DESIGN OF AN ACCUMULATOR CONTAINER FOR A FORMULA SAE ELECTRIC RACECAR

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A. Introduction

The purpose of this document is to design an accumulator container for the RF21 Electric car, for the Ryerson Formula Racing FSAE Team. Design, Simulation, and FEA will be done on Solidworks 2020, and Solidworks 2021.

B. Requirements

- Must satisfy all rules for 2021 FSAE Rulebook (check "Relevant Rules" section)
- Must accommodate for the following components/systems:
    - Battery Management System or Accumulator Management System (AMS)
    - Accumulator Isolation Relays (AIR's)
    - Cooling fans
    - Voltage indicator
    - Safety shutdown circuit
    - Maintenance plugs
    - Insulation Monitoring Device (IMD)
    - Energy Meter
    - Venting for cooling systems
- Must satisfy all team goals
    - Reliability
    - Serviceability
    - Manufacturability
    - Driveability

1. Design

As per the calculations shown in the Battery Data Chart, for the Samsung 30Q battery, we will need about 6 segments, with about 138 battery cells per segment.

1.1 Initial Draft

A rough draft was made that was estimated to be big enough to hold all the cells in place.

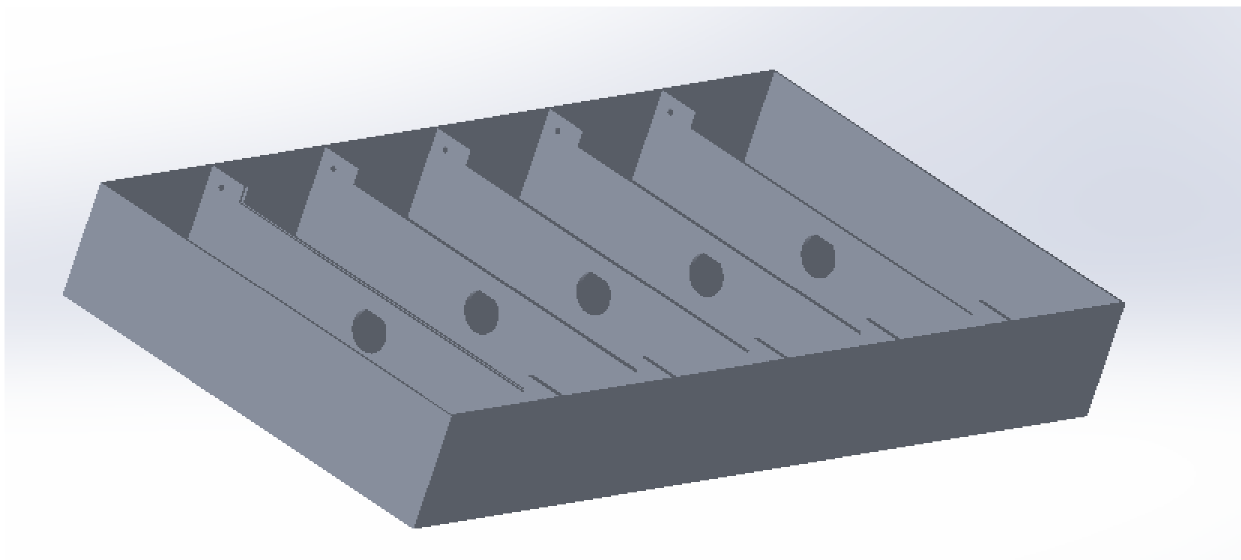

Figure 1.1: Draft #1 of the initial Accumulator Container

Update (January 24th): Setbacks were made after rules were discovered about the overcurrent protection needed on the individual battery cells. Once that was finalized, a new battery was chosen (Samsung 30Q), from which a battery module was made, meant to become a single segment. Calculations were made to make 7 segments for a single accumulator. After another meeting with the team captain and other members in the accumulator design team, a lot of decisions were finalized, and a list of everything that wasn't finalized was made.

Things that were finalized:

- Firstly, other new materials were also intended to be explored, such as 1020 steel and 1040 steel.

- The accumulator and its segments will be one welded structure, unlike the previous version, which was 6 individual segments that would be bolted together. This would improve serviceability (no need to waste time disassembling segments, just unplug module from maintenance plug and remove from container), and would also improve manufacturability (cheaper, no need for bolts). Even though welding would be weaker than fasteners from fatigue loading, this can be taken care of during manufacturing.
- All electronics would be mounted in it's own separate "segment" that would be inside the container. This would ensure proper insulation (good for competition rain test) for all the electronics and its wiring.

The purpose of this rough draft was to do a material weight comparison, between the different types of aluminum or steel. It may seem logical to use aluminum due to its lower weight, but as per the rules, aluminum must be of a thicker material compared to steel, if aluminum is the choice (3.25mm thick for aluminum vs. 1.5mm thick for steel). Also, we must investigate the different types of aluminum and steel. Hence, some analysis must be done.

The first step was to find the weight difference between the different series of aluminum and steel. The material choices are as follows:
- 6061 Aluminum
- 6063 Aluminum
- 7075 Aluminum
- 4340 Steel
- 4130 Steel
- Stainless Steel

The weights of the accumulators with each of their weights are given below.

Material	**Mass**
6061 Aluminum	7.19 kg
6063 Aluminum	7.19 kg
7075 Aluminum	7.19 kg
4340 Steel	20.77 kg

4130 Steel	20.77 kg
Cast Stainless Steel	20.77 kg
Chrome Stainless Steel	20.77 kg
Wrought Stainless Steel	20.77 kg

Based on the data from the table above, the aluminum container has a mass of 11.58kg, and the steel container has a mass of 12.24 kg.

1.2 Final Draft

The final draft of the accumulator container is shown below in Figure 1.2, and the final draft of the accumulator with all its components are shown below in Figure 1.3.

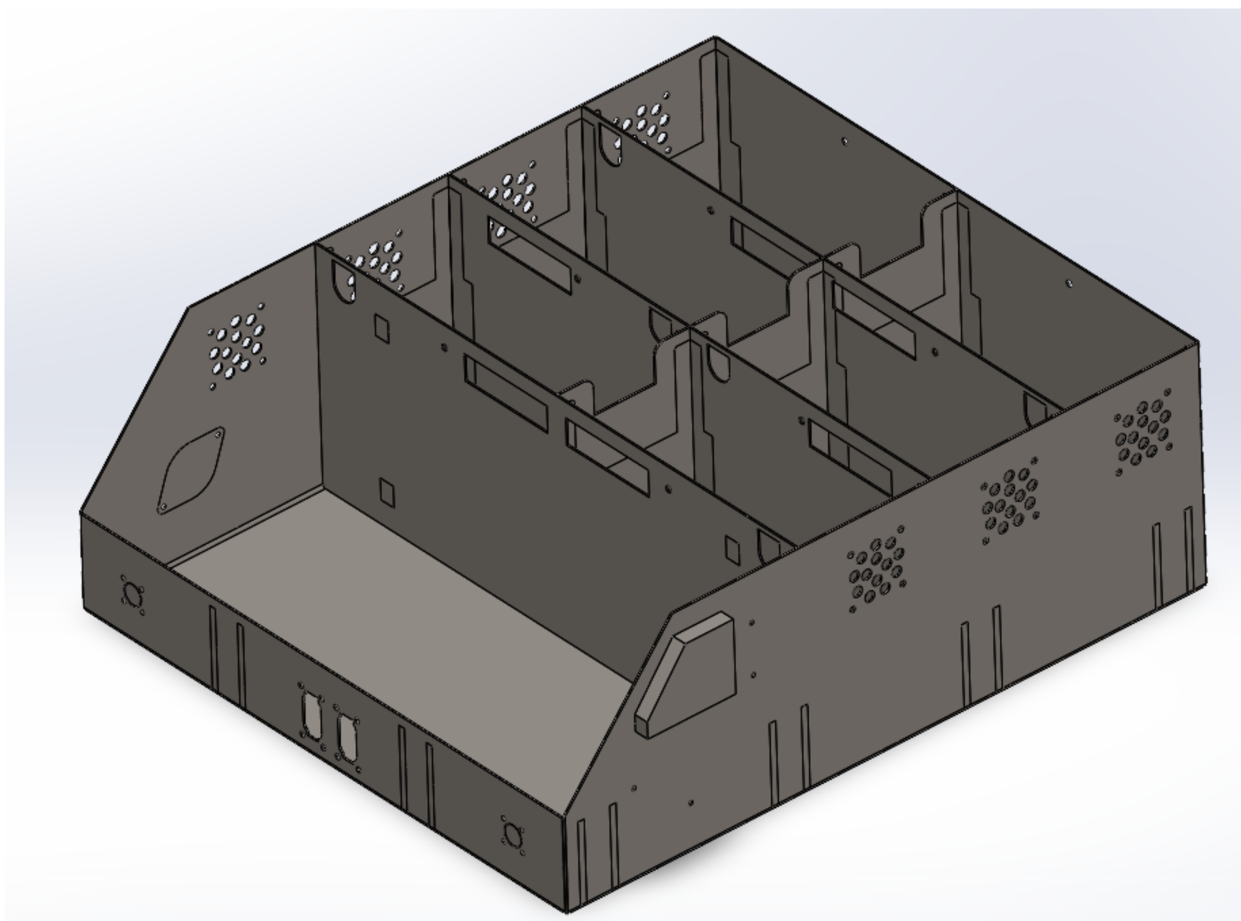

Figure 1.2: Final Draft of the Accumulator Container

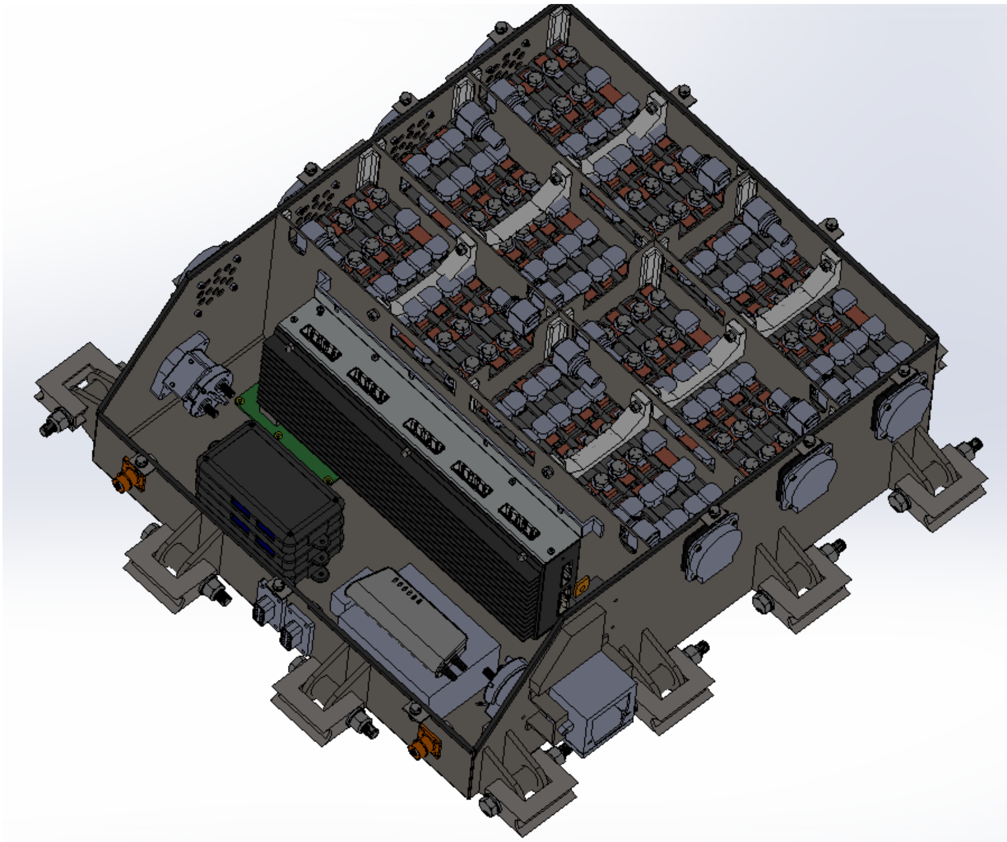

Figure 1.3: Accumulator Container with all components and chassis mounts

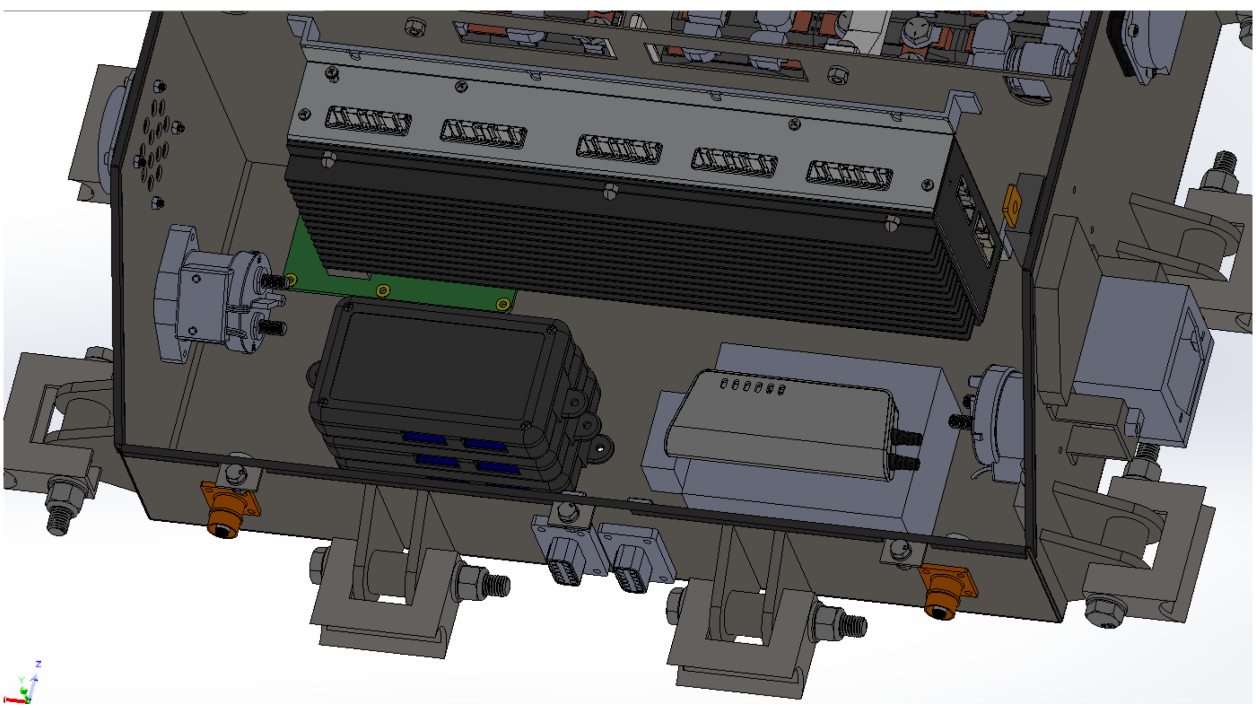

Figure 1.4: Accumulator Container 7th segment with all components

Changes from the first draft include adding an additional section, along with the 6 segments for each of the battery pack segments, inside the accumulator container to house extra components that would be required to run the accumulator and monitor its performance safely, such as the Battery Management System, the Insulation Monitoring Device, the Accumulator Isolation Relays, the Thermistor Expansion Modules, the Energy Meter, the voltage indicator, and all connectors. A close-up of this is shown in Figure 1.4.

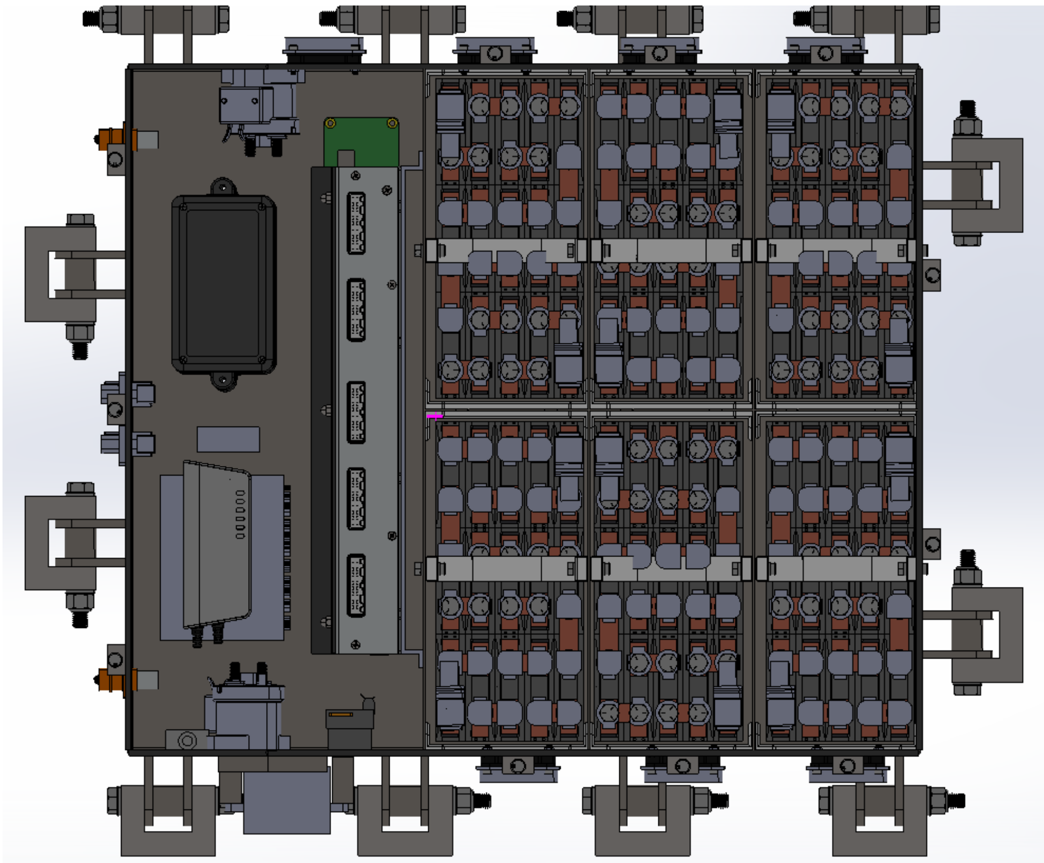

Figure 1.5: Top view of the accumulator container, with battery segments

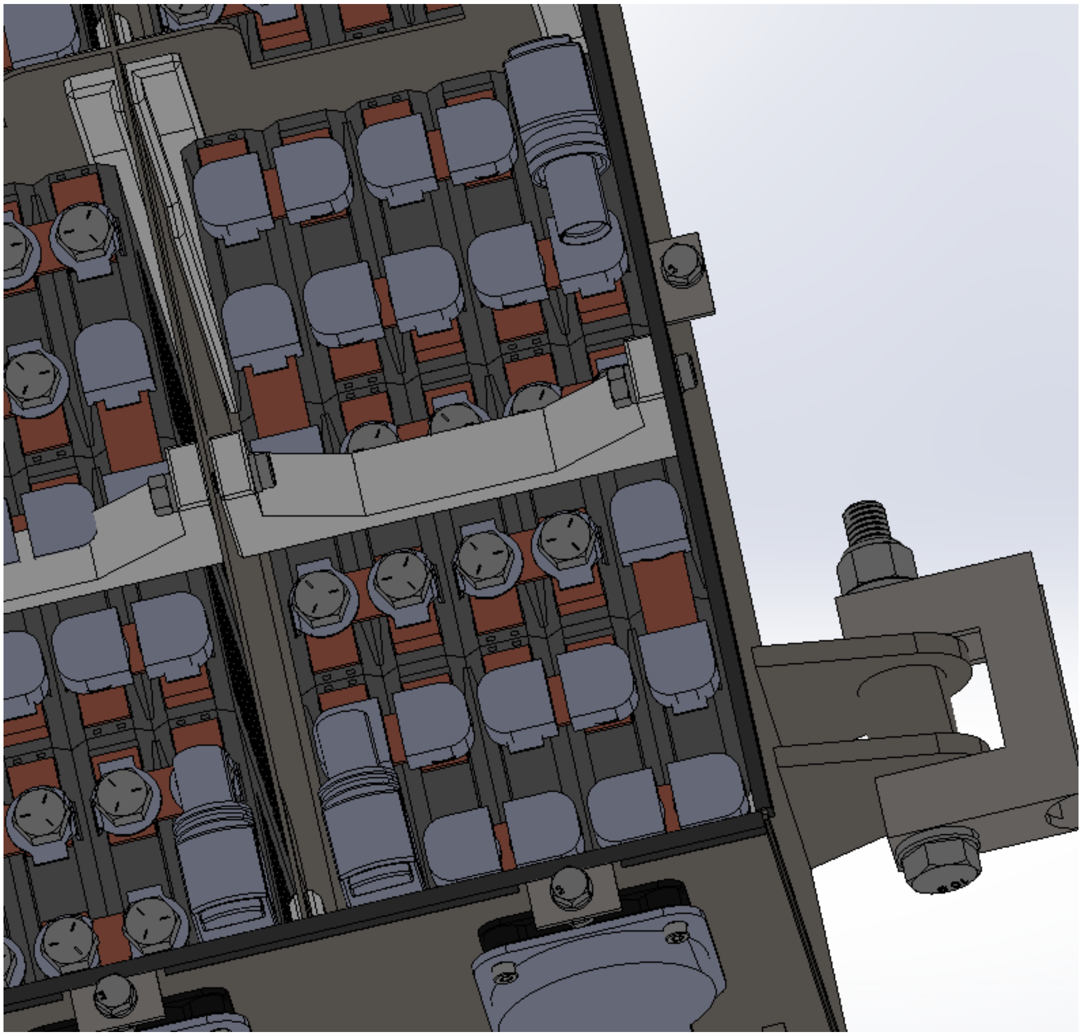

Figure 1.6: Top view of the accumulator container, with battery segments

A small space was left around the perimeter, between each battery segment and its surrounding walls, as shown in Figure 1.6. This space was measured to be the thickness of a human hand, plus an extra 15%, which was around 9.18mm. This was implemented so that a qualified team member could reach in with both hands and be able to lift out each battery segment for servicing.

Also, as shown in Figure 1.6, there are white spacers mounted to each corner of the battery segments. The purpose of these spacers are to prevent any lateral or longitudinal movement of the battery segments within the inner walls. There is also a white mount on the top of each battery segment, similarly shown in Figure 1.6, bolted to the opposite of inner and outer walls, which prevent any vertical movement of the batteries.

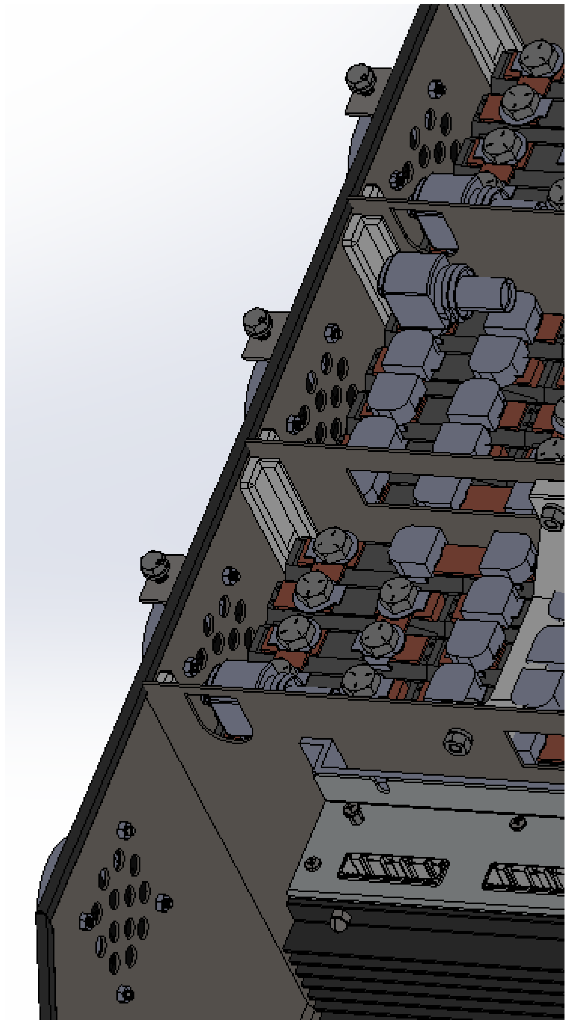

Figure 1.7: Cooling vent holes

Vent holes were made for cooling the batteries, as shown in Figure 1.7, to allow airflow from the atmosphere via the fans to flow through the inner walls of the accumulator container, pushing out any heat radiating from the batteries. The small holes were made to satisfy the rulebook, as any holes on the outer walls cannot be larger than 10mm.

2. <u>Container FEA</u>

Firstly, based on the information initial draft above, a basic list of the useful steels were made:

- 1000-Series Steels (1020, 1040, 1045)
- 4000-Series Steels (4340, 4130, 4140)

As the material strengths of the 1000 series steels, and 4000-series steels were similar, along with the fact that only two materials were tested (1020 and 4130, as both are most commonly available of each of the types of steel), to compare the 1000-series steels, and 4000-series steels.

It was decided that for the load tests, the 3 heaviest components would be used to simulate the forces applied to the container: The battery segments (5.52 kg per segment; 6 segments total), The BMS (2.18 kg), and the 2 AIR's (0.5 kg each). All the other components were significantly lighter, hence they were seen as negligible mass whose forces would not induce significant loads on the container.

