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STRUCTURAL ANALYSIS

for the

ROOFTOP PV SOLAR INSTALLATION

Project: Michael Blevins, 89 Fairfield Lane, Lillington, NC 27546

Prepared for:

FREEDOM SOLAR POWER

Freedom Solar, LLC

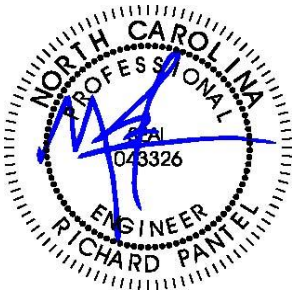
4801 Freidrich Ln, Ste 100 - Austin, TX 78744

Calculation Report Index

Project Number: 36.111894, Rev. 0

Report Date: 08/31/2023

Report Prepared by:



Richard Pantel, P.E.

NC License No. 43326

Ver. 230827 a

Richard Pantel

Digitally signed by Richard Pantel
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Date: 2023.08.31 19:35:47 -04'00'

Loading Summary

Exposure and Occupancy Categories		
B		*Exposure Category (ASCE 7-16 Table 26.7.3, Page 266)*
II		*Building Use Occupancy / Risk Category (ASCE 7-16 Table 1.5-1, Page 4)*

Wind Loading:			
v	117	*mph*	*ASCE 7-16, Figure 26.5-1 A, B or C, pp 249-251. [(117 mph, 50 year wind MRI)]*
qz	20.77	*psf*	*Velocity qz, calculated at height z [ASD]*

Snow Loading			
pg	15	*psf*	*Ground Snow Load pg (ASCE 7-16 Table 7.2-1, Page 52-53)*
Total Snow Load			
ps	15.00	*psf*	*Effective snow load on roof and modules*

Module Data			
WAAREE ENERGIES LIMITED: WSMD-400			
Dimensions	*mm*	*ft*	*in*
Length	1,923	6.31	75.70
Width	1,039	3.41	40.90
Area (m^2, ft^2)	2.0	21.50	
Weight	kg	lb	
Module	22.00	48.50	

Roof Panel (Cladding) Loading Summary		Module Loading Summary			
Support Point Loads		*Upward*	*Upward*	*Upward*	*Downward*
Roof Zones		1,2e,2r	2n,3r	3e	All
Net total load / support point	*lb*	-41	-86	-104	129

Positive values indicate net downward force

Stanchion Fastener Pull-out and Spacing Calculations		
Framing spacing	*ft*	2.00
Max stanchion span	*ft*	4.00
# fasteners per stanchion		1
Depth of bolt penetration	*in*	3
Safety Factor		1.25
Pull-out for 5/16 fasteners	*lb/in*	206
Max uplift capacity of stanchion	*lb*	495

Roof Zones			*1,2e,2r*	*2n,3r*	*3e*
Lift Per Module		*lb*	41	86	104
Factored maximum lift to counteract		*lb*	51	107	130
Net uplift pressure	7. 0.60D - 0.6W	*psf*	-2.91	-4.31	-6.38
Allowable lift area / fastener		*sf*	169.84	114.83	77.55
Landscape Modules					
Length along rafter		*ft*	3.41		
Maximum stanchion EW spacing		*ft*	4.00	4.00	4.00
Maximum module area / support point		*sf*	6.8	6.8	6.8
Factored lift per support point		*lb*	-20	-29	-43
Portrait Modules					
Length along rafter		*ft*	6.31		
Maximum stanchion EW spacing		*ft*	4.00	4.00	4.00
Maximum module area / support point		*sf*	12.6	12.6	12.6
Factored lift per support point		*lb*	-37	-54	-80

Stanchion support Lag Bolts sizes are indicated in the Module Loading Summary table above. Lift forces were determined from GCp and other coefficients contained in the ASCE nomographs

Conclusions

Princeton Engineering was asked to review the roof of Michael Blevins, located at 89 Fairfield Lane, Lillington, NC, by Freedom Solar, LLC, to determine its suitability to support a PV solar system installation.

The referenced building's roof structure was field measured by Freedom Solar, LLC on 08/17/2023. The attached framing analyses reflect the results of those field measurements combined with the PV solar module locations shown on the PV solar roof layout design prepared by Freedom Solar, LLC. Loads are calculated to combine the existing building and environmental loads with the proposed new PV array loads.

