STRUCTURAL ANALYSIS
OF
200 MPH WIND RATED
ALUMASHIELD UPGRADE OPTION
FOR
OD, 2OD, & 3OD ENCLOSURES

Prepared for:

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August 5, 2016

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Executive Summary

On December 1, 2011, SolidBox published a report regarding a series of structural analyses that were conducted on the OD, 2OD, & 3OD (Outdoor) enclosures to verify their integrity in high-wind conditions, specifically winds up to 150MPH. Since the publication of the original report, the ASCE has updated its Basic Wind Speeds charts to reflect increases in overall wind speed. The peak design wind speeds have increased from 150MPH to 181MPH, per ASCE 7-10. As a result, DDB contracted SolidBox to reanalyze its enclosures for these higher wind speeds. Initial findings of the analysis showed loads and stresses near the conservative, self-imposed, limits requested by DDB. SolidBox suggest slight modifications to the Alumashield brackets, rivets, and mounting hardware. DDB created an upgrade option to the Alumashield cover specifically for locations where the peak sustained wind speed can exceed 150MPH. This report details the steps taken to verify compliance of the upgraded Alumashield cover. This analysis proves that the upgraded Alumashield covers for the OD, 2OD, & 3OD enclosures are safe for operation in winds up to 200MPH.

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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 upgraded Alumashield covers for the OD, 2OD, & 3OD are safe for operation in winds up to 200MPH. The 200MPH value is chosen as it is 19MPH higher than the highest value of the wind speed specified by the most recent International Building Council code (ACSE 7-10).

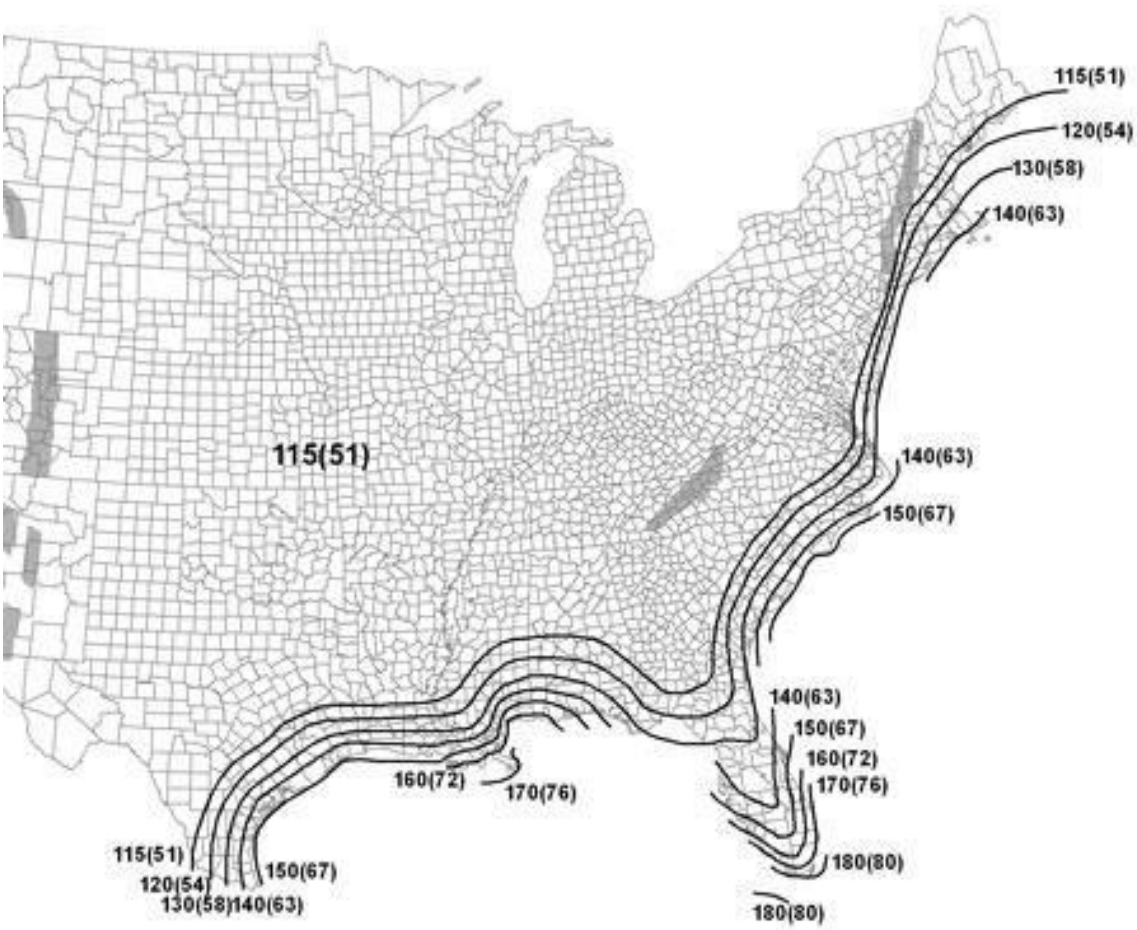

Figure 1: Updated IBC Basic Wind Speeds (ASCE 7-10)

