STRUCTURAL ANALYSIS
OF
OD, 2OD, & 3OD ENCLOSURES
FOR
150 MPH WIND LOADING

Prepared for:

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Executive Summary

Several structural analyses were performed on the OD, 2OD, & 3OD (Outdoor) enclosures to verify their integrity in high-wind conditions. There is no single comprehensive design code that governs enclosures of this nature, especially in terms of structural integrity. This analysis combined several ASCE codes along with general engineering principals to develop criteria to verify these enclosures' structural integrity. This report details the steps taken to verify compliance. This analysis proves that the OD, 2OD, & 3OD enclosures are safe for operation in winds up to 150MPH.

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Scope

There is no single comprehensive design code that governs enclosures of this nature, especially in terms of structural integrity. This analysis combined the ASCE along with general engineering principals to develop criteria to verify these enclosures' structural integrity. The purpose of this analysis is to prove that the OD, 2OD, & 3OD are safe for operation in winds up to 150MPH. The 150MPH value is chosen as it is the highest value of wind speed specified by the International Building Council in regards to Wind Loading.

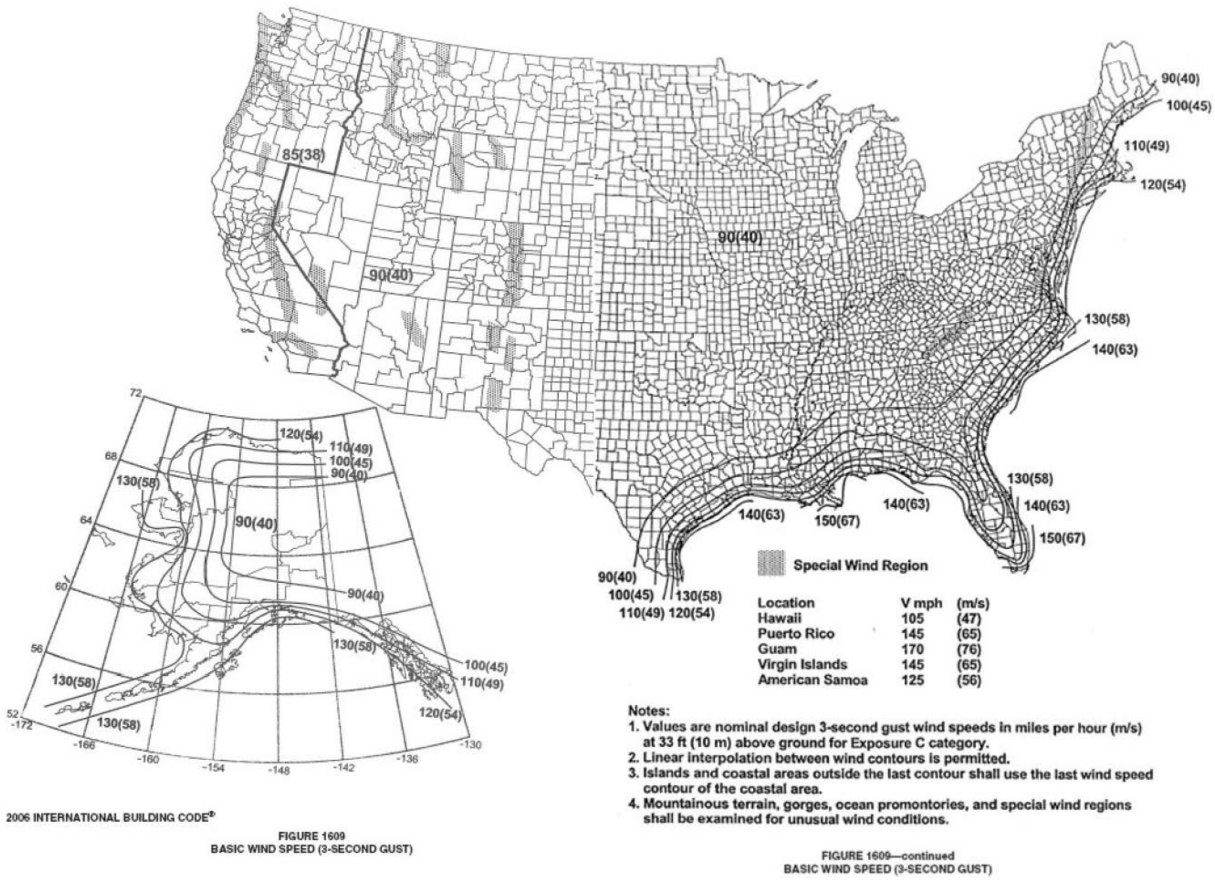

Figure 1: IBC Basic Wind Speeds (ASCE 7-05)