Freedom Solar, LLC selected the SunPower InvisiMount 6000 series racking with QuickBolt 17662 stanchions for this project. The racking and support stanchions shall be placed as shown on their plans, dated 08/31/2023, and shall be fastened to the roof framing using fastener sizes indicated in this report. Rack support spacing shall be no more than that shown above. Note that support points for alternating rows shall share the same truss. Intermediate rows shall move the support points laterally to the next truss. The support rail can be cantilevered up to 1/3 of the maximum span between modules. 1/3 maximum span = 16.00 inches.

Google Location Map

Framing Summary

Based upon the attached calculations, the existing roofs framing systems are capable of supporting the additional loading for the proposed PV solar system along with the existing building and environmental loads. No supplemental roof framing structural supports are required. Minimum required anchorage fastening is described above.

Notes: (1) Bolt threads must be embedded in the side grain of a roof support structural member or other structural member integrated into the building's structure. (2) Lag bolts must be located in the middle third of the structural member. (3) Install lag bolts with head and washer flush to surface (no gap). Do not over-torque.

References and Codes:

1) *ASCE 7-16 Minimum Design Loads for Buildings and Other Structures*
2) *IBC 2018*
3) *2018 NC Building Code*
4) *American Wood Council, NDS 2005,Table 11.2A, 11.3.2A.*
5) *American Wood Council, Wood Structural Design, 1992, Figure 6.*

Location: MP 1

Member: Truss - Total Length 21.5 ft, Unsupported 21.5 ft

Geometric Data			
Θ	*deg.*	45.00	*Angle of roof plane from horizontal, in degrees*
L	*ft.*	28.70	*Length of roof plane, in feet (meters)*
W	*ft.*	15.25	*Plan view width of roof plane, in feet (meters)*
h	*ft.*	25.00	*Average height of roof above grade, in feet (meters)*

Roof Wind Zone Width			
	use, a =	3.00	*ft*

Wind Velocity Pressure, q_z evaluated at the height z						
q_z=	20.77	*psf*	*Vasd* q_z=	12.61	*psf*	Basic wind pressure
V=	117	mph				

Framing Data		
Wood type	US Spruce	
Wood source, moisture content	White 0.12%	
# Framing Members / Support		1
Rafter / Truss OC	*in*	24.00
Member Total Length	*ft*	21.50

2	# Rafters / Rack Support Width
4.00	Rack Support Spacing (ft)
48	Max. Rack Support Spacing (in)
3	Max # of mod's / Top truss chord

Member Properties		**Member**
Name		(1) 2x4
Repetitive Member Factor (Cr)		1.15

** Mem properties based upon field measurements*

Top truss chord

Module Physical Data			
Weight	kg	lb	psf load
Module	22.00	48.50	2.26
4 Stanchions	1.36	3.0	0.14
Total Module and Support load	23.36	51.5	2.40

Existing Dead Loads	*Units*	*Value*	*Description*
Roof Deck & Surface	*psf*	4.40	*Truss members' self weight added to FEA analysis*

Rack Support Spacing and Loading				
Across rafters	*ft*	4.0		
Along rafter slope	*ft*	3.4		
Area / support point	*sf*	6.8		
Uphill gap between modules	*in*	1.0	0.08	*ft*

Member Total Length	*ft*	21.50	
Maximum member free span	*ft*	21.50	Top truss chord span

ASCE 7-16 **Method for Calculating Uplift on PV Modules**

Notation
Lp = Panel chord length.
p = uplift wind pressure
γa = Solar panel pressure equalization factor, defined in Fig. 29.4-8.
γE = Array edge factor as defined in Section 29.4.4.
θ = Angle of plane of roof from horizontal, in degrees.

29.4.4 Rooftop Solar Panels Parallel to the Roof Surface on Buildings of All Heights and Roof Slopes.

Θ >= 7 deg TRUE

	Exposed	**FALSE**
	1.5(Lp) =	9.46
γE =	1	
γa =	0.67	

$p = qh(GCp)\ (\gamma_E)\ (\gamma_a)$ (lb/ft2) (29.4-7)

Zones	1,2e,2r	2n,3r	3e
p, Windload (psf)	-12.35	-14.67	-18.12

ASCE 7-16 Chapter 2 Combinations of Loads, Table 2.4, Page 8 (in psf)				
Zones	1,2e,2r	2n,3r	3e	All Zones
2.2 SYMBOLS AND NOTATION	*Module Upward*	*Module Upward*	*Module Upward*	*Downward*
D = dead load of PV Module + Stanchion	2.40	2.40	2.40	2.40
S = snow load	15.00	15.00	15.00	15.00
W = wind load	-12.35	-14.67	-18.12	9.67