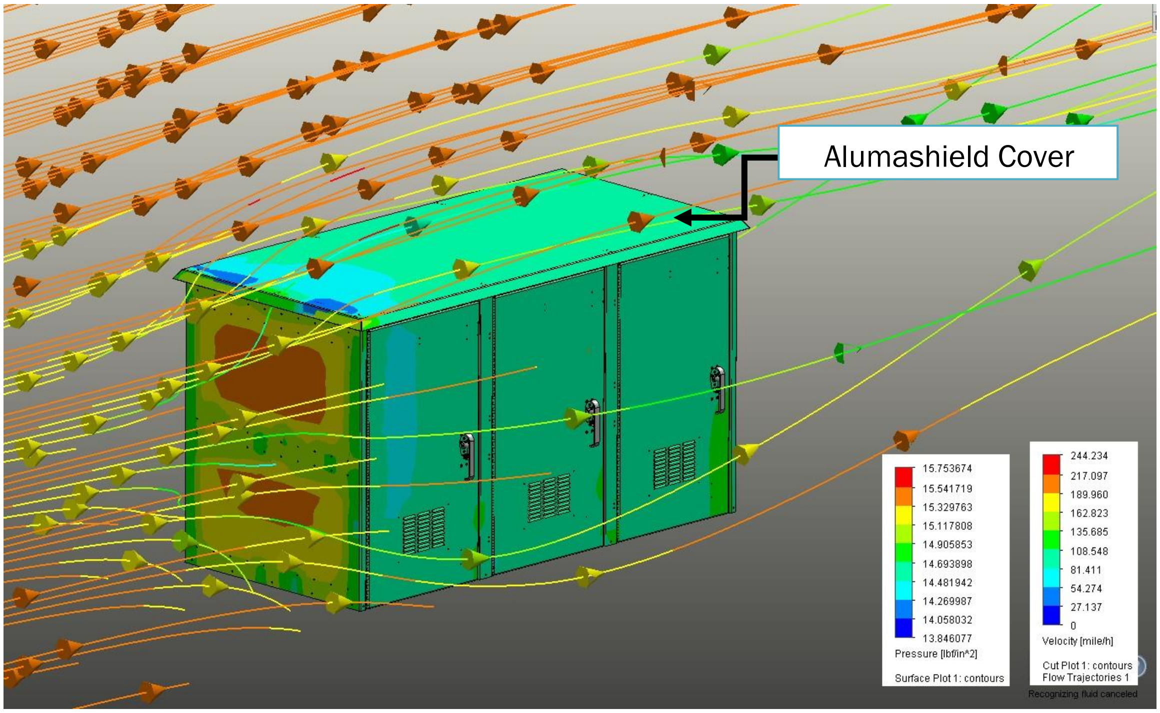

Figure 2: 3OD Enclosure in 200MPH Winds

Analysis

This analysis uses Computational Fluid Dynamics (CFD) software to determine the pressures exerted on each surface of the OD enclosures during sustained 200MPH 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 2016 SP2.0. 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 Xdirection 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 200MPH 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.