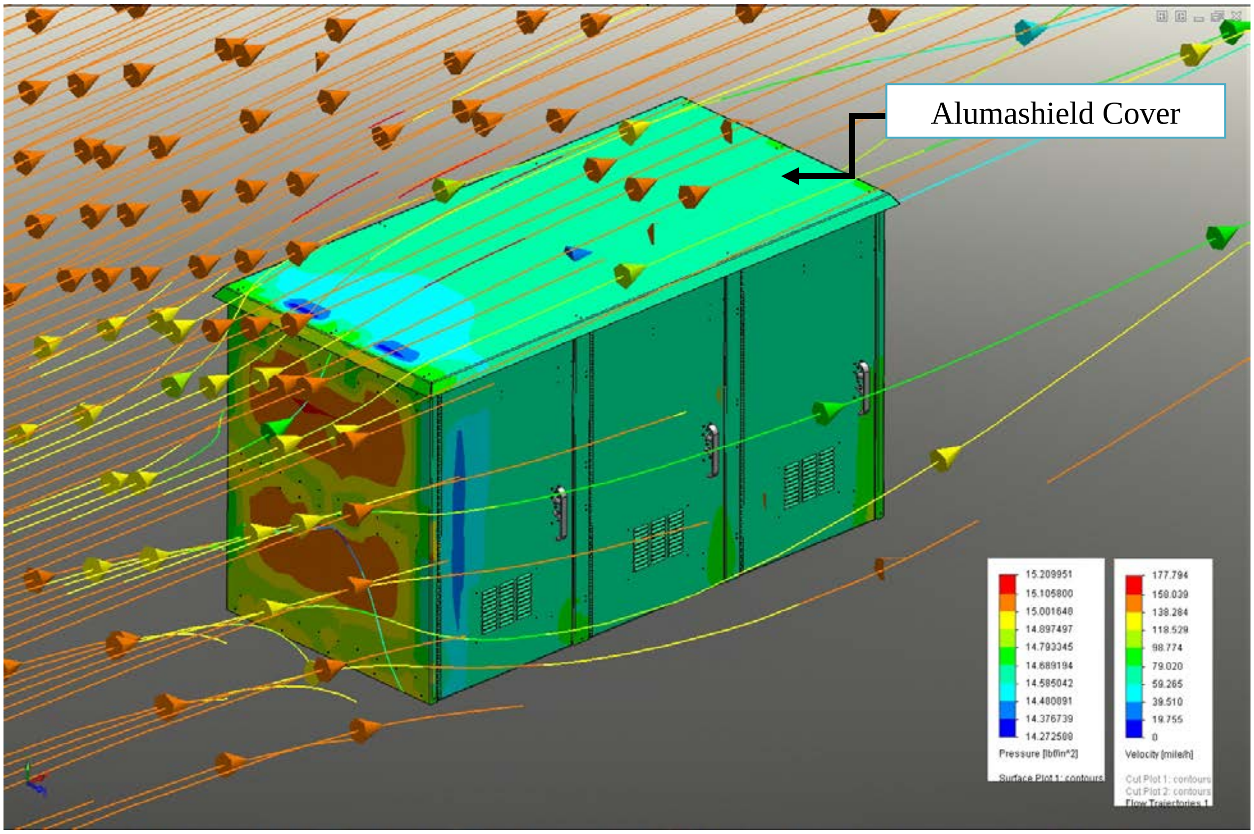

Figure 2: 3OD Enclosure in 150MPH Winds

Analysis

This analysis uses Computational Fluid Dynamics (CFD) software to determine the pressures exerted on each surface of the OD enclosures during sustained 150MPH winds. These pressures are then imported into Finite Element Analysis (FEA) software where the corresponding forces and stresses are calculated.

Computational Fluid Dynamics Software (Numerical Method)

The CFD software used in this analysis is SolidWorks Flow Simulation, version 2012 SP1.0. This is a commercially available CFD code.

CFD Study Type

An external CFD study is used to determine the pressures exerted on each exposed surface of each OD enclosure panel. The wind direction is applied in the positive X-direction of the model to create a "worst case scenario" in terms of lift force on the Alumashield panel. To further ensure worst case scenario conditions, a sustained 150MPH wind load is applied to determine the steady-state pressures.

CFD Model Simplification

To simplify the CFD analysis, only the exterior panels and their corresponding structure were used in the CFD model.

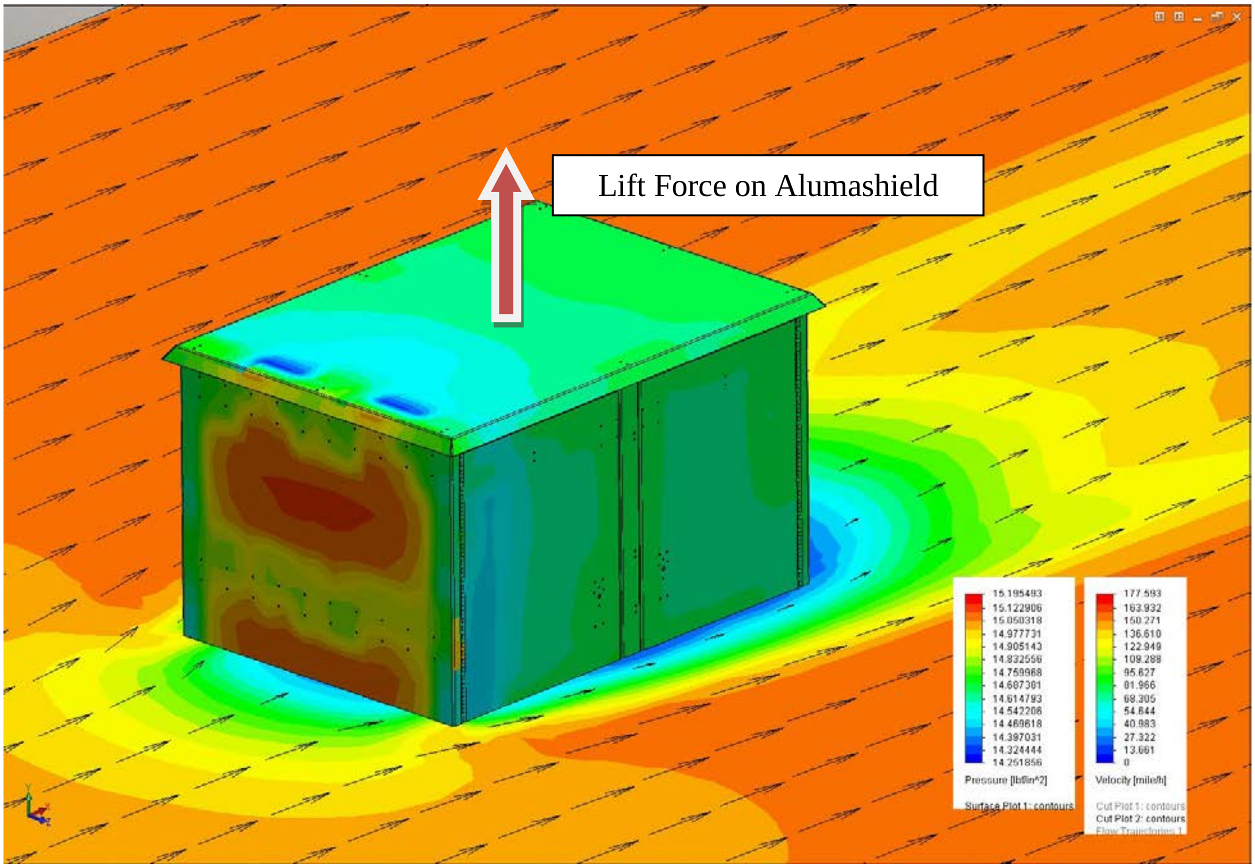

Figure 3: 2 OD Surface Pressures in 150MPH Winds

Finite Element Analysis Software (Numerical Method)

The FEA software used in this analysis is SolidWorks Simulation Premium, version 2012 SP1.0. This is a commercially available FEA code.