2.1 Setup

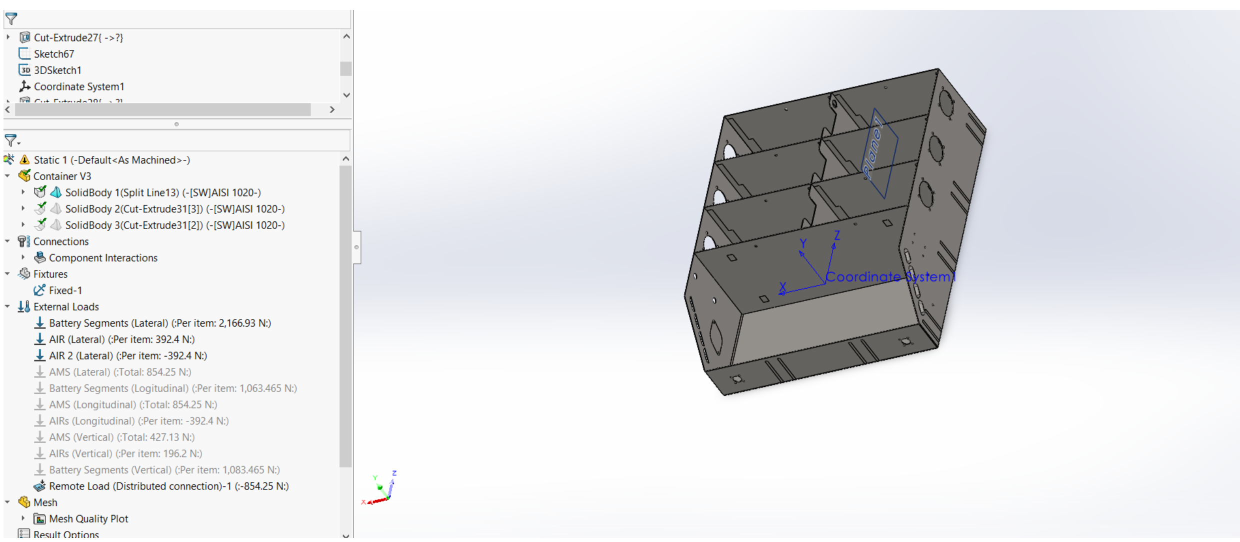

Figure 2.1: FEA Static Test Overall Setup

Firstly, the "Split Line" function was made to implement surface areas where each of the forces would act upon. Figure 2.1 shows the split lines made for the surface areas from which the forces from each of the 6 battery segments would act upon in the lateral direction. Split lines were made on opposite sides of the internal walls, as simulations were done in the positive and negative X-axis direction (both sides of the lateral direction). The same was also done for the longitudinal direction (Z-axis), as shown in Figure 2.3 (Just like in the lateral test, both opposite inner walls had identical split lines for both directions of the longitudinal test; forwards and reverse direction loads).

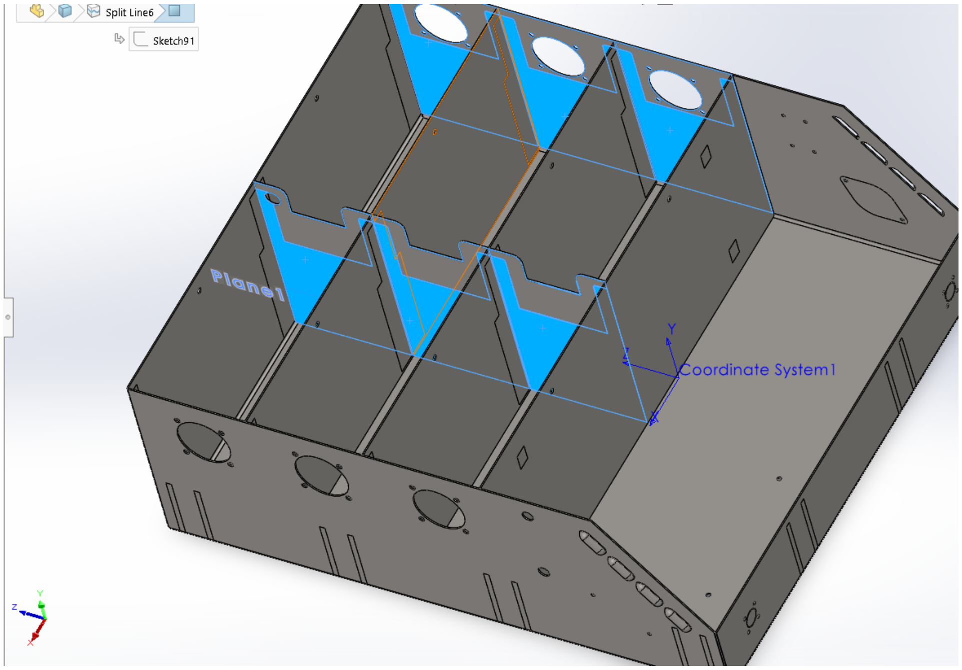

Figure 2.2: Battery Segment Lateral Split Lines Locations

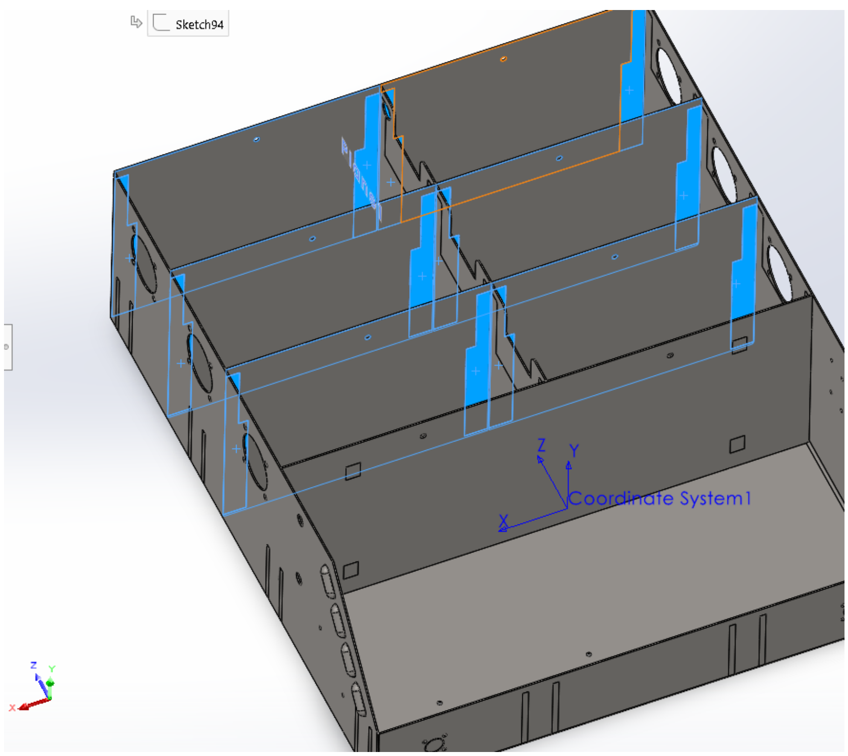

Figure 2.3:Battery Segment Longitudinal Split Lines Locations

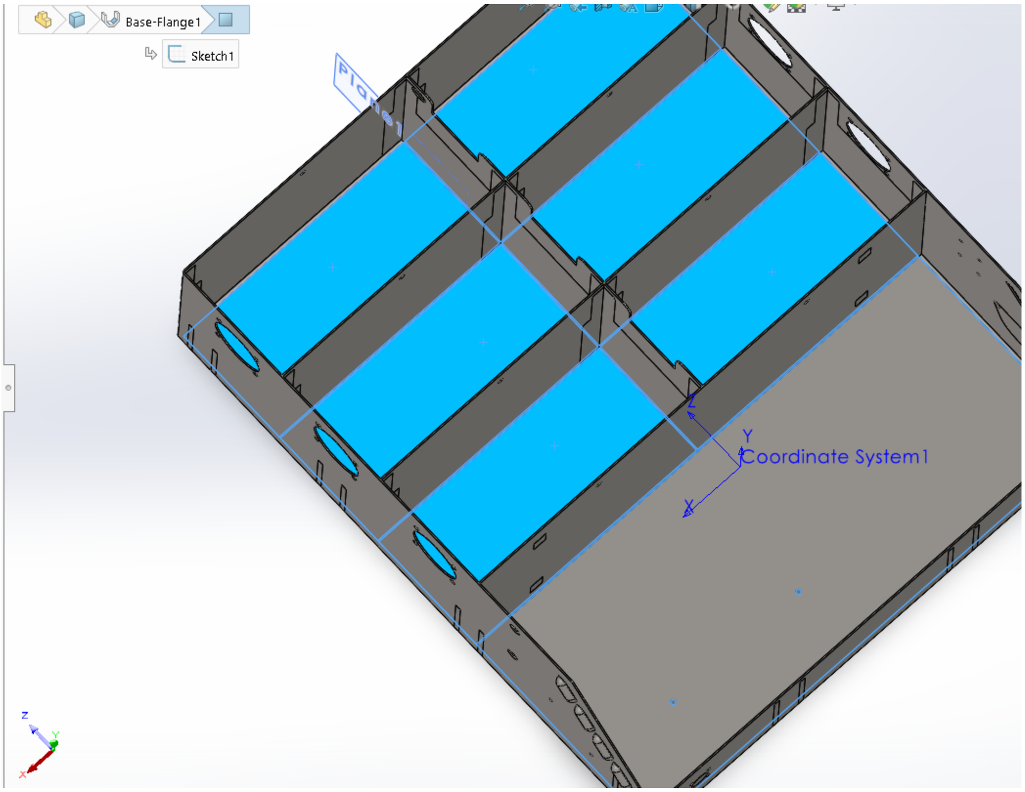

Figure 2.4: Load surfaces for battery segments vertical load test

For the vertical load test in the negative Y-direction, forces from the battery segments would act upon the container floor, as shown in Figure 2.4. While for the vertical load test in the positive Y-direction, forces from the battery segments would act upon the holes made in the inner walls, where bolts would go through to mount the battery segments, as shown in Figure 2.5 (Split lines were made on the holes such that the forces would only act on the top half of the holes, as shown in Figure 2.6).

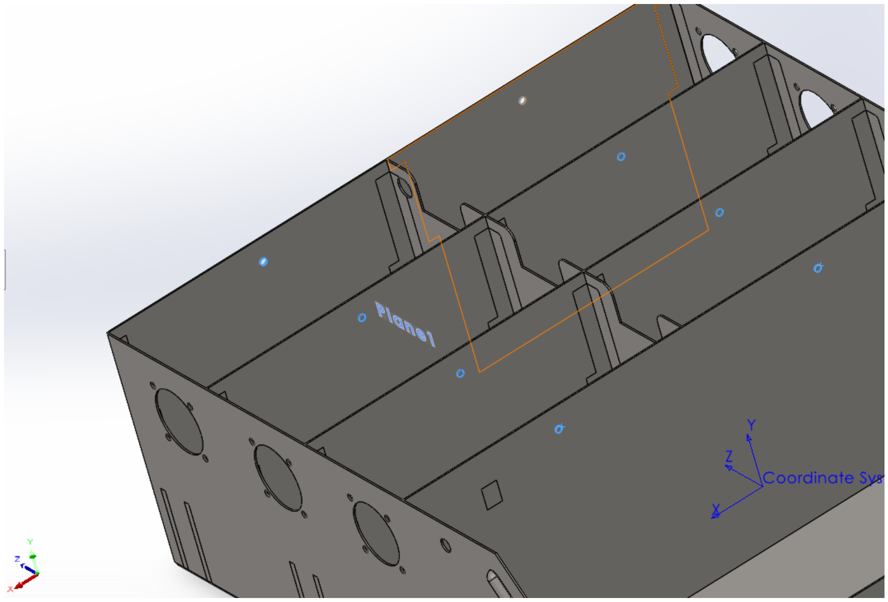

Figure 2.5: Segment mount holes for battery segment vertical load test (highlighted in blue)

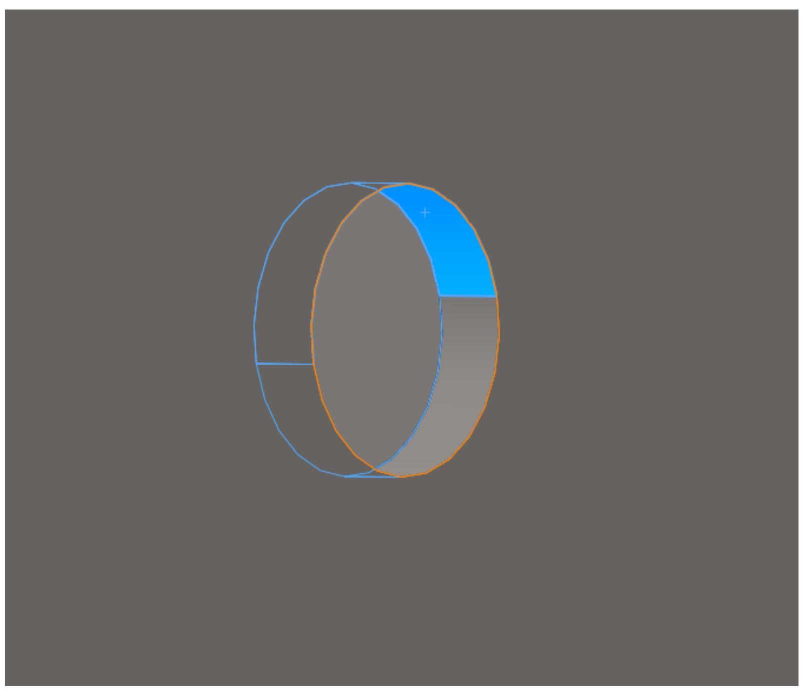

Figure 2.6: Close-up of segment mount hole

Split lines were then made for the surface areas where the forces from the BMS would act upon, as shown in Figure 2.7. These surfaces remain the same for the vertical, longitudinal, and lateral load tests, as the forces will be acting on those surfaces, since the BMS is bolted to mounts that are welded to those surfaces on the inner wall.

The loads from the BMS were made as a remote load, as the forces applied from the weight of the BMS would create a bending moment. Hence, a coordinate system was included in the model of the accumulator container, with the intention to implement a center of gravity location of the container, to include in the remote load parameters (also shown in Figure 2.7, as “CoordinateSystem1”).

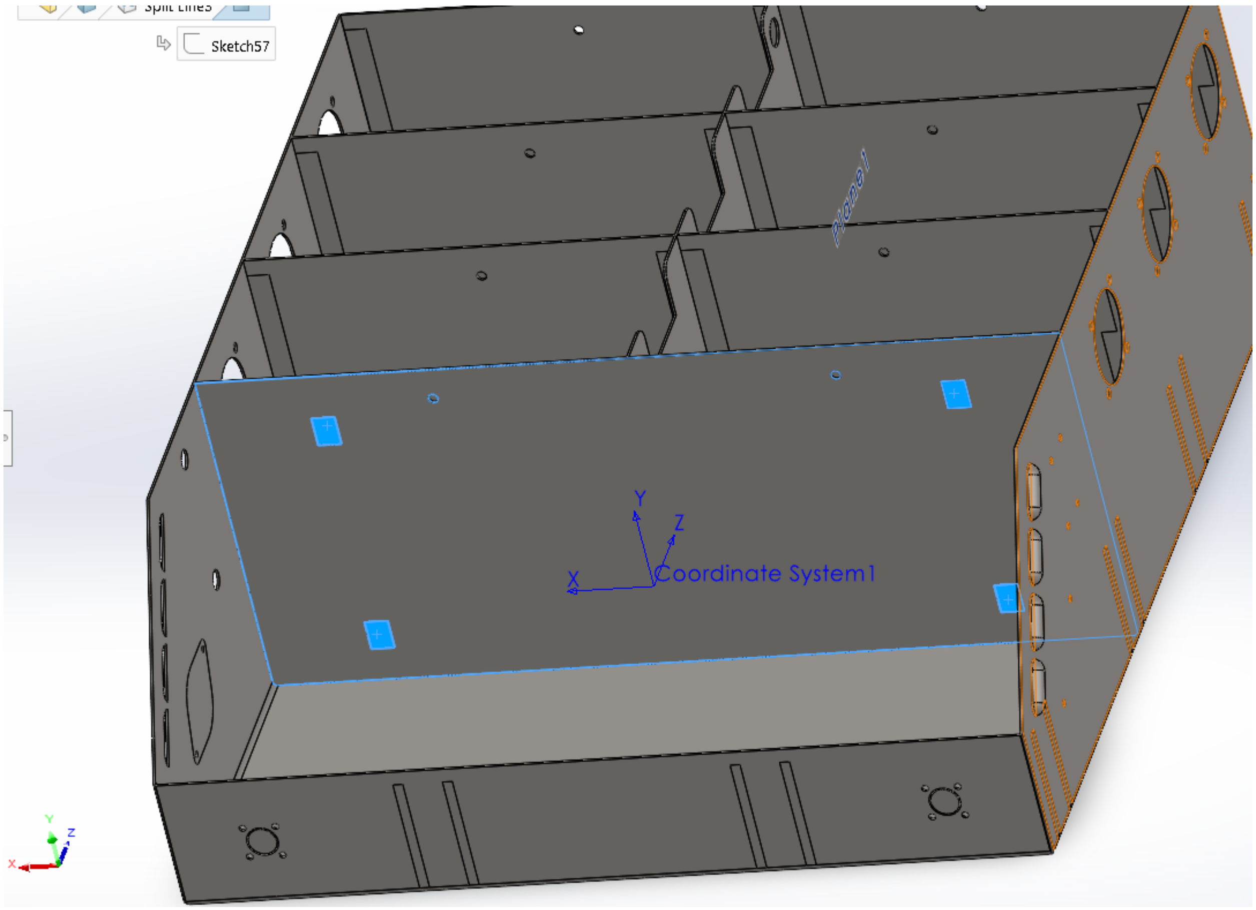

Figure 2.7: Split lines for location of BMS mounts

Split lines for the 2 AIR’s are shown in Figure 2.8. The split line surface areas are the same for the lateral, longitudinal and vertical load tests, for the same reasons as the BMS split lines, aforementioned.

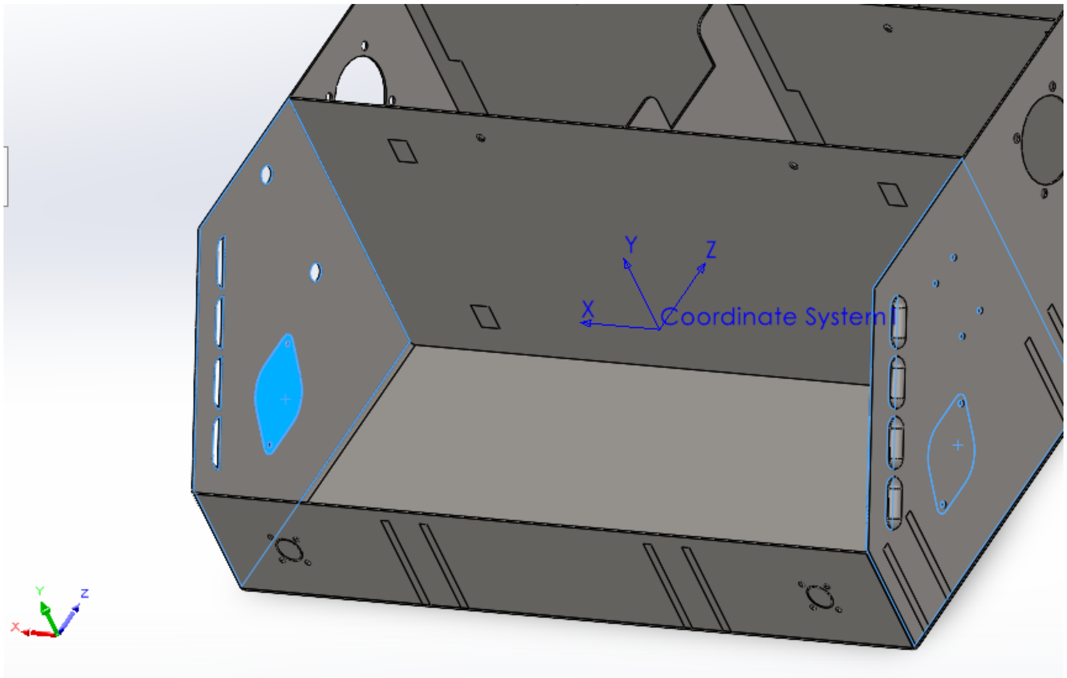

Figure 2.8: Split line locations for two AIR's in container

Split lines were made, from the accumulator container mounts. These are shown in Figure 2.9, highlighted in green. These split line surface areas were implemented as fixtures (Fixed Geometry) in the load tests.

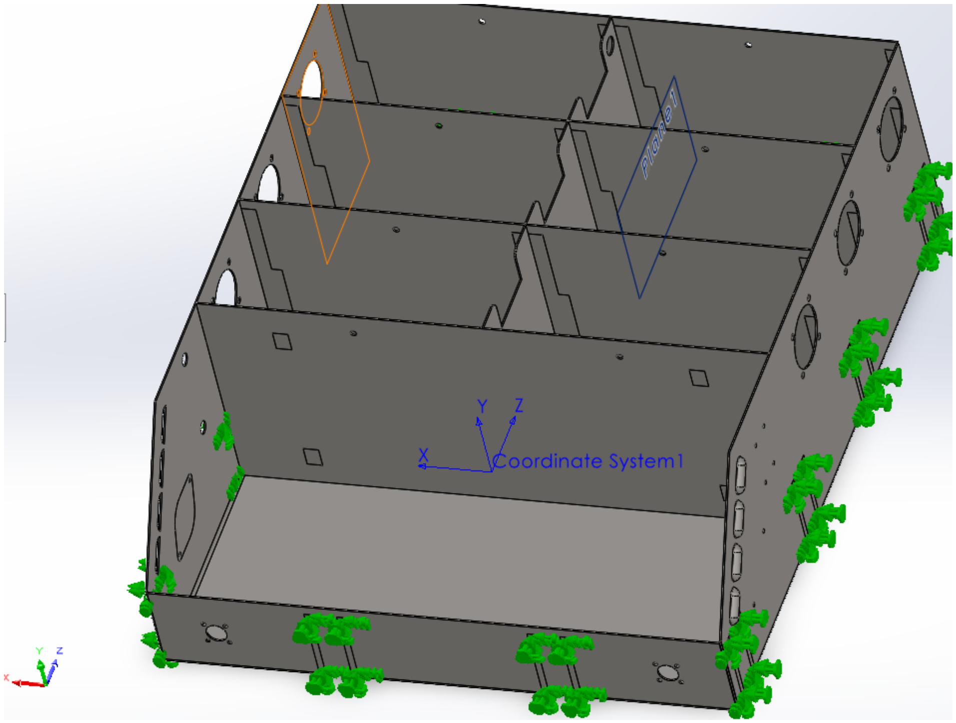

Figure 2.9: Fixture locations, from split lines for container mounts (in green)

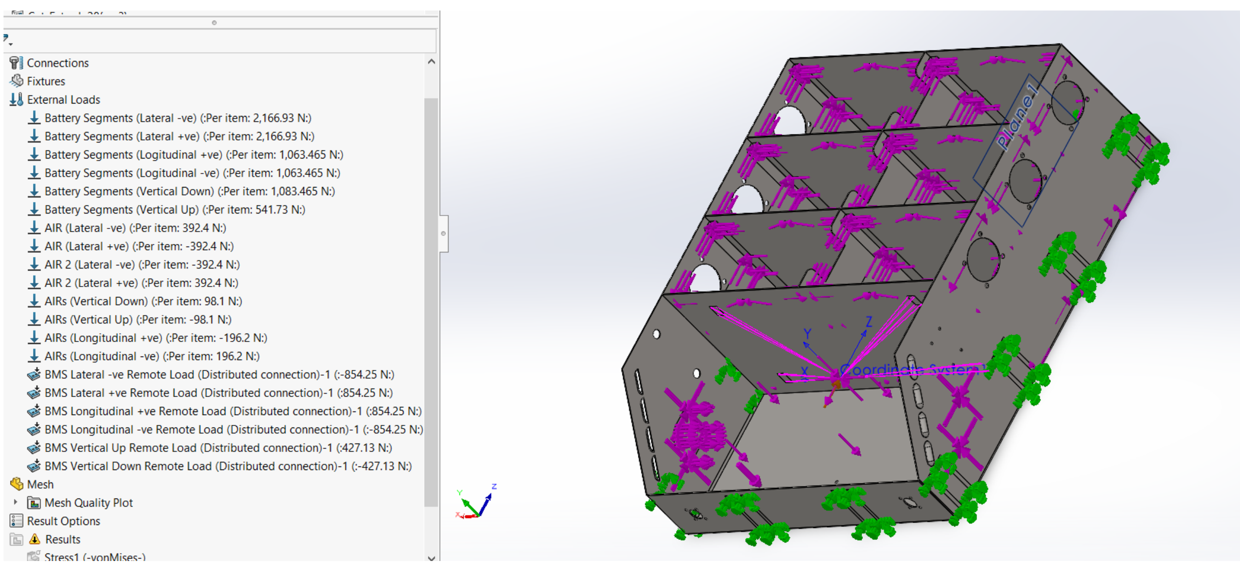

Figure 2.10: List of all external loads for accumulator container load tests

All the external loads needed to implement the FEA tests are shown in Figure 2.10. As mentioned earlier, the load tests are: 40 G in the lateral direction, 40 G in the longitudinal direction, and 20 G in the vertical direction.

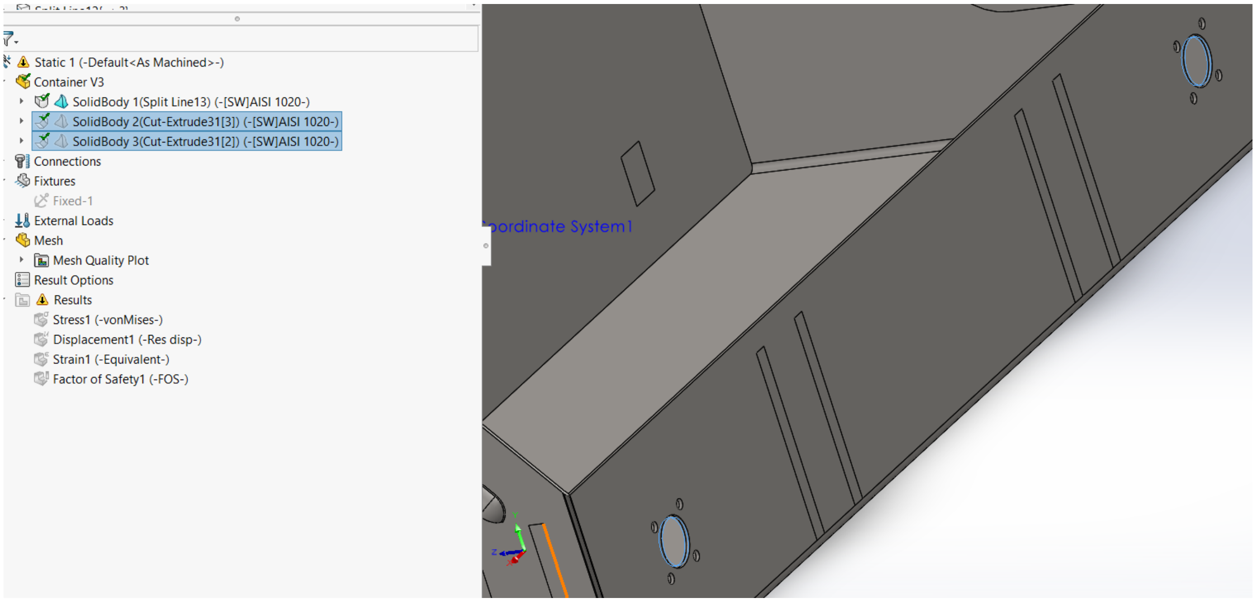

Figure 2.11: Location of "SolidBody 2" and "SolidBody 3" features (shown in blue)

To ensure that the mesh produced no errors and looked reasonable, a few settings were adjusted. Firstly, "SolidBody 2" and "SolidBody 3" were excluded from the analysis, as they were simple representations of the cutouts for the High Voltage Connectors coming out from the container (shown in Figure 2.11). Secondly, the container model itself was set to run as a solid, instead of a shell. Thirdly, "SolidBody 1", which is the container itself, was set to "Make Deformable". And finally, the mesh used was a Curvature-based mesh.