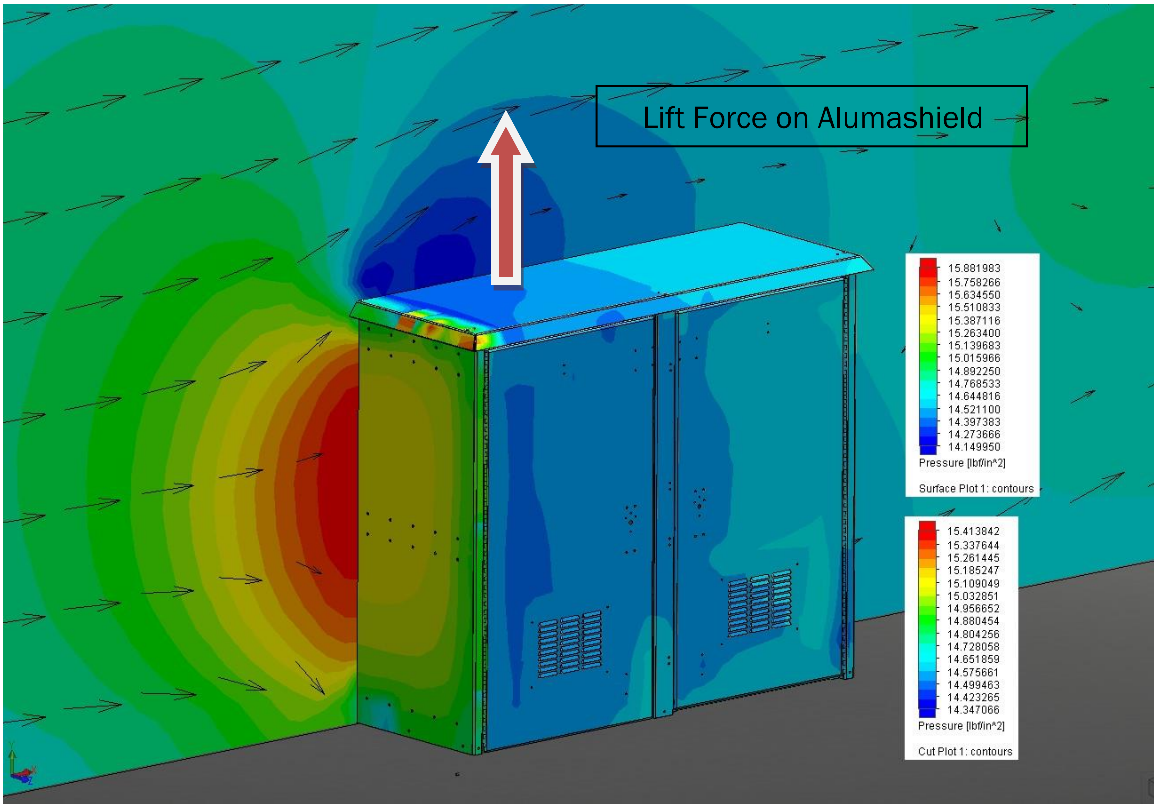

Figure 3: 2OD Surface Pressures in 200MPH Winds

Finite Element Analysis Software (Numerical Method)

The FEA software used in this analysis is SolidWorks Simulation Premium, version 2016 SP2.0. 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 riveted connection of the Alumashield brackets to the Alumashield cover. The pin connectors allow the rivet 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).

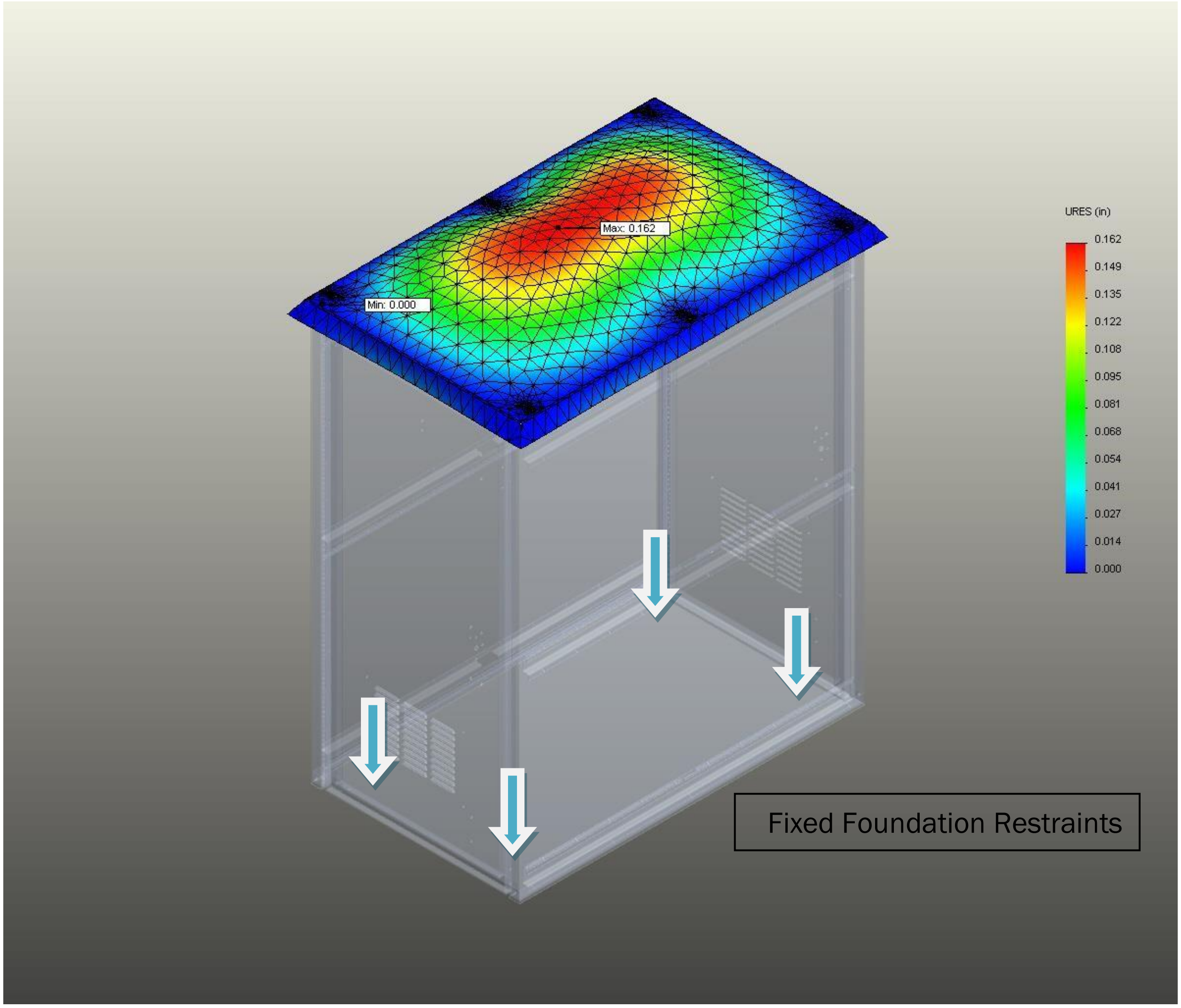

Figure 4: OD Enclosure Fixed Restraints for FEA (Image from 150MPH Study)

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

<u>Loads & Pressures</u>

Primary Loads & Pressures: There are two major components of force that result from the pressures exerted by the 200MPH wind loads. The most critical is the lifting force applied on the Alumashield cover 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 Alumashield brackets into tension.

