167,941	Lbf

The loadings depicted in Table 46 show that the columns require 2,670[in²] (1,720,647[mm²]) to be held with 5[ksi] concrete (with FS 30[%]). The mating plates will require (x)8 – 4[in] diameter bolts (A490 Type 3). The rebar will be per ASTM A615, G60. All steel will be galvanized.

Note: ASTM A490 was officially withdrawn and replaced by ASTM F3125

The concrete pad will go to bedrock, approximately 12.5[m] from Z0 (ground level). The pad will be a minimum of 85[m] w/r North – South and 67[m] w/r East – West. Base calculations for the footing were performed utilizing the “Sky Civ’s” tool/s within reference SkyCiv⁽²⁶⁾.

Panel Rivet Plan:

The cross will be surfaced with aluminum panes, with a nominal size of 47.986 (+/-)0.015[in] or 1218.84 (+/-)0.38[mm]. The fabrication of the aluminum panels should follow the 6-Sigma protocol; where-in 99.73[%] of the product is with respect to 6 – Sigma (6*SD). Utilizing the standard Gaussian curve, the probability of a panel length of 48.000[in] is about 0.026[%] and the panel length of 48.001[in] is about 0.013[%]: The rivet strength and the rarity of a 48.001[in] panel-length appearing during construction, make it acceptable to design the paneling with a maximum length of 48.000[in].

Per the Navy Aviation Structural Mechanics (AM)⁽³⁷⁾ standard rivet pitch protocol, the minimum rivet pitch (separation) is (3*RivetDiameter) and the Diameter of the rivet is (3*PlateThickest). The maximum pitch is (8*RivetDiameter): Some reference a maximum pitch of (12*RivetDiameter). Since the thickest plate is (1/8)[in] (3.175[mm]), the rivet diameter is (3/8)[in] and the minimum separation is 1.125[in] (38.1[mm]). The transverse pitch is usually (0.75*RivetDiameter) (see Figure 162: General Rivet Layout).

Table 47: Panel Rivet Pitch & Edge Distance

	[in]	[mm]
Rivet Diameter	0.375	9.525
Pitch (Minimum)	1.125	28.575
Pitch (Maximum)	3.75	95.25
Edge Distance (Minimum)	0.75	19.05
Edge Distance (Maximum)	1.5	38.1

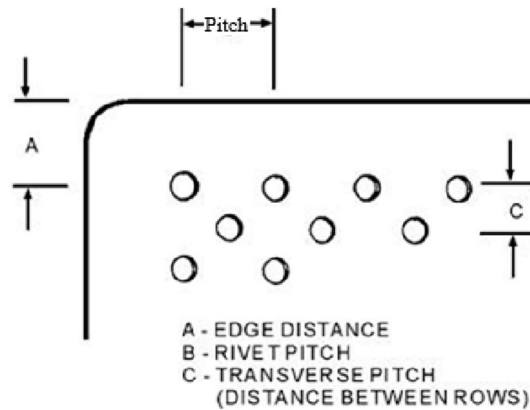


Figure 162: General Rivet Layout

Thin Plate to Membrane:

The panels or plates used for the skin of the Glorious Cross will be thin sheets of aluminum. FEA may be achieved utilizing a 3D plate, or simplifying it to a membrane. Kirchhoff's thin plate with small deflections relies upon the plate being elastic, homogenous, and isotropic (and other hypotheses): Often referred to as classical or Kirchhoff's plate theory. Similar to this, membrane theory states that the boundaries are free from shear forces and moments, displacements are normal to the middle surface and the membrane is smooth and continuous.

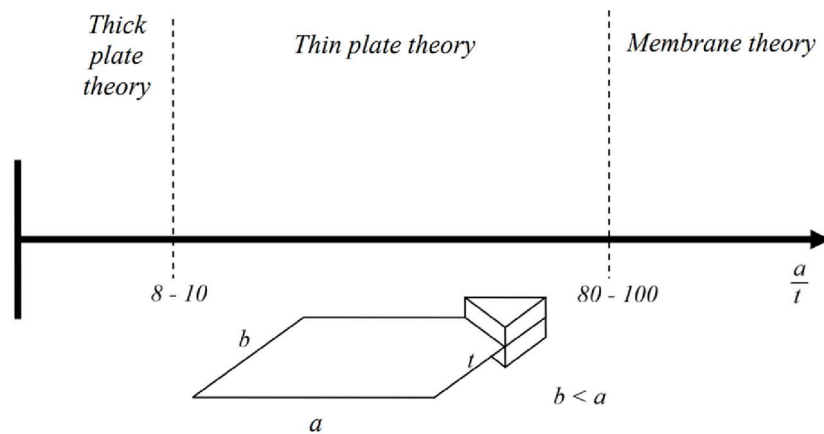


Figure 163: Thick-plate, Thin-plate & Membrane

The maximum thickness of a panel is 0.0625[in] and one side-length (a , in Figure 163) is about 48[in]; yielding an $(a/t) = 768 \gg 100$. Since the surface of the cross meets thin-plate theory requirements, taking the middle-plane is acceptable in FEA.

A thick plate would be modeled in 3D. The panels/plates will be modeled as a shell (FEA translation for a thin-plate, or membrane) where the thickness of an element is, graphically, zero.

The Glorious Cross is placed on a hill with an altitude of about 97.5[m], with a height of 738[m]. The velocity at the top of the cross (per Equation 50) is $(-)\dot{64.54}[\text{m/s}]$. A base study was conducted on the flat panels with the maximum possible dynamic pressure. The dynamic pressure was obtained by using the maximum velocity (64.5[m/s]) and the maximum air density of 1.35[kg/m³]; calculated from the previous study (see Figure 134 and related). The maximum possible dynamic pressure on a flat panel is 0.409[psi] or 2,820[Pa]. The minimum pressure is taken from Figure 151 and Figure 152, and valued at -0.106[psi] or -730[Pa].

The average weather in Dozule, list the maximum wind speed as 24.1[km/hr], or 6.7[m/s].⁽³⁸⁾ This about (x)3.6 slower than 24[m/s] (per Eurocode-1). Thus, the maximum daily pressure on a flat panel is about 220[Pa]. A statistical analysis of the atlas wind data represented within ss shows that the 6 – Sigma high velocity would be about 8[m/s]. The dynamic pressure of a high-density wind (1.35[kg/m³]) at 8[m/s] yields a pressure of 330[Pa]. In 500 years, there are less than 183,000[days]. The lifetime of the cyclic nature will end be defined to end at 250,000[cycles].

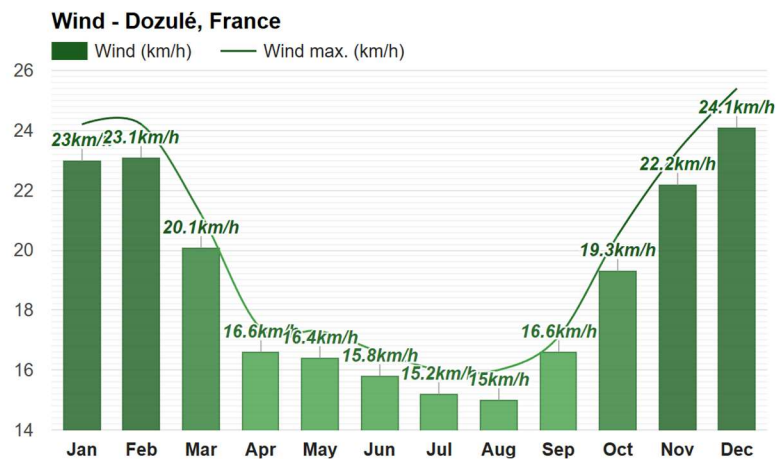


Figure 164: Maximum Wind, Dozule France⁽³⁸⁾

The panel analysis will be expected to perform with $N_{1k} = 1,000[\text{cycles}]$ at a pressure of 2,820[Pa] and $N_{250k} = 250,000[\text{cycles}]$ at -730[Pa]. The target material stress was calculated per the Kohout/Vechet equation.⁽³⁹⁾ Thus, for N_{1k} the target stress limit is 59,200[psi] and for N_{250k} the target stress limit is 24,300[psi]. Published documentation lists the endurance stress for 7075-T6 AL as 23,000[psi], however, the Kohout/Vechet equation yields a stress of 20,200[psi]. Since the Kohout/Vechet equation is more stringent, σ_e (the endurance stress) will be taken as 20,200[psi].

The rivet hole will be modeled with a no penetration boundary; effectively making the rivet a fixed entity. Imagine a hole where 150[deg] of the hole is fixed, as in Figure 165, this would be the boundary of contact between the rivet and the hole. Also, the normal vector displacement of (up/down) is zero. The “no penetration” condition differs from Figure 165, in that the boundaries are not fixed: They may deform.