Also, a new constraint was added to the fixtures, using the "On Flat Faces" Fixtures feature. This is to show that the inner walls (highlighted in the Figures below) will not deflect, as extra rigidity is provided to those areas, due to the structural rigidity of the components inside the accumulator container segments, such as the battery segments themselves and the segment mounts.

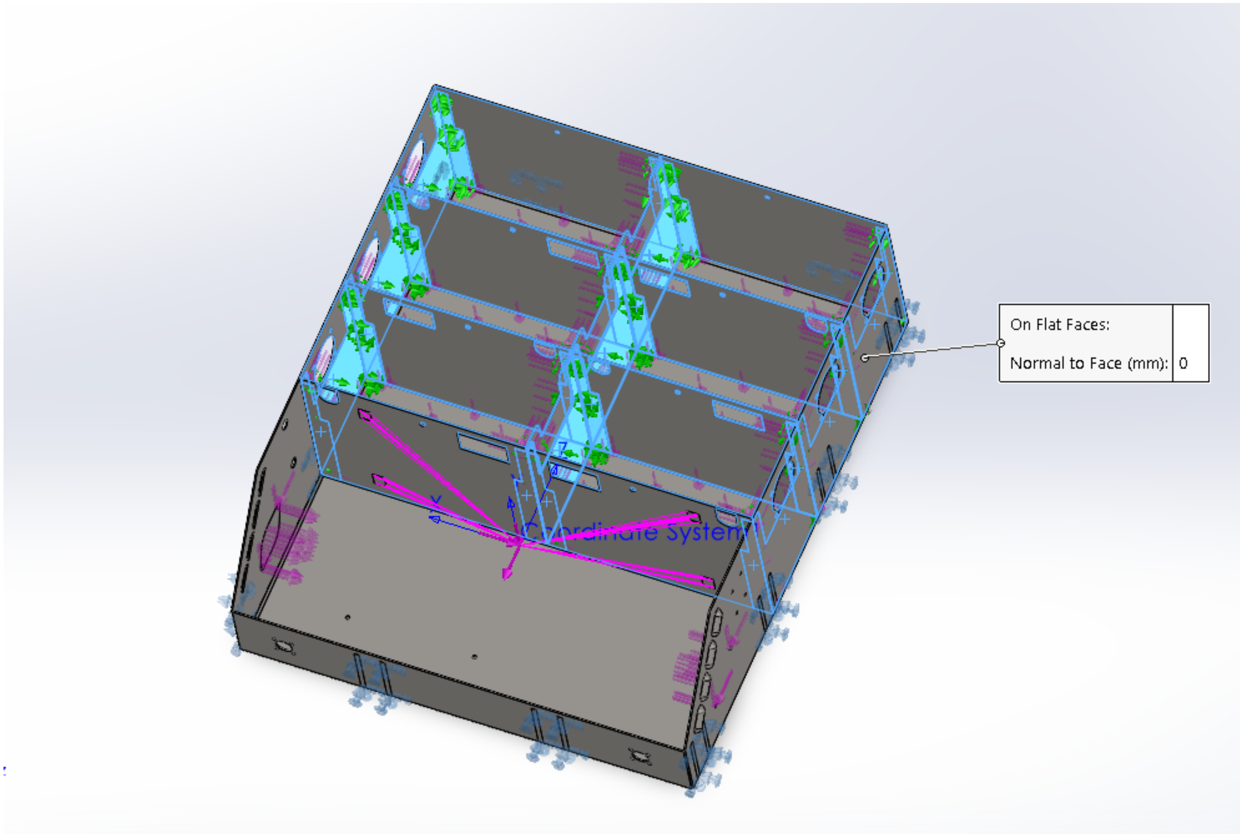

Figure 2.12: Location of "On Flat Faces" Fixture for right sides of walls (shown in blue)

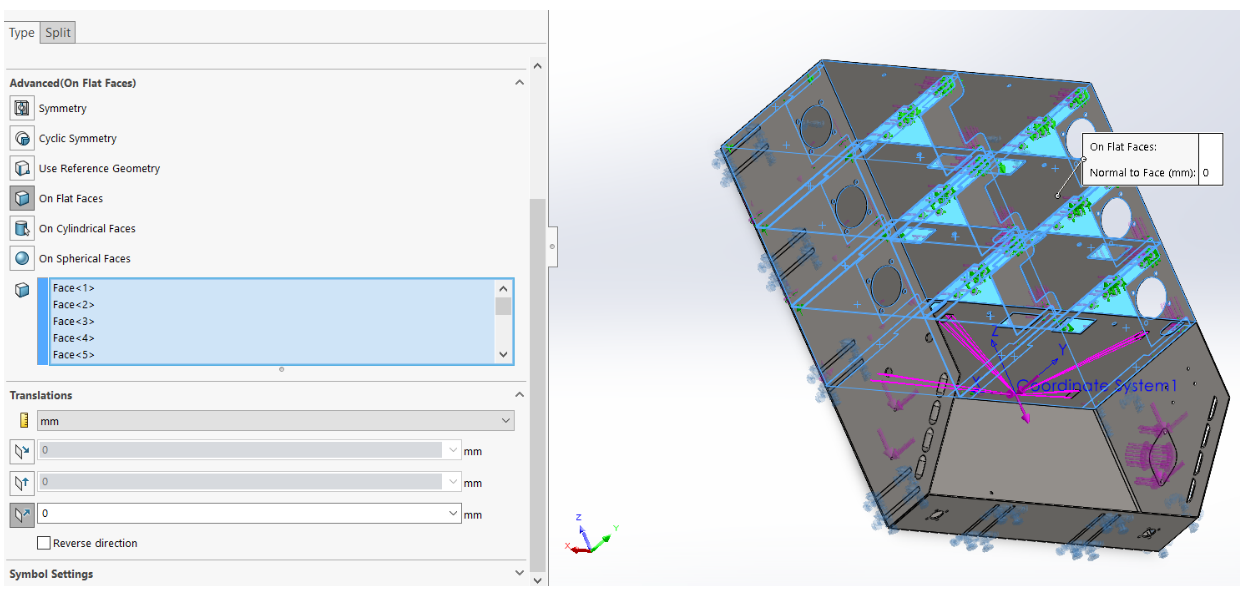

Figure 2.13: Location of "On Flat Faces" Fixture for left sides of walls (shown in blue)

The following tests were carried out: 2 lateral test showing 40 G force in the lateral direction (both left and right separately), 2 longitudinal tests showing 40 G force in the longitudinal direction (both forwards and backwards separately), and 2 vertical tests showing 20 G in the vertical direction (both upward and downward separately). The resulting load studies are shown in the appendix below.

3. Miscellaneous Appendix

3.1 Relevant Rules (from the 2022 Formula SAE Rulebook)

F: CHASSIS AND STRUCTURAL RULES

- F.10.2.2: Accumulator Container design requirements:
    - a. The floor or bottom must be constructed of steel 1.25 mm minimum thickness or aluminum 3.2 mm minimum thickness.
    - b. The external vertical walls must be constructed of steel 0.9 mm minimum thickness or aluminum 2.3 mm minimum thickness.
    - c. Internal vertical walls separating cells and/or segments must be:
        - Minimum of 75 percent of the height of the external vertical walls
        - Constructed of steel 0.9 mm minimum thickness or aluminum 2.3 mm minimum thickness
    - d. The floor and walls must be joined by welds and/or fasteners. Any fasteners must be 6 mm or 1/4” minimum diameter Critical Fasteners, see T.8.2
        - **T.8.2 Critical Fastener Requirements**
            - T.8.2.1 Any Critical Fastener must meet, at minimum, one of the following:
                - a. SAE Grade 5
                - b. Metric Grade 8.8
                - c. AN/MS Specifications
                - d. Equivalent to or better than above, as approved by a Rules Question or at Technical Inspection

- T.8.2.2 All threaded Critical Fasteners must be one of the following:
  - Hex head
  - Hexagonal recessed drive (Socket Head Cap Screws or Allen screws/bolts)
- T.8.2.3 All Critical Fasteners must be secured from unintentional loosening by the use of Positive
  - Locking Mechanisms see T.8.3
- T.8.2.4 A minimum of two full threads must project from any lock nut.
- T.8.2.5 Some Critical Fastener applications have additional requirements that are provided in the
- applicable section.

- **T.8.3 Positive Locking Mechanisms**
  - T.8.3.1 Positive Locking Mechanisms are defined as those which:
    - a. Technical Inspectors / team members can see that the device/system is in place (visible).
    - b. Do not rely on the clamping force to apply the locking or anti vibration feature. Meaning If the fastener begins to loosen, the locking device still prevents the fastener coming completely loose
  - T.8.3.2 Acceptable Positive Locking Mechanisms include, but are not limited to:
    - a. Correctly installed safety wiring
    - b. Cotter pins
    - c. Nylon lock nuts (where temperature does not exceed 80°C)
    - d. Prevailing torque lock nuts
  - Lock washers, bolts with nylon patches and thread locking compounds (Loctite®), DO NOT meet the positive locking requirement.
- **T.8.4 Requirements for All Fasteners**
  - Adjustable tie rod ends must be constrained with a jam nut to prevent loosening.

- e. Internal vertical walls divide the Accumulator Container into “Sections”:

- A maximum of 12 kg is allowed in any Section
- Fastened connections between the floor and any vertical wall of each Section must have a minimum of two fasteners.
- Fastened connections between internal vertical walls and external vertical walls must be located in the top half of the internal vertical wall.
- Sections containing 8 kg or less must have a minimum of two fasteners connecting any two vertical walls.
- Sections containing between 8 kg and 12 kg must have a minimum of three fasteners connecting any two vertical walls.

Folding or bending plate material to create flanges or to eliminate joints between walls is Recommended.

[Example: An Accumulator Container with 2 internal walls has 3 Sections. Each Section contains less than 8 kg. Therefore 18 floor to wall joints are required in total with a minimum two fasteners per joint.]

- f. Covers and lids must be constructed of steel 0.9 mm minimum thickness or aluminum 2.3 mm minimum thickness.
- g. Covers and lids must be fastened with a minimum of one fastener for each external vertical wall per section.
- h. Alternate / Composite materials are allowed with proof of equivalency per F.4.3.
- i. Substituting one 6 mm or 1/4” bolt with two 5 mm or #12 bolts or three 4 mm or #10 bolts is allowed.

F.10.2.3 The cells and/or segments must be appropriately secured against moving inside the Container.

a. This mounting system must be designed to withstand the following accelerations:
   40 g in the longitudinal direction (forward/aft)
   40 g in the lateral direction (left/right)
   20 g in the vertical direction (up/down)

b. Calculations and/or tests proving these requirements are met must be included in the SES.

EV: ELECTRIC VEHICLES RULES

- 5.3.2: must be removable from vehicle
- 5.3.3: must be closed at all times, without any extra protective covers
- 5.3.4: any holes, internal or external, should only be for ventilation, cooling, wiring, or fasteners. Must follow EV.7.1.1 and EV.7.1.2
    - 7.1.1: nonconductive material/covers must prevent inadvertent human contact with any Tractive System Voltage
      Covers must be rigid and secure
      No removable bodywork around tractive system connectors
    - 7.1.2: Contact with a 100mm long, 60mm diameter insulated test probe must not be possible when enclosures are in place
- 5.3.5: any explosive gases in accumulator must have a ventilation system or pressure relief valve, to prevent gas from reaching high concentration inside container
- 5.3.6: completely sealed containers must have pressure relief valves to prevent high pressure in container
- 5.9.2: If the housing material for anything on the tractive system except the motor housings is electrically conductive, or even possibly electrically conductive, then it must have a low resistance connection to the GLV system ground
- 6.2.2: If the accumulator container is made from an electrically conductive material:
    - Poles and cells of accumulator segments must be isolated from the walls of the container with an insulating material that is rated for the tractive system
    - All conductive surfaces on the outside of the container must have low resistance connection to GLV system ground
    - Any conductive penetrations (ex.fasteners or sources of sharp edges) should be protected from puncturing the insulating barrier
- 6.2.3: Each segment of the container must be electrically insulated with a suitable insulating material (not air) in between the segments and on top of the container. [*purpose is to prevent arc flashes caused by inter segment contact and/or by parts/tools accidentally falling into the container during maintenance for example*]
- 6.2.4: soldering electrical connections in the high current path is prohibited

(soldering wires to cells for AMS input is allowed, these wires are not part of the high current path)

- 6.2.5: all wires used in container, regardless of whether its a part of the GLV or tractive system, must be rated to the max tractive system voltage
- 6.4.1: container must have minimum one fuse and minimum 2 AIR’s
- 6.7: container must have a voltage indicator when High Voltage is present at vehicle side of AIR’s
    - 6.7.1 The Voltage Indicator must always function, including when the Accumulator Container is disconnected or removed
    - 6.7.2 The voltage being present at the connectors must directly control the Voltage Indicator using hard wired electronics with no software control.
    - 6.7.3 The control signal which closes the AIRs must not control the Voltage Indicator
    - 6.7.4 The Voltage Indicator must:
        - a. Be located where it is clearly visible when connecting/disconnecting the Accumulator Tractive System connections
        - b. Be labeled “High Voltage Present”
- 6.9: tractive system connectors outside of a housing must meet one of the two:
    - Contain interlock which must open the shutdown circuit
    - Be sealed at tech inspection
- 7.1.3: tractive system components and accumulator container must be insulated from moisture, rain or puddles
    - Recommended for IP65 rating
- 7.2.1: Insulation material must:
    - Appropriate for expected surrounding temperature
    - Have minimum temperature rating of 90 degrees Celsius
- 7.2.2: Insulating tape or rubber may be part of the insulation, but it must not be the only insulation used
- 7.5.2: there must be no connection between chassis (or any part that may be touched by someone), and any part of the tractive system
- 7.5.4: Any GLC components, except for the AIR’s, parts of the Pre-Charge and Discharge circuits, HV AC/DC converters, AMS, IMD, parts of the TSAL and cooling fans must not be inside the accumulator container.
- **7.7 Grounding**

- EV.7.7.1 Parts of the vehicle which are 100 mm or less from any Tractive System component must have a resistance to GLV System Ground less than the values specified below.
    - a. Electrically conductive parts 300 mOhms (measured with a current of 1 A) Examples: parts made of steel, (anodized) aluminum, any other metal parts
    - b. Parts which may become electrically conductive 5 Ohm Example: carbon fiber parts. Carbon fiber parts may need special measures such as using copper mesh or similar to keep the ground resistance below 5 Ohms.
- EV.7.7.2 Electrical conductivity of any part may be tested by checking any point which is likely to be conductive. Where no convenient conductive point is available, an area of coating may be removed.

1020 Tests

The following tests were carried out: 2 lateral test showing 40 G force in the lateral direction (both left and right separately), 2 longitudinal tests showing 40 G force in the longitudinal direction (both forwards and backwards separately), and 2 vertical tests showing 20 G in the vertical direction (both upward and downward separately)

Lateral tests

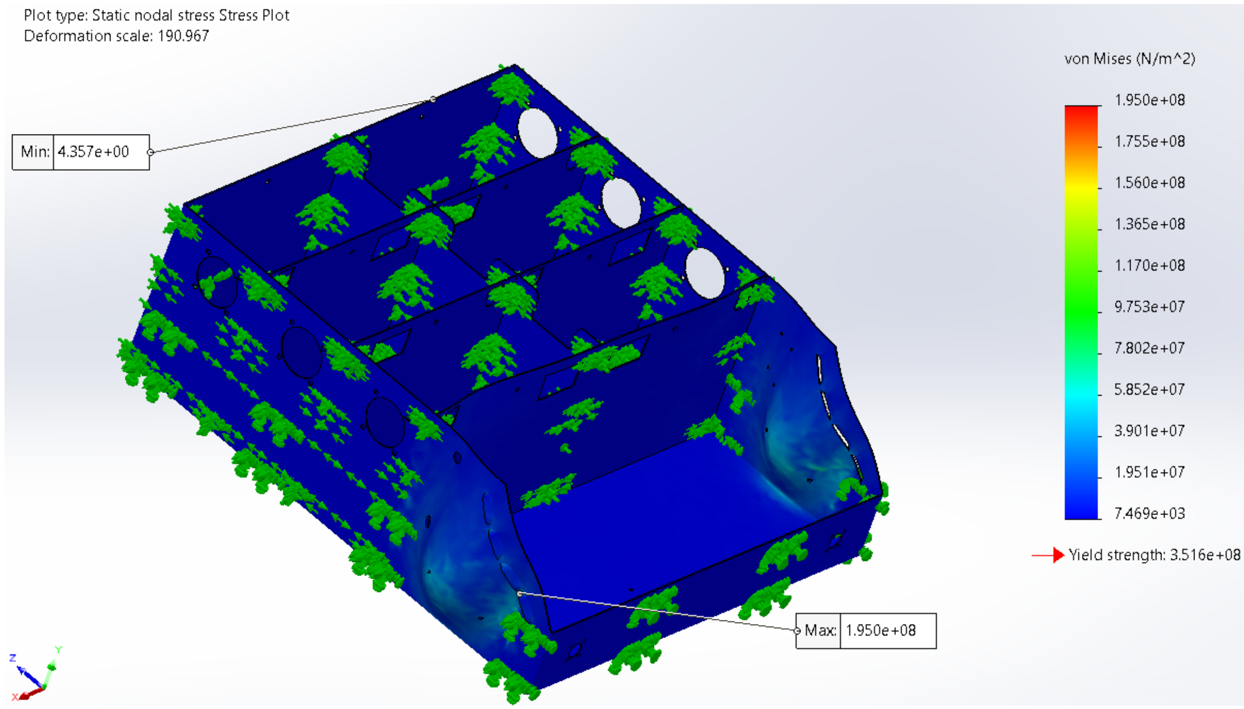

Figure 3.1: Lateral test Stress Plot (in positive x-axis direction)

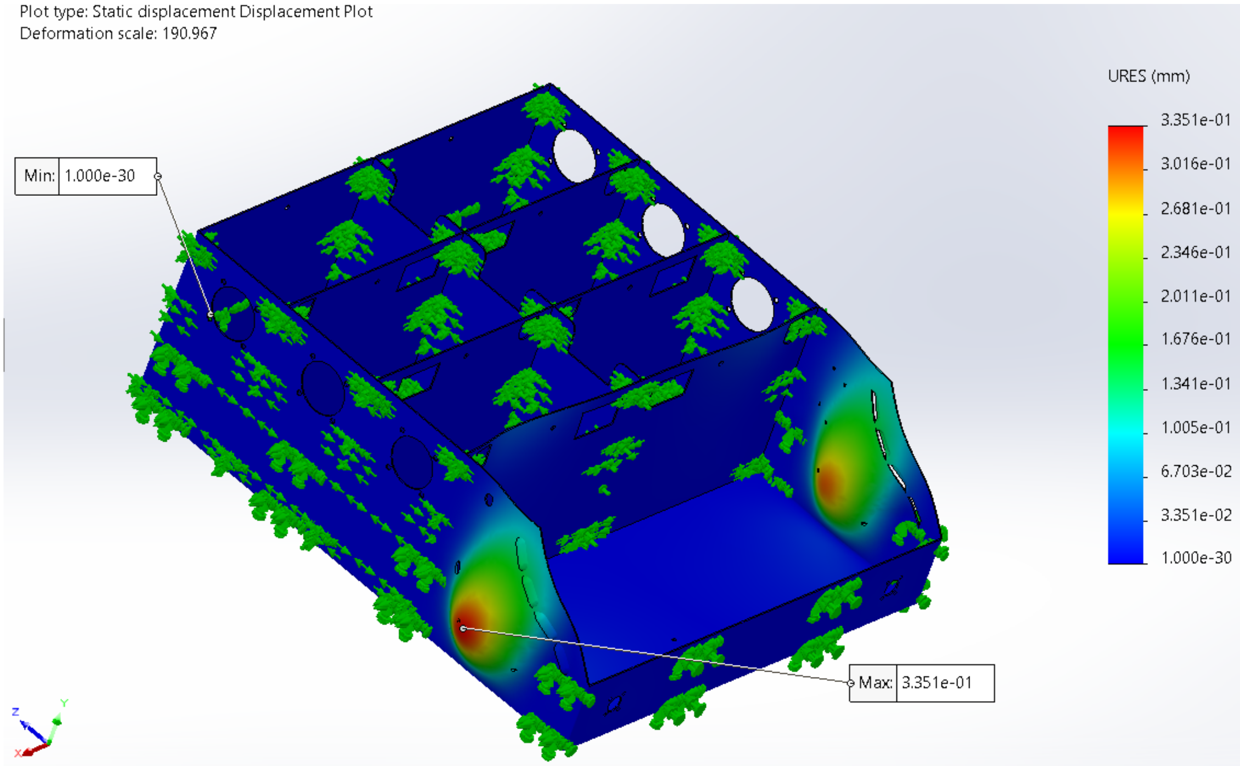

Figure 3.2: Lateral test Displacement Plot (in positive x-axis direction)

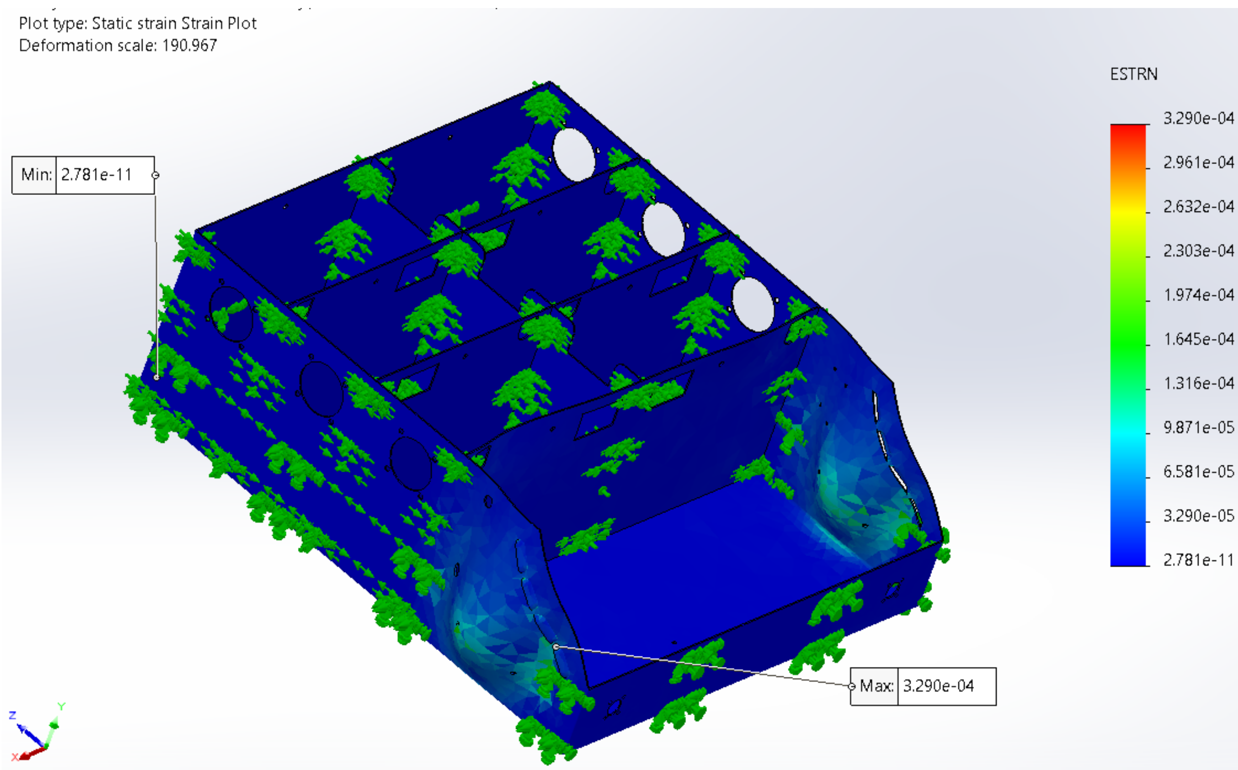

Figure 3.3: Lateral test Strain Plot (in positive x-axis direction)

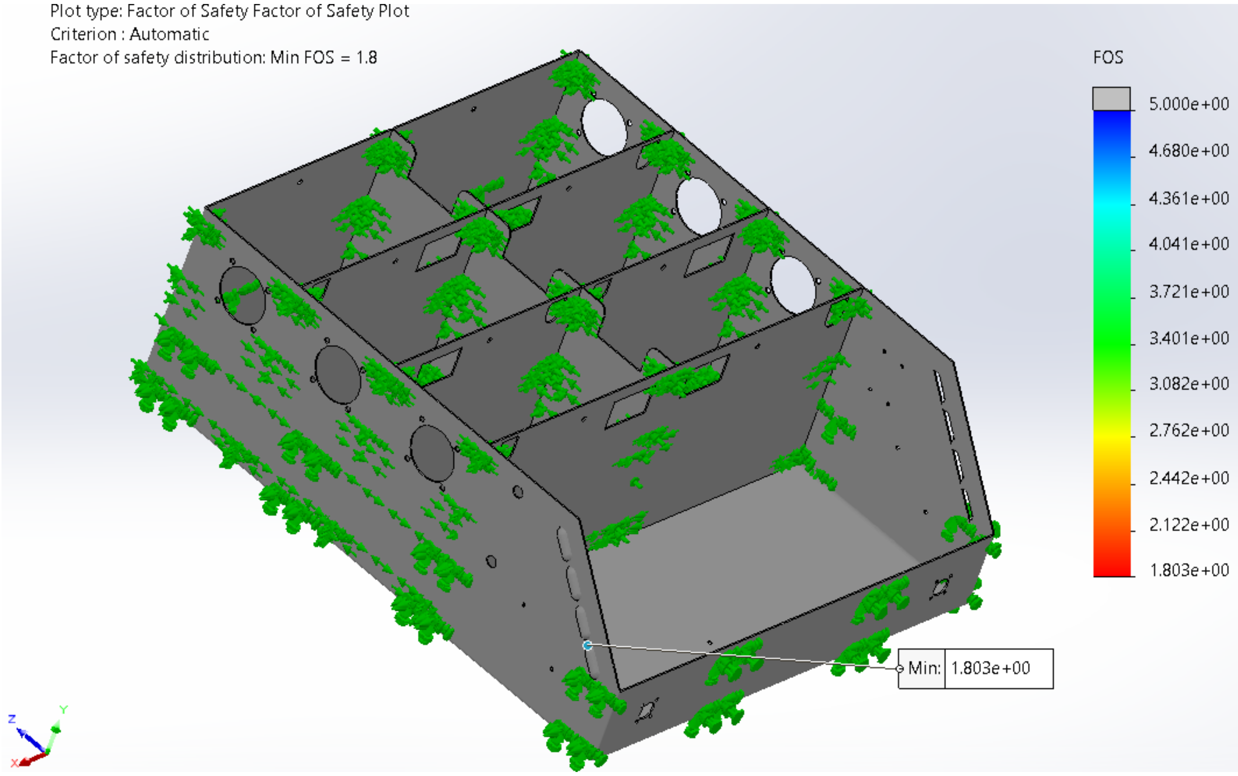

Figure 3.4: Lateral test FOS Plot (in positive x-axis direction)

As shown in Figure 3.5-3.8, the lateral tests in the negative x-axis direction showed similar results as the tests in the positive x-axis direction, albeit with small deviations, in the minimum and maximum values.