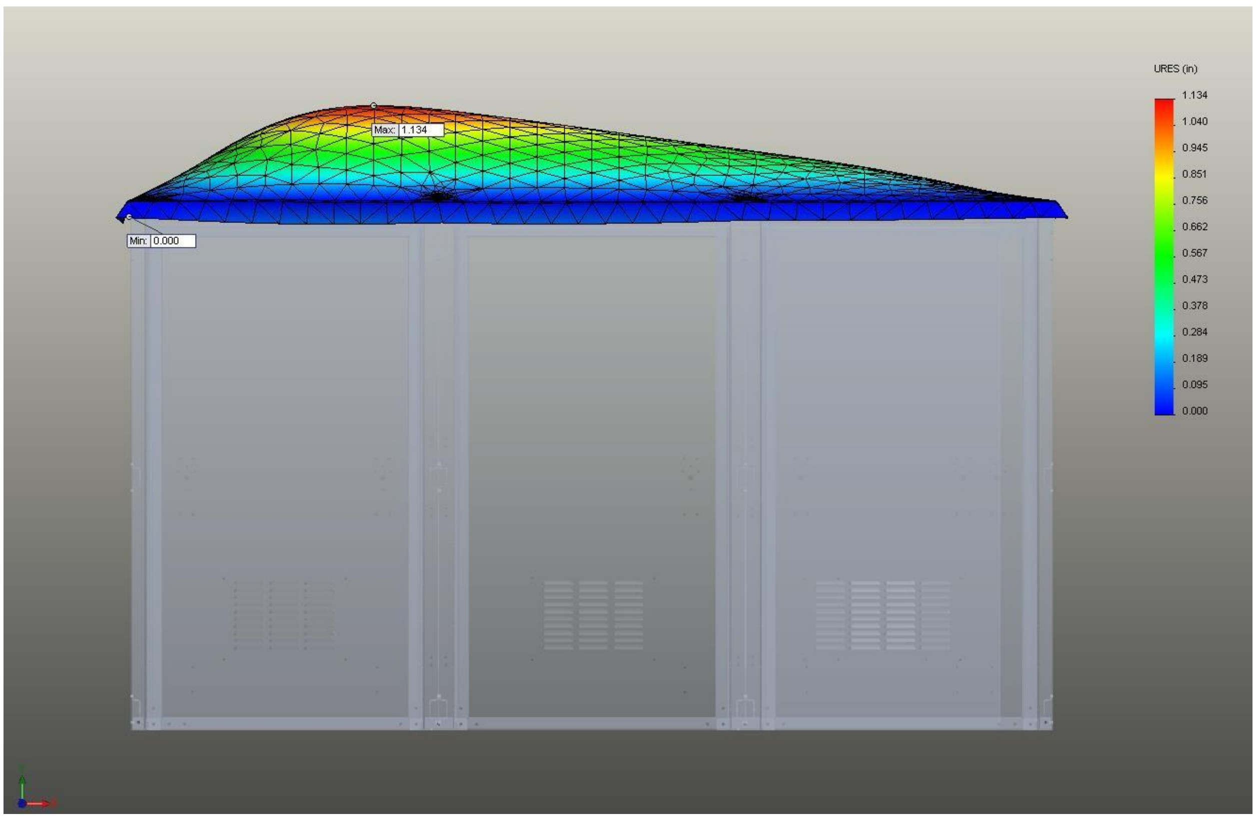

Figure 5: Alumashield Panel Deflection on 3OD (Image from 150MPH Study)

The lateral loads imposed on the side panels are highest on the Single OD enclosure. The worst case value is approximately 1,050 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.