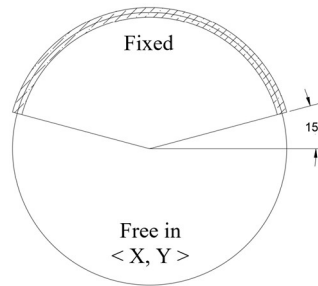


Figure 165: 150[deg] Fixed/F Portion of Rivet Hole

Table 48: Rivet Separation by Distance & Number of Rivets

Rivet Separation w/r ϕ Rivet [-]	Rivet Separation w/r ϕ Rivet [in]	Design Distance to Edge [in]	Design Rivet Separation [in]	Rivets per Side [-]	Rivets per Panel [-]
3 (ϕ Rivet)	1.125	1.193	1.14	41	162
4 (ϕ Rivet)	1.5	1.193	1.52	31	122
5 (ϕRivet)	1.875	1.193	1.9	25	98
6 (ϕ Rivet)	2.25	1.193	2.28	21	82
7 (ϕ Rivet)	2.625	1.213	2.68	18	70
8 (ϕ Rivet)	3	1.193	3.04	16	62
9 (ϕ Rivet)	3.375	1.243	3.5	14	54
10 (ϕ Rivet)	3.75	1.193	3.8	13	50

Table 49: Rivet Hole Separation w/r Hole Stress

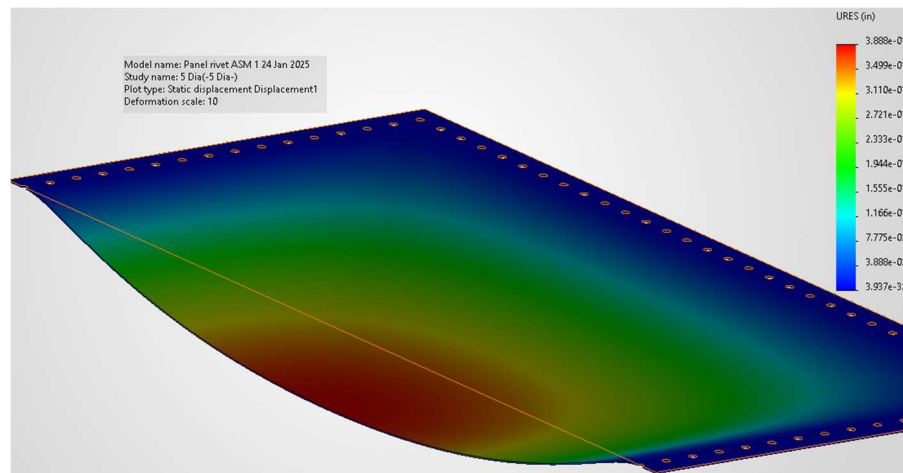
Rivet Separation w/r ϕ Rivet [-]	Rivet Hole Max-Stress @ 2,820[Pa] [psi]	Rivet Hole Max-Stress @ 2,820[Pa] [Mpa]	Rivet Hole Min-Stress @ -730[Pa] [psi]	Rivet Hole Min-Stress @ -730[Pa] [MPa]
3 (ϕ Rivet)				
4 (ϕ Rivet)	15,020	103.6	-6,236	-43.0
5 (ϕRivet)	22,180	152.9	-11,450	-78.9
6 (ϕ Rivet)	32,830	226.4	-13,520	-93.2
7 (ϕ Rivet)				
8 (ϕ Rivet)	49,340	340.2		
9 (ϕ Rivet)				
10 (ϕ Rivet)	45,260	312.1		

The maximum and minimum flat panel stresses were calculated to reflect the dynamic pressure, obtaining the critical stresses for the Goodman equation (taken from Table 49):

- $\sigma_{\max}(2,820[\text{Pa}]) = 22,180[\text{psi}] (+10[\%])$
- $\sigma_{\min}(-730[\text{Pa}]) = -11,450[\text{psi}] (+10[\%])$
- The Goodman equivalent stress is 18,300[psi]

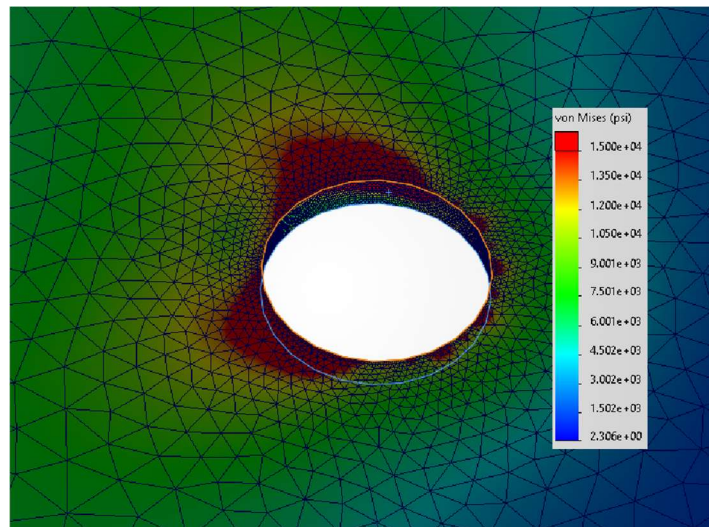
Panel, Square, Deformation & Stress

Table 50: 5-Dia Rivet Separation, Deflection



Note: The deformation scale is (x)10

Table 51: 5-Dia Rivet Separation, Hole Stress



Note: The deformation scale is (x)50

The deflection of a 0.0625[in] panel made with 7075-T6 Al plate is on the order of 0.389[in] (9.875[mm]). Though, technically, the thickness may be reduced to 0.057[in] (1.45 [mm]), the thickness will remain 0.0625[in] (1.5875[mm]): This represents about a 10[%] factor of safety for 7075-T6 Al.

Panel (x9) Array, 48[in] (47.986[in]) Std:

The outer skin is a set of panel assemblies, set in a consistent orientation. They are connected to the main structure via braces, connected to C10 channels.

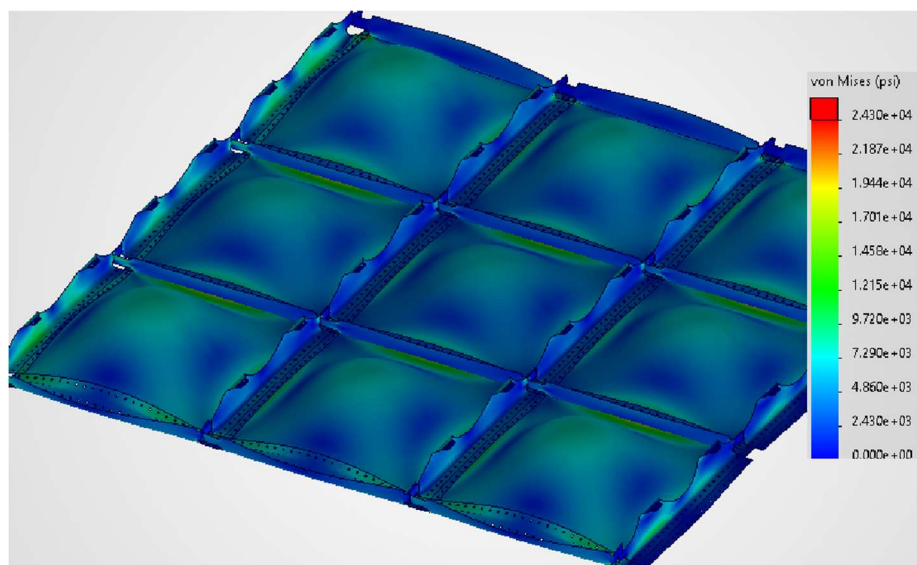


Figure 166: Panel Assembly w/Interlocking Tabs

Shear Flow:

The skin stress will be affected by the shear flow. As in aircraft, the shear flow is directly proportional to the torque and inversely proportional to the sectional area.

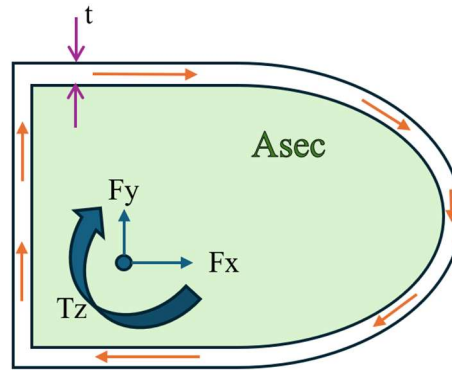


Figure 167: Shear Flow (General)

Equation 60: Shear Flow, Closed-cell

$$q = \frac{\text{Torque}}{2(A_{sec})} = \frac{T}{2A}$$

Where:
Units are consistent
 τ = Shear Stress
 t = Skin Thickness
 T = Torque
 A = Sectional Area

Equation 61: Shear Flow w/r Angle of Twist

$$\gamma = \frac{TLp}{4A^2tG}$$

Where:
Units are consistent
 γ = Angle of Twist [rad]
 T = Torque
 L = Cord Length
 P = Perimeter
 t = Skin Thickness
 A = Sectional Area
 G = Shear Modulus

The torque noted in the CFD study ($M_z = 222[\text{MNm}]$ ($8.43(10^6)\text{Lbf-ft}$) amounts to about 250[psi] (1.66[MPa]) of shear flow. Because the shear flow is minor, it will be taken-up within the factor of safety for the aluminum panels.

Panel, STD, Blind Rivet:

The corners of the panels are bonded with blind rivets. With three blind rivets, the FS is high in this region.

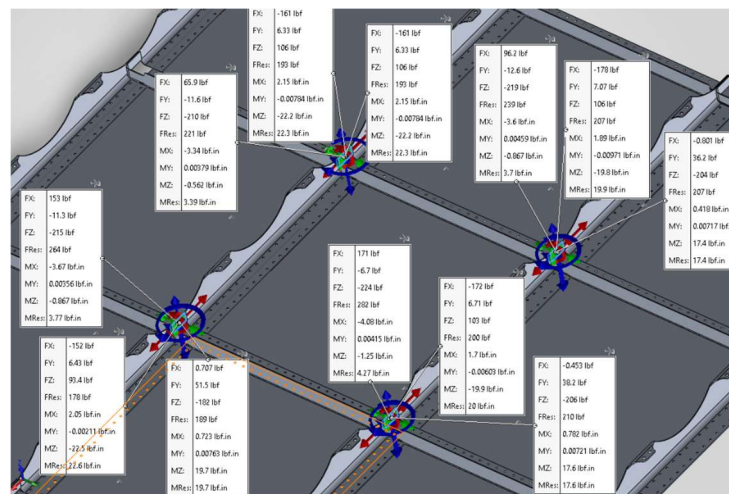


Figure 168: Std Panel Tab Loads @ 2,820[Pa]

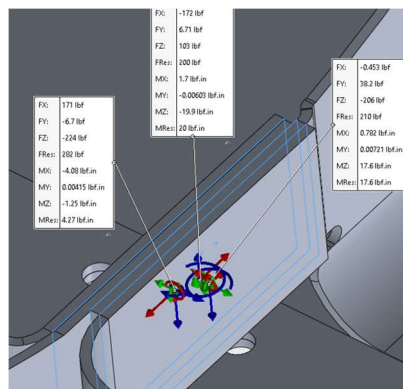


Figure 169: High Load on Interlocking Tab

The panel assembly is stable without the tab arrangement. A FS of 4.0[-], (x)3 high strength blind rivets will be used (such as McMaster Carr #93372A385, Aluminum 5052-H32) to secure the tabs together. The total panel deflection is expected to be near 1.2[in] (30[mm]): About 0.17[in] (4.0[mm]) less deflection than without the tabs. Adding the tabs increases the rigidity and stability of the panels; reducing panel stress hot-spots.