2.4 Combining Nominal Loads Using Allowable Stress Design (in psf)				
2.4.1 Basic Combinations. Loads listed herein shall be considered to act in the following combinations; whichever produces the most unfavorable effect in the building, foundation, or structural member being considered. Effects of one or more loads not acting shall be considered.				
Combination Formulae	*Upward*	*Upward*	*Upward*	*Downward*
Use this loading combination for DOWNWARD for Proposed PV Dead Load				
6. D + 0.75L - 0.75(0.60W) + 0.75(Lr or S or R)	17.40	17.40	17.40	21.75
Module Support point load (lb)	119	119	119	148
Cr Factored Module Support point load (lb)	103	103	103	129

Use this loading combination for UPWARD for Proposed PV Dead Load				
7. 0.60D - 0.6W	-2.91	-4.31	-6.38	7.49
Module Support point load (lb)	-20	-29	-43	51

DOWNWARD

Presume loading directly over member.

Combined Dead and Wind Pressure Downward Loading					
	Top truss chord span				
PV Module Row	Point load loc's from Left support	Point Load #'s	Module Support Point Load	Comment	Module Orientation
	ft from left		*lb*		
1	1.47		129		Portrait
1	7.78			Support placed on adjoining truss	Portrait
2	7.86			Support placed on adjoining truss	Portrait
2	14.17		129		Portrait
3	14.25		129		Landscape
3	17.66			Support placed on adjoining truss	Landscape

Truss Data and Loading for MP 1

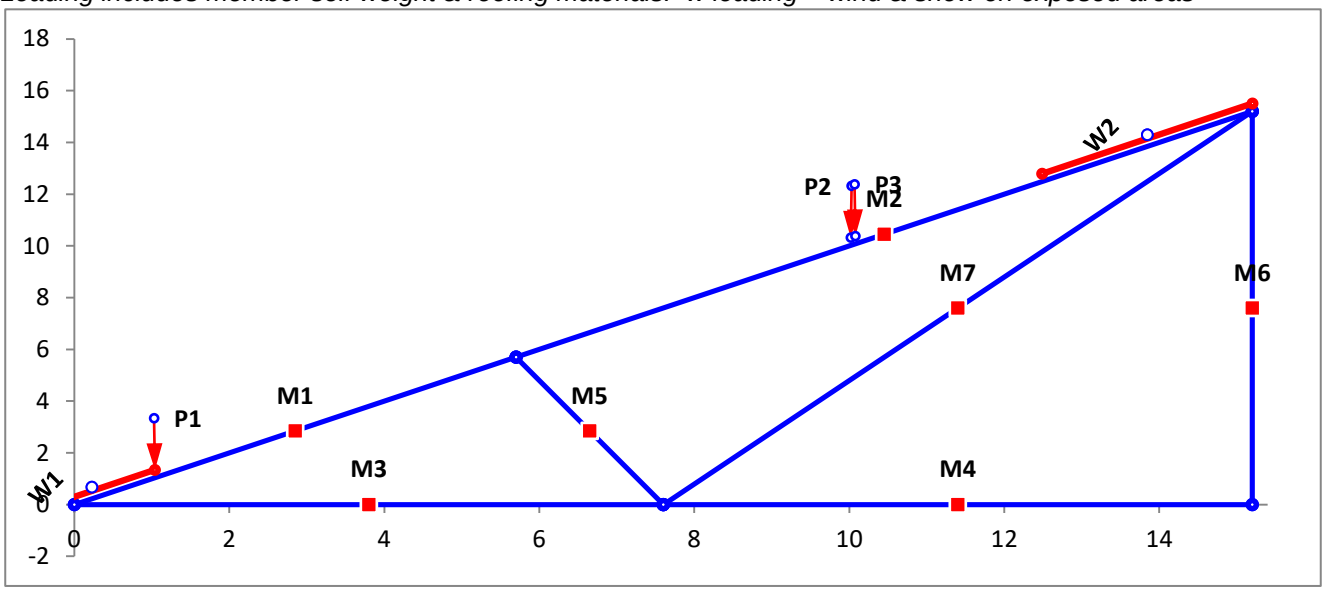
Roof slope (degrees)	45.00
Top ridge height above floor plane	15.20

	Length of roof plane	21.50
	Length of floor plane	15.25

Truss Segments

Roof Plane		*Floor Plane*		*Diagonals*		*Diagonals*	
Mem #	*Mem Type*	Mem #	*Mem Type*	Mem #	*Mem Type*	Mem #	*Mem Type*
1	2x4	3	2x4	5	2x4	7	2x4
2	2x4	4	2x4	6	2x4		