FEA Study Type

The "elastic stress analysis method" is used to satisfy all of the design by analysis. The study type used for all analyses is "static." A fatigue analysis is not required as these loads are far beyond the regularly applied cyclic loads. Thermal, resonance, dynamic, and non-linear studies were also not required based on the operating conditions.

FEA Elements

In each FEA study performed in this analysis, a triangular shell element is used. The shell element has 6 nodes; 3 at its vertices, and 3 at its mid-sides. Each node on the shell element has 3 translational & 3 rotational degrees of freedom.

Mesh Refinement

In each FEA study performed in this analysis, a uniform density mesh is applied globally to keep error below 5%. However, in areas of fillets, "mesh control" is applied. The locally refined mesh is typically 10-25% of the global mesh size. In the analyses of specific high-stress regions of the casting, the mesh is refined locally until a 5% von Mises convergence criterion is satisfied.

Bolted/Pin Connections

Pin connectors are used to simulate the Alumashield flange bolts. The pin connectors allow the bolt preload to be applied on the appropriate bearing area and also include the effects of the bolt's elasticity. The calculation of pin (Rivet) stresses is shown in Appendix B.

Model Simplification

Only "Primary" structure is analyzed herein. Primary structure includes the side panels, Alumashield, and inner support rails. All hardware connecting primary structure is replaced by pin connectors.

FEA Boundary Conditions & Connections

The OD enclosures are fixed at the structures' bottom (a minimum of four points).

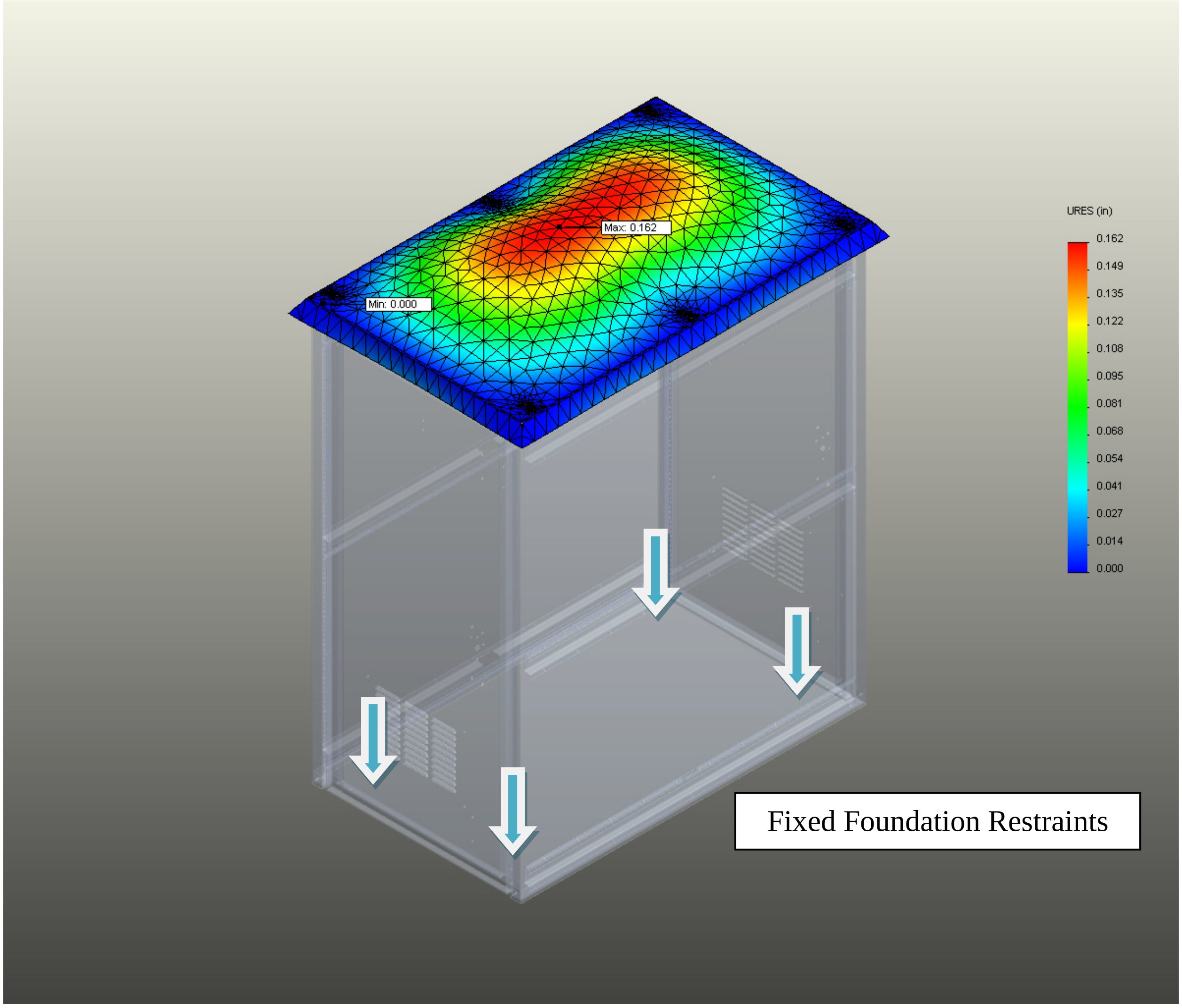

Figure 4: OD Enclosure Fixed Restraints for FEA

Materials

The following material properties are used in this analysis.