Utilizing thin plate theory, a 3x3 array of panels was analyzed and the stresses were minimal. The average panel stress was about 3,600[psi], with a maximum of 10,500[psi]. The stresses were below the endurance stress of 24,300[psi]. The thin plate deflection was on the order of 1.0[in] (25.4[mm]).

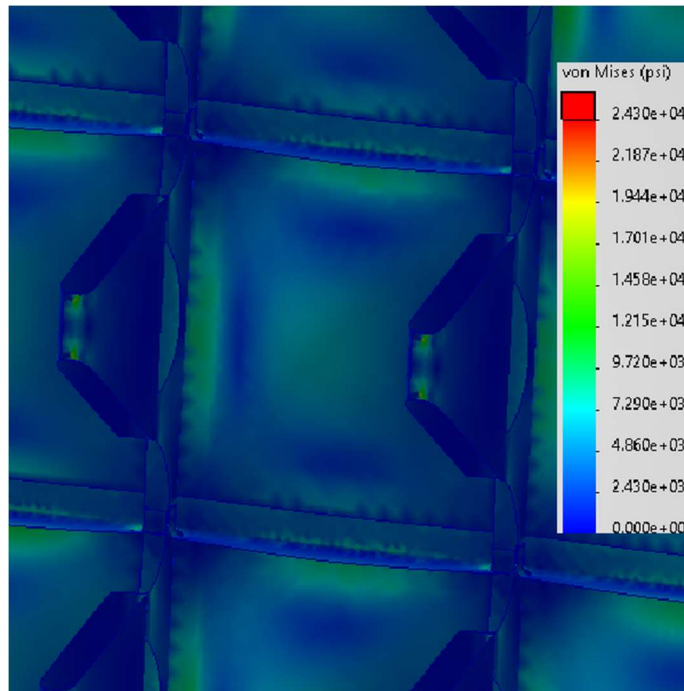


Figure 170: 47.986" Square Panel, 3x3 Array, Thin Plate Stresses

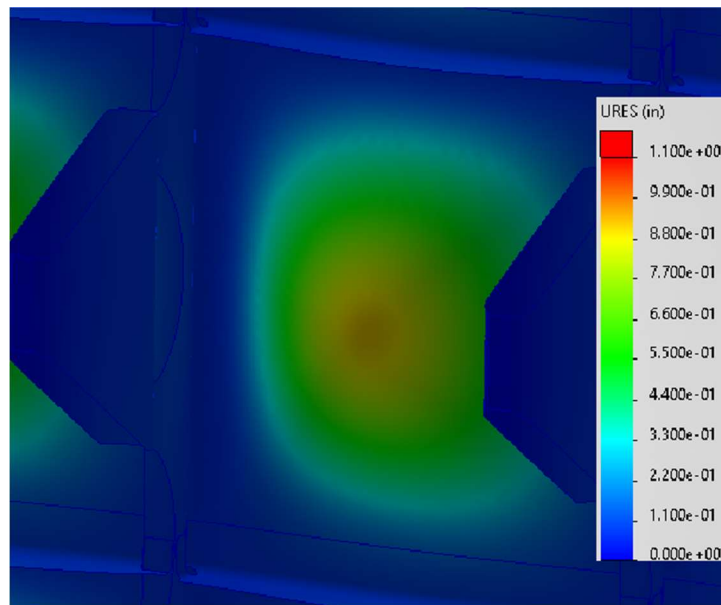


Figure 171: 47.986" Square Panel, 3x3 Array, Thin Plate Deflection

The above model (Figure 170 and Figure 171) included the **maximum wind pressure (0.409[psi] or 2,820[Pa])** and gravity. The maximum sag was about than 0.003[in] (0.08[mm]).

The connecting brace underwent a design change, to reduce weight (Figure 172). The maximum panel stress increased to 12,000[psi]. The maximum panel deflection increased to 1.2[in] (30.5[mm]). The maximum sag increased to about 0.004[in] (0.10[mm]). The weight savings is about 6.8[Lb/brace]

(3.1[kg/brace]). Since the stresses are below the endurance stress and the sag/deflection increase was minimal, the design will move forward with the lighter brace.

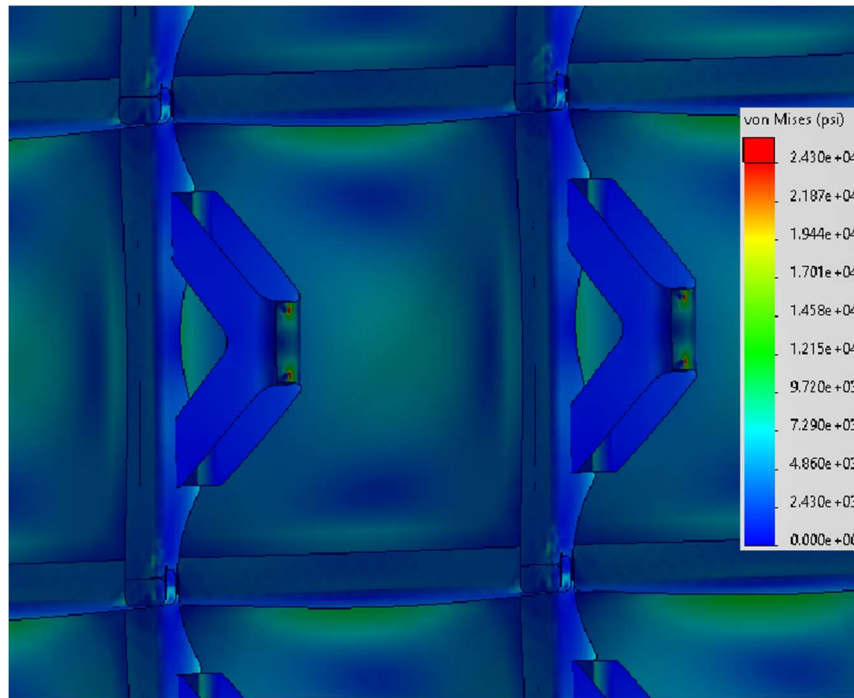


Figure 172: 47.986" Square Panel, 3x3 Array, Thin Plate Deflection, Light Weight Brace

Panel, Radii Flow Field:

The radiused panels have a radius of 48.2[in] (1224.28[mm]) and are attached in a similar fashion as the 48[in] standard panel/s. The maximum panel loading is found at an angle of attack of 45[deg], while a standard flow condition is represented by an angle of attack of 0[deg].

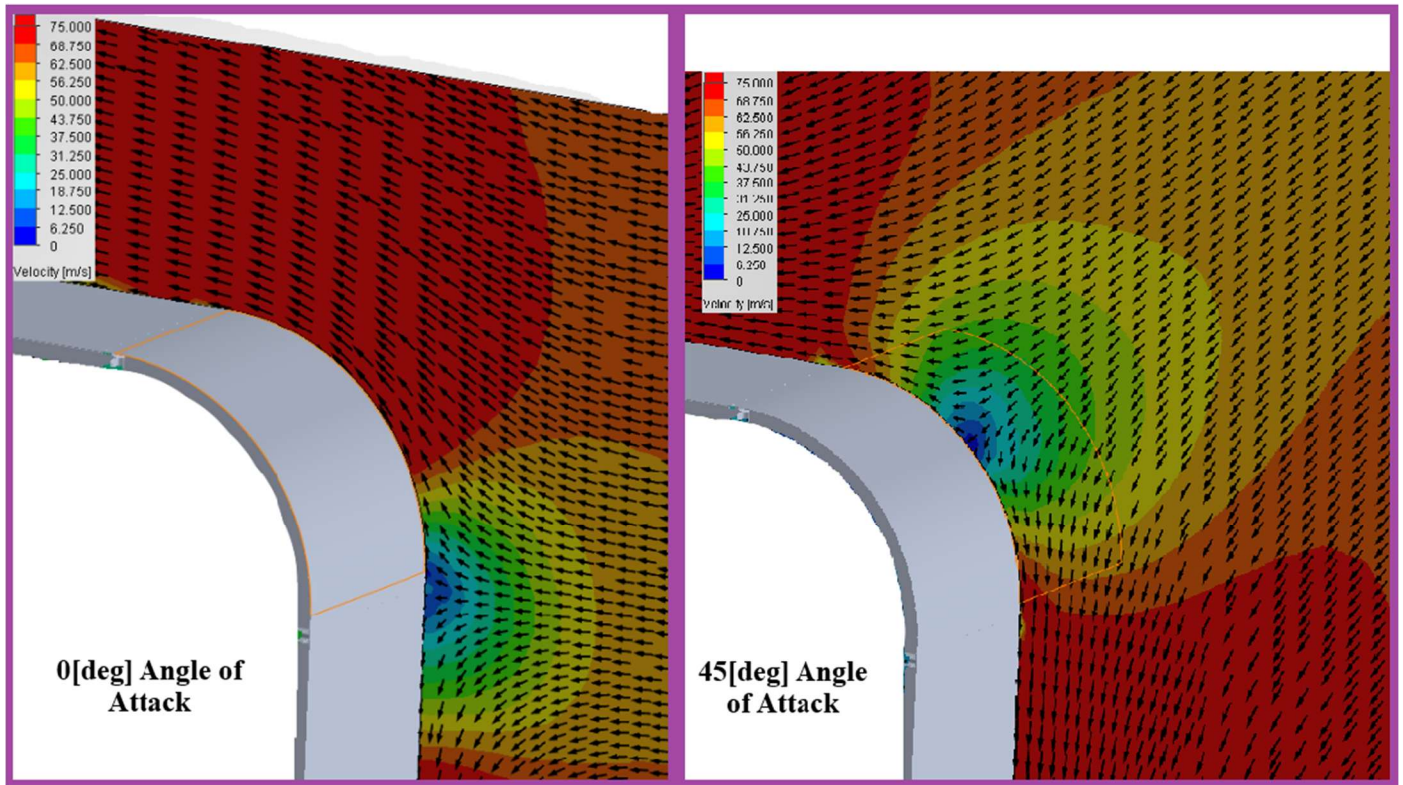


Figure 173: Radii Panel, STD, 0[deg] Angle (Left) & 45[deg] (Right)