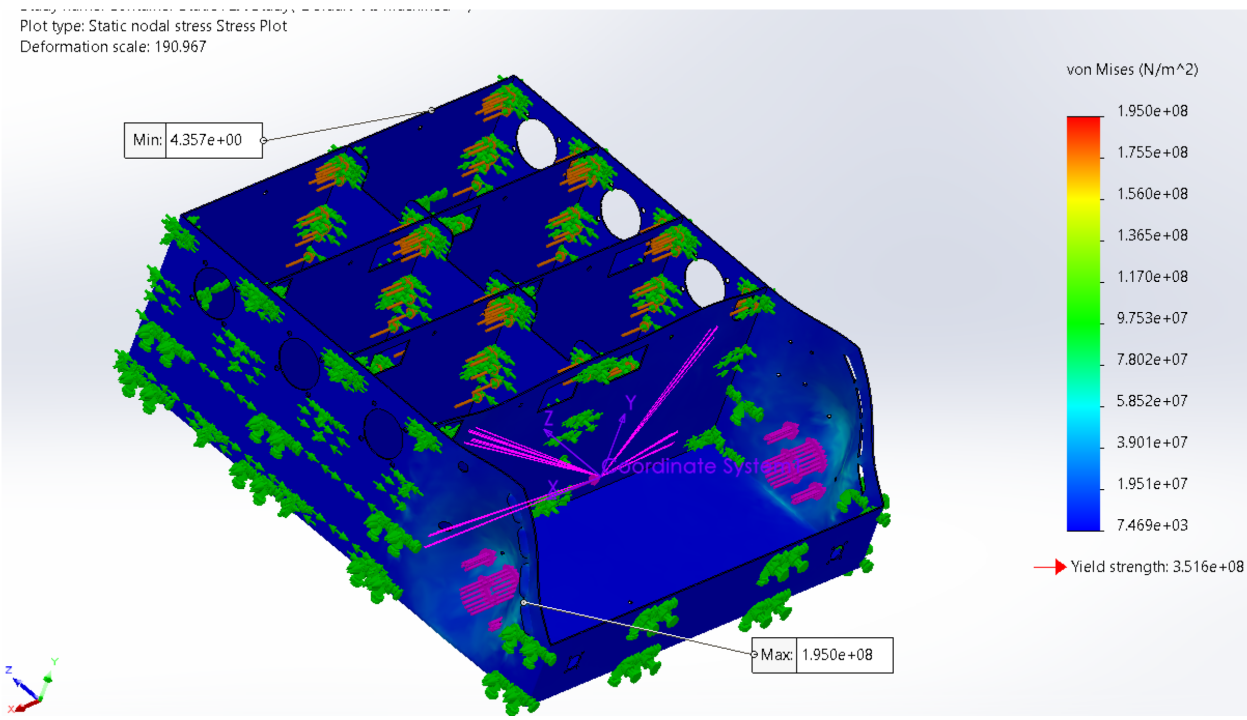

Figure 3.5: Lateral test Stress Plot (in negative x-axis direction)

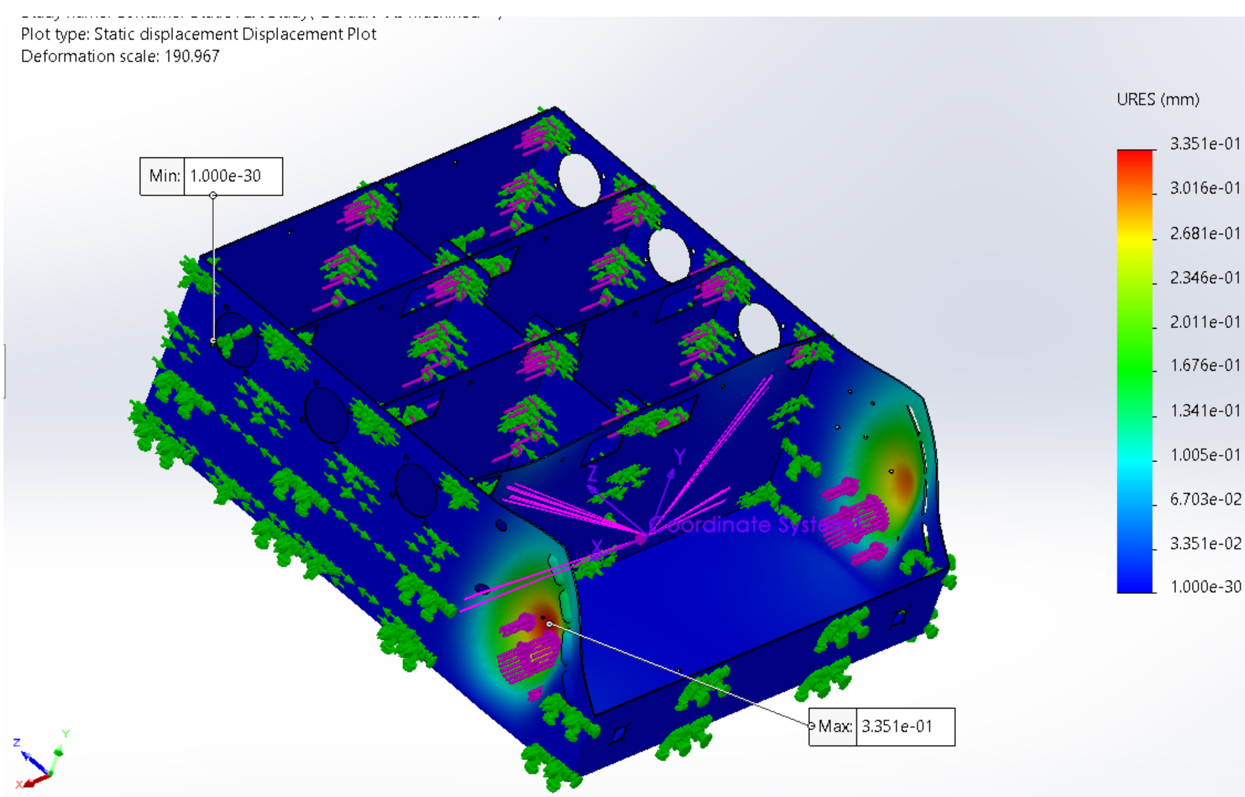

Figure 3.6: Lateral test Displacement Plot (in negative x-axis direction)

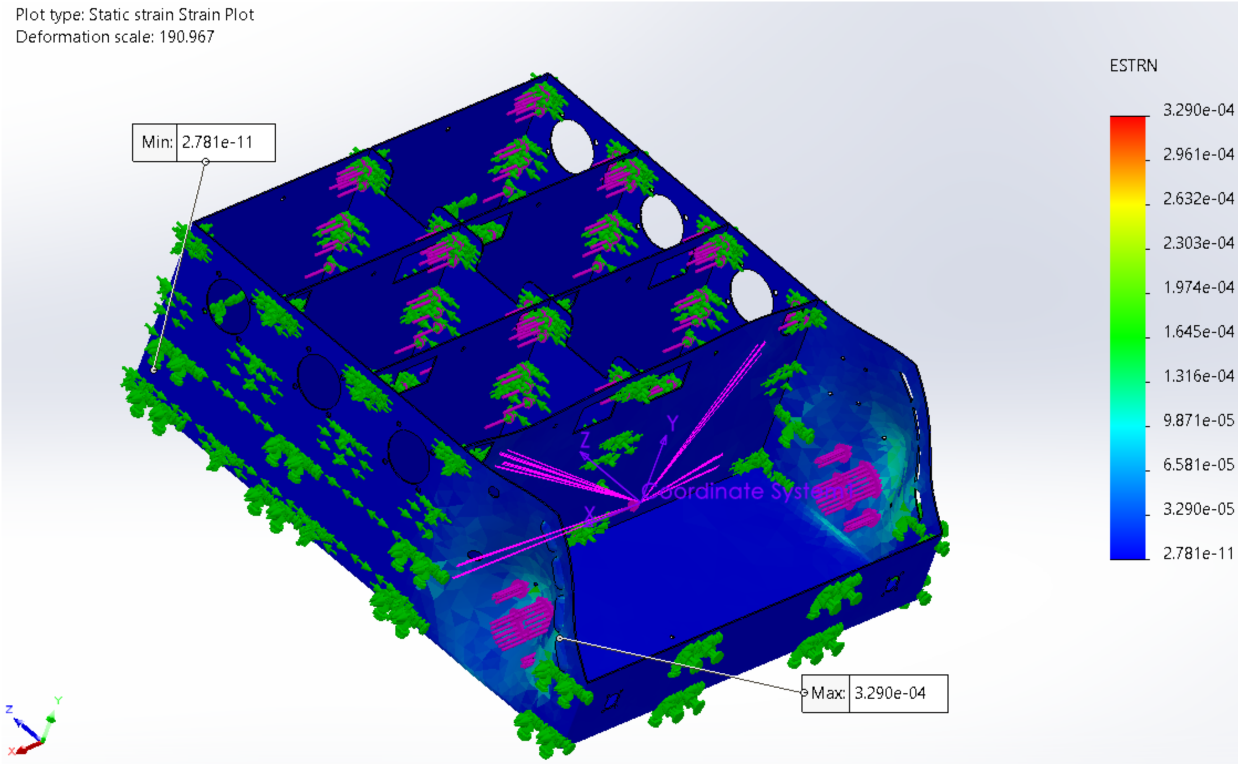

Figure 3.7: Lateral test Strain Plot (in negative x-axis direction)

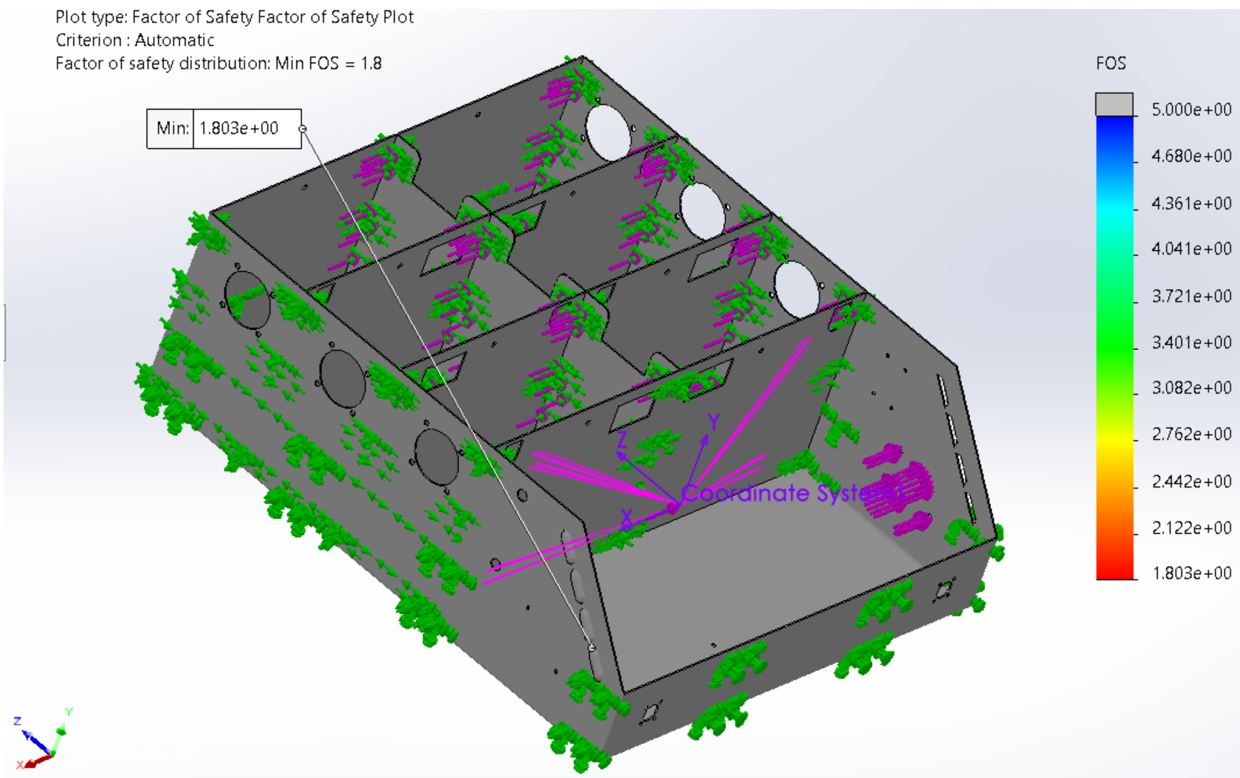

Figure 3.8: Lateral test FOS Plot (in negative x-axis direction)

<u>Longitudinal Tests</u>

Figures 3.9-3.12 shows the longitudinal tests in the negative z-axis direction, while Figures 3.13-3.16 shows the longitudinal tests in the positive z-axis direction.

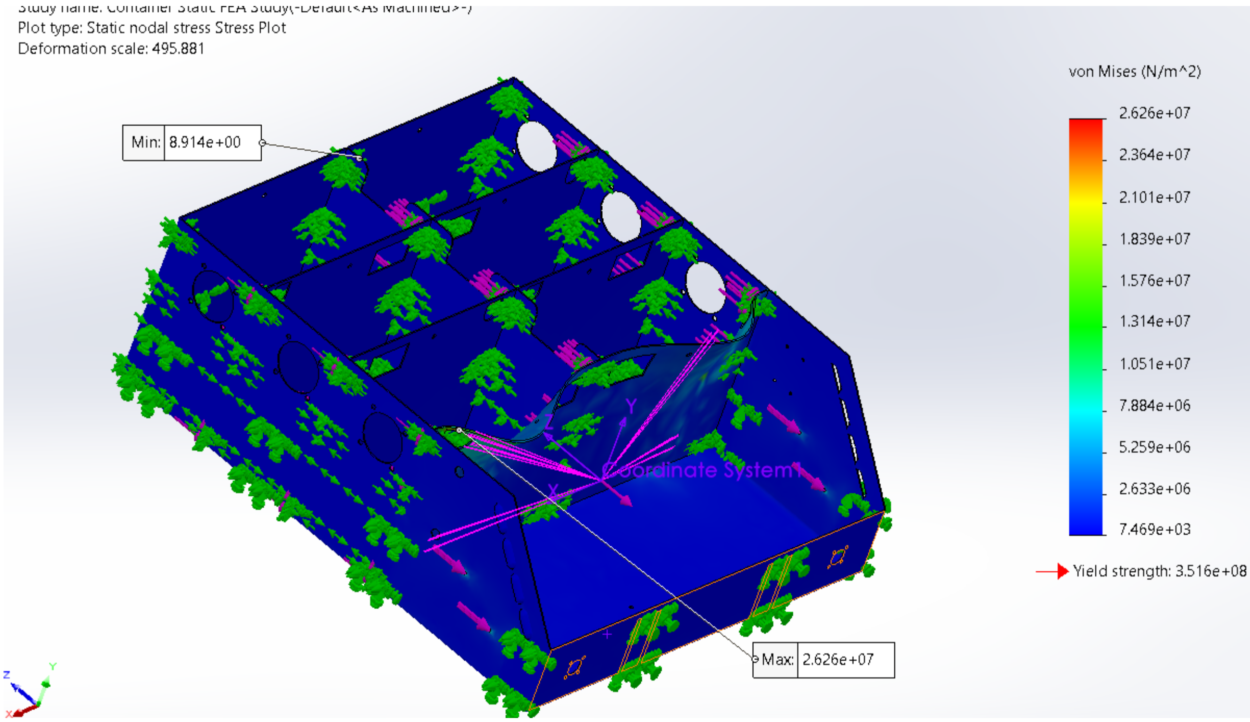

Figure 3.9: Longitudinal test Stress Plot (in negative z-axis direction)

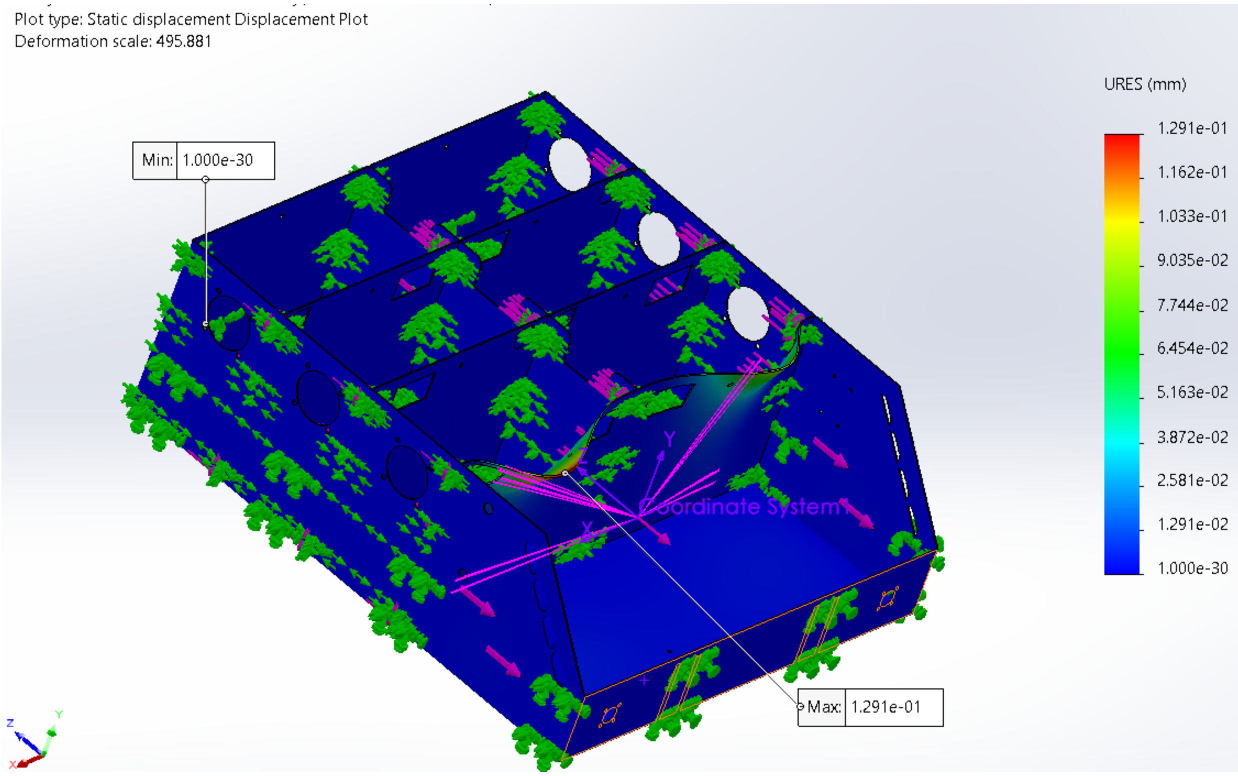

Figure 3.10: Longitudinal test Displacement Plot (in negative z-axis direction)

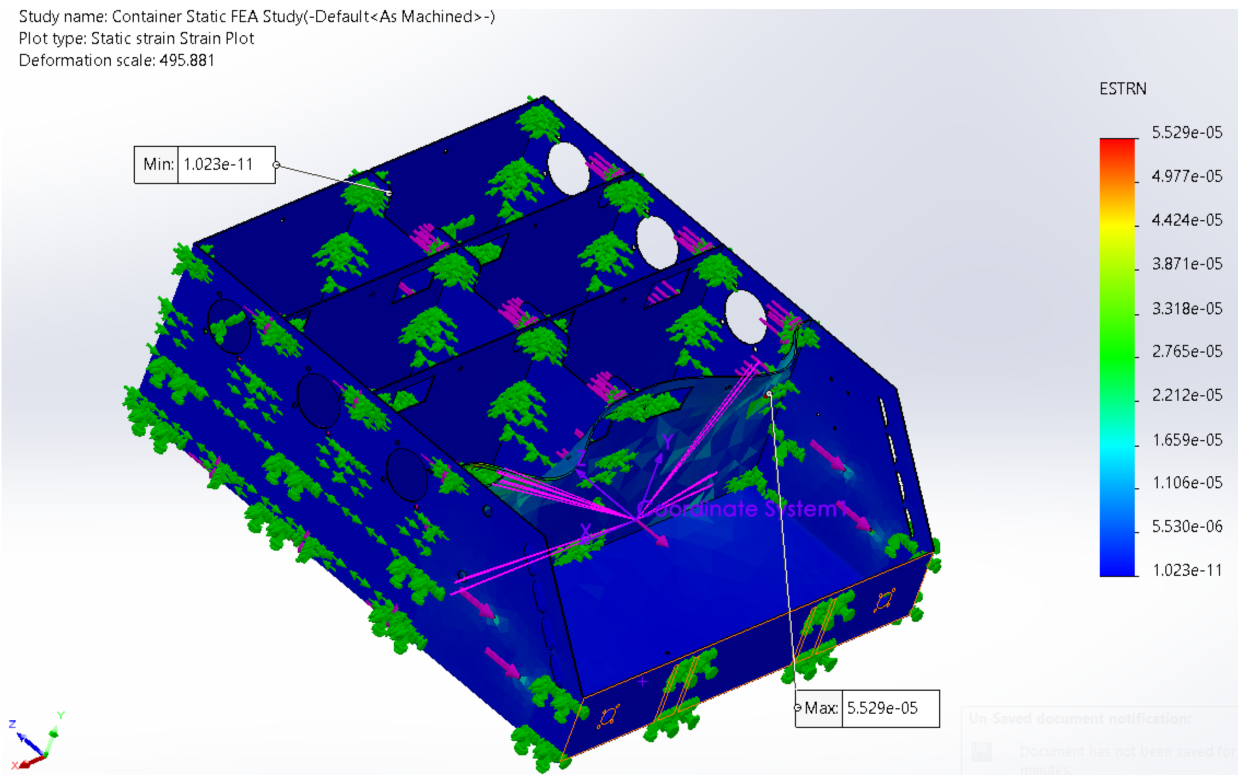

Figure 3.11: Longitudinal test Strain Plot (in negative z-axis direction)

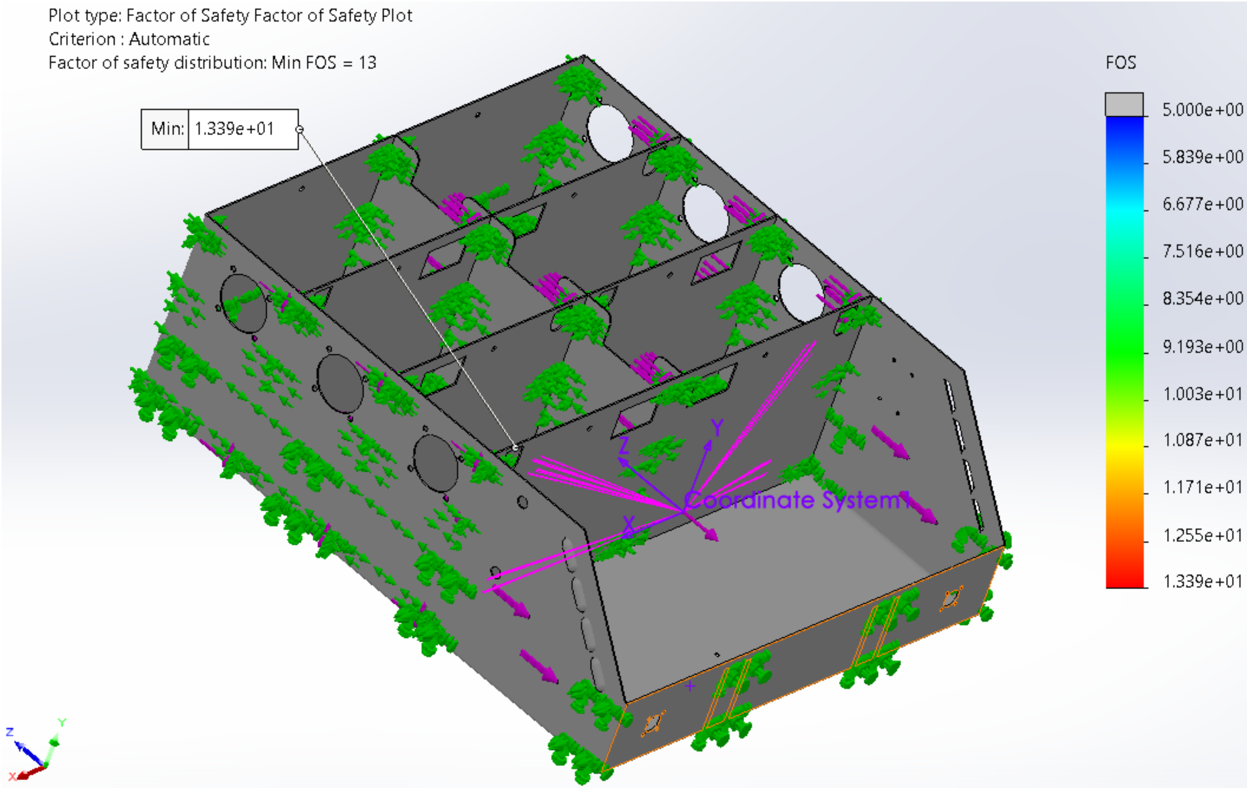

Figure 3.12: Longitudinal test FOS Plot (in negative z-axis direction)