** Loading includes member self weight & roofing materials. w loading = wind & snow on exposed areas*



Location: MP 2

Member: Truss - Total Length 16.8 ft, Unsupported 16.8 ft

Geometric Data			
Θ	*deg.*	25.00	*Angle of roof plane from horizontal, in degrees*
L	*ft.*	24.83	*Length of roof plane, in feet (meters)*
W	*ft.*	15.25	*Plan view width of roof plane, in feet (meters)*
h	*ft.*	25.00	*Average height of roof above grade, in feet (meters)*

Roof Wind Zone Width			
	use, a =	3.00	*ft*

Wind Velocity Pressure, q_z evaluated at the height z						
q_z=	20.77	*psf*	*Vasd* q_z=	12.61	*psf*	Basic wind pressure
V=	117	mph				

Framing Data		
Wood type	US Spruce	
Wood source, moisture content	White 0.12%	
# Framing Members / Support		1
Rafter / Truss OC	*in*	24.00
Member Total Length	*ft*	16.80

2	# Rafters / Rack Support Width
4.00	Rack Support Spacing (ft)
48	Max. Rack Support Spacing (in)
3	Max # of mod's / Top truss chord

Member Properties		**Member**
Name		(1) 2x4
Repetitive Member Factor (Cr)		1.15

** Mem properties based upon field measurements*

Top truss chord

Module Physical Data			
Weight	kg	lb	psf load
Module	22.00	48.50	2.26
4 Stanchions	1.36	3.0	0.14
Total Module and Support load	23.36	51.5	2.40

Existing Dead Loads	*Units*	*Value*	*Description*
Roof Deck & Surface	*psf*	4.40	*Truss members' self weight added to FEA analysis*

Rack Support Spacing and Loading				
Across rafters	*ft*	4.0		
Along rafter slope	*ft*	3.4		
Area / support point	*sf*	6.8		
Uphill gap between modules	*in*	1.0	0.08	*ft*

Member Total Length	*ft*	16.80	
Maximum member free span	*ft*	16.80	Top truss chord span

ASCE 7-16 **Method for Calculating Uplift on PV Modules**

Notation
Lp = Panel chord length.
p = uplift wind pressure
γa = Solar panel pressure equalization factor, defined in Fig. 29.4-8.
γE = Array edge factor as defined in Section 29.4.4.
θ = Angle of plane of roof from horizontal, in degrees.

29.4.4 Rooftop Solar Panels Parallel to the Roof Surface on Buildings of All Heights and Roof Slopes.

Θ >= 7 deg TRUE

	Exposed	**FALSE**
	1.5(Lp) =	9.46
γE =	1	
γa =	0.67	

$p = qh(GCp)\ (\gamma_E)\ (\gamma_a)$ (lb/ft2) (29.4-7)

Zones	1,2e	2n,2r,3e	3r
p, Windload (psf)	-12.46	-17.96	-20.18

ASCE 7-16 Chapter 2 Combinations of Loads, Table 2.4, Page 8 (in psf)				
Zones	1,2e	2n,2r,3e	3r	All Zones
2.2 SYMBOLS AND NOTATION	*Module Upward*	*Module Upward*	*Module Upward*	*Downward*
D = dead load of PV Module + Stanchion	2.40	2.40	2.40	2.40
S = snow load	15.00	15.00	15.00	15.00
W = wind load	-12.46	-17.96	-20.18	5.71

2.4 Combining Nominal Loads Using Allowable Stress Design (in psf)				
2.4.1 Basic Combinations. Loads listed herein shall be considered to act in the following combinations; whichever produces the most unfavorable effect in the building, foundation, or structural member being considered. Effects of one or more loads not acting shall be considered.				
Combination Formulae	*Upward*	*Upward*	*Upward*	*Downward*
Use this loading combination for DOWNWARD for Proposed PV Dead Load				
6. D + 0.75L - 0.75(0.60W) + 0.75(Lr or S or R)	17.40	17.40	17.40	19.97
Module Support point load (lb)	119	119	119	136
Cr Factored Module Support point load (lb)	103	103	103	118

Use this loading combination for UPWARD for Proposed PV Dead Load				
7. 0.60D - 0.6W	-2.98	-6.28	-7.61	7.49
Module Support point load (lb)	-20	-43	-52	51

DOWNWARD

Presume loading directly over member.