Table 52: Loading, Normal to Panel Surface

Angle of Attack [deg]	[Lbf]	[N]
0	1,200	5,300
45	2,600	11,500

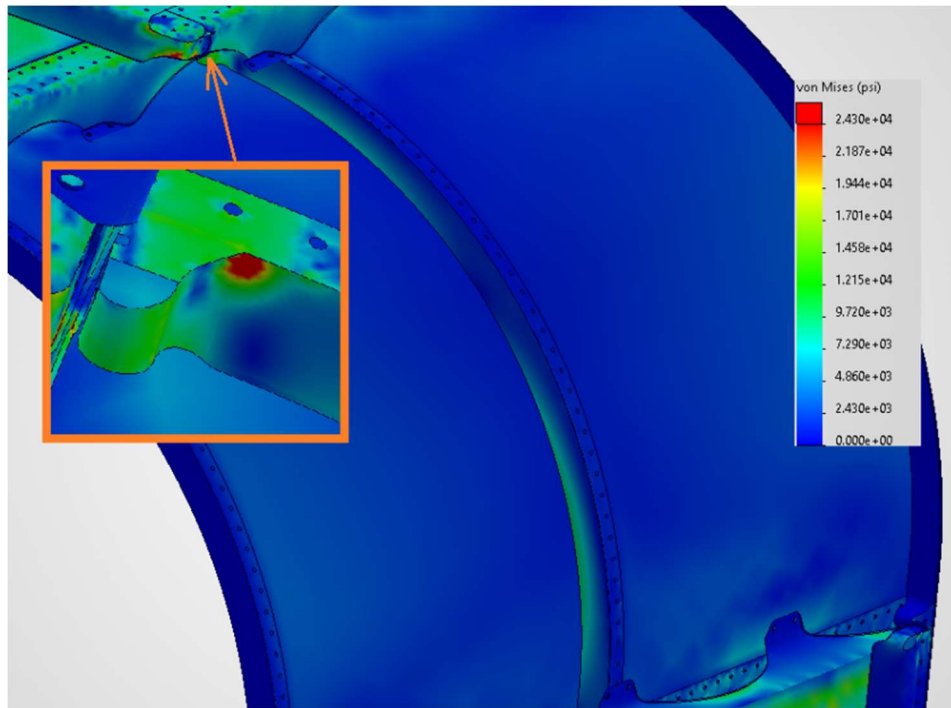


Figure 174: Radiused Panel, 0[deg] Attack Angle, Rib Stress

Note: The high stress (88.7[ksi]) is due to a corner and due to the relatively low average stress it may be ignored.

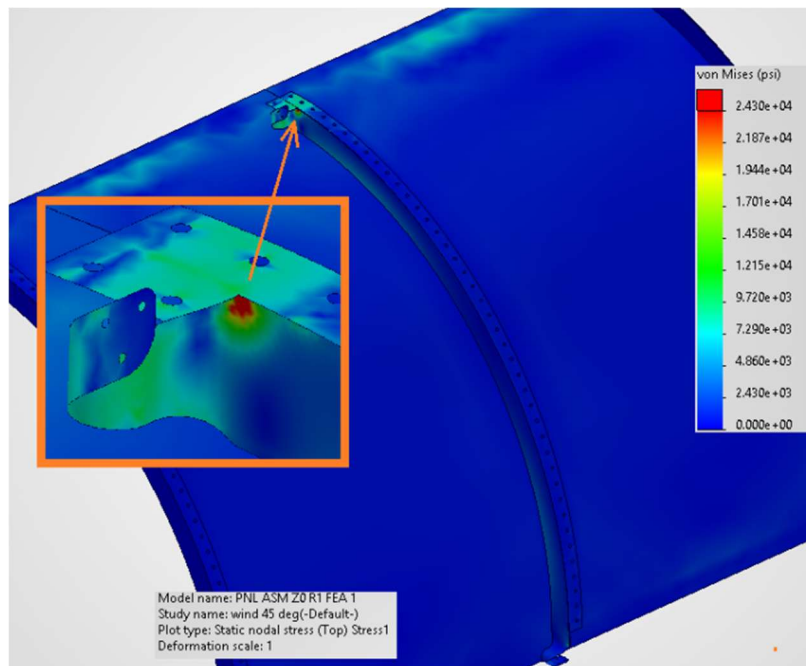


Figure 175: Radiused Panel, 45[deg] Attack Angle, Rib Stress

Note: The high stress (61.4[ksi]) is due to a corner and due to the relatively low average stress it may be ignored.

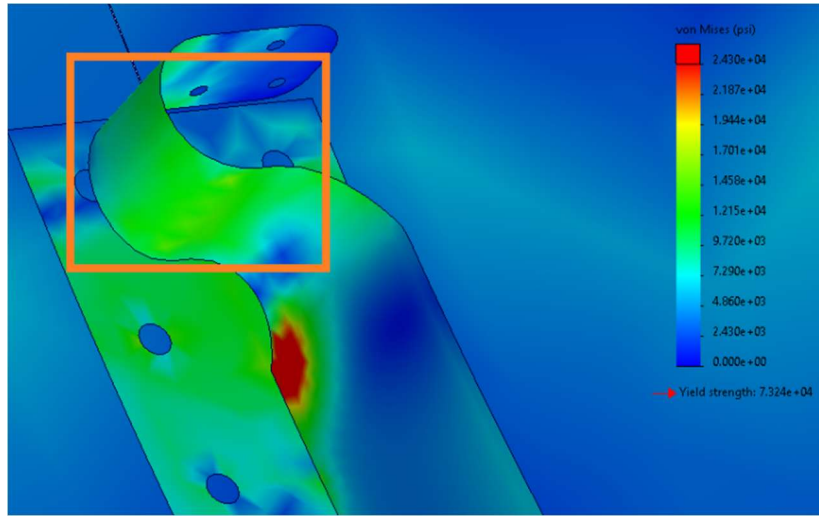


Figure 176: Radiused Rib High Stress Zone on Tab

The high stress region, on the radial rib, is in the tab zone. The maximum stresses are less than 18.4[ksi] (126.5[MPa]). This value is less than 24.3[ksi] and is likely influenced by the unusually high stress value at the “corner” of the rib (the rib is welded, so the “corner” will not exist).

As seen in Figure 174, though the rib loading and stresses are greater at 0[deg] Angle of Attack. These results show that a radial rib of 3[in] is sufficient to operate for more than 500[years]; where the fatigue stress is 24,300[psi]. Since the connection (blind rivet) tab loadings are minor, no adjustment to the feature is required (see Figure 177).

Table 53: Radii Panel, Force and Stress at 0[deg] & 45[deg] Angle of Attack

F _{Rib} @ 0[deg]		σ_{ave} @ 0[deg]	
200	[Lbf]	3,700	[psi]
700	[N]	25.69	[MPa]

F _{Rib} @ 45[deg]		σ_{ave} @ 45[deg]	
70	[Lbf]	1,700	[psi]
300	[N]	11.87	[MPa]

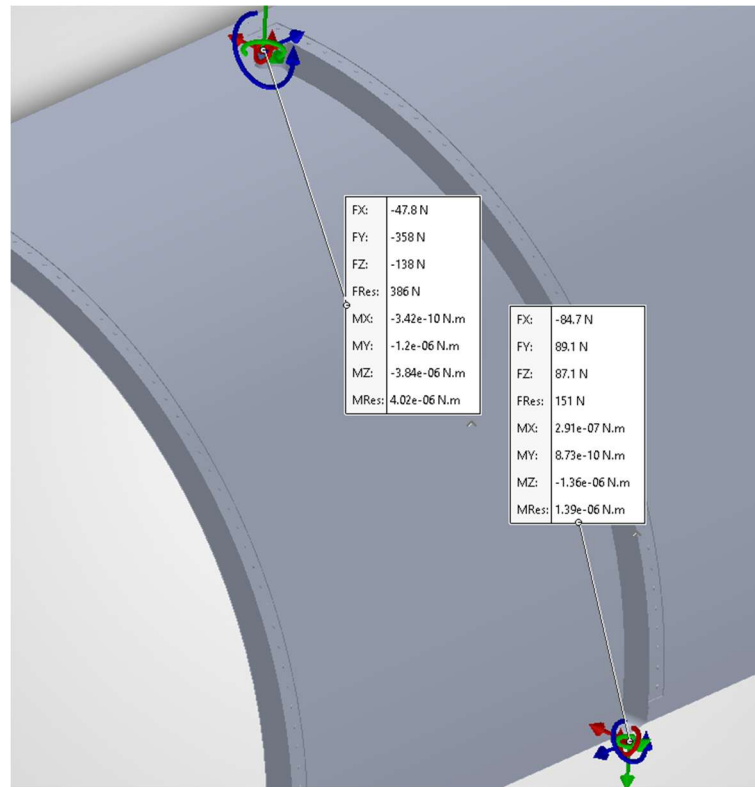


Figure 177: Radii Panel at 0[deg] Angle of Attack, Tab Loading

System Frequency:

The harmonics of the system will depend on the material properties of the structure. The natural frequency of its bending behavior will be modeled as a cantilever-spring system, while the torsional frequency will be modeled as a torsional-mass-spring system. The controlling values are the elastic and shear modulus's along with the distribution of mass.