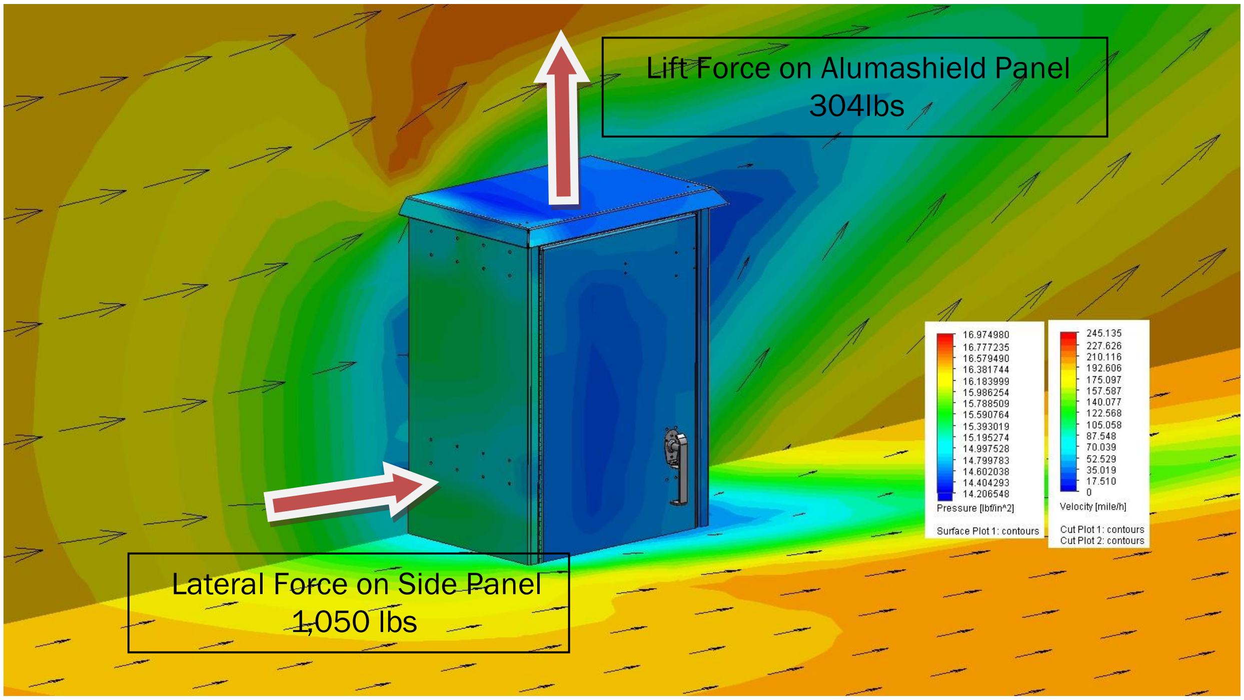

Figure 6: Lateral Pressure on OD Enclosure in 200MPH Winds

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:

$2P_1 \square S$

Local Failure Requirements:

$2P_{vm} \square S$

Rivet Failure Requirements:

$2P_{bolt} \square S$

where:
P_1 = General primary von Mises equivalent membrane stress
P_{vm} = Local primary membrane 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 304 lbs.

Table 2: Resultant Loads on OD (Single) Alumashield

Units	Sum X	Sum Y	Sum Z	Resultant
lbf	3.3	303.8	2.4	303.8

Deflection

The maximum deflection on the OD Alumashield is 0.298 in.

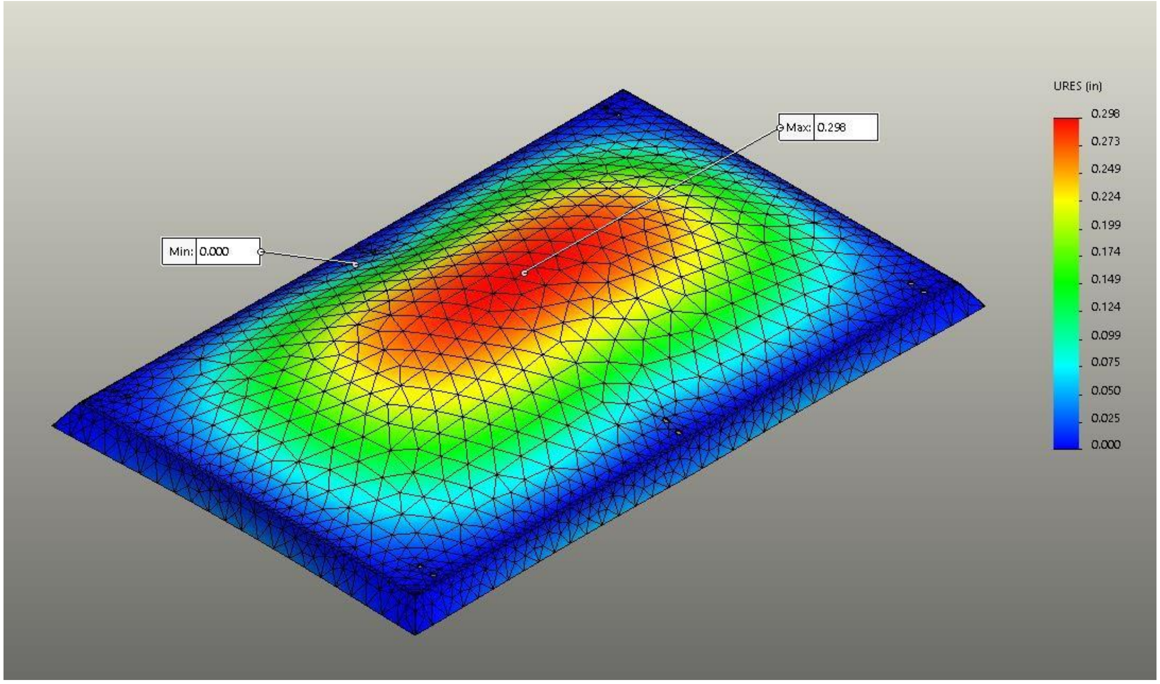

Figure 7: Max Deflection on OD Enclosure in 200MPH Winds

Stresses

The maximum primary membrane stress is 3.0 ksi.