Table 1: Material Properties

Component	Material	Modulus of Elasticity	Poisson's Ratio	Density	Ultimate Strength	Yield Strength
Alumashield Panel	ASM 5052-H32	10,200 ksi	0.33	0.100 lb/in^3	33.0 ksi	28.0 ksi
Side Panels	ASM 5052-H32	10,200 ksi	0.33	0.100 lb/in^3	33.0 ksi	28.0 ksi
Alumashield Brackets	ASM 5052-H32	10,200 ksi	0.33	0.100 lb/in^3	33.0 ksi	28.0 ksi
Connecting Hardware	ASM 5052-H32	10,200 ksi	0.33	0.100 lb/in^3	33.0 ksi	28.0 ksi

Loads & Pressures

Primary Loads & Pressures: There are two major components of force that result from the pressures exerted by the 150MPH wind loads. The most critical is the lifting force applied on the Alumashield panel. The second is the lateral force acting on the side panel. The lifting force is the most critical, as the lifting load "pulls" on the panel, placing the brackets into tension.

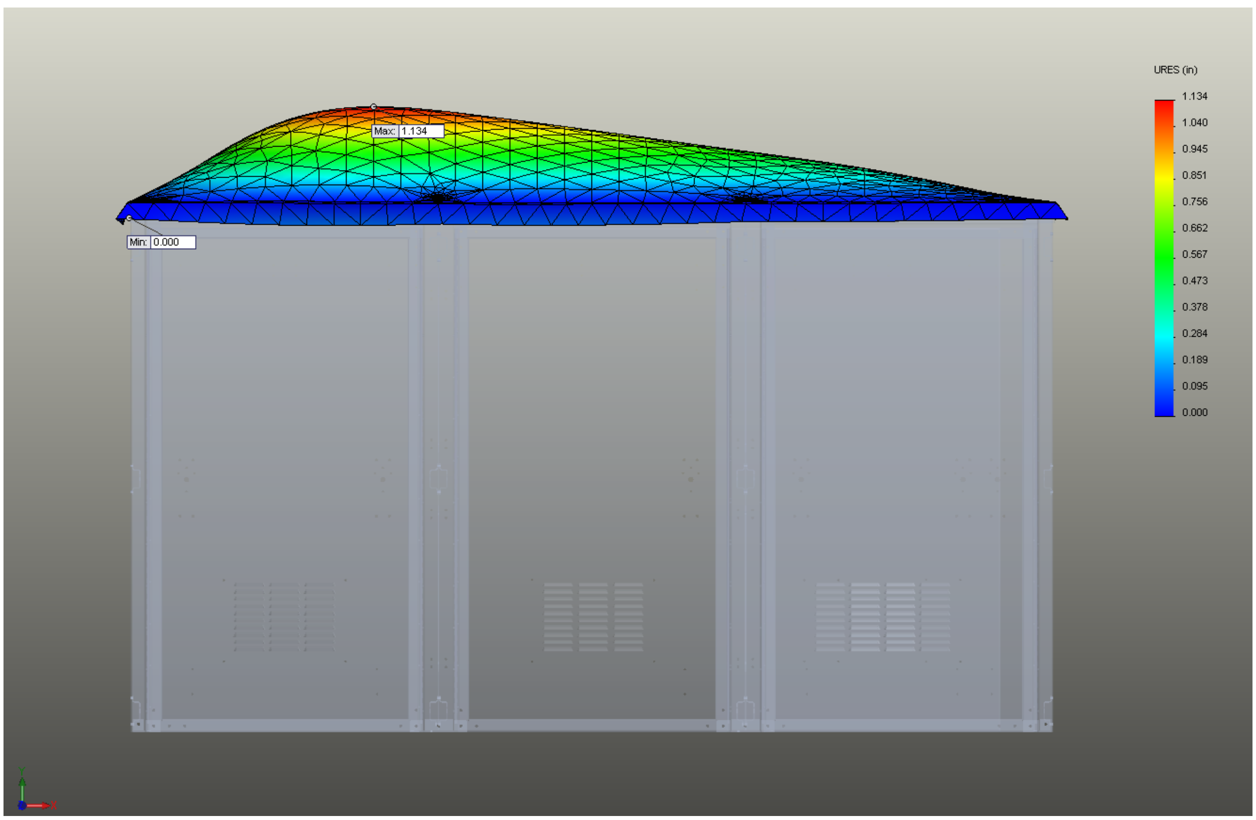

Figure 5: Alumashield Panel Deflection on 3OD (Worst Case Scenario) in 150MPH Winds

The lateral loads imposed on the side panels are highest on the Single OD enclosure. The worst case value is approximately 790 lbs. However, because the lateral load places the supporting members in compression, and because the load creates very low stress values, the analysis excludes the effects of lateral forces on the overall structural analysis.