Combined Dead and Wind Pressure Downward Loading					
	Top truss chord span				
PV Module Row	Point load loc's from Left support	Point Load #'s	Module Support Point Load	Comment	Module Orientation
	ft from left		*lb*		
1	0.17		118		Portrait
1	6.48			Support placed on adjoining truss	Portrait
2	6.56			Support placed on adjoining truss	Portrait
2	12.87		118		Portrait
3	12.95		118		Landscape
3	16.36			Support placed on adjoining truss	Landscape

Truss Data and Loading for MP 2

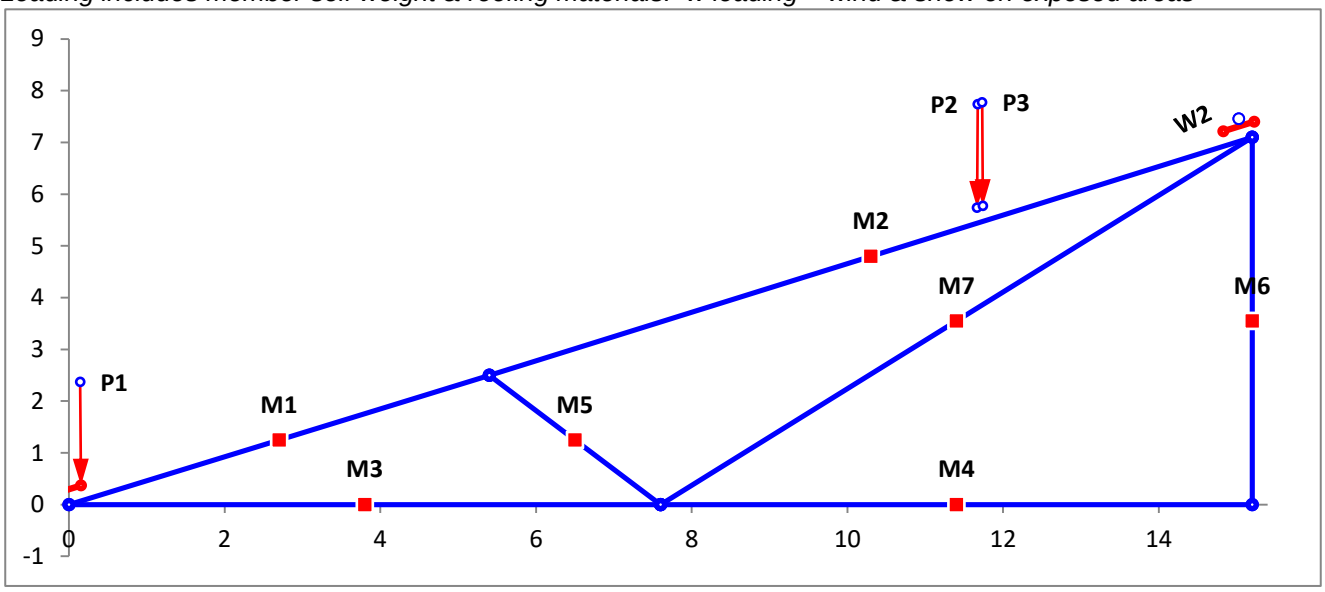
Roof slope (degrees)	25.00
Top ridge height above floor plane	7.10

	Length of roof plane	16.80
	Length of floor plane	15.25

Truss Segments

Roof Plane		*Floor Plane*		*Diagonals*		*Diagonals*	
Mem #	*Mem Type*	Mem #	*Mem Type*	Mem #	*Mem Type*	Mem #	*Mem Type*
1	2x4	3	2x4	5	2x4	7	2x4
2	2x4	4	2x4	6	2x4		

** Loading includes member self weight & roofing materials. w loading = wind & snow on exposed areas*



Snow Loading Analysis

where:

		Fully Exposed	Exposure category
Ce	=	0.9	Exposure Factor, Ce (ASCE 7-16 Table 7.3-1, Page 58)
Ct	=	1.0	Thermal Factor, Ct (ASCE 7-16 Table 7.3-2, Page 58)
Is	=	1.0	Snow Importance Factor, Is (ASCE 7-16 Table 1.5-2, Page 5)
p_g	=	15	Ground Snow Load pg (ASCE 7-16 Table 7.2-1, Page 52-53)
p_f	=	**0.7CeCtIsPg**	Flat Roof Snow Load, pf (ASCE 7-16 Table 7.3-1, Page 58)
p_f	=	**9.45**	psf
			but where Pf is not less than the following:
			Minimum Snow Load pm (ASCE 7-16 Table 7.3.4, Page 53)
p_m	=	**15**	When Pg <=20 psf, then use Pf = Pg x Is
p_f	=	**15**	psf. Resultant Snow pressure to be used with Roof slope factor below
p_s	=	$C_s p_f$	Sloped Roof Snow Load ps (ASCE 7-16 Table 7.4, Page 54)