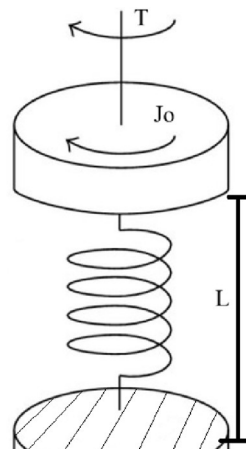


Figure 178: Torsional-spring mass (General)

Equation 62: Natural Frequency, Torsional-mass

$$\omega_n = \sqrt{\frac{JG}{mL}} = \sqrt{\frac{J_o G}{LI_o}}$$

Where:
Units are consistent
 $\omega_n = [\text{rad/s}]$

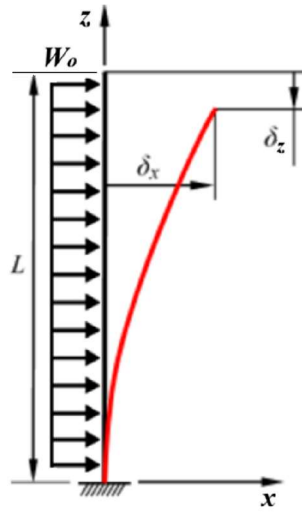


Figure 179: Cantilever-spring mass (General)

Equation 63: Natural Frequency, Vertical Cantilever-mass

$$\omega_n = \sqrt{\frac{k_x}{m}} = \sqrt{\frac{8EI}{mL^3}} \approx \sqrt{\frac{g}{\delta}}$$

Where:
Units are consistent
“L” is the distance to Cg
“E” is the elastic modulus
“I” is the area moment of inertia
“ρ” is the average material density
“a” is
 $\omega_n = [\text{rad/s}]$

The natural frequency Equation 62 and Equation 63 are valid for small deflections.

Equation 64: Period (T_p)

$$T_p = \frac{1}{f_n} = \frac{2\pi}{\omega_n} [s]$$

Equation 63 contains an inverse-cubic relationship to the period of the cross. By this relationship, the overall period of the cross will be proportional to the height to the power of 1.5.

Arm Study:

The various CFD studies contained various values for the loading on the arm. A the greatest (absolute) values were utilized in generating the arm structure. Further exhaustive iterations may be executed to reduce weight. The following design succeeds in low endurance stresses at the base of the arm/s; near 24.3[ksi].

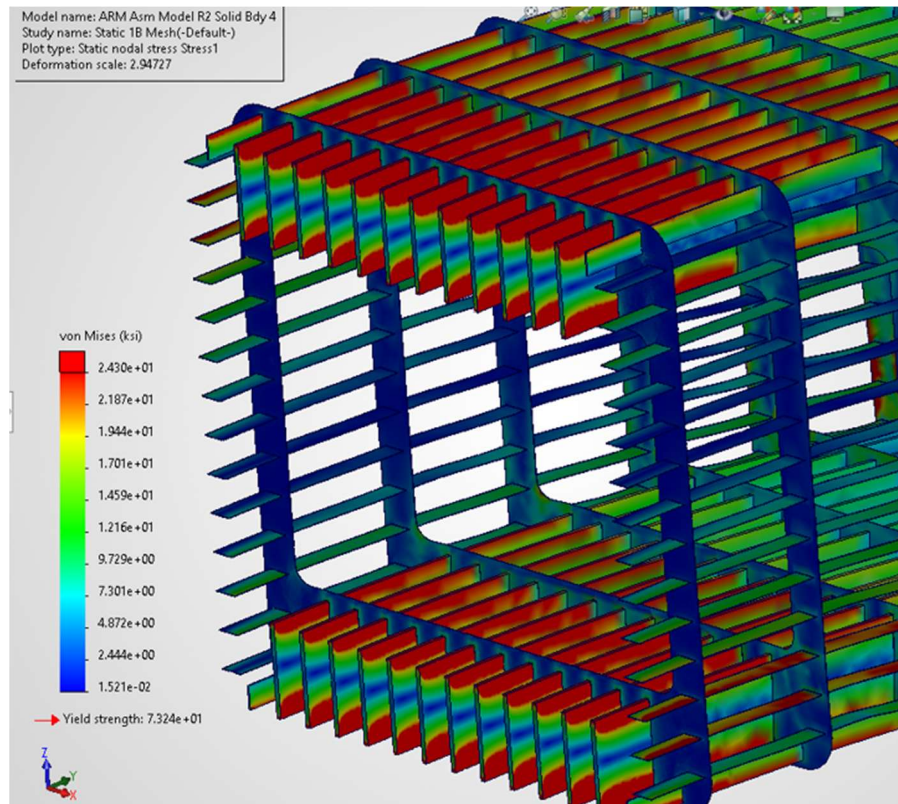


Figure 180: Arm-to-Cross(Body) Rib Support

Arm Support:

The main structure of the arm consists of 118[in] x6[in] (3000[mm]x152.4[mm]) beams with lateral supports every (x)2 panel distance (48[in] or 1219[mm]). The maximum stresses in the main support beams are minor.

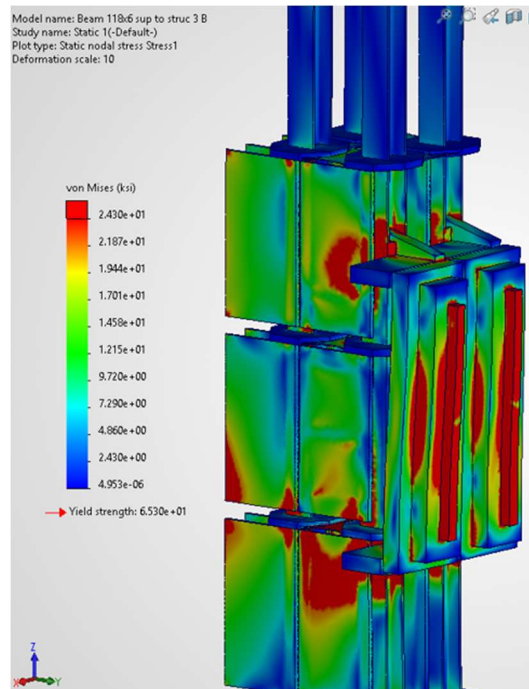


Figure 181: Arm, Main Beam Support Rib Stress

The arm structure depicted in Figure 180 shows rib stresses over 24.3[ksi]. The maximum planer-geometric stress, on the greatest load bearing longitudinal beam (118[in] or 3,000[mm] tall) was on the order of 15. Since the ribs do not yield and the geometric area is relatively minor, the structure was approved.

To achieve these results, the lateral ribbing was set at 12[in] (305[mm]) taller than the longitudinal ribbing; every (x3) panels (12[ft] or 3,658[mm]). The main longitudinal ribbing was 118x6[in] (3000x152[mm]).

An important item at the transition is galvanic corrosion, the transition from aluminum to steel must be treated with caution. No raw aluminum is to touch raw steel.

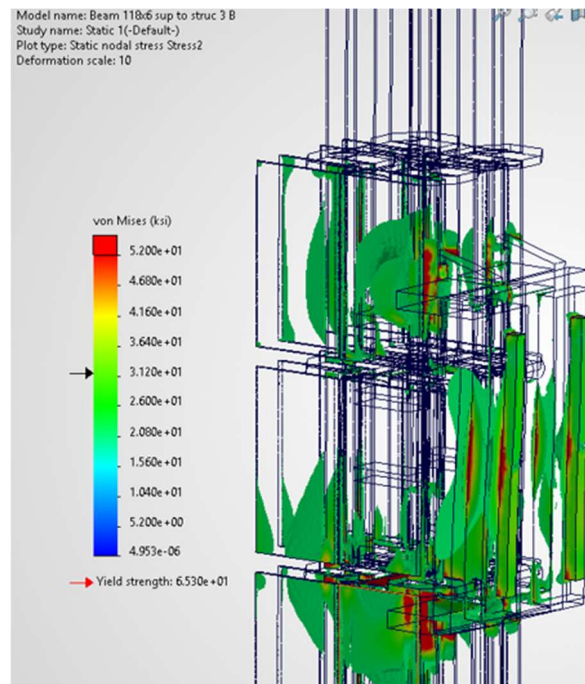


Figure 182: Arm, Main Beam Support 24.3[ksi] Volumetric Rib Stress

The expected maximum deflection of the W193 beams is expected to be on the order of 1[in] or 25[mm]. Considering that the total number of maximum-stress events will number less than 1,000[-] and that the volumetric fraction of the stresses that exceeds the target stress is minor, the system will survive 500[y].

Since the construction of the arm-transition segment will be difficult it is suggested that arm transition zone be given priority. No lower aluminum panels are to be placed until after $\frac{1}{3}$ rd of the arms are constructed, with paneling.

The construction of the Glorious Cross should begin with the leveling of the foundation/base. The target vertical grade is no greater than 0.005[deg] or 8.7[mm] for every 100[m].