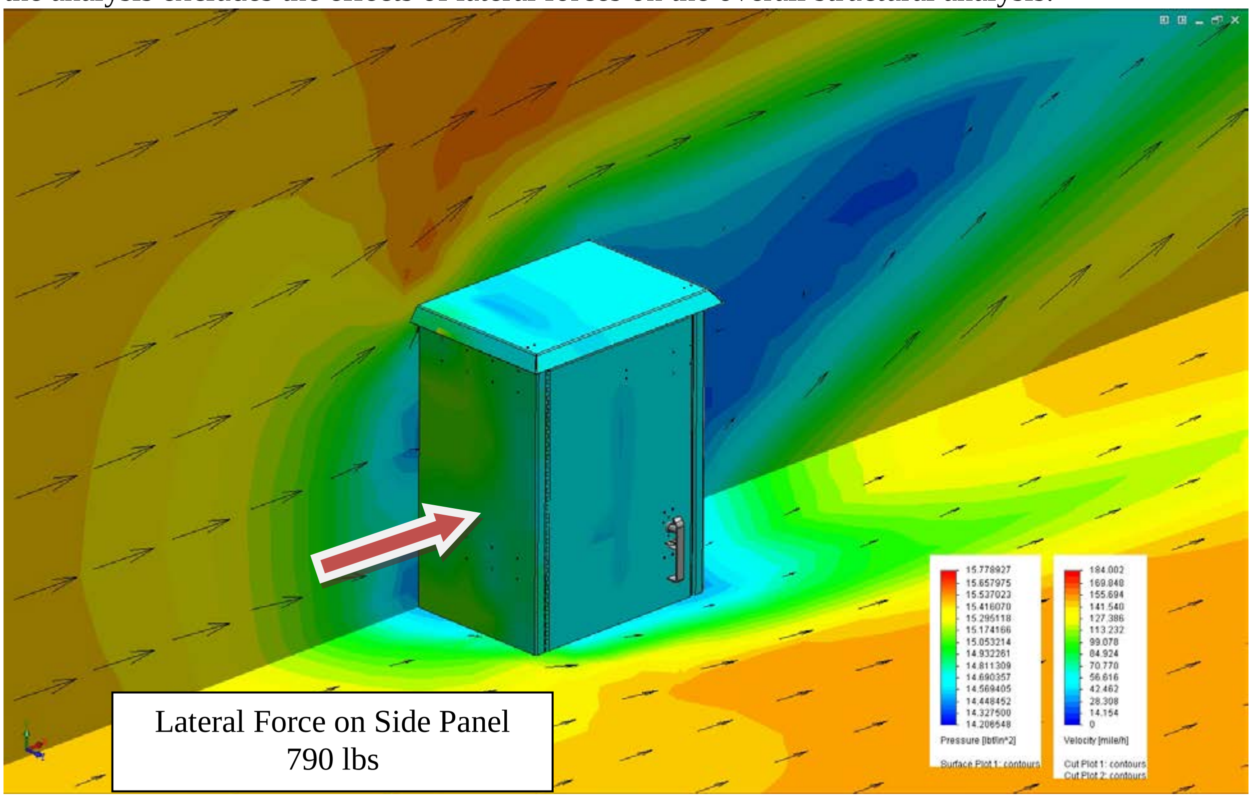

Figure 6: Lateral Pressure on OD Enclosure in 150MPH Winds

Structural Requirements

There are no conclusive requirements for “Structural Integrity” of enclosures of this type. The IBC and ASCE codes simply recommend that the structure “endure” wind loading. It is not safe to simply “endure” realistic conditions. Therefore, custom requirements were developed to ensure the enclosures exceeded the basic structural requirements.

The Alumashield and its supporting hardware have become the focus of this analysis. Because the loading places the components into tension, each component is required to have a minimum factor of safety (FOS) of 2. This FOS value is based on generally accepted engineering practice and is based on the tensile value of the material.

General Requirements:

$P_1 \leq 2S$

Local Failure Requirements:

$P_{vm} \leq 2S$

Rivet Failure Requirements:

$P_{bolt} \leq 2S$

where:
P_1 = General primary membrane equivalent stress
P_{vm} = Local von Mises equivalent stress
P_{bolt} = Pin connector tensile stress
S = Allowable tensile stress

The allowable stress value is obtained from information provided by *The Aluminum Association, Inc. from Aluminum Standards and Data 2000 and/or International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys (Revised 2001)*, is 33 ksi.

Results for OD (Single) Enclosure

Forces

The lifting component on the OD Alumashield is 280 lbs.

Table 2: Resultant Loads on OD (Single) Alumashield

Units	Sum X	Sum Y	Sum Z	Resultant
lbf	-16.9396	-280.711	-0.313207	281.222

Deflection

The maximum deflection on the OD Alumashield is 0.168 in.

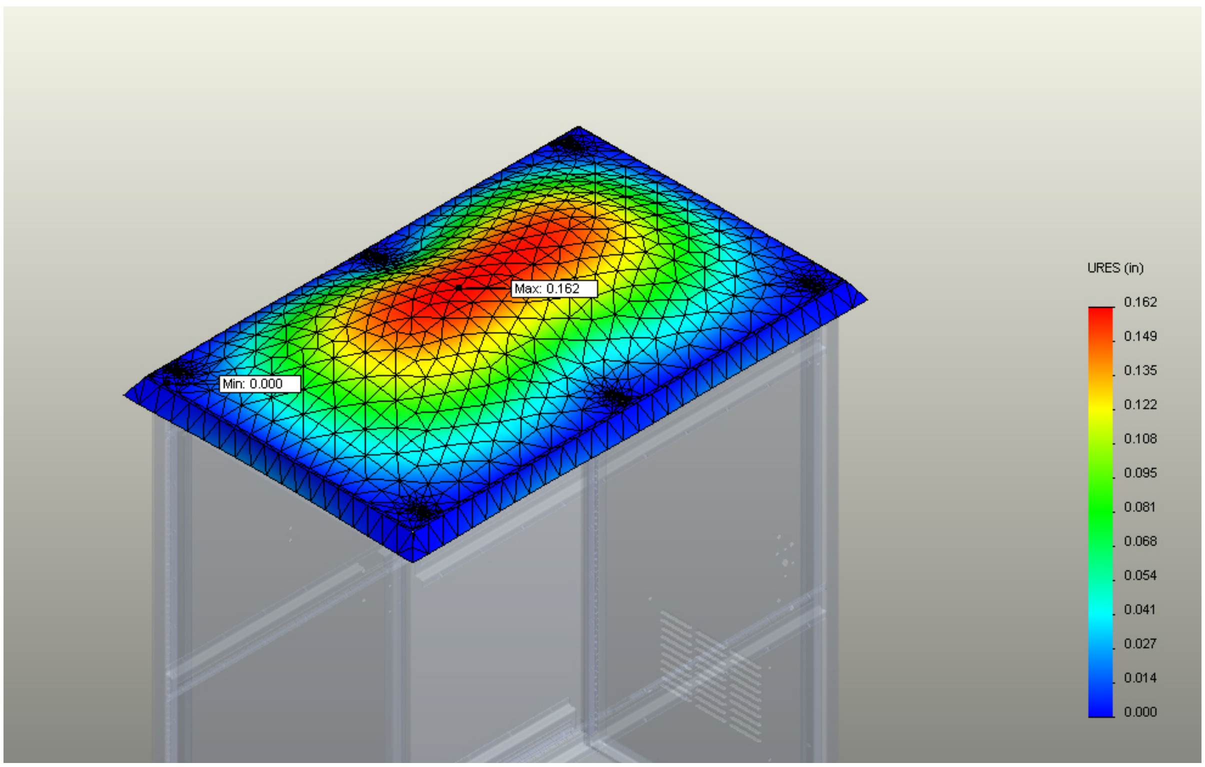

Figure 7: Max Deflection on OD Enclosure in 150MPH Winds

Stresses

The maximum primary membrane stress is 11.9 ksi.