Roof Type Warm Roofs

Roof slope factor Cs for Warm Roofs, where Ct = 1.0

Roof surface condition = Slippery Roof

C_s	=	1.00	Roof Slope Factor, Cs (ASCE 7-16 Table 7-2a, Page 36)

Total Snow Load

p_s	=	**15.00**	**psf**	Roof snow load

FEA Calculation Results for Roof Plane MP 1 for Freedom Solar, LLC Client Michael Blevins

IDSPL - 2D Frame Analysis of a 2D frame subject to distributed loads, point loads and moments

Equilibrium check	FX	FY
Total applied forces	0.00	2295
Total output reactions	0.00	-2295
Output error	-1.99E-13	4.55E-13

1.5E-05

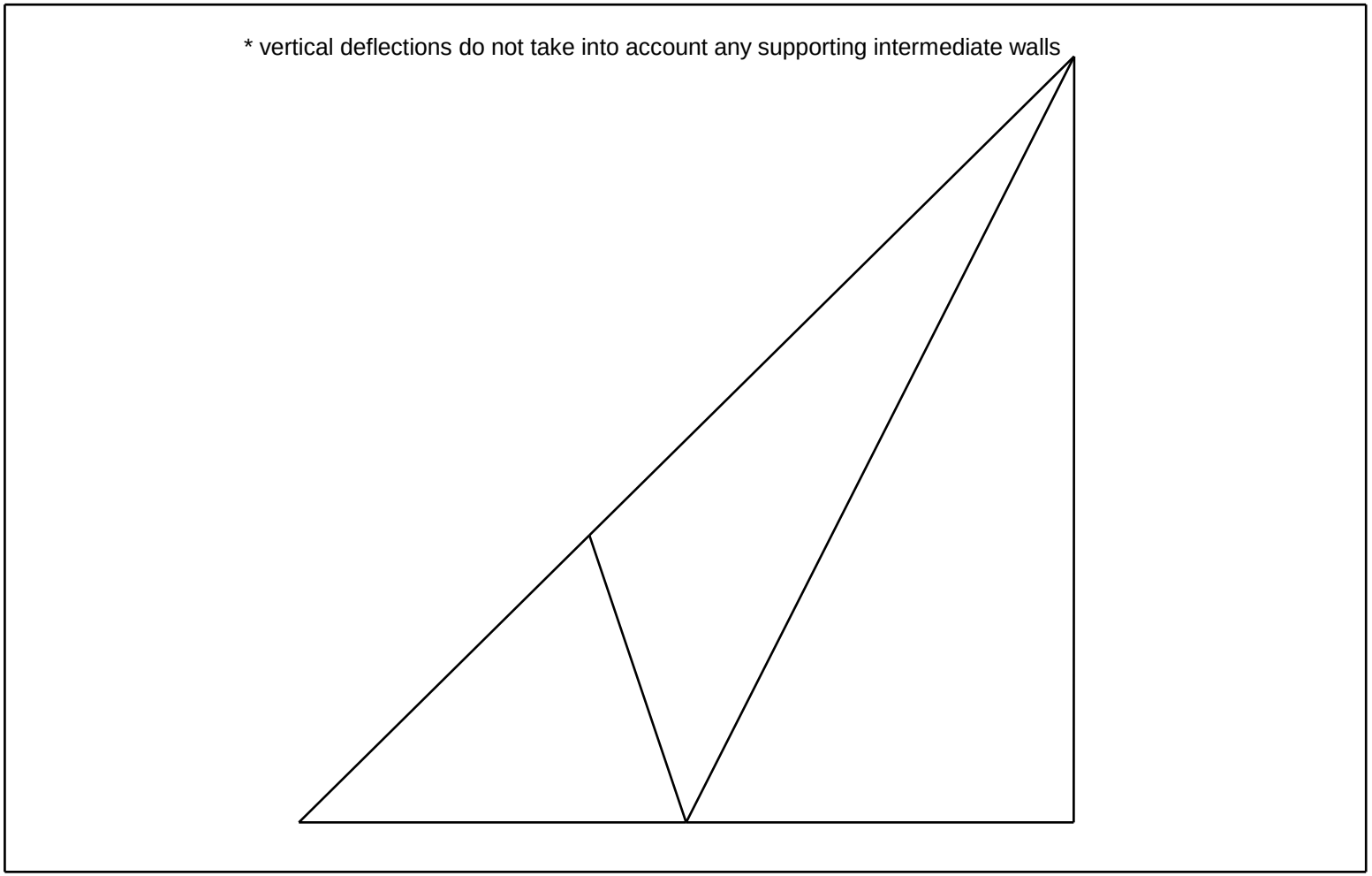
# of segments/beam	1

Maximum Deflections	
4.94E-03	-1.69E-03

** vertical deflections do not take into account any supporting intermediate walls*

Node Results			Beam End Results			
Direction	Deflection	Reaction	Beam	Shear	Ax	BM
DX1	0.00E+00	-356	1-1	-807	1311	2418
DY1	0.00E+00	-1361	1-2	-638	1141	-3531
RZ1	-1.95E-04	0	2-1	-3097	2006	-5325
DX2	-1.86E-04	0	2-2	-2028	937	-42837
DY2	1.69E-03	0	3-1	137	0	-2418
RZ2	-5.19E-04	0	3-2	368	0	462
DX3	4.94E-03	0	4-1	0	0	0
DY3	0.00E+00	2950	4-2	0	0	0
RZ3	0.00E+00	-40879	5-1	-319	2609	134
DX4	0.00E+00	496	5-2	-326	2587	-1795
DY4	0.00E+00	-3844	6-1	141	40	-1068