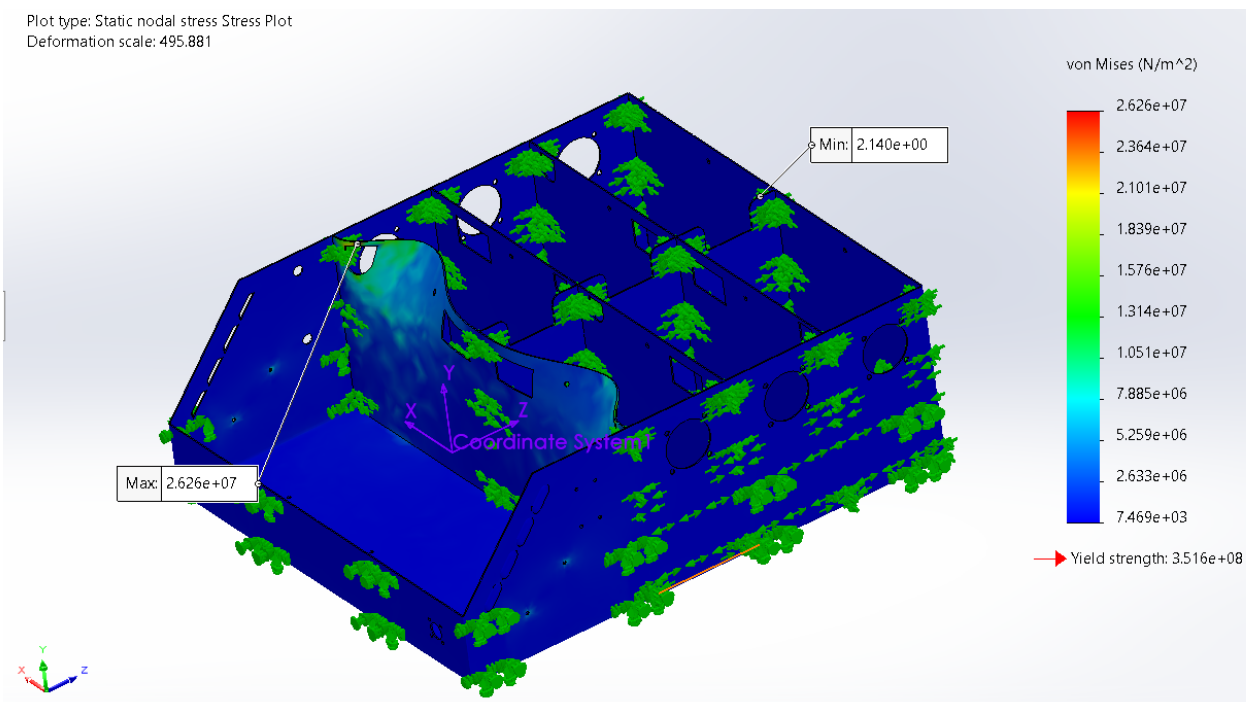

Figure 3.13: Longitudinal test Stress Plot (in positive z-axis direction)

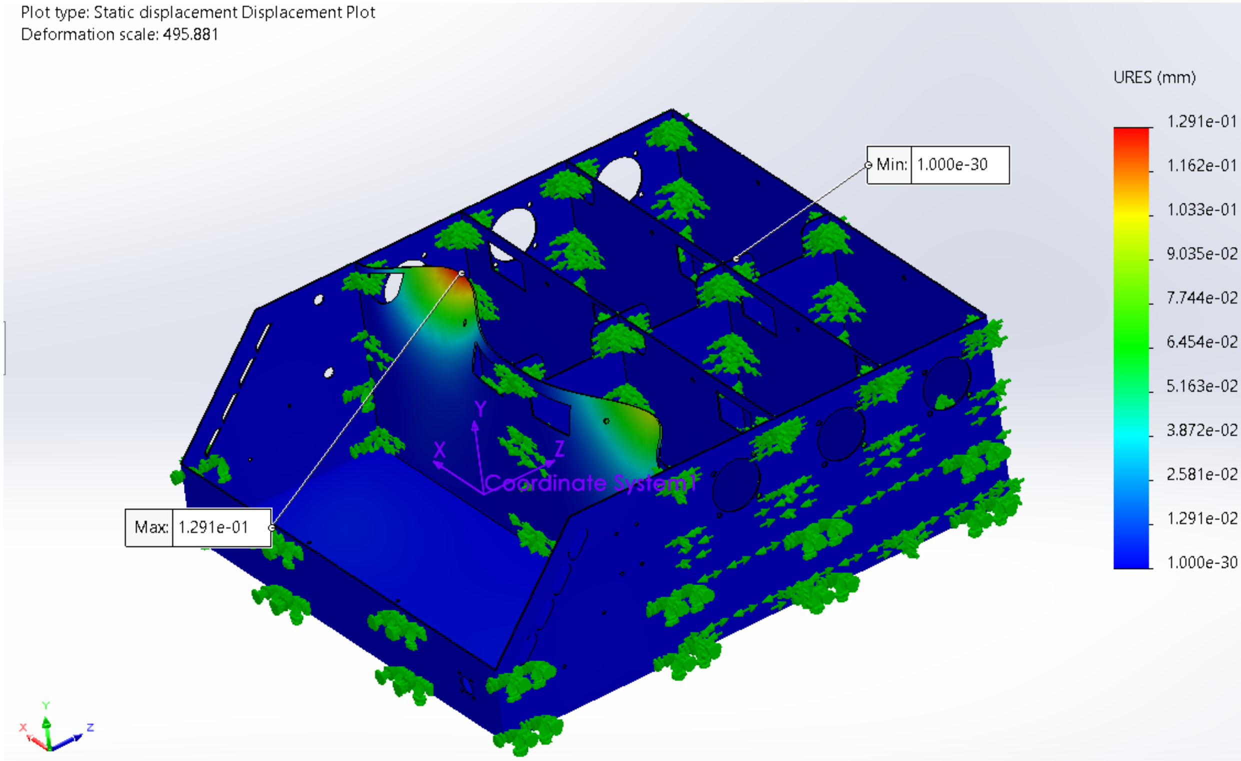

Figure 3.14: Longitudinal test Displacement Plot (in positive z-axis direction)

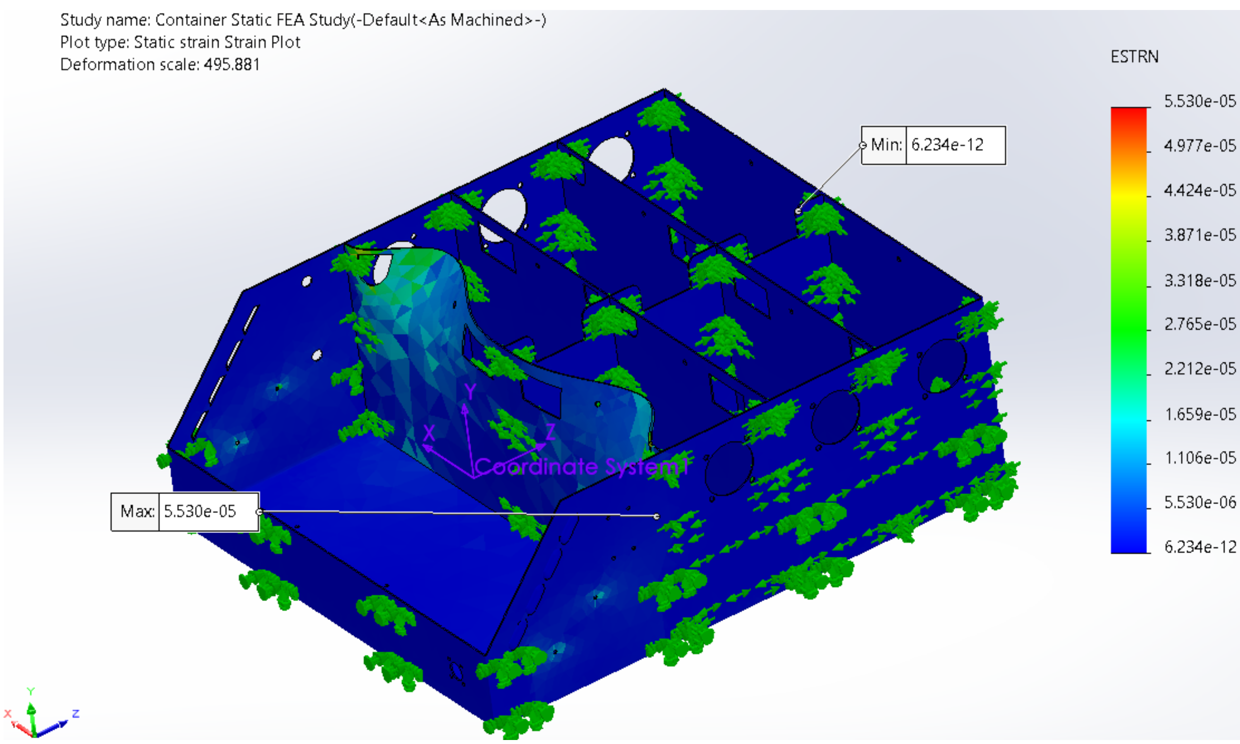

Figure 3.15: Longitudinal test Strain Plot (in positive z-axis direction)

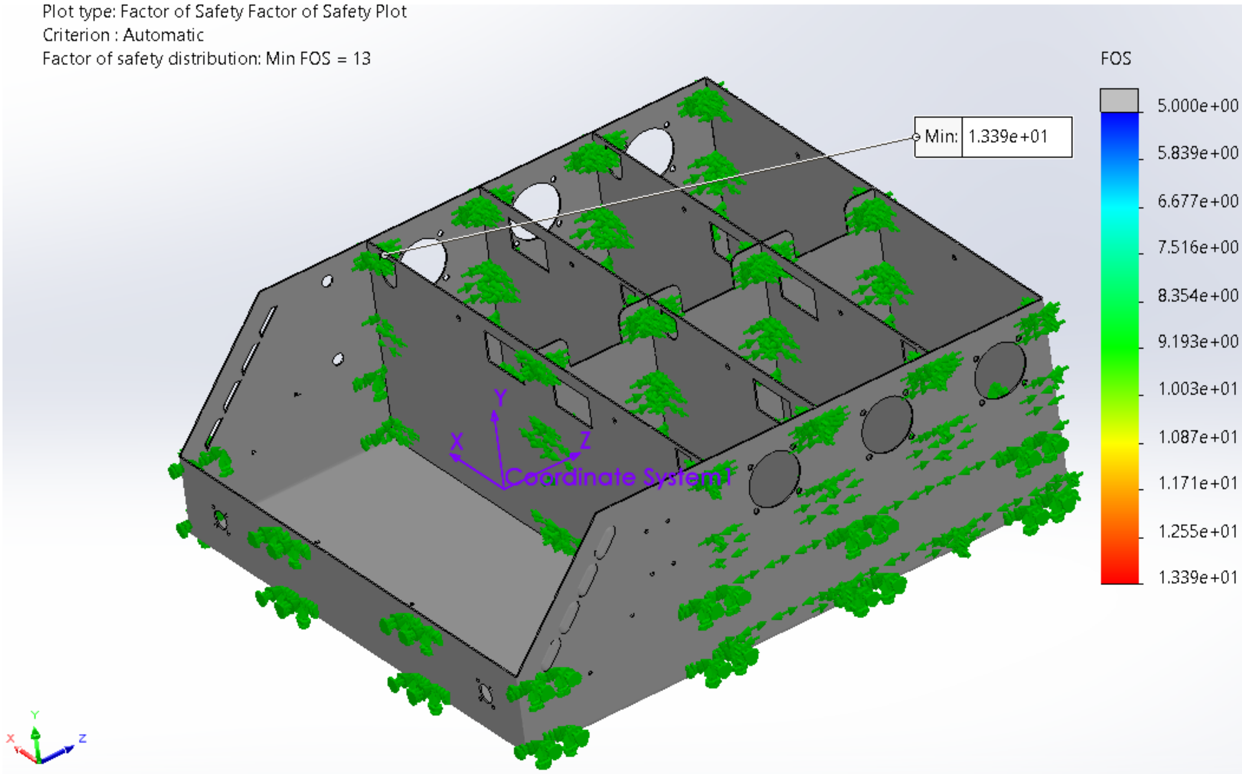

Figure 3.16: Longitudinal test Strain Plot (in positive z-axis direction)

Vertical Tests

Figures 3.17-3.20 shows the vertical tests in the positive y-axis direction, while Figures 3.21-3.24 shows the vertical tests in the negative y-axis direction.

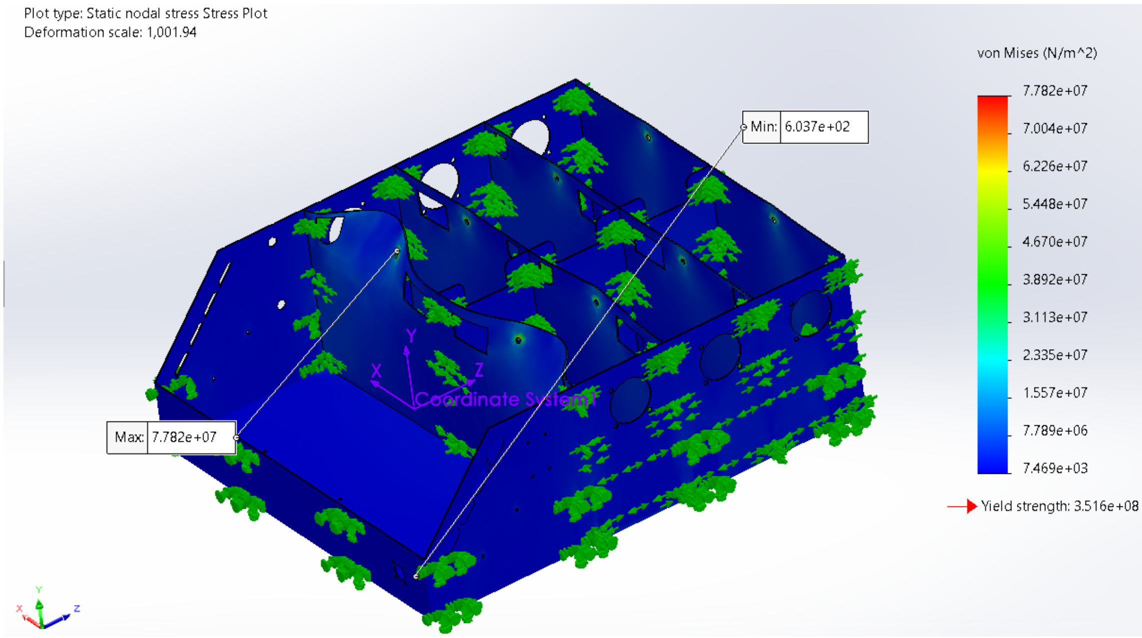

Figure 3.17: Vertical test Stress Plot (in positive y-axis direction)

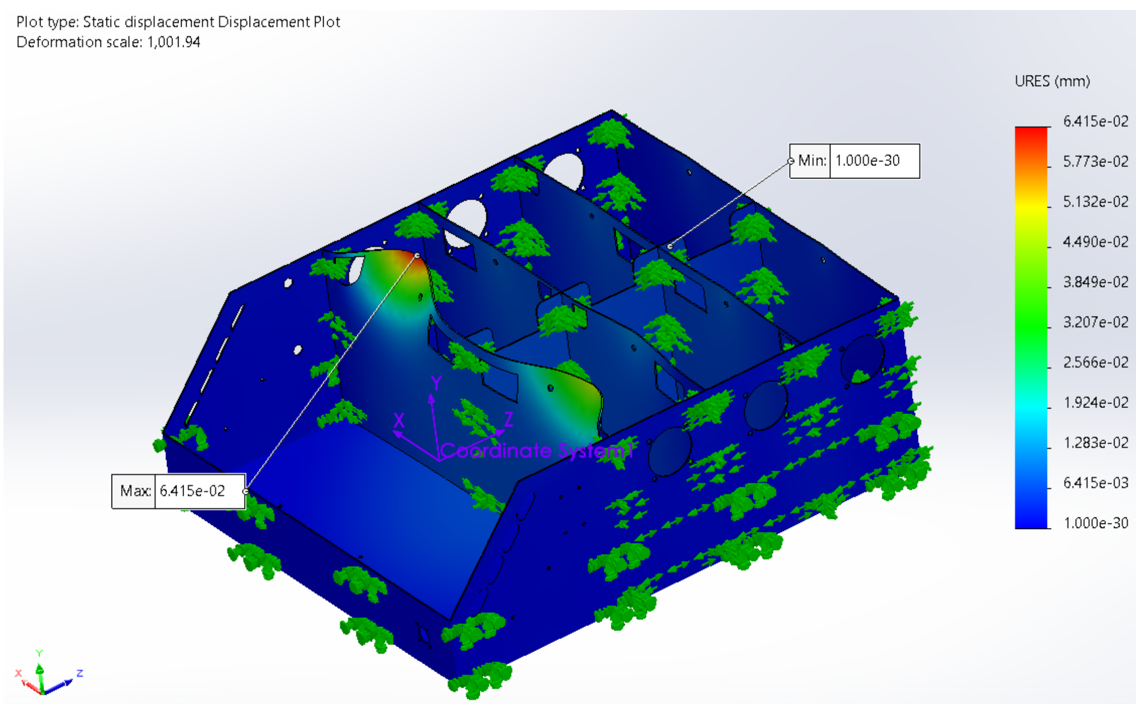

Figure 3.18: Vertical test Displacement Plot (in positive y-axis direction)

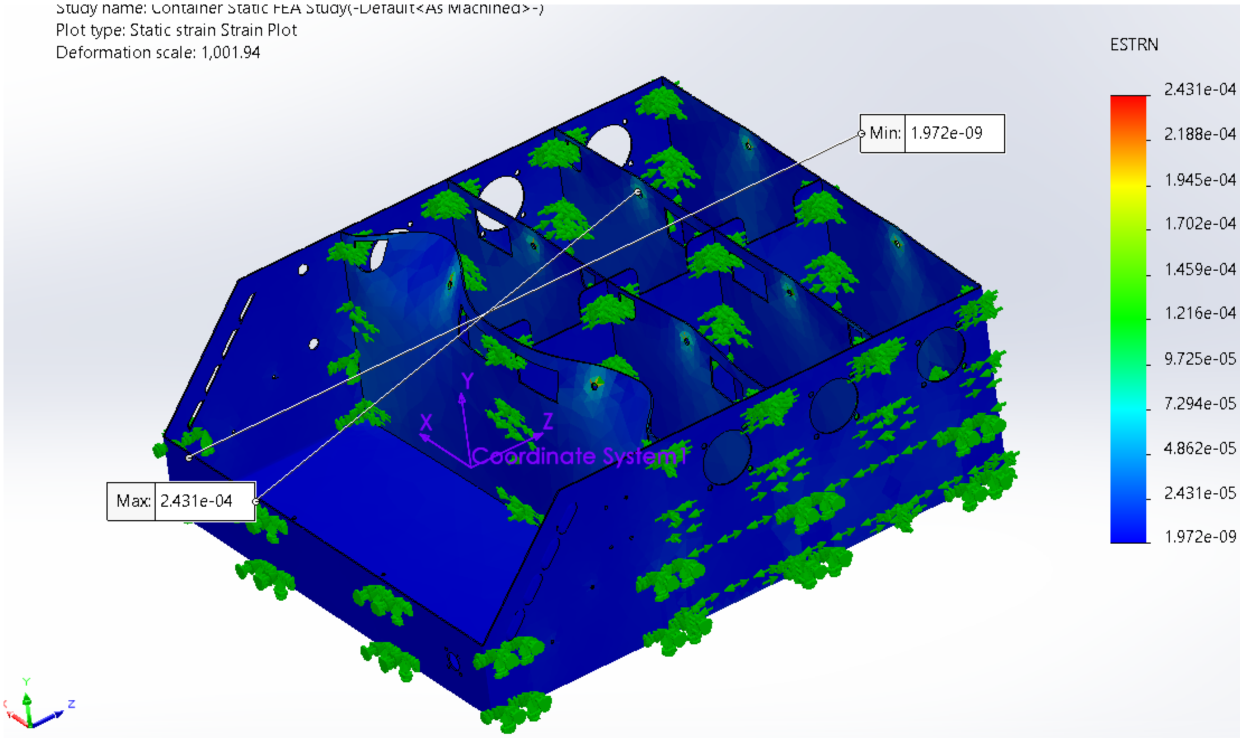

Figure 3.19: Vertical test Strain Plot (in positive y-axis direction)

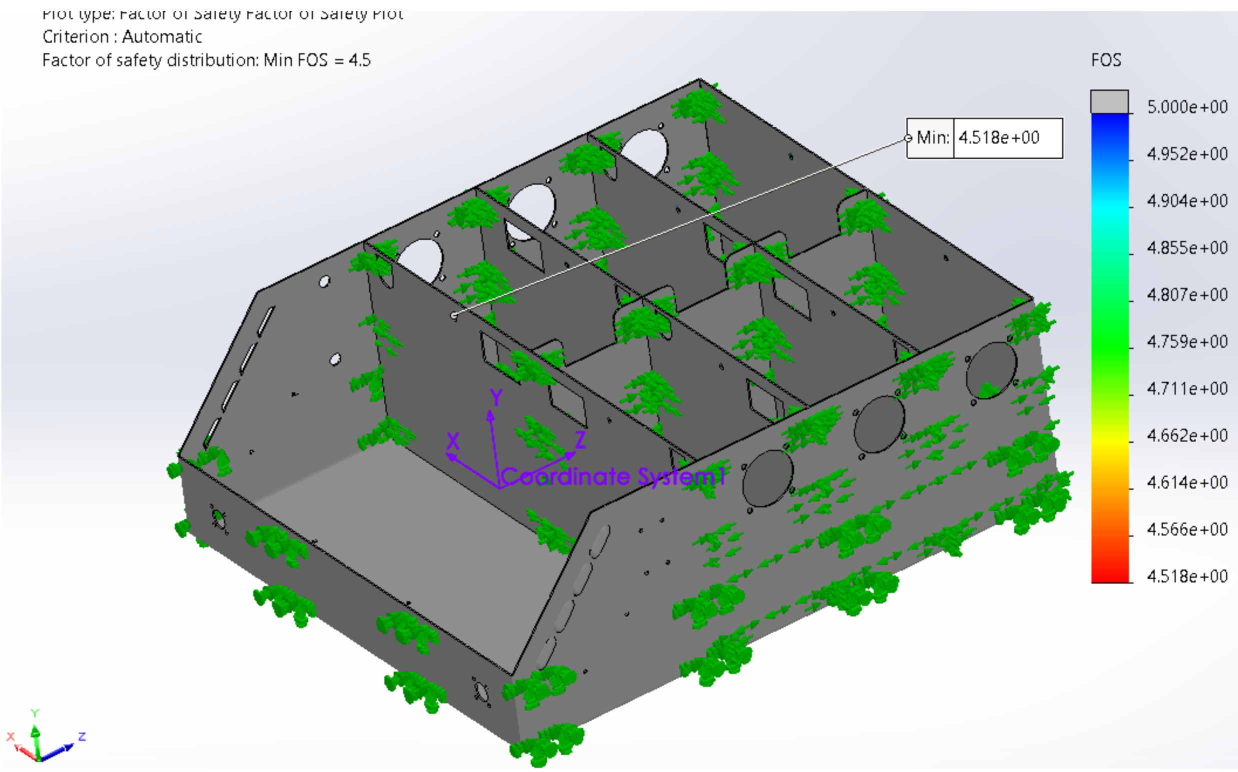

Figure 3.20: Vertical test FOS Plot (in positive y-axis direction)

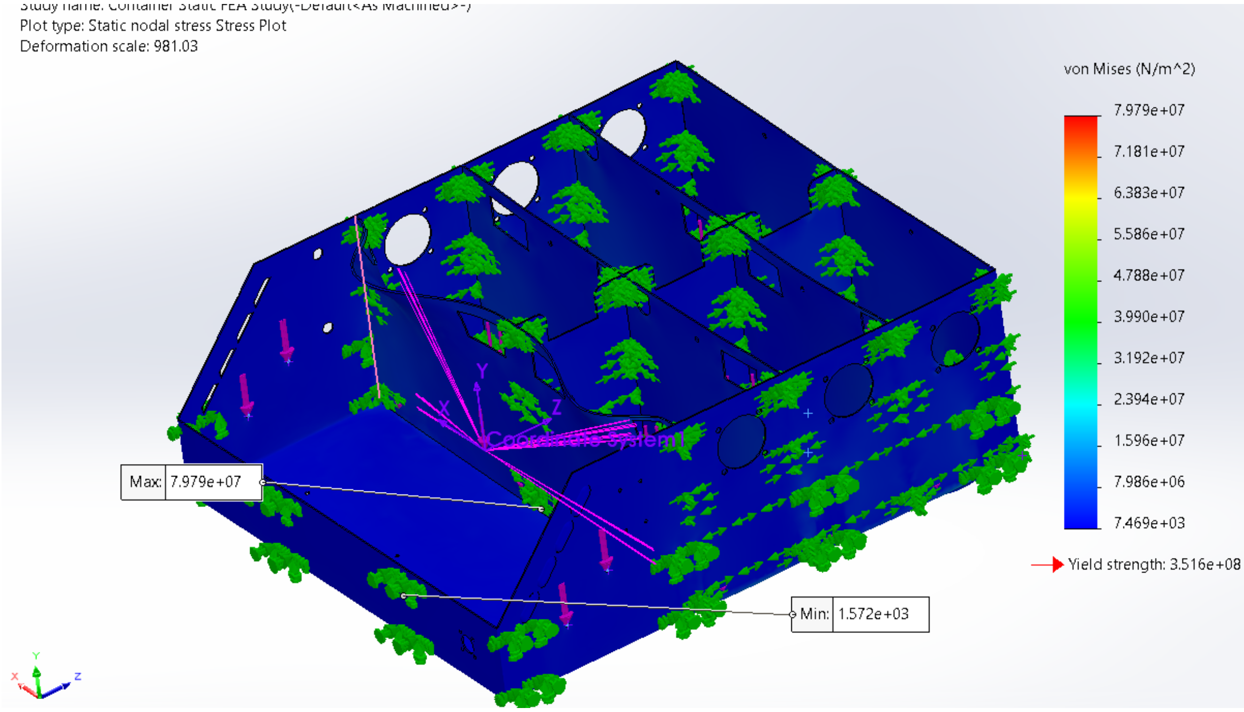

Figure 3.21: Vertical test Stress Plot (in negative y-axis direction)