The north and south support for the arm structures undergo significant moments and can twist the beams out of position, if not supported properly. Thick material was utilized to reduce stress.

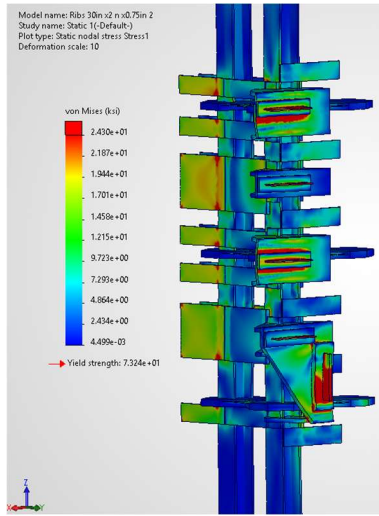


Figure 183: Arm Rib Support, w/Corner Structure, Stress

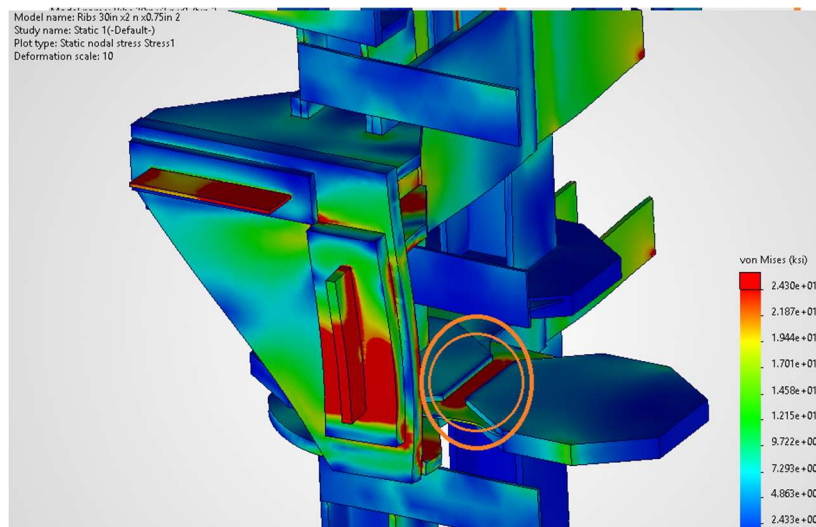


Figure 184: Arm Rib Support, w/Corner Structure, Stress on 1/2" Cross-plate

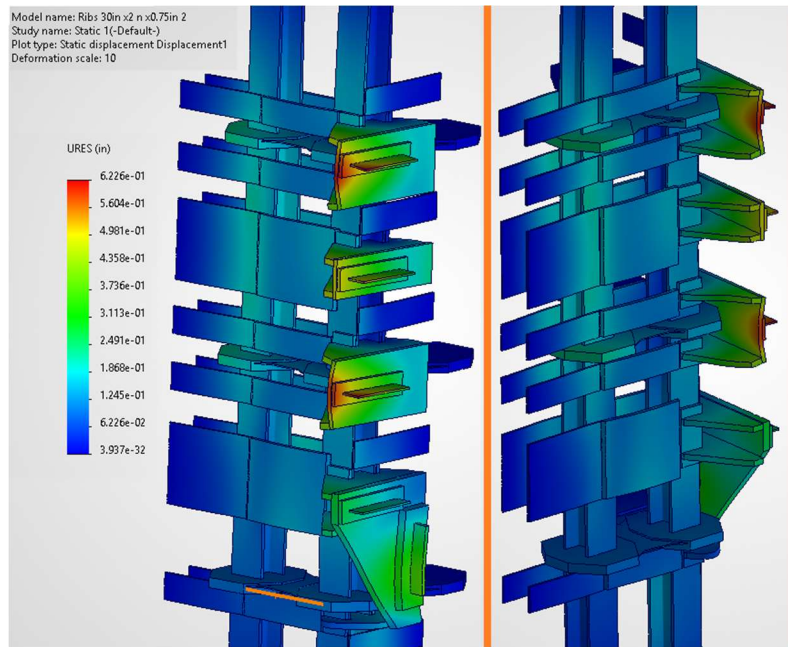


Figure 185: Arm Rib Support, Expected Deflection

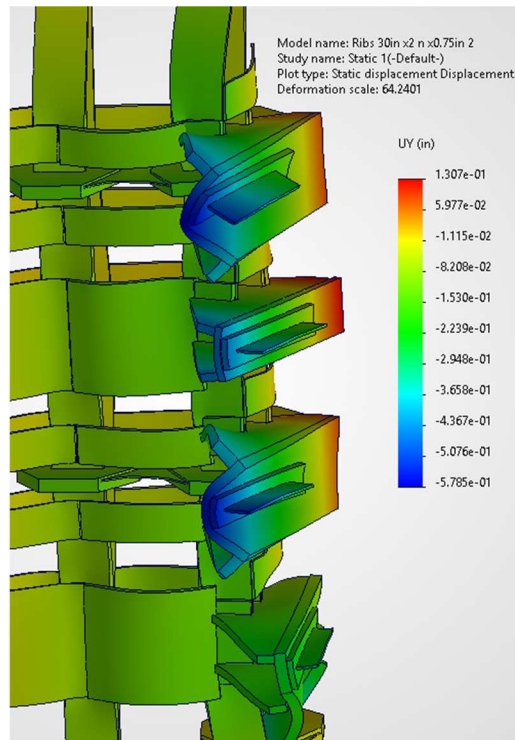


Figure 186: Arm Rib Support, Expected Deflection – In “Y”

Maximum negative deflections of 0.6[in] (16[mm]) occur on the bridge, over the lower portion of the horizontal ribbing. This deflection may be reduced by adding a bridging-plate. The inner (or rearward/top)

deflection $\langle 0, U_y, 0 \rangle$ are on the order of 0.15[in]; away from the body (see Figure 186, with a deformation scale of 64.2[-]). Comparatively, the ratio to the deflection is minor when compared to the size of the arm.

The geometric volume of the model over 24.3[ksi] is less than 5[%]; some of this is due to modeling the ribbing as 6[in] nubs (rather than 123[m]). The stress on the $\frac{1}{2}$ [in] cross-plate (see Figure 184) rises to the neighborhood of 40[ksi]. The model stresses are low and will support the arm/s for 500[y].

Arm Structure:

The aluminum arm structure extends 123[m] from the middle of the cross. The support structure of the arm is welded to the cross-support structure. The total weight of the arm is $10.64(10^6)$ [Lbf] (47.33[MN]) with a center of gravity about 2,340[in] (59.44[m]) from the cross-centerline. The maximum deflection due to gravity is expected to be on the order of 2[ft] (600[mm]); representing an angle of about 0.3[deg]. This deflection may be compensated for with a “weld-shim” (see print/s A1-M1-S1-0001 for more detail).

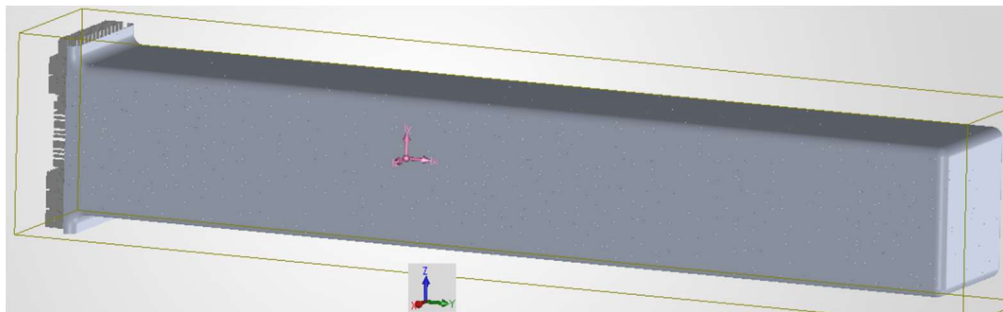


Figure 187: Arm with Panels and Support Structure

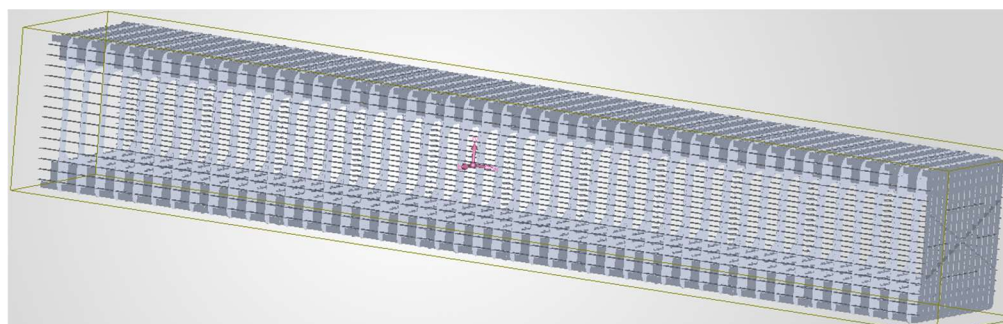


Figure 188: Arm Frame-Structure (No Support Structure to Main Body)

Table 54: Arm Weight/s

	Lbm	Lbf	kg	N
Weight of Support-structure to body and Panels	10,640,000	10,640,000	4,830,000	47,330,000
Weight of Support-structure to body w/o Panels	10,480,000	10,480,000	4,760,000	46,620,000
Body Panel (Weight)	160,000	160,000	73,000	710,000
Frame only (Weight)	8,230,000	8,230,000	3,740,000	36,610,000
Frame with Body Panels (Weight)	8,390,000	8,390,000	3,810,000	37,320,000

Note: Weights do not include welding.