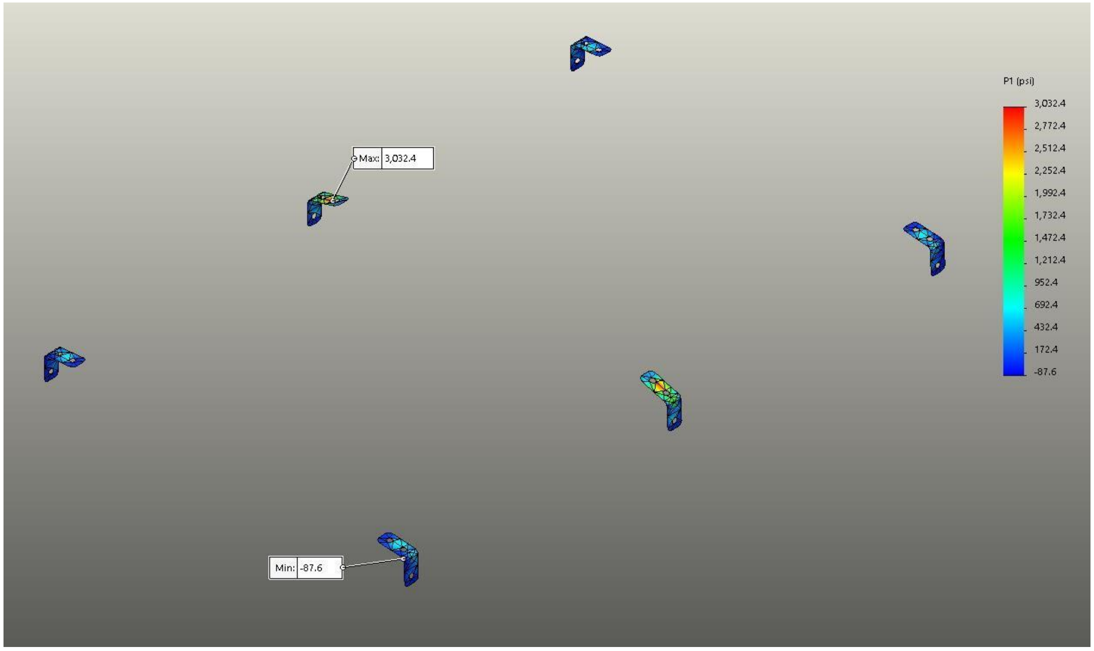

Figure 8: Max P1 on OD Enclosure in 200MPH Winds

The maximum von Mises membrane stress is 2.5 ksi.