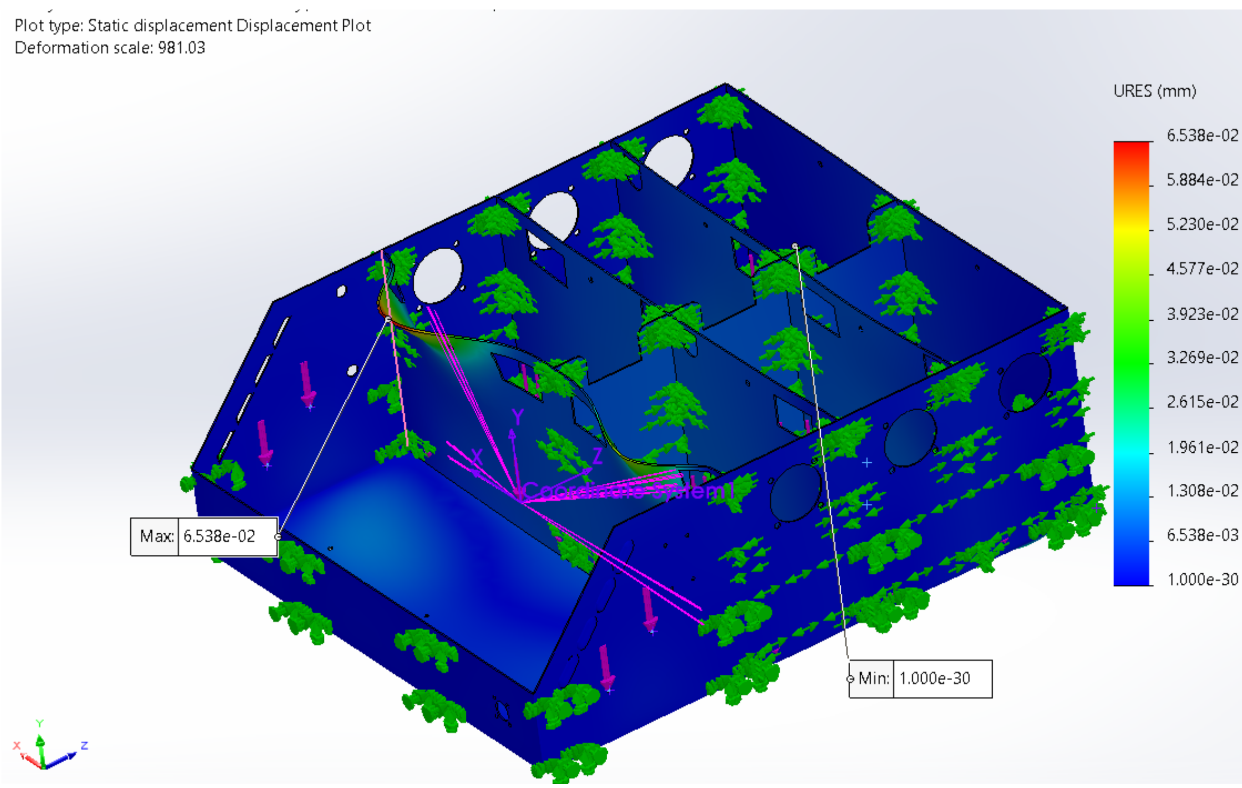

Figure 3.22: Vertical test Displacement Plot (in negative y-axis direction)

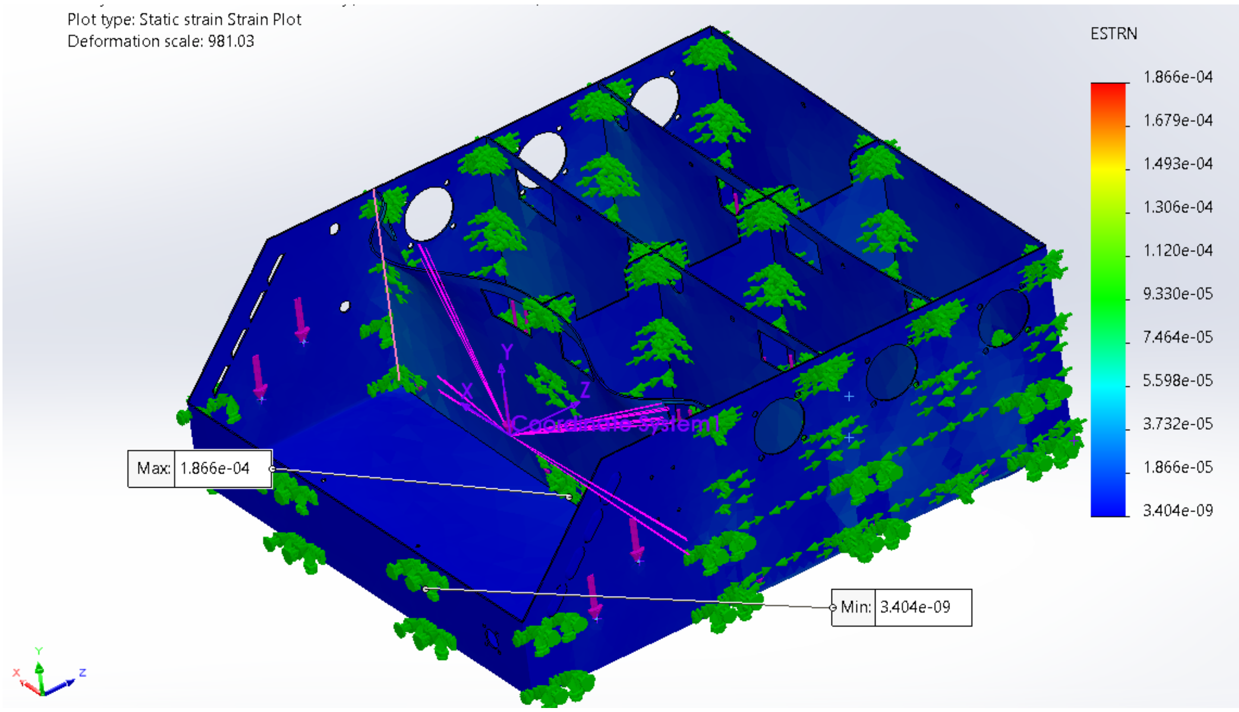

Figure 3.23: Vertical test Strain Plot (in negative y-axis direction)

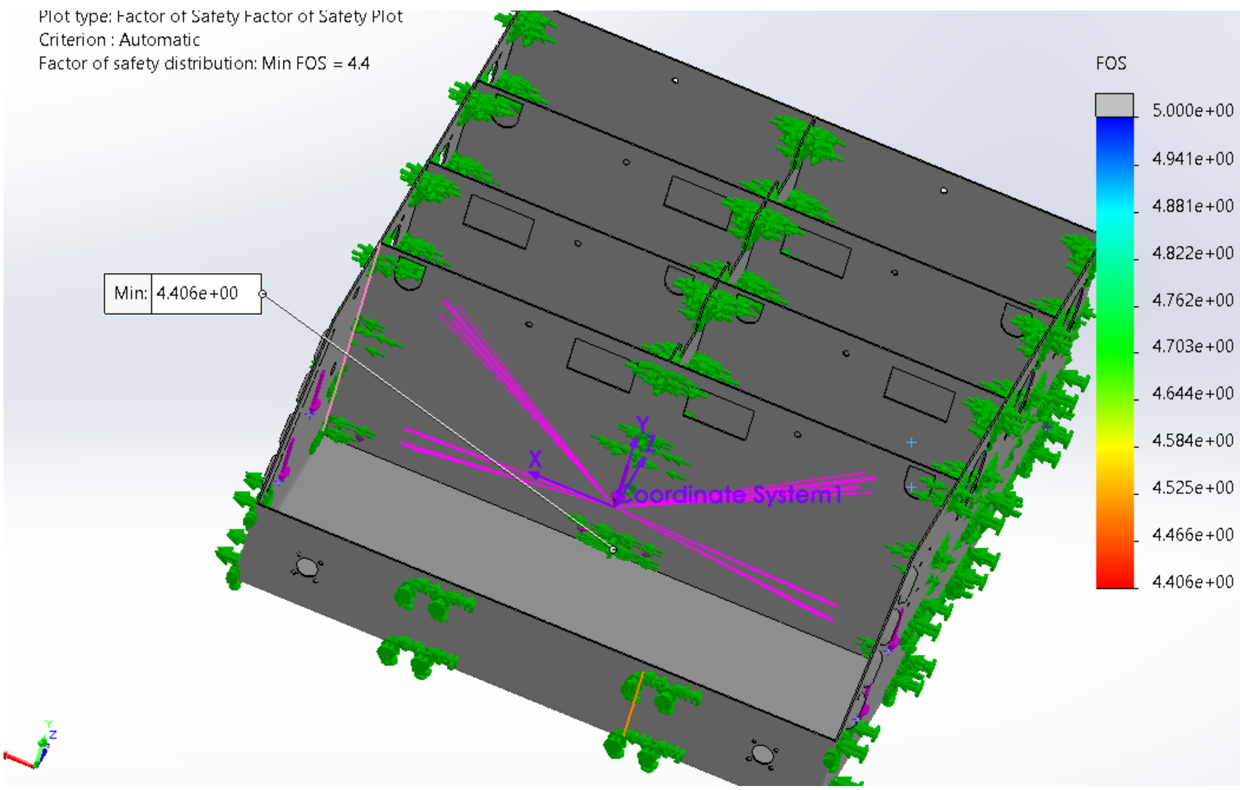

Figure 3.24: Vertical test FOS Plot (in negative y-axis direction)

Combined Load Test

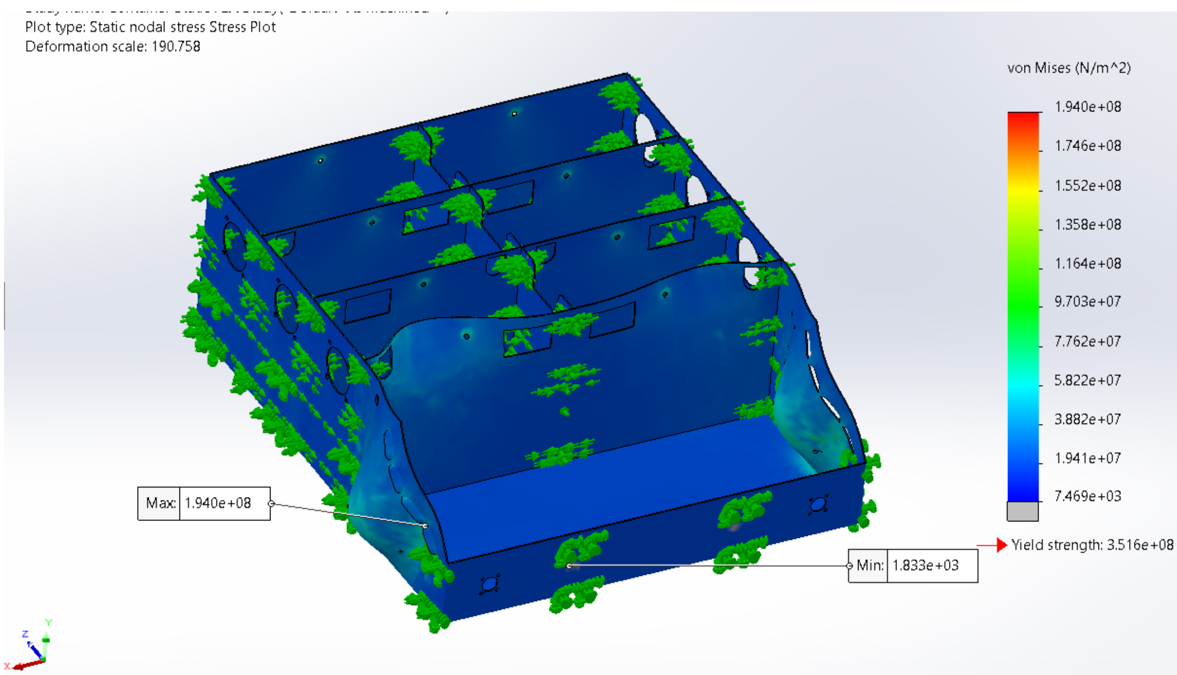

Figure 3.25: Combined Load Test Stress Plot (+ve axis directions)

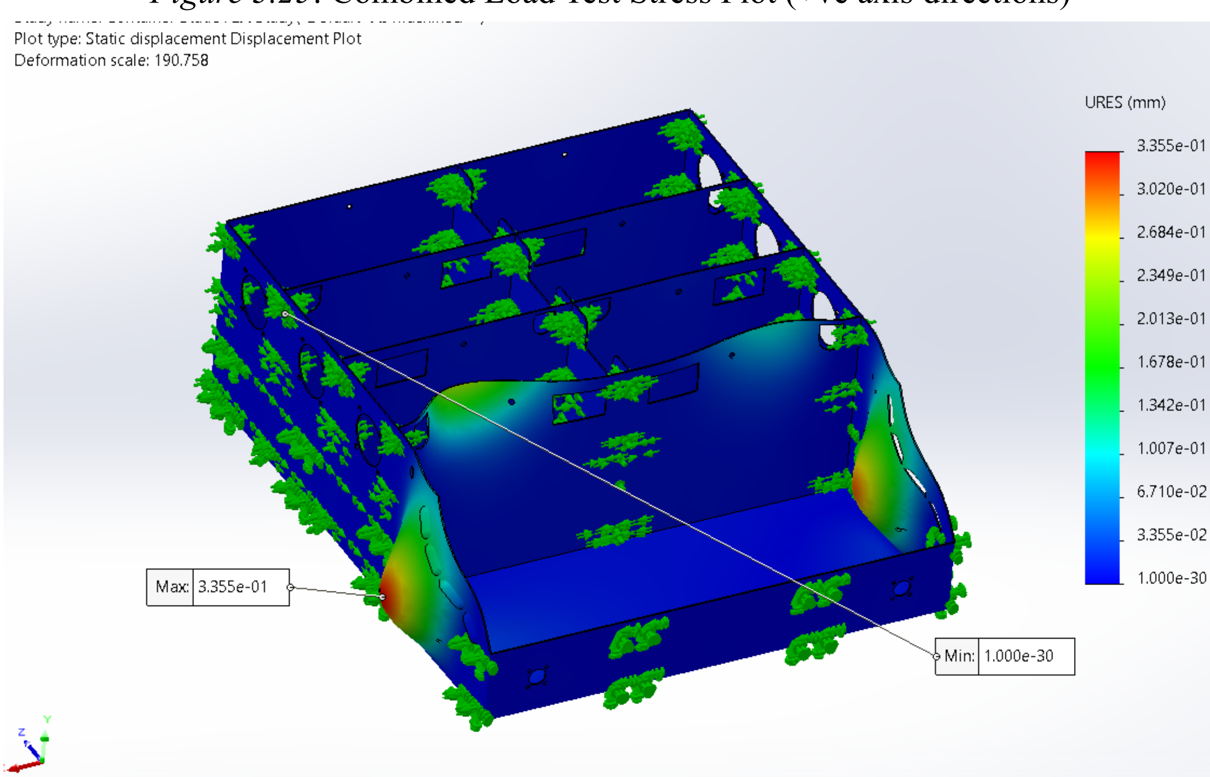

Figure 3.26: Combined Load Test Displacement Plot (+ve axis directions)

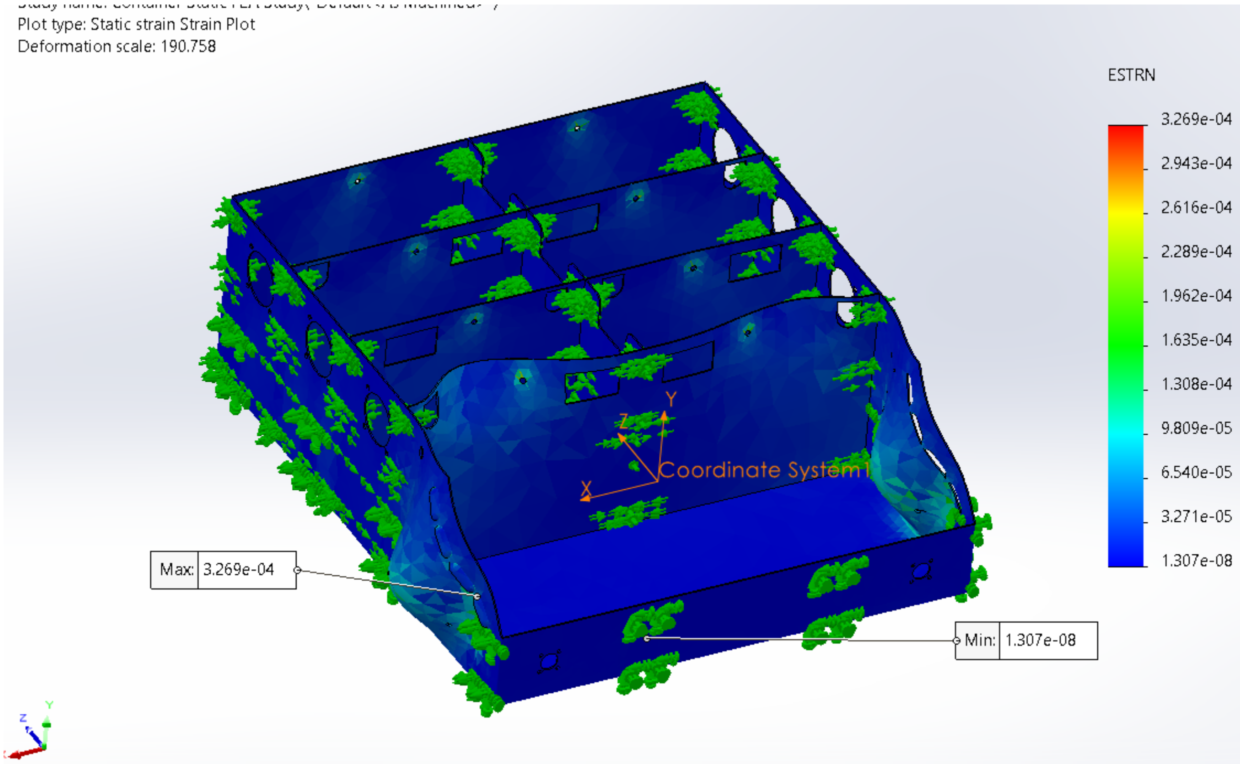

Figure 3.27: Combined Load Test Strain Plot (+ve axis directions)

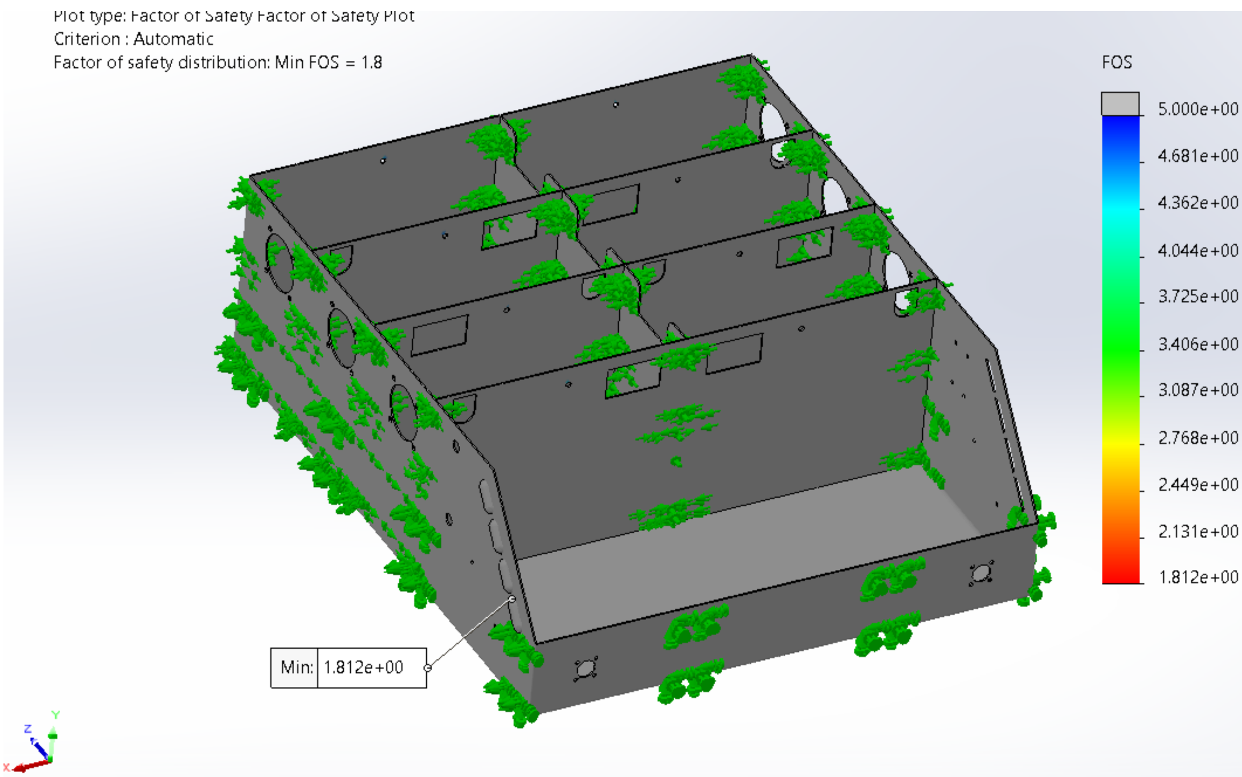

Figure 3.28: Combined Load Test FOS Plot (+ve axis directions)

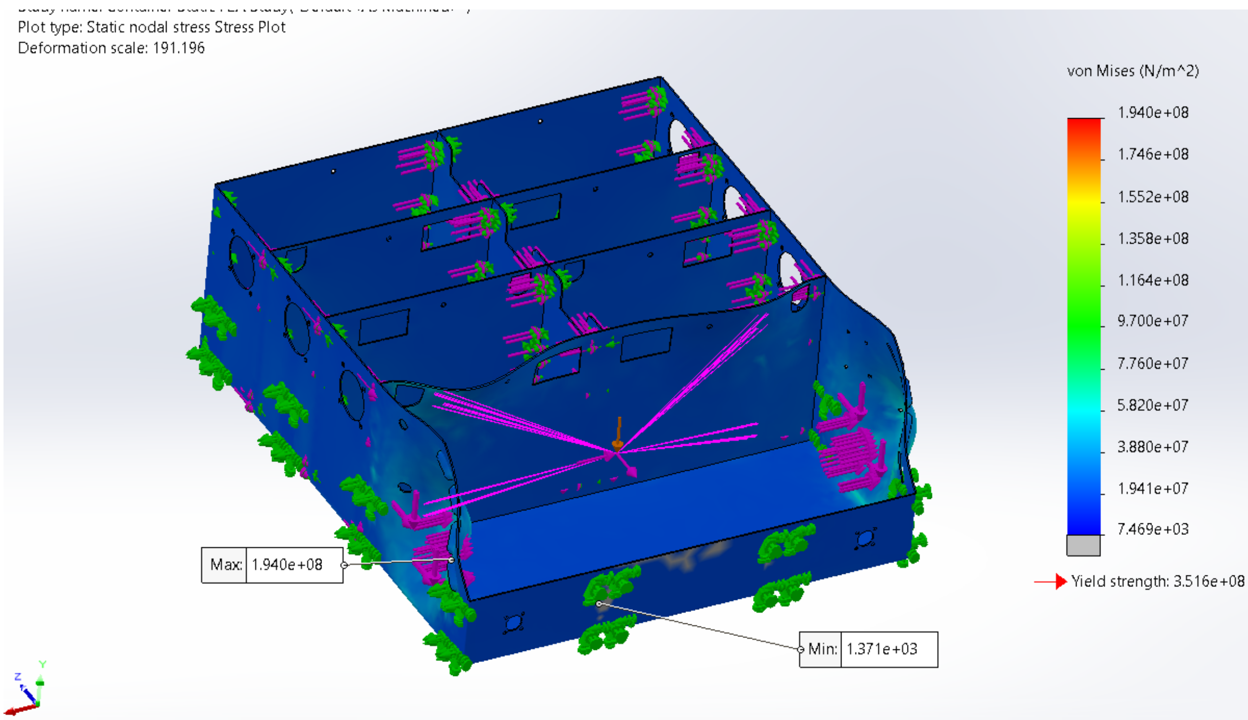

Figure 3.29: Combined Load Test Stress Plot (-ve axis directions)

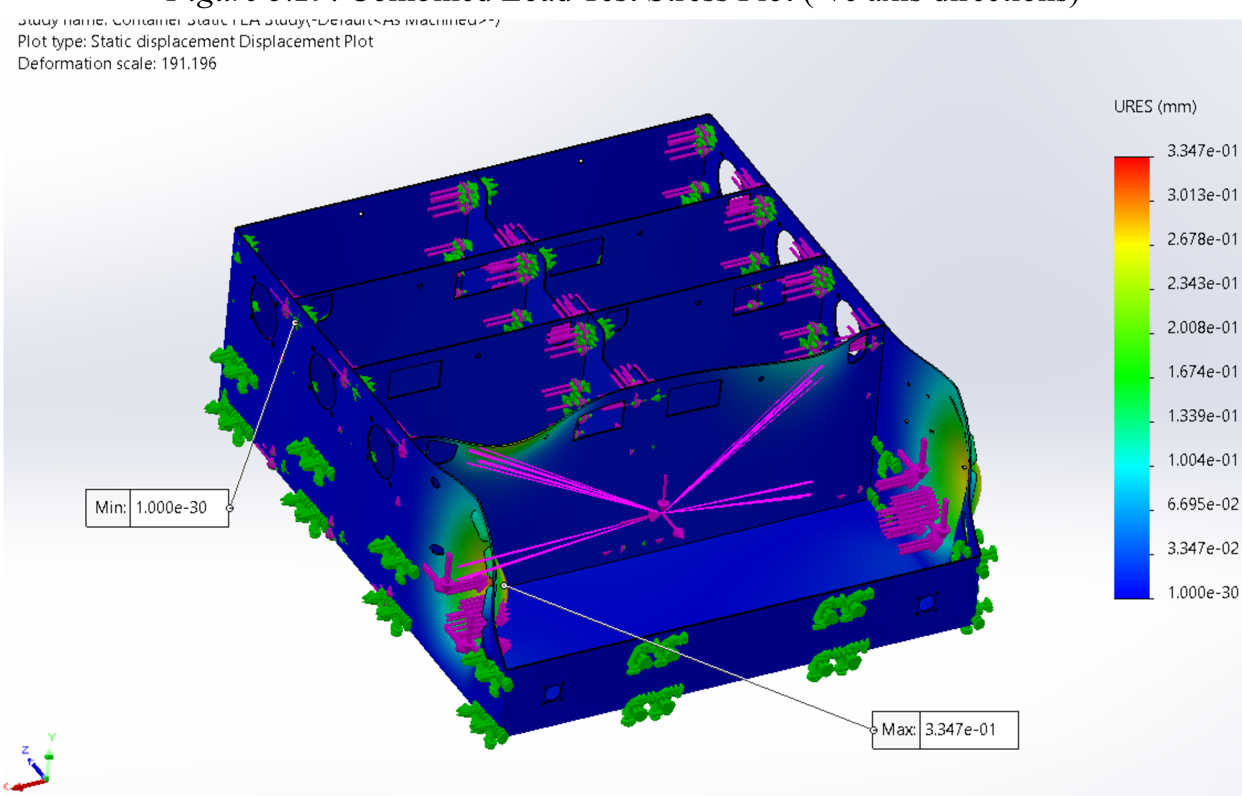

Figure 3.30: Combined Load Test Displacement Plot (-ve axis directions)