Table 55: Arm-frame Inertial Values

Inertia of Frame At intersection to Body w/o Support-structure or Panels		
	Lb-in2	kg-m2
Ixx	45,598,400,000,000	13,300,000,000
Iyx	-23,610,000	-6,900
Izx	-147,600,000	-43,200
Ixy	-23,610,000	-6,900
Iyy	983,400,000,000	300,000,000
Izy	-654,100,000	-191,400
Ixz	-147,600,000	-43,200
Iyz	-654,100,000	-191,400
Izz	45,207,700,000,000	13,200,000,000

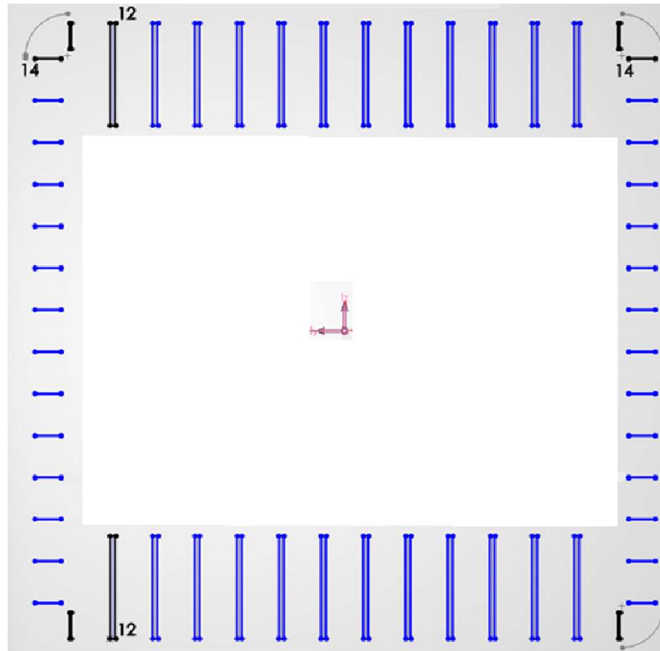


Figure 189: Main Support Section -to- Body

The section-view in Figure 189 contains the beam cross-section at the transition to the main body of the cross. The lowest area of inertia, at the base connection to the main body, is 27,130 [ft⁴] (234[m⁴]). Utilizing the cantilever beam theory, the first three natural harmonic frequencies are represented in Table 56.

Table 56: Arm Harmonic Frequencies w/r an Updraft, Along < Z > Axis

Natural frequency - 1 (ω)	9.32	rad/s
Linear frequency - f1	1.48	1/s
Period - T1	0.674	s
Natural frequency - 2 (ω)	58.41	rad/s
Linear frequency - f2	9.30	1/s
Period - T2	0.108	s
Natural frequency - 3 (ω)	163.50	rad/s
Linear frequency - f3	26.02	1/s
Period - T3	0.038	s

Note: A steady updraft is required, which is highly improbable.

Table 57: Arm Harmonic w/r Resist Wind, Along < X > Axis

Natural frequency - 1 (ω)	4.82	rad/s
Linear frequency - f1	0.77	1/s
Period - T1	1.304	s
Natural frequency - 2 (ω)	30.19	rad/s
Linear frequency - f2	4.81	1/s
Period - T2	0.208	s
Natural frequency - 3 (ω)	84.50	rad/s
Linear frequency - f3	13.45	1/s
Period - T3	0.074	s

Note: Normal wind conditions would excite this mode.

The theoretical (hand calculations) for the first harmonic frequency that is feasible under natural conditions has a period of 1.304[s] and the vortex-shedding reported from the CFD (Table 31) was 1.11[s], yielding a FS of 14.8[%]. These factors suggest no vortices will cause harmonic vibrations in the arms. This combined with the previous result of no contiguous vorticity production suggest that there is no concern for harmonics in the structure.

A simplified model, not as stiff as the original, was created and a frequency study was performed. The study shows that the lateral braces significantly increase the harmonic frequency of the system.

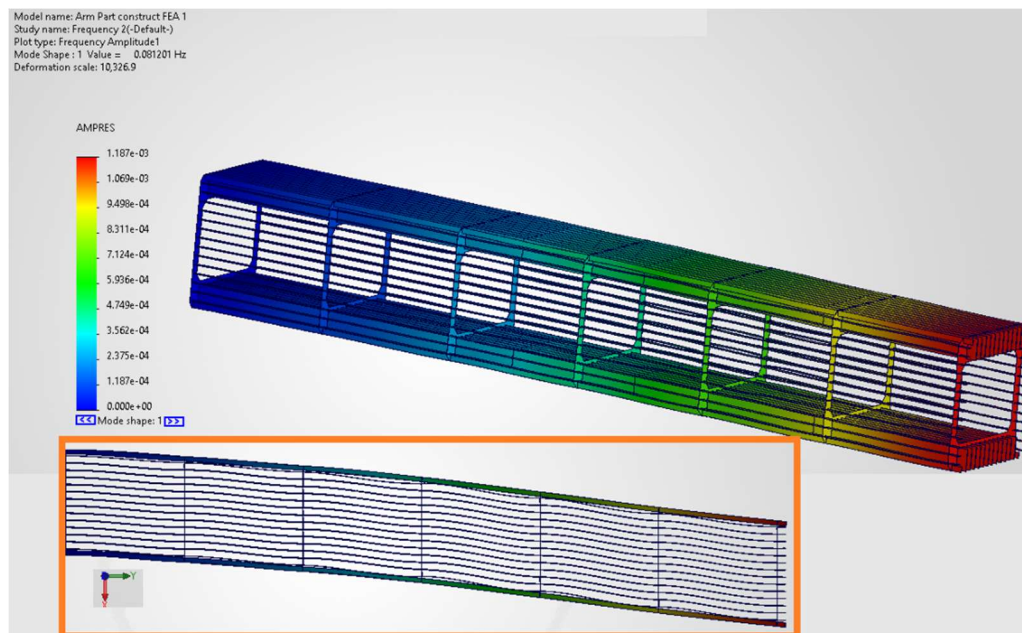


Figure 190: Arm, Simplified Model, 1st Harmonic Movement (Amplitude)

Note: The movement/deflection scale is 10,327[-].

Table 58: Arm, Simplified Model, Harmonic Frequency/Period (Amplitude)

Mode No.	Natural Frequency [Rad/sec]	Frequency [Hertz]	Period [Seconds]
1	0.5102	0.081201	12.315
2	0.8844	0.14076	7.1045
3	1.2088	0.19239	5.1977
4	1.2423	0.19771	5.0578
5	1.5327	0.24393	4.0995
6	1.5363	0.2445	4.0899

As in the theoretical study, the 1st harmonic is fore-aft (along the $< X >$ axis); representing a north/south wind. The natural frequency of vortex production is 5.65[rad/s] (Table 31), while the 1st harmonic natural frequency of the simplified (reduced stiffened) structure is less than 0.5[rad/s]. This represents a factor that is greater than 10[-], therefore there is no danger (what so ever) of harmonic resonance.

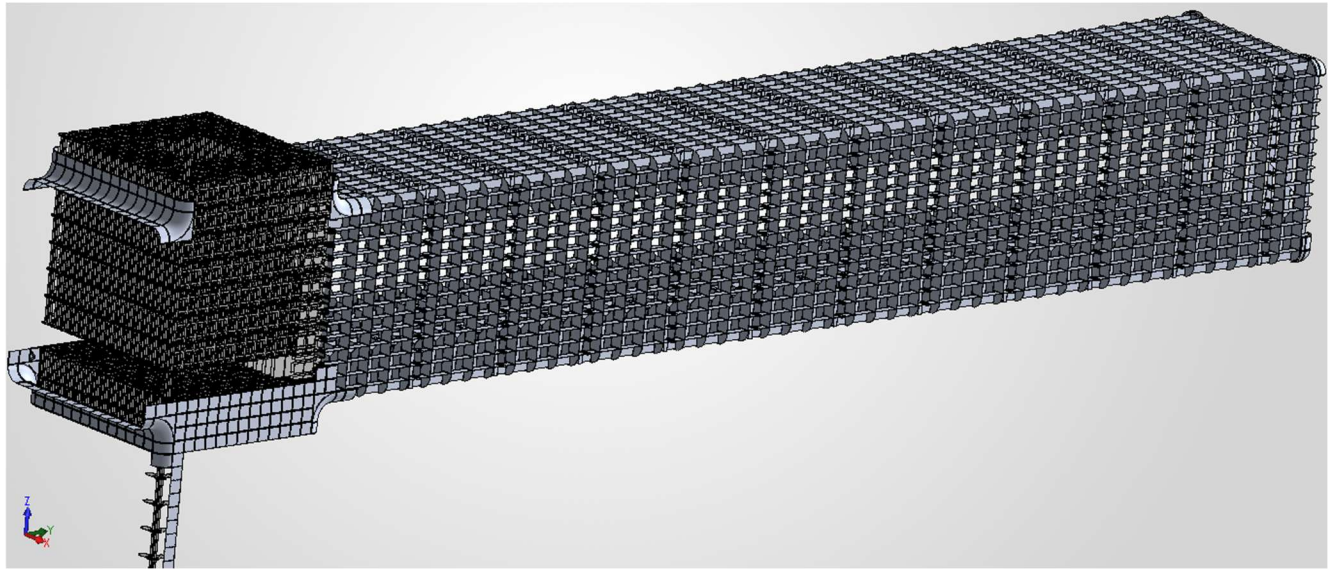


Figure 191: Arm RH Sub-structure

The top stem is configured with a ring of W193 beams; as seen in Figure 192. The area of inertia is on the order of 10,730[ft⁴] (92.6[m⁴]). The FEA simulation results yield a natural frequency of 0.3[rad/s]. This represents a FS on the order of 17[-]: Therefore, the top segment will not harmonize with any vorticity shedding, should any occur.