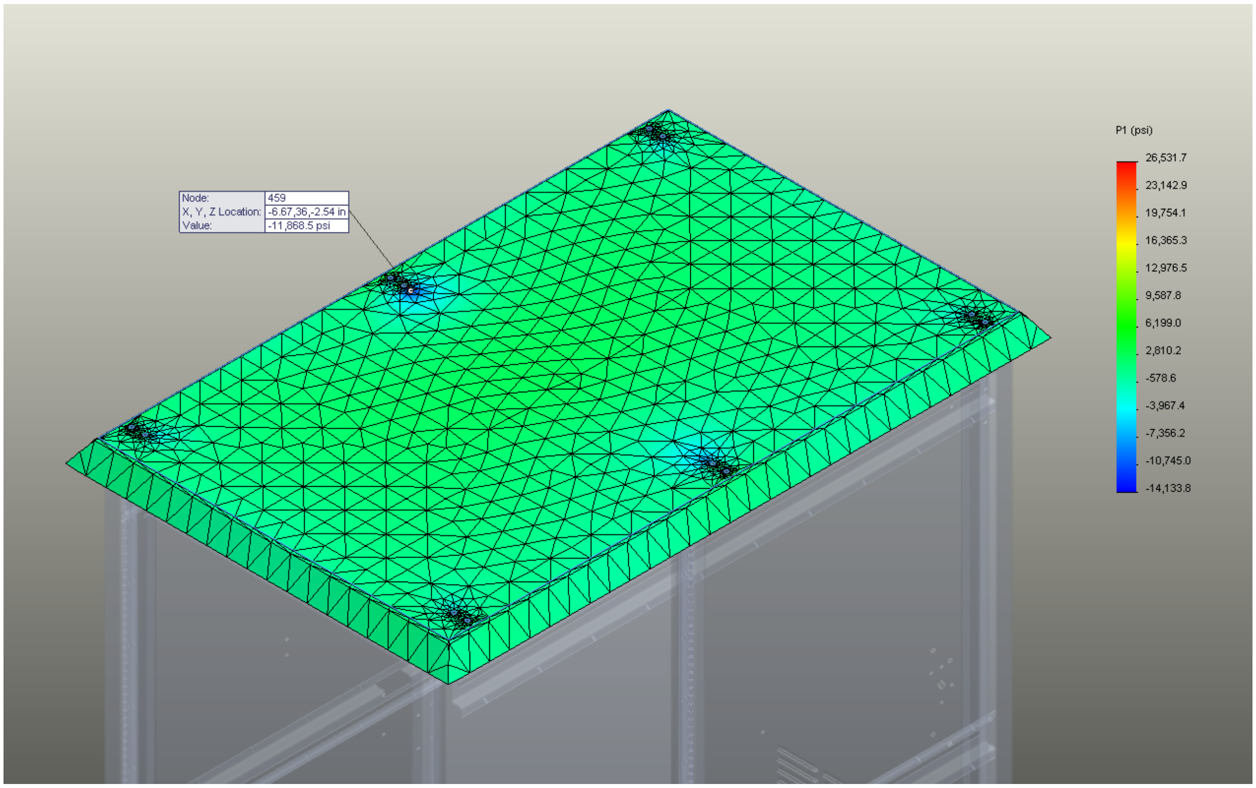

Figure 8: Max P1 on OD Enclosure in 150MPH Winds

The maximum von Mises membrane stress is 14.6 ksi.

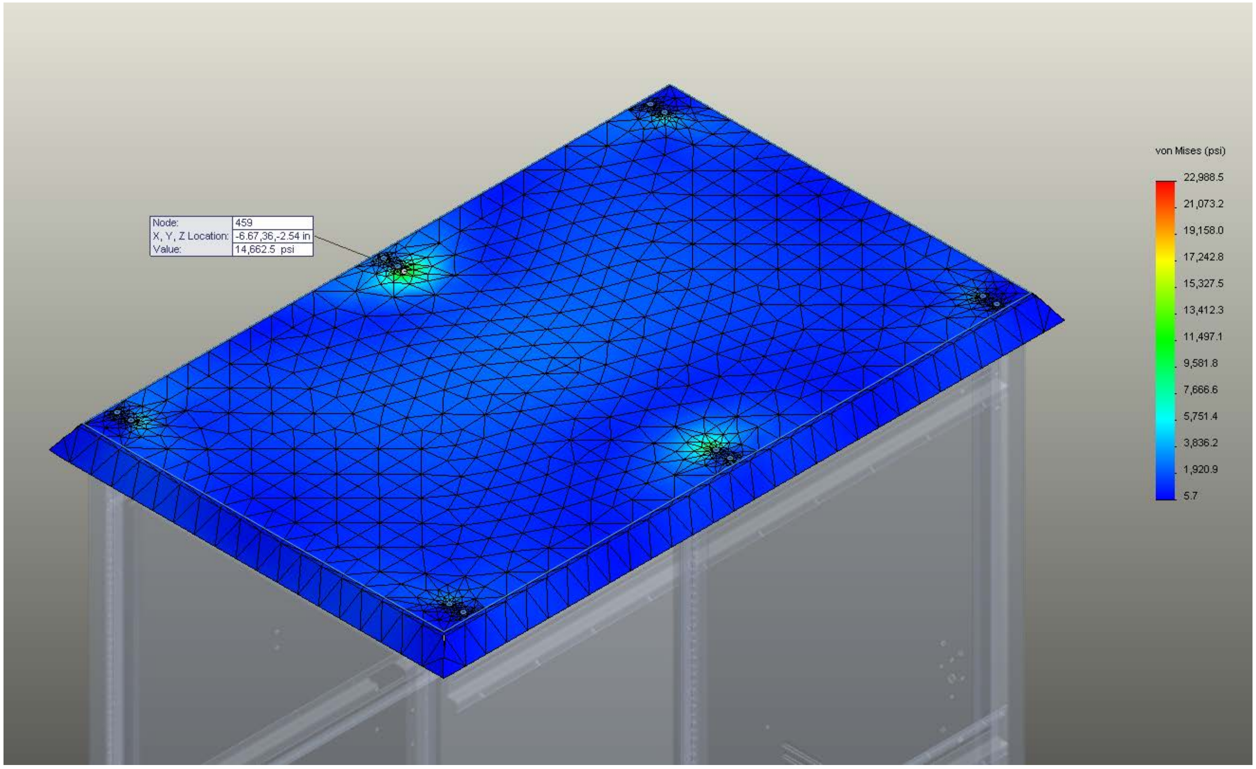

Figure 9: Max von Mises on OD Enclosure in 150MPH Winds

The maximum pin connector tensile stress 2 ksi.