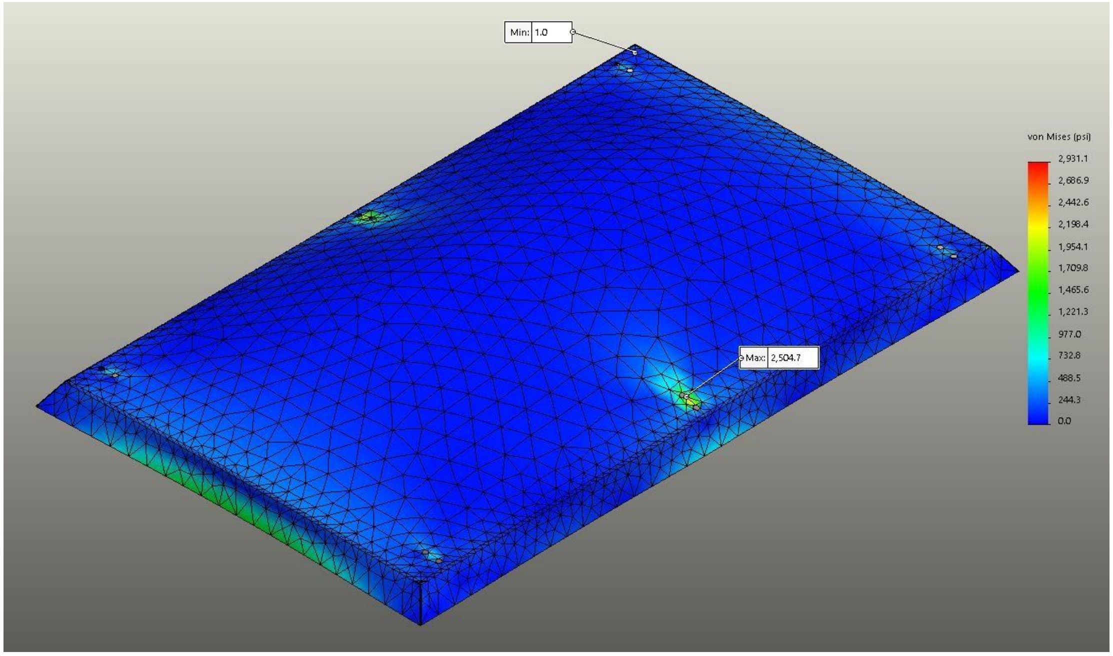

Figure 9: Max von Mises on OD Enclosure in 200MPH Winds

The minimum rivet FOS is 2.9

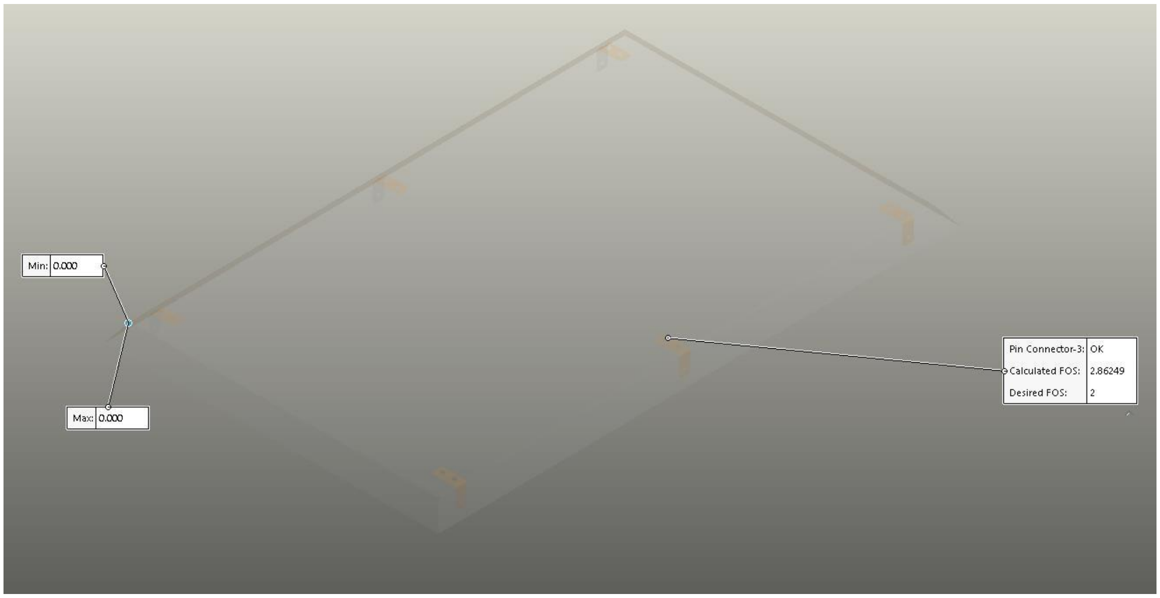

Figure 10: Max Pin Stress on OD Enclosure in 200MPH Winds

Table 3: Stress Summary for OD Enclosure

Requirement	Calculated Value (ksi)	Allowable Stress (ksi)	Calculated FOS	Required FOS	PASS/FAIL
General Stress	2.5	33	13.2	2	PASS
Local Stress	3.0	33	11	2	PASS
Weakest Rivet	11.4	33	2.9	2	PASS
Weakest Fastener	0.7	33	46	2	PASS

Conclusion for OD (Single) Enclosure:

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

Results for 2OD Enclosure

Forces

The lifting component on the 2OD Alumashield is 597.3 lbs.

Table 4: Resultant Loads on 2OD Alumashield

Units	Sum X	Sum Y	Sum Z	Resultant
lbf	1.3	597.3	0.7	597.3

Deflection

The maximum deflection on the 2OD Alumashield is 1.454 in.