RZ4	0.00E+00	1038	6-2	141	-89	1068
DX5	0.00E+00	-141	7-1	72	1268	-710
DY5	0.00E+00	-40	7-2	143	1125	890
RZ5	0.00E+00	1068				

Beam	X	Shear	Mom	Ax	DX	DY	RZ
1	0.00	-807	2418	1311	0.00E+00	0.00E+00	-1.95E-04
1	8.06	-683	-3295	1187	-2.04E-04	-1.67E-03	-7.53E-04
2	0.00	-3097	-5325	2006	-1.86E-04	-1.69E-03	-5.19E-04
2	13.44	-2496	-33775	1405	4.26E-03	6.82E-04	-2.47E-02
3	0.00	137	-2418	0	0.00E+00	0.00E+00	-1.95E-04
3	7.60	308	776	0	0.00E+00	-4.82E-20	1.20E-04
4	0.00	0	0	0	0.00E+00	0.00E+00	0.00E+00
4	7.60	0	0	0	0.00E+00	0.00E+00	0.00E+00
5	0.00	-319	134	2609	0.00E+00	0.00E+00	0.00E+00
5	6.01	-325	-1796	2591	-1.86E-04	-1.69E-03	-5.25E-04
6	0.00	141	-1068	40	0.00E+00	0.00E+00	0.00E+00
6	15.20	141	1068	-75	4.94E-03	6.26E-07	2.17E-05
7	0.00	72	-710	1268	0.00E+00	0.00E+00	0.00E+00
7	16.99	136	893	1138	4.94E-03	5.60E-07	1.34E-05



Scaled 2X Deflected Truss Plot
Roof Plane MP 1 for Freedom Solar, LLC Client Michael Blevins

FEA Calculation Results for Roof Plane MP 2 for Freedom Solar, LLC Client Michael Blevins

IDSPL - 2D Frame Analysis of a 2D frame subject to distributed loads, point loads and moments

Equilibrium check	FX	FY
Total applied forces	0.00	1270
Total output reactions	0.00	-1270
Output error	3.41E-13	2.50E-12