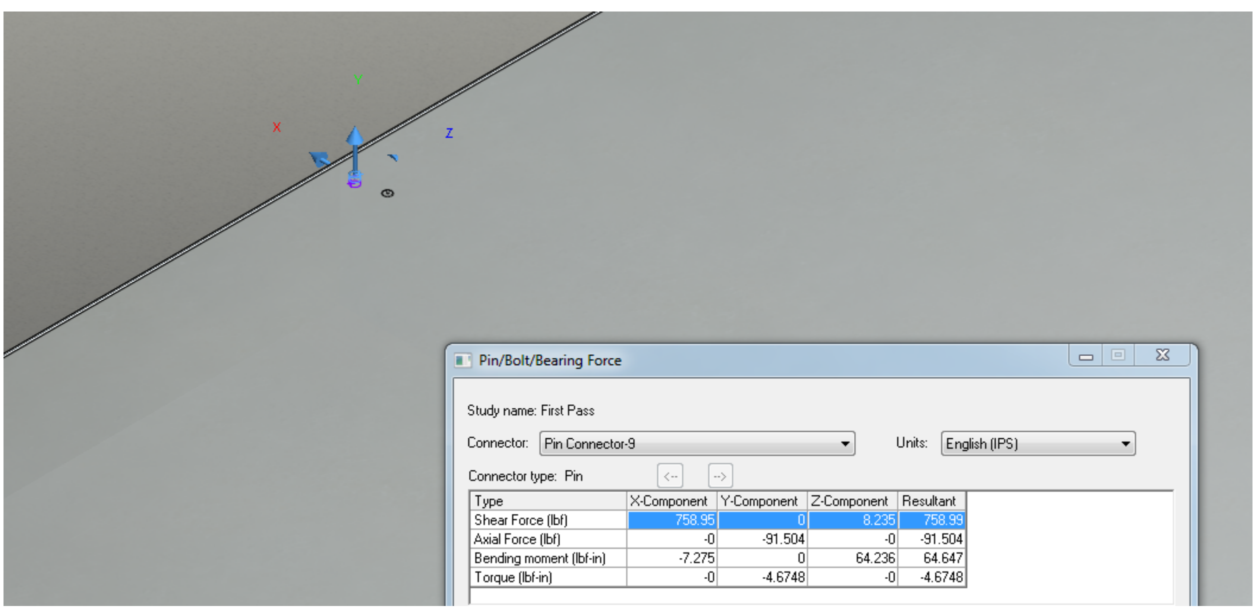

Figure 10: Max Pin Stress on OD Enclosure in 150MPH Winds

Table 3: Stress Summary for OD Enclosure

Requirement	Calculated Value (ksi)	Allowable Stress (ksi)	Calculated FOS	Required FOS	PASS/FAIL
General Stress	11.9	33	2.8	2	PASS
Local Stress	14.6	33	2.3	2	PASS
Rivet Stress	2	33	16.5	2	PASS

Conclusion for OD (Single) Enclosure:

Based on the analysis presented, the OD (Single) enclosure meets all the requirements for structural integrity.

Results for 2OD Enclosure

Forces

The lifting component on the 2OD Alumashield is 487 lbs.

Table 4: Resultant Loads on 2OD Alumashield

Units	Sum X	Sum Y	Sum Z	Resultant
lbf	-18.074	-487.307	8.68047	487.719

Deflection

The maximum deflection on the 2OD Alumashield is 0.854 in.

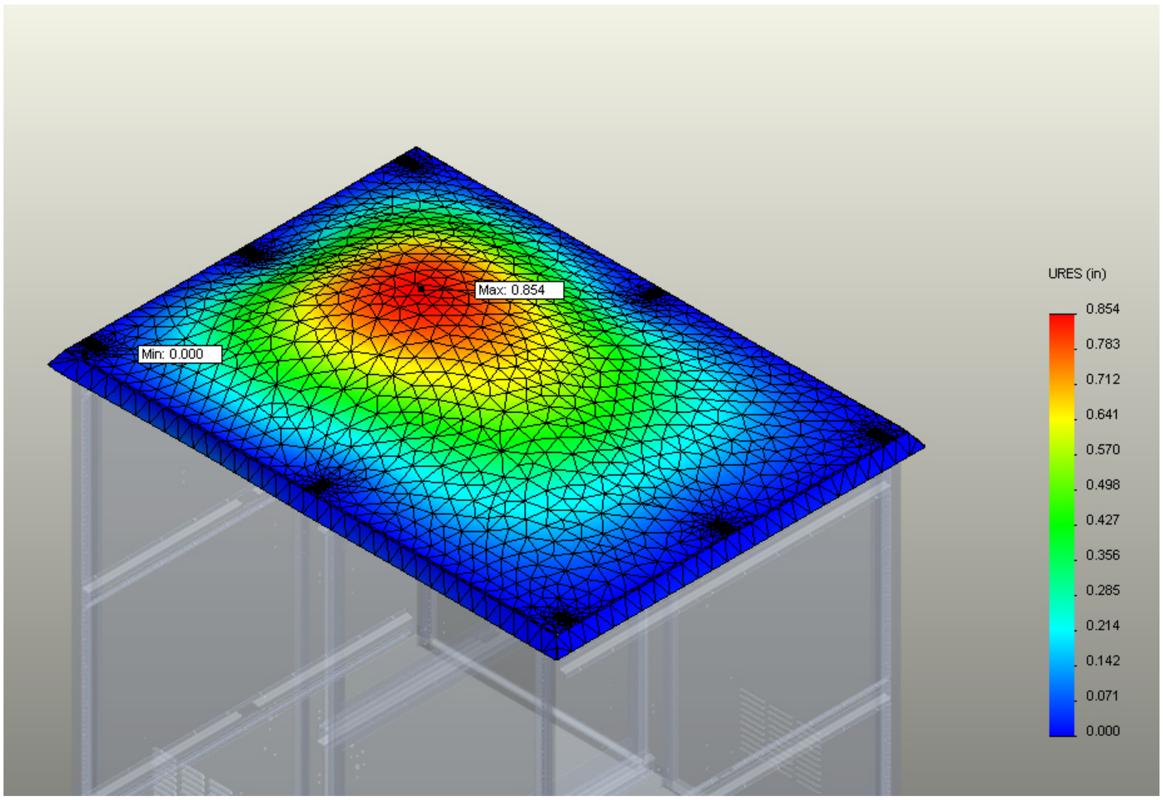

Figure 11: Max Deflection on 2OD Enclosure in 150MPH Winds

Stresses

(see appendix for plots)