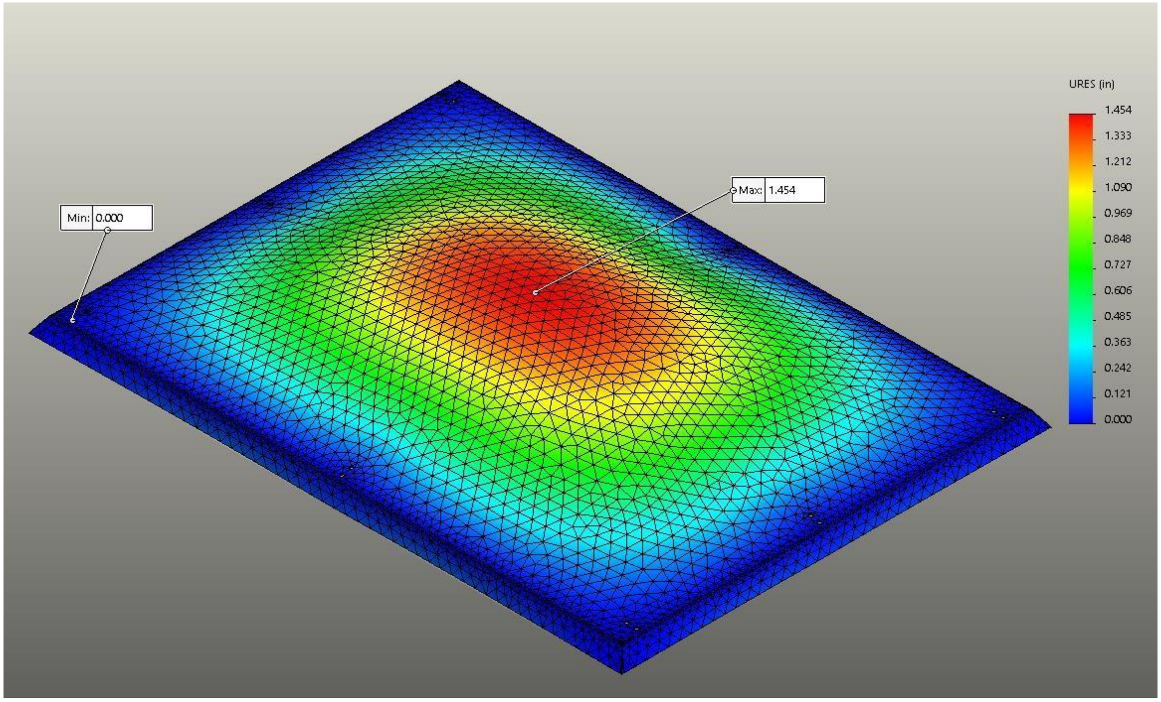

Figure 11: Max Deflection on 2OD Enclosure in 200MPH Winds

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	7.6	33	4.3	2	PASS
Local Stress	8.9	33	3.7	2	PASS
Weakest Rivet	11	33	3.0	2	PASS
Weakest Fastener	1.4	33	23.7	2	PASS

Conclusion for 2OD Enclosure:

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

Results for 3OD Enclosure

Forces

The lifting component on the 3OD Alumashield is 619 lbs.

Table 6: Resultant Loads on 3OD Alumashield

Units	Sum X	Sum Y	Sum Z	Resultant
lbf	32.1	618.3	1.3	619.1

Deflection

The maximum deflection on the 3OD Alumashield is 1.407 in.

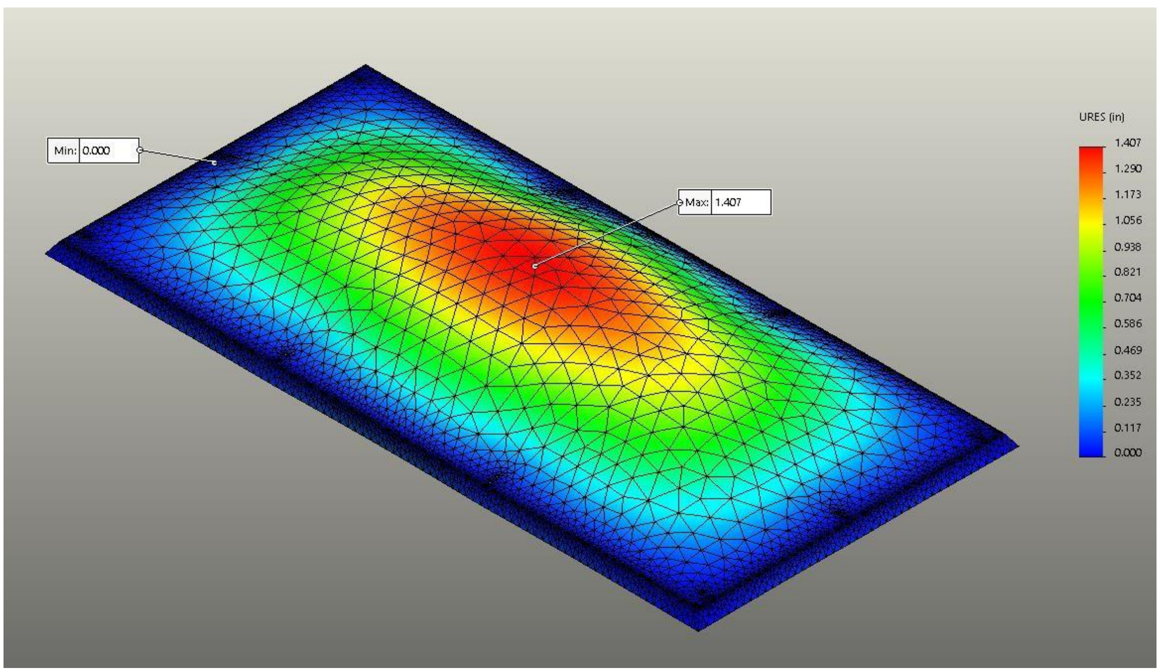

Figure 12: Max Deflection on 3OD Enclosure in 200MPH Winds

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	7.4	33	4.5	2	PASS

Local Stress	7.5	33	4.4	2	PASS
Weakest Rivet	9.5	33	3.5	2	PASS
Weakest Fastener	0.9	33	36.7	2	PASS

Conclusion for 3OD Enclosure:

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

Overall Summary

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

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Appendix A

CFD & FEA Results (OD)

https://mysolidbox.sharefile.com/d-sf9a7265473d484a9

CFD & FEA Results (2OD)

https://mysolidbox.sharefile.com/d-s1d2787c9f2247cfb

CFD & FEA Results (3OD)

https://mysolidbox.sharefile.com/d-s47d11c99c61450c8

Appendix B – Pin/Fastener Shear Stress Calculations

F_b ___

□$_b$ □

A_t

where:

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

F_b = pin force [lbs]

$\square_b$ = pin stress [psi]

Reference List

- Minimum Design Loads for Buildings and Other Structures (ASCE/SEI 7-10) (2013). American Society of Civil Engineers.
- 2012 International Building Code (2012). International Code Council.