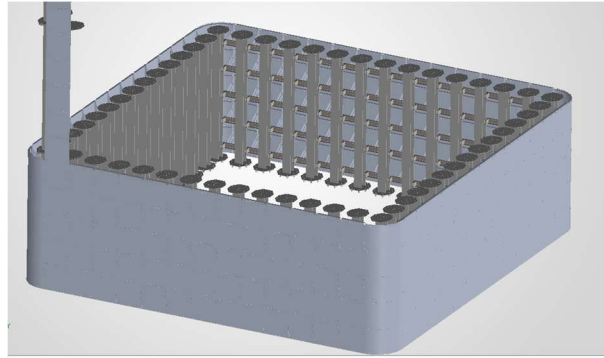


Figure 192: Top Stem (Section) - Ring of W193 Beams

The body of the Glorious Cross is now complete. The ground beams (W730's) maintain a consistent configuration to until about 60[ft] (18[m]) above the arms. At the transition altitude of about 2,150[ft]] (654[m]).

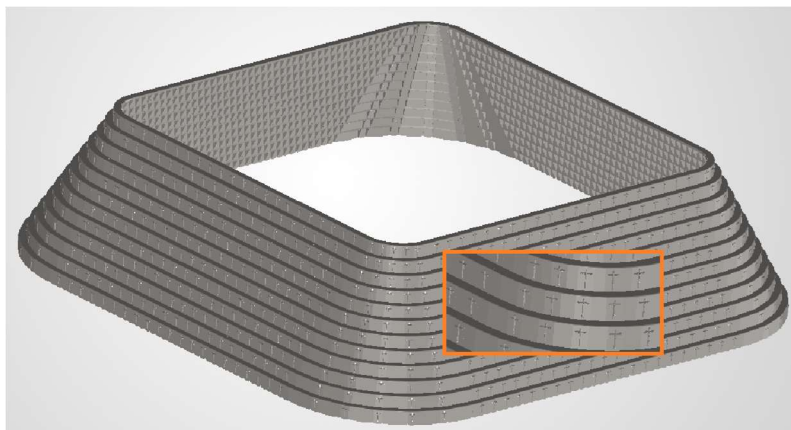


Figure 193: Glorious Cross Molding-Base

The molding about the base is depicted in ss, where a stairway to heaven is represented. The base-molding is about ($\frac{1}{8}$)" thick, 304ss and electroplated with gold. The total mass of the base is on the order of 45[tons].

According to the 3rd apparition, "Tell the priest to have the Glorious Cross erected at this spot, with a shrine at its base. Everyone will come here to repent and find peace and joy." (Thursday, December 7, 1972)."⁽⁴¹⁾ Therefore, the Cross of Crucifixion (Conyers, GA) will be the shrine, between the Purification Pool and the Glorious Cross.

*Thus, the shrine at Conyers, GA is connected to the Glorious Cross.
Both sites are holy to the Lord.*

Zechariah 14, "And his feet shall stand in that day upon the mount of Olives, which is over against Jerusalem toward the **east**: and the mount of Olives shall be divided in the midst thereof to the east, and to

the **west** with a very great opening, and half of the mountain shall be separated to the north, and half thereof to the south.” Thus, the arms of the Glorious Cross are east & west.

References:

- (01) “Principles of Corrosion Engineering and Corrosion Control” by Zaki Ahmad, 2006
- (02) ASCE Seismic Tool: <https://ascehazardtool.org/>
- (03) Maps: Google Earth (<https://earth.google.com/>)
- (04) Maps: Bing (<https://www.bing.com/maps/>)
- (05) Topography: (<https://en-us.topographic-map.com/>)
- (06) Topography: Google Earth (<https://earth.google.com/>)
- (07) Soil in GA: <https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>
- (08) Dampening Ratio: V. Adams and A. Askenazi, Building Better Products with Finite Element Analysis, OnWord Press, Santa Fe, N.M., 1999
- (09) Viscous Damping Ratio ζ (as percentages of critical damping), by Solidworks: https://help.solidworks.com/2025/english/SolidWorks/cworks/r_viscous_damping_ratios.htm?verRedirect=1
- (10) Eurocode 8 EN1998: Design of Structures for Earthquake Resistance: [Calculation of elastic response spectrum \(chart & table\) - Eurocode 8](https://eurocodeapplied.com/design/en1998/elastic-response-spectrum) : <https://eurocodeapplied.com/design/en1998/elastic-response-spectrum>
- (11) Environmental Maps: [Snow Load, Wind Speed, and Seismic Load Maps](https://www.dlupal.com/en/solutions/online-services/snow-wind-seismic-load-maps) : <https://www.dlupal.com/en/solutions/online-services/snow-wind-seismic-load-maps>
- (12) France Soil: GeoPortail, <https://www.geoportail.gouv.fr/donnees/carte-des-sols>
- (13) Eurocode 1, Snow: <https://eurocodes-tools.com/en/snow-zones-map-france/>
- (14) Eurocode 1, Wind: [Wind Zone of France According to Eurocode \(https://www.dlupal.com/en/load-zones-for-snow-wind-earthquake/wind-nf-en-1991-1-4.html?#¢er=49.225655588131694,-0.04900932312011719&zoom=15&marker=49.222611,-0.052252\)](https://www.dlupal.com/en/load-zones-for-snow-wind-earthquake/wind-nf-en-1991-1-4.html?#¢er=49.225655588131694,-0.04900932312011719&zoom=15&marker=49.222611,-0.052252)
- (15) Swiss Windpower: <https://wind-data.ch/tools/profile.php?lng=en>
- (16) Dozule Weather: <https://weatherspark.com/>
- (17) Dozule Weather II: <https://www.extremeweatherwatch.com/countries/france>
- (18) Conyers, GA, Weather: (<https://www.worldweatheronline.com/>), [Conyers Weather Averages - Georgia, US](https://www.worldweatheronline.com/US/Georgia/US)
- (19) Distance w/r Long/Lat: <https://www.thoughtco.com/degree-of-latitude-and-longitude-distance-4070616>
- (20) Human Body Weight/Volume: [Weight to Volume conversions for select substances and materials](https://www.bodyvolumecalculator.com/)
- (21) Human Body Volume: [Body Volume Calculator - Calculator Academy](https://www.bodyvolumecalculator.com/)
- (22) “Weight, Volume, and Center of Mass of Segments of the Human Body” by C. Clauser, J. McConville & J. Young, 1969
- (23) [Conyers Climate, Weather By Month, Average Temperature \(Georgia, United States\) - Weather Spark](https://www.conyersclimate.com/)
- (24) “Estimation of fatigue S-N curves for aluminum based on tensile strength – proposed method” by P. Strzelecki, J. Correia and J. Sempruch P. Strzelecki, J. Correia and J. Sempruch (International Primary Aluminum Institute, 2021)
- (25) Astrological Software: <https://stellarium.org/>
- (26) [Free Concrete Footing Calculator | SkyCiv](https://skyciv.com/concrete-footing-calculator/) : (<https://skyciv.com/concrete-footing-calculator/>)
- (27) [Isaiah 62](https://www.sefaria.org/Isaiah.62?lang=bi) : <https://www.sefaria.org/Isaiah.62?lang=bi>

- (28) Isaiah 62 DRB : <https://biblehub.com/drb/isaiah/62.htm>
- (29) Our Lady of Guadalupe: The Secret Code Within the Tilma of Our Lady of Guadalupe – EpicPew : <https://epicpew.com/secret-code-within-lady-guadalupe/>
- (30) Solar Eclipse: A Guide to April’s Solar Eclipse : <https://magazine.remindermedia.com/articles/guide-to-aprils-solar-eclipse/>
- (31) Morning Sky: The Nature Conservancy: A World Where People & Nature Thrive : <https://www.nature.org/en-us/>
- (32) GIMP - GNU Image Manipulation Program : <https://www.gimp.org/>
- (33) Color Codes: HTML Color Codes : <https://htmlcolorcodes.com/>
- (34) Color Codes: HTML Color Codes Chart : <https://www.rapidtables.com/web/color/html-color-codes.html>
- (35) AISI SS: Fatigue properties and endurance limits of stainless steels – British Stainless Steel Association : https://bssa.org.uk/bssa_articles/fatigue-properties-and-endurance-limits-of-stainless-steels/
- (36) “Development of Fatigue Design Curve for Austenitic Stainless Steels in LWR Environments: A Review” by O. K. Chopra, Energy Technology Division, Argonne National Laboratory, Argonne IL, USA
- (37) Navy Aviation Structural Mechanic (AM): <https://navyaviation.tpub.com/14315/Figure-4-44-Rivet-Spacing-And-Edge-Distance-142.html>
- (38) Climate and monthly weather forecast, Dozulé, France: [Yearly & Monthly weather - Dozulé, France](#)
- (39) KOHOUT, J., VECHET, S.: A New Function for Description of Fatigue Curves and Its Multiple Merits, International Journal of Fatigue, 2/2001, pp. 175–183
- (40) A572 Se: “Weibull S-N Fatigue Strength Curve Analysis for A572 Gr. 50 Steel, Based on the True Stress—True Strain Approach” by A. Molina, M. Piña-Monarez and Jesús Barraza-Contreras, 2020: <https://www.mdpi.com/2076-3417/10/16/5725>
- (41) Glorious Cross (Home): [Home - The Glorious Cross of Dozulé](#) (<https://croix-glorieuse-dozule.fr/en/>)

The computer used for calculations and documentation: Intel(R) Core(TM) Ultra 7 265K (3.90 GHz), 192 GB (192 GB usable), NVIDIA GeForce RTX 4070 SUPER (12 GB) with 64-bit operating system, x64-based processor. The bulk of the calculations were completed on/in Solidworks 2026.