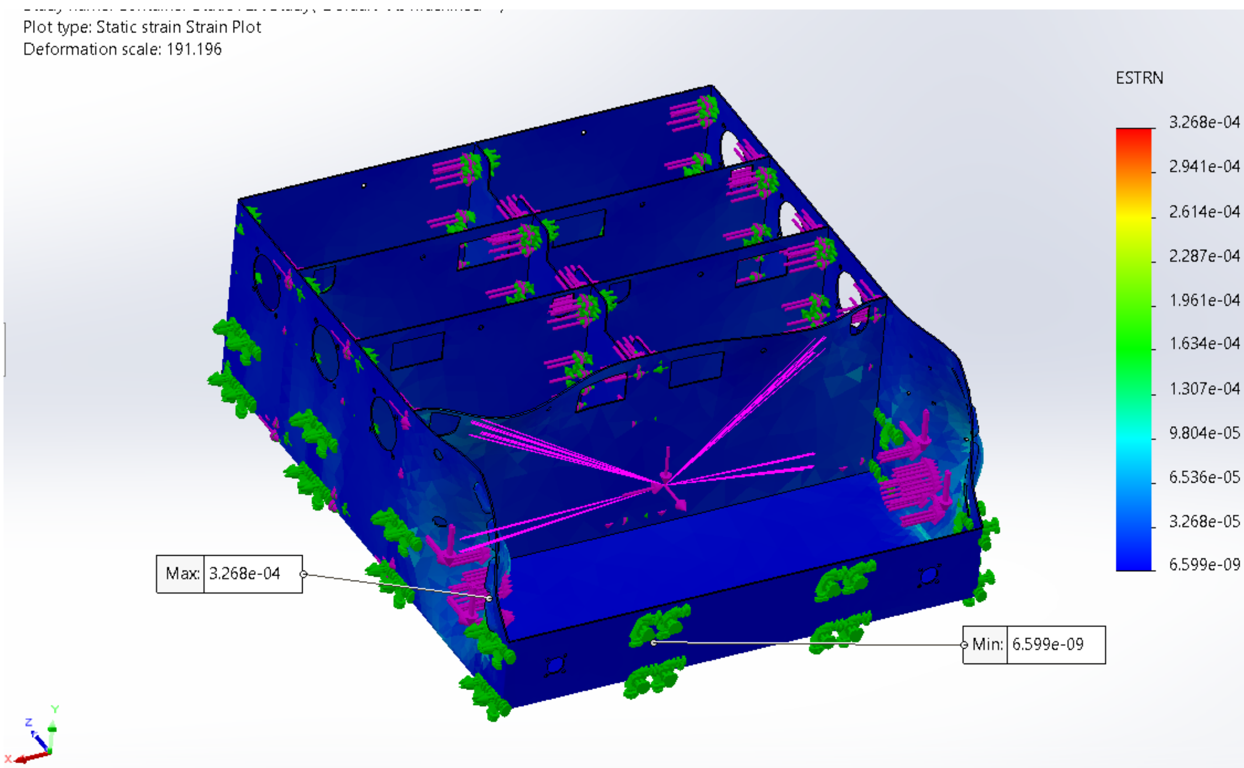

Figure 3.31: Combined Load Test Strain Plot (-ve axis directions)

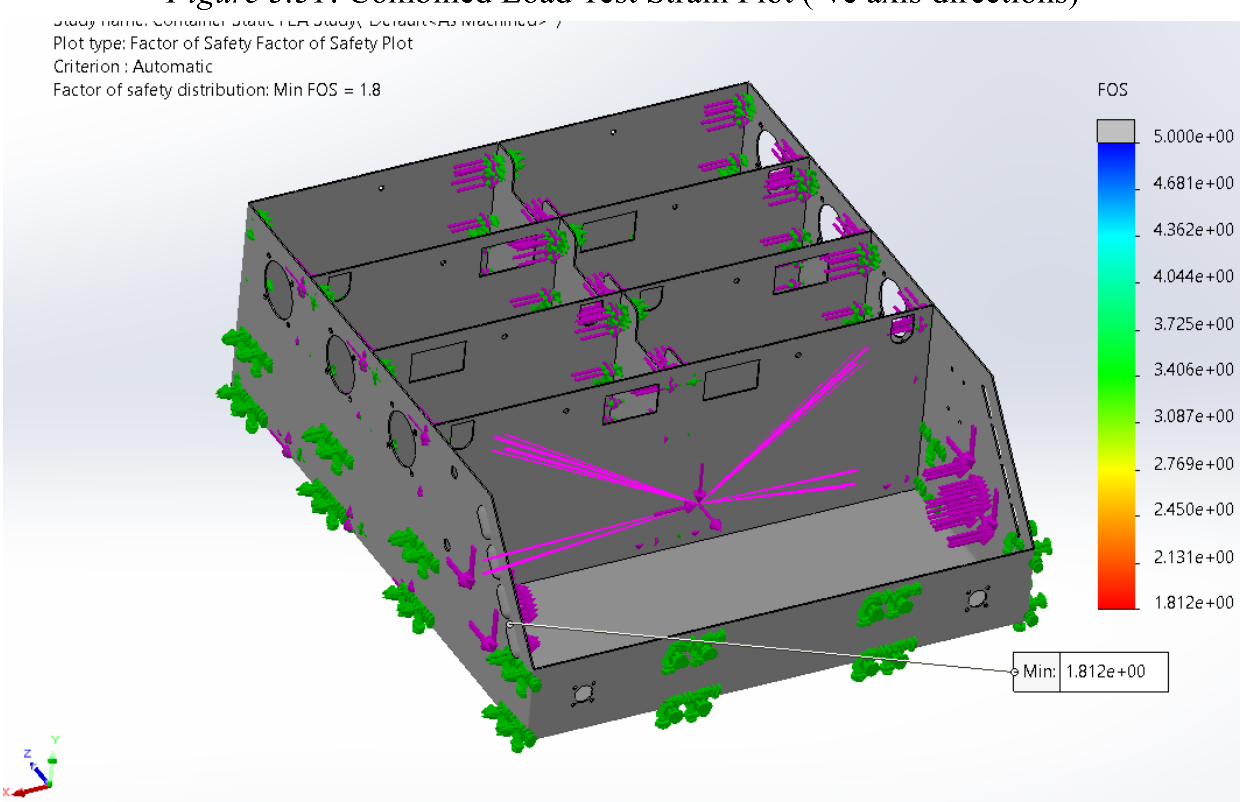

Figure 3.32: Combined Load Test FOS Plot (-ve axis directions)

4130 Tests

Lateral Tests

Figures 3.33-43.36 shows the lateral tests in the positive x-axis direction, while Figures 3.37-3.40 shows the lateral tests in the negative x-axis direction.

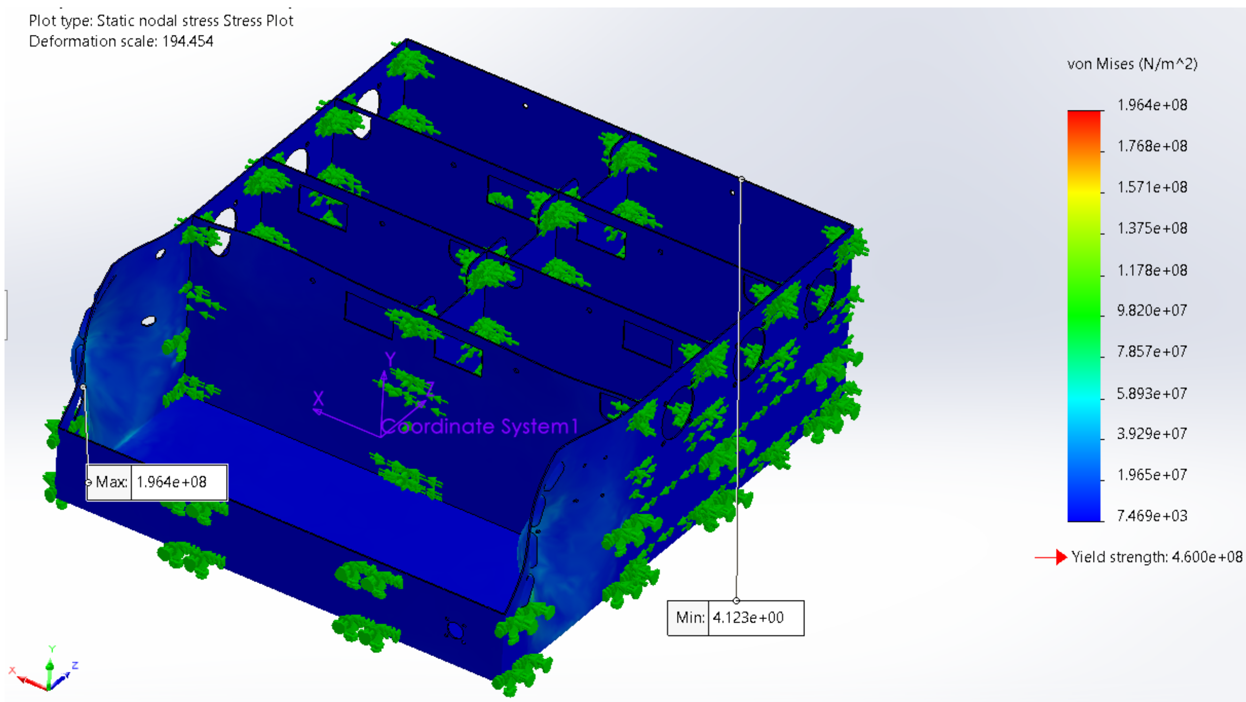

Figure 3.33: Vertical test Stress Plot (in positive x-axis direction)

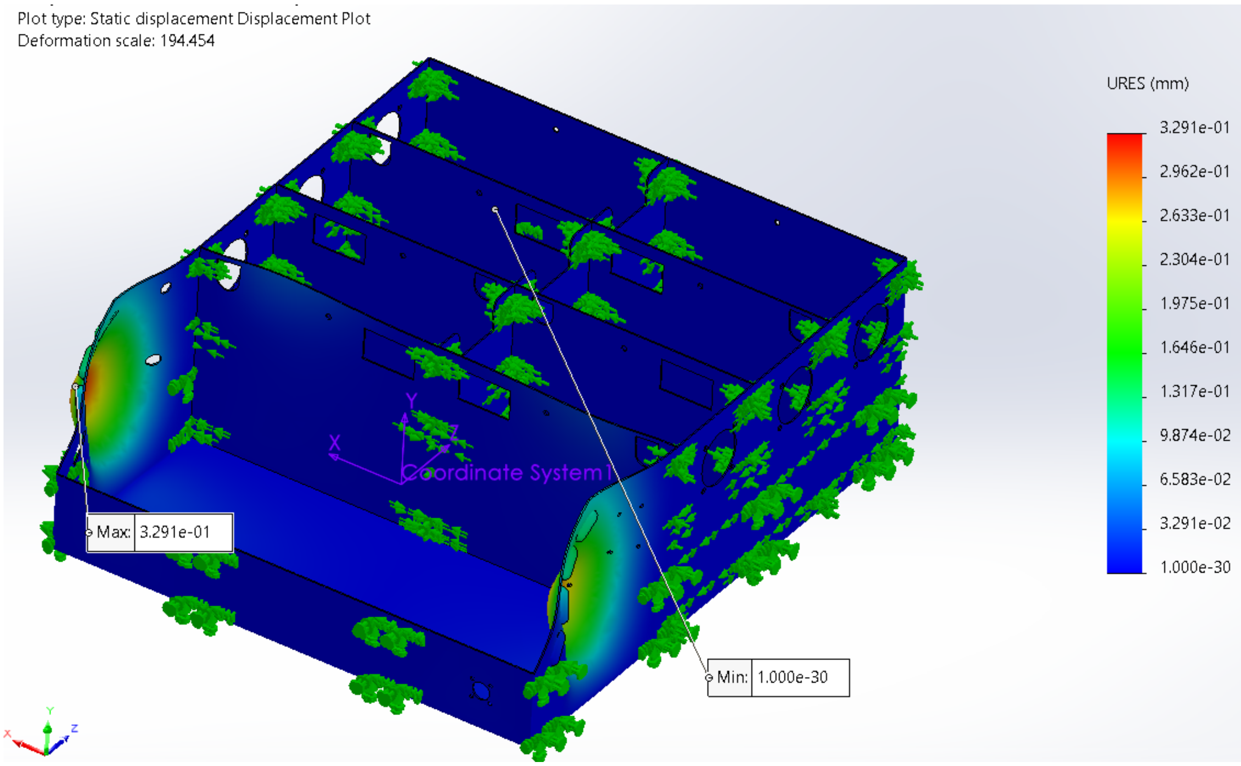

Figure 3.34: Lateral test Displacement Plot (in positive x-axis direction)

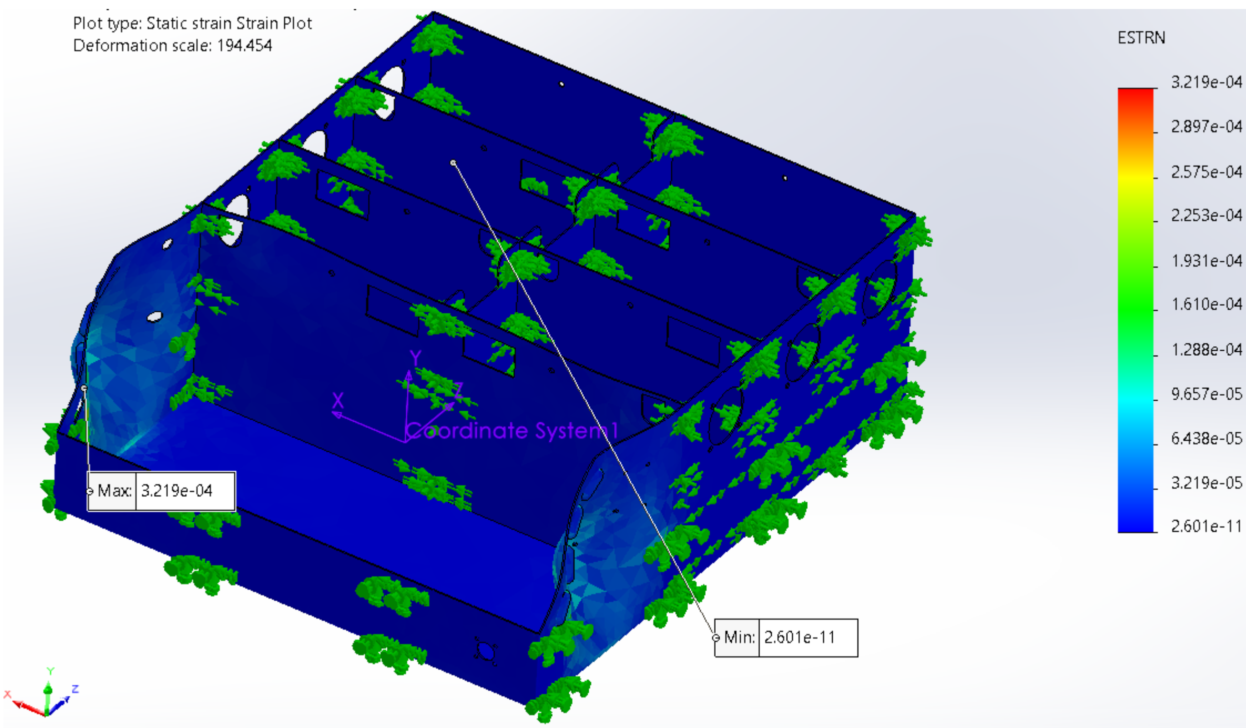

Figure 3.35: Lateral test strain Plot (in positive x-axis direction)

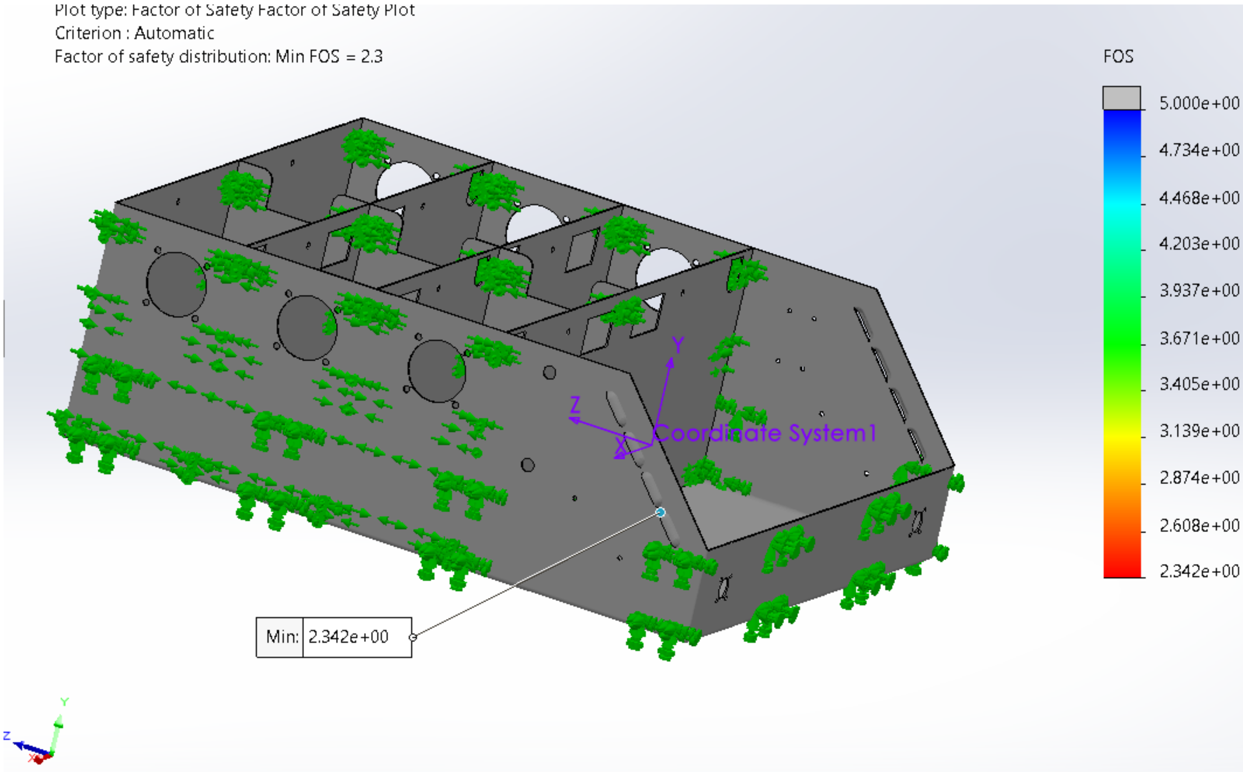

Figure 3.36: Lateral test FOS plot (in positive x-axis direction)

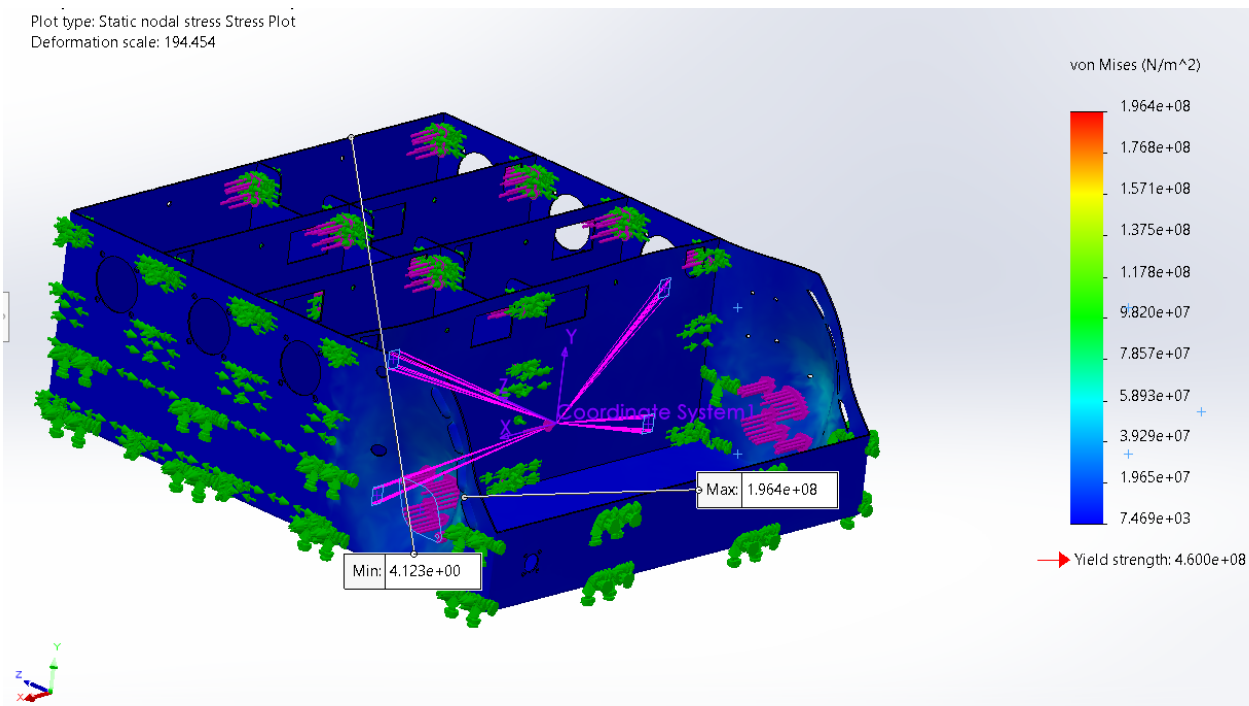

Figure 3.37: Lateral test Stress Plot (in negative x-axis direction)

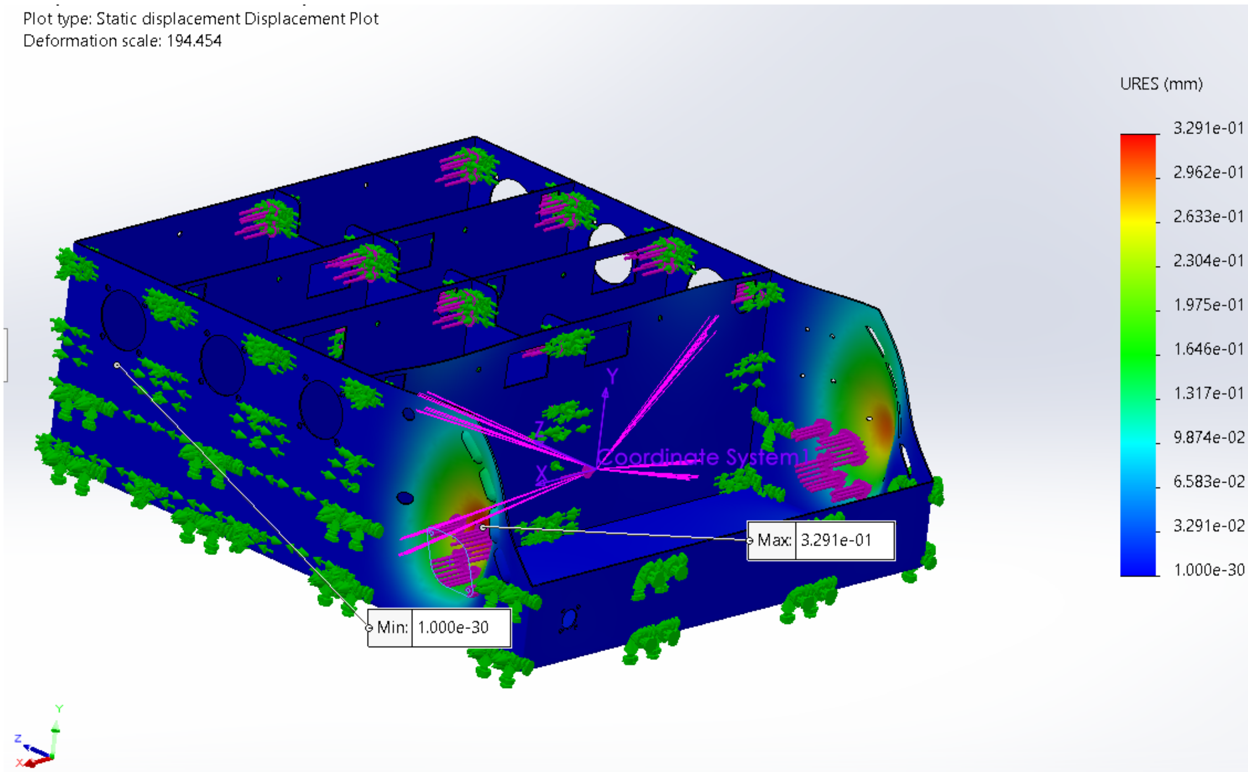

Figure 3.38: Lateral test Displacement Plot (in negative x-axis direction)