Table 5: Stress Summary for 2OD Enclosure

Requirement	Calculated Value (ksi)	Allowable Stress (ksi)	Calculated FOS	Required FOS	PASS/FAIL
General Stress	13.4	33	2.5	2	PASS
Local Stress	13.6	33	2.4	2	PASS
Rivet Stress	3.3	33	10	2	PASS

Conclusion for 2OD Enclosure:

Based on the analysis presented, the 2OD enclosure meets all the requirements for structural integrity.

Results for 3OD Enclosure

Forces

The lifting component on the 3OD Alumashield is 516 lbs.

Table 6: Resultant Loads on 3OD Alumashield

Units	Sum X	Sum Y	Sum Z	Resultant
lbf	-22.3315	-515.765	1.00452	516.249

Deflection

The maximum deflection on the 3OD Alumashield is 1.134 in.

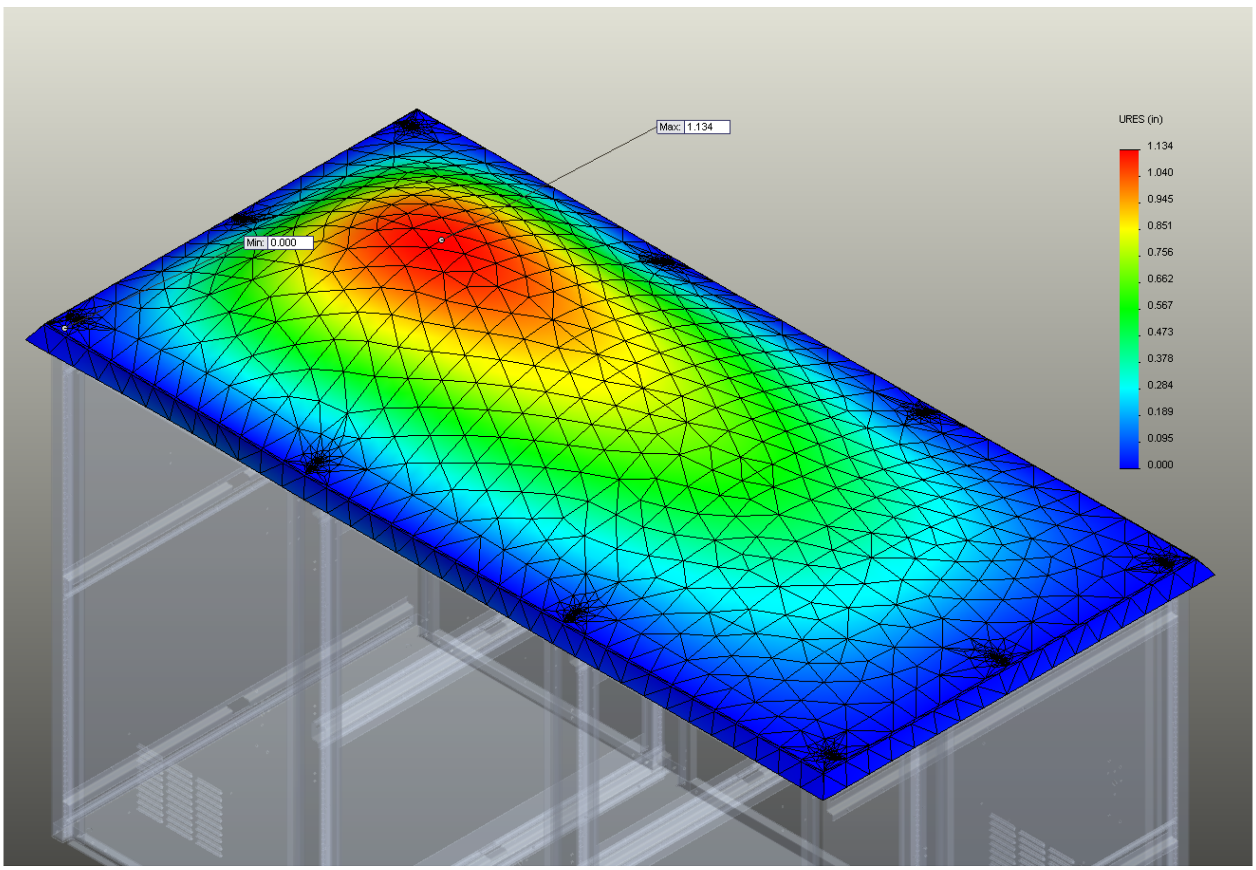

Figure 12: Max Deflection on 3OD Enclosure in 150MPH Winds

Stresses

(see appendix for plots)

Table 7: Stress Summary for 3OD Enclosure

Requirement	Calculated Value (ksi)	Allowable Stress (ksi)	Calculated FOS	Required FOS	PASS/FAIL
General Stress	14.2	33	2.3	2	PASS
Local Stress	16.4	33	2.0	2	PASS
Rivet Stress	5.5	33	6	2	PASS

Conclusion for 3OD Enclosure:

Based on the analysis presented, the 3OD enclosure meets all the requirements for structural integrity.

Overall Summary

All three OD enclosures meet the requirements for stress and thus should be fit for service.

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Appendix B – Pin Stress Calculations (Rivet Strength)

$$\sigma_b = \frac{F_b}{A_t}$$

where:

A_t = pin tensile area (based on the min diameter) [in^2]

F_b = pin force [lbs]

σ_b = pin stress [psi]