1.5E-05

# of segments/beam	1

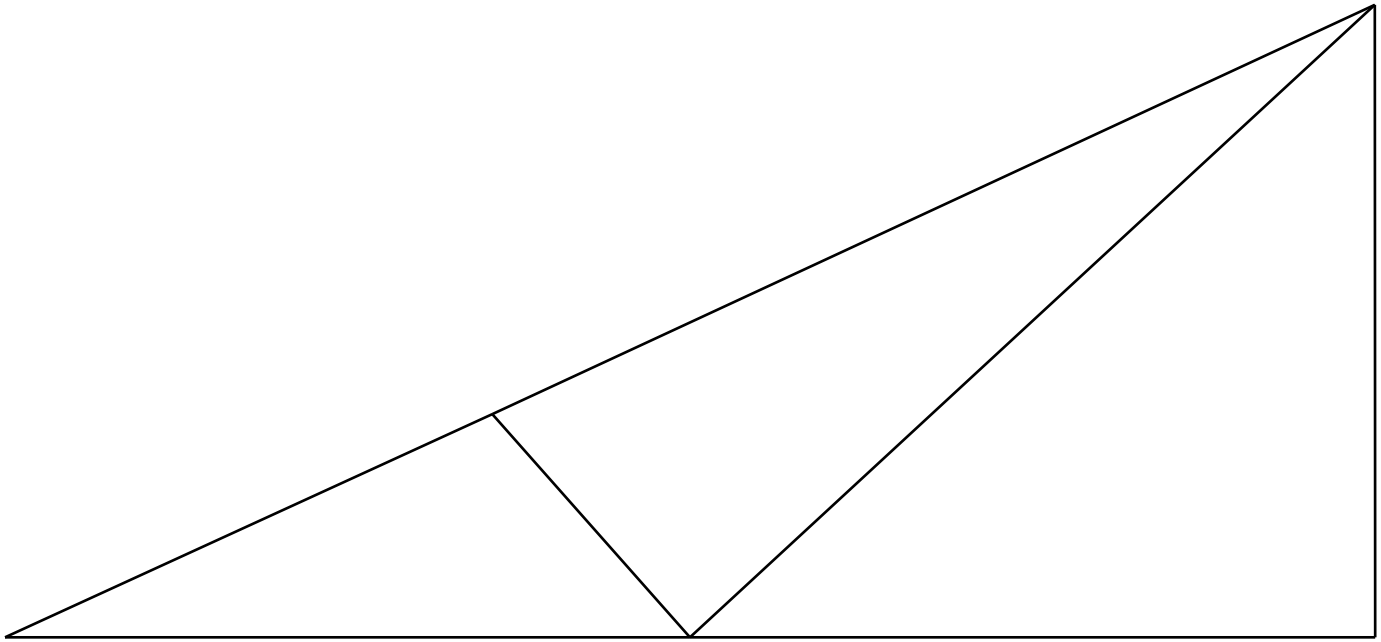
Maximum Deflections	
2.82E-03	2.69E-03

** vertical deflections do not take into account any supporting intermediate walls*

Node Results			Beam End Results			
Direction	Deflection	Reaction	Beam	Shear	Ax	BM
DX1	0.00E+00	-187	1-1	-4522	2300	1681
DY1	0.00E+00	-5069	1-2	-4346	2219	-24691
RZ1	3.03E-04	0	2-1	8405	-2390	-57254
DX2	2.82E-03	0	2-2	9085	-2710	42948
DY2	-2.68E-03	0	3-1	1	0	-1681
RZ2	-6.68E-03	0	3-2	222	0	-392
DX3	-1.99E-03	0	4-1	0	0	0
DY3	0.00E+00	-10264	4-2	0	0	0
RZ3	0.00E+00	41106	5-1	-7997	-10934	-5927
DX4	0.00E+00	-188	5-2	-8003	-10941	-32563
DY4	0.00E+00	14072	6-1	-376	9	1334
RZ4	0.00E+00	4962	6-2	-376	-22	-1334
DX5	0.00E+00	376	7-1	-118	-1302	573
DY5	0.00E+00	-9	7-2	-72	-1345	-508
RZ5	0.00E+00	-1334				

Beam	X	Shear	Mom	Ax	DX	DY	RZ
1	0.00	-4522	1681	2300	0.00E+00	0.00E+00	3.03E-04
1	5.95	-4388	-24470	2238	2.81E-03	2.69E-03	-6.94E-03
2	0.00	8405	-57254	-2390	2.82E-03	2.68E-03	-6.68E-03
2	10.83	8923	44456	-2633	-2.06E-03	3.20E-05	3.24E-03
3	0.00	1	-1681	0	0.00E+00	0.00E+00	3.03E-04
3	7.60	161	-78	0	0.00E+00	-9.42E-21	-6.91E-05
4	0.00	0	0	0	0.00E+00	0.00E+00	0.00E+00
4	7.60	0	0	0	0.00E+00	0.00E+00	0.00E+00
5	0.00	-7997	-5927	-10934	0.00E+00	0.00E+00	0.00E+00
5	3.33	-8001	-32563	-10939	2.82E-03	2.68E-03	-6.13E-03
6	0.00	-376	1334	9	0.00E+00	0.00E+00	0.00E+00
6	7.10	-376	-1334	-16	-1.99E-03	2.87E-07	-5.80E-05
7	0.00	-118	573	-1302	0.00E+00	0.00E+00	0.00E+00
7	10.40	-78	-505	-1339	-1.99E-03	1.98E-07	-1.68E-05

* vertical deflections do not take into account any supporting intermediate walls



Scaled 2X Deflected Truss Plot
Roof Plane MP 2 for Freedom Solar, LLC Client Michael Blevins