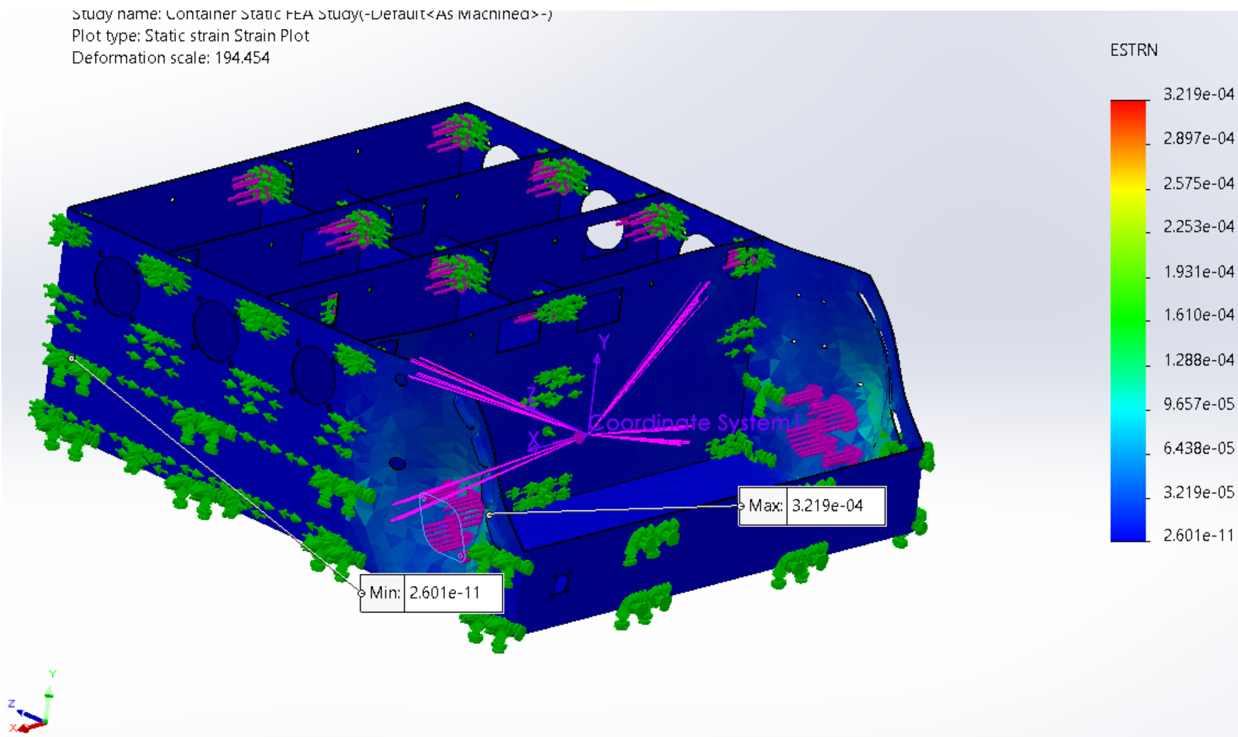

Figure 3.39: Lateral test Strain Plot (in negative x-axis direction)

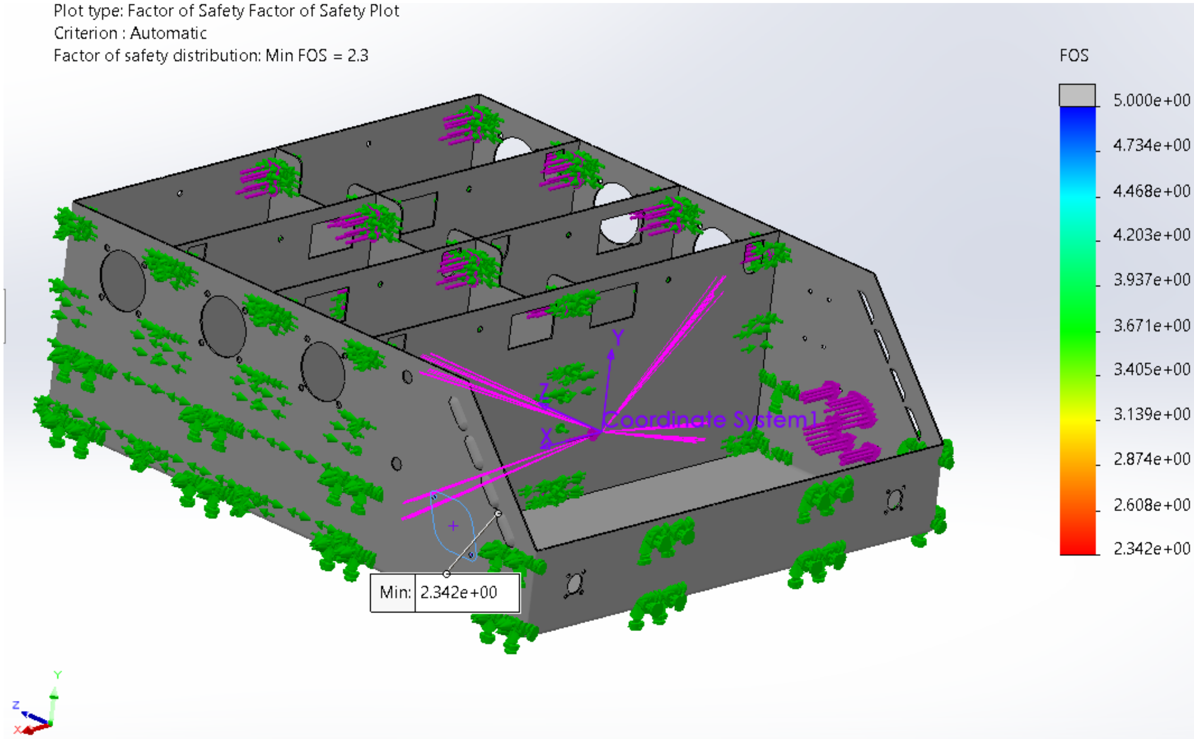

Figure 3.40: Lateral test FOS Plot (in negative x-axis direction)

Longitudinal Tests

Figures 3.41-3.44 shows the longitudinal tests in the negative z-axis direction, while Figures 3.45-3.48 shows the longitudinal tests in the positive z-axis direction.

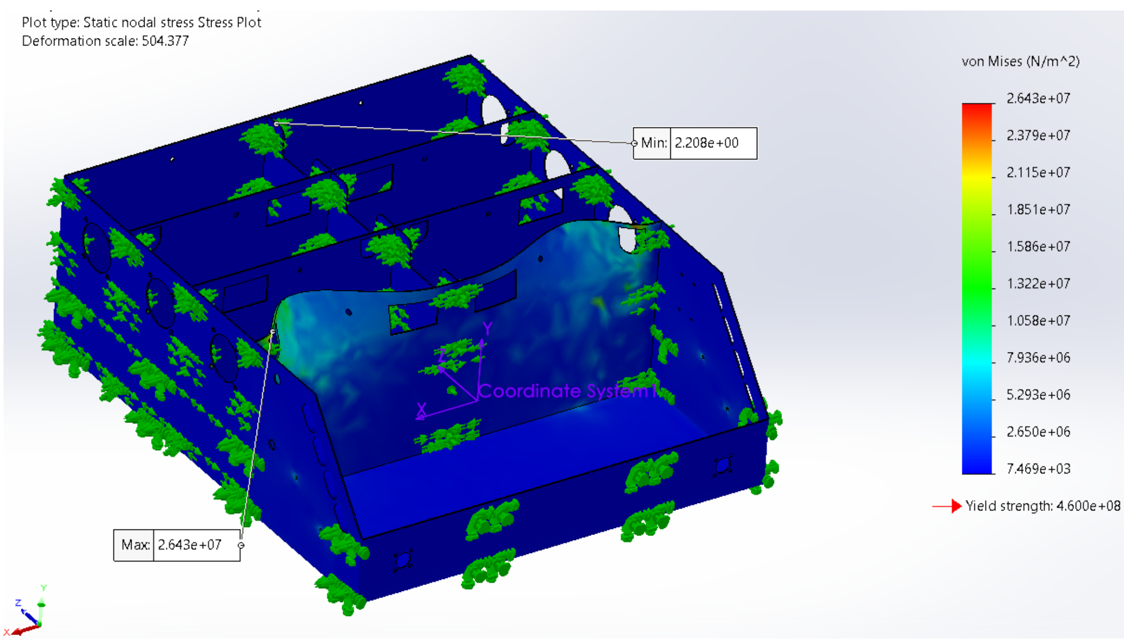

Figure 3.41: Longitudinal test Stress Plot (in negative z-direction)

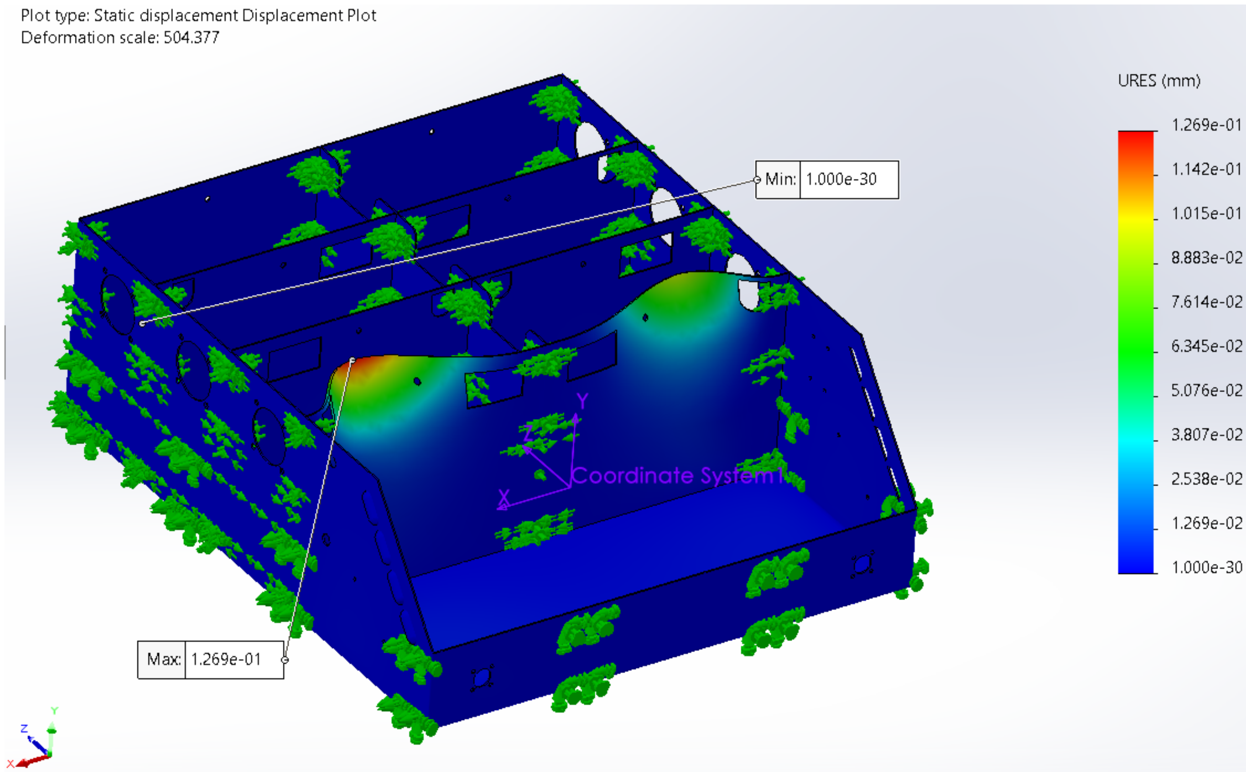

Figure 3.42: Longitudinal test Displacement plot (in negative z-direction)

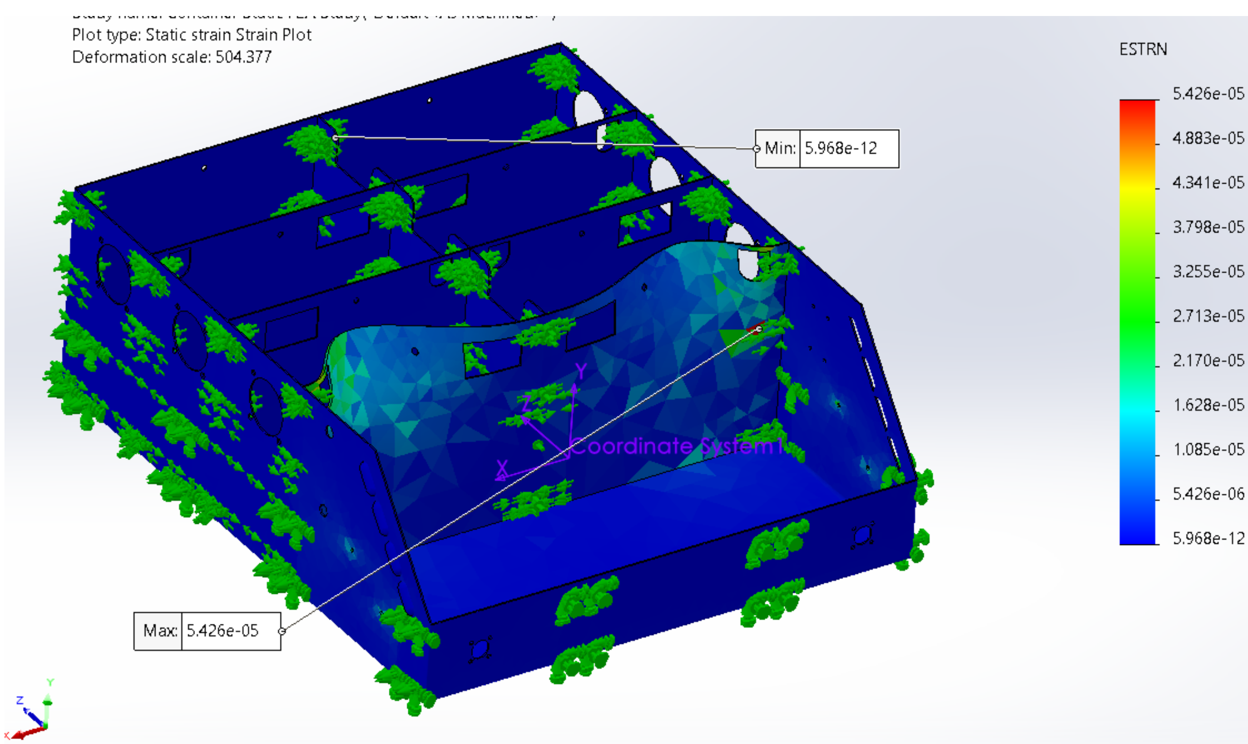

Figure 3.43: Longitudinal test Strain Plot (in negative z-direction)

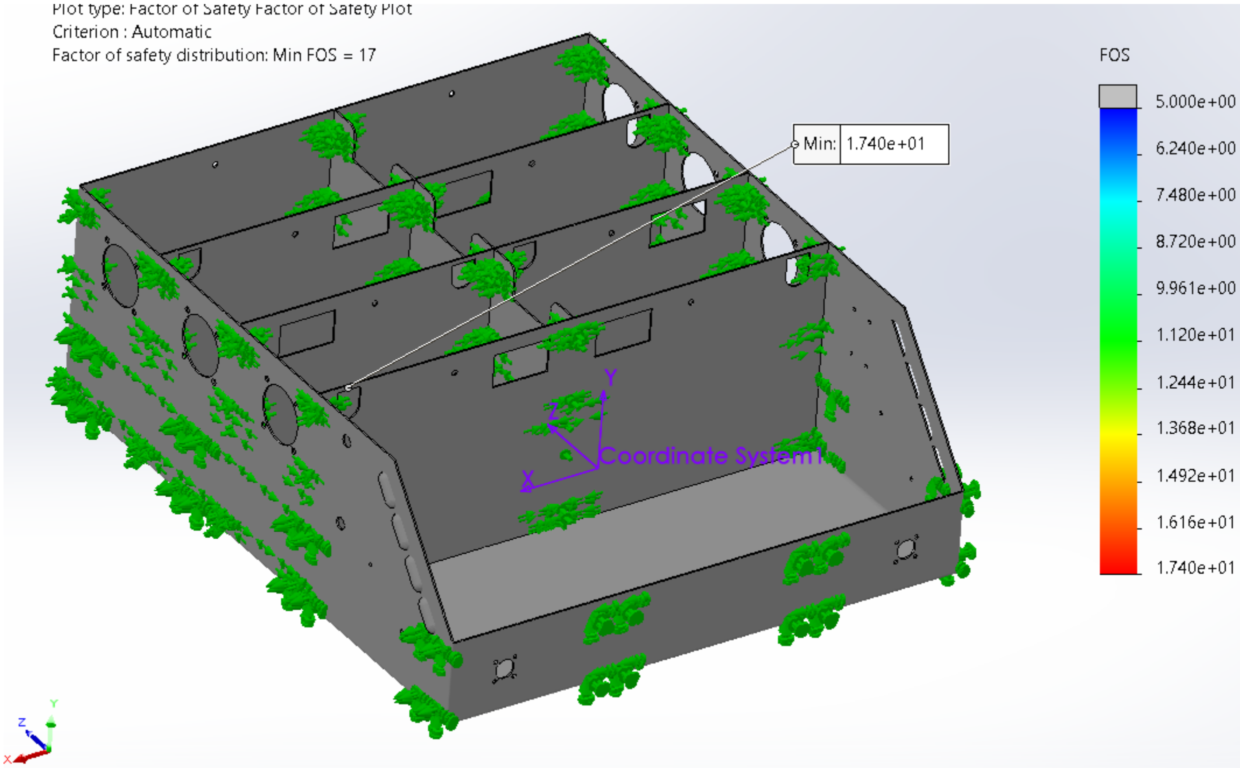

Figure 3.44: Longitudinal test FOS Plot (in negative z-direction)

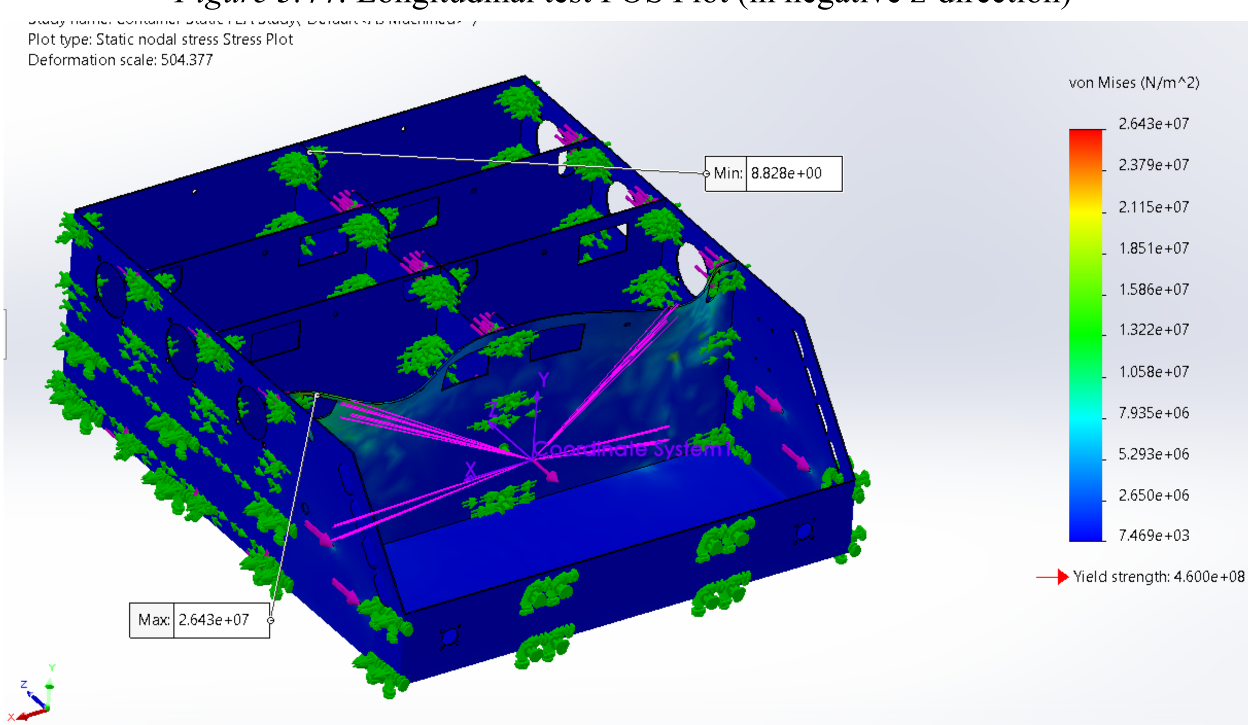

Figure 3.45: Longitudinal test Stress Plot (in positive z-direction)

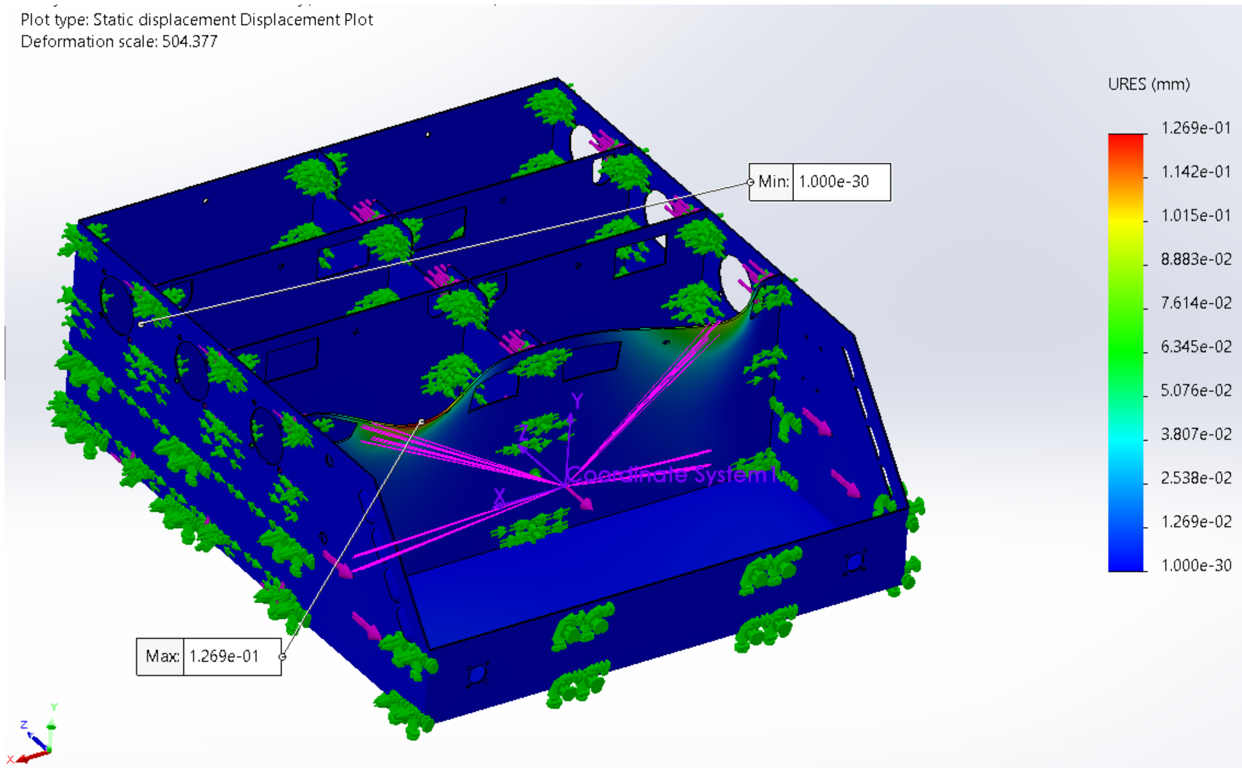

Figure 3.46: Longitudinal test Displacement Plot (in positive z-direction)

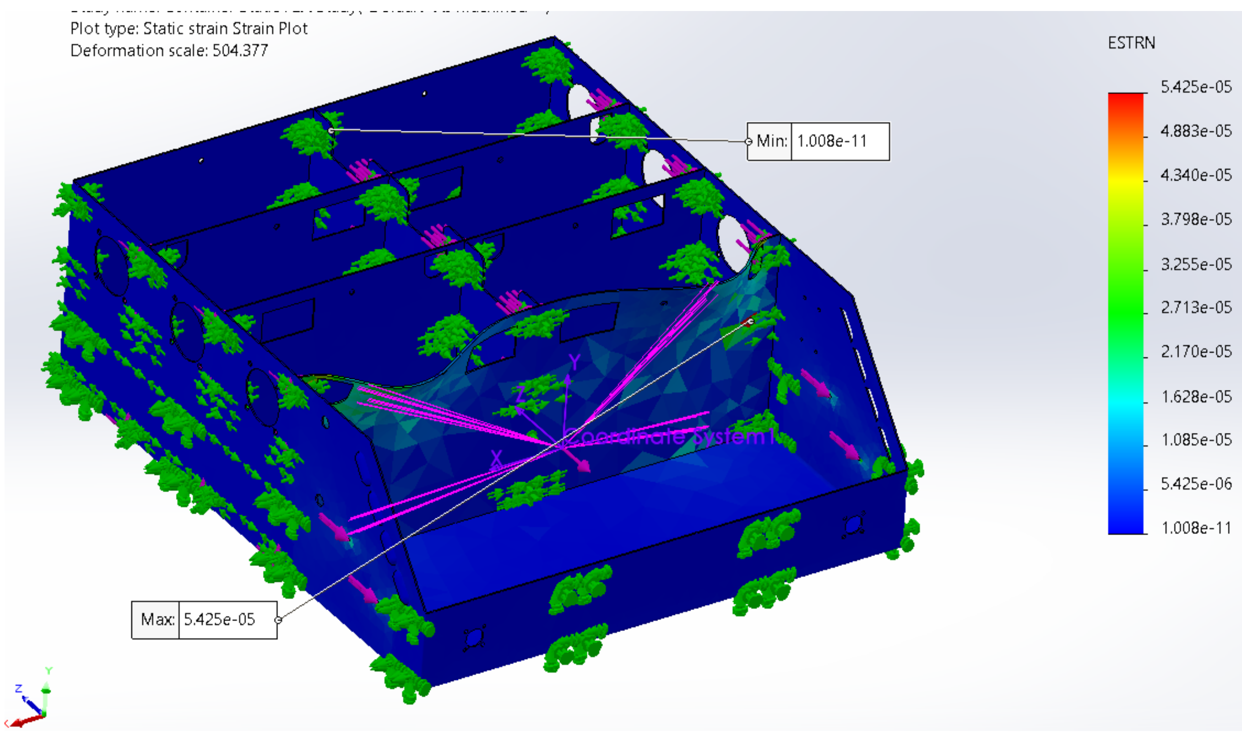

Figure 3.47: Longitudinal test Strain Plot (in positive z-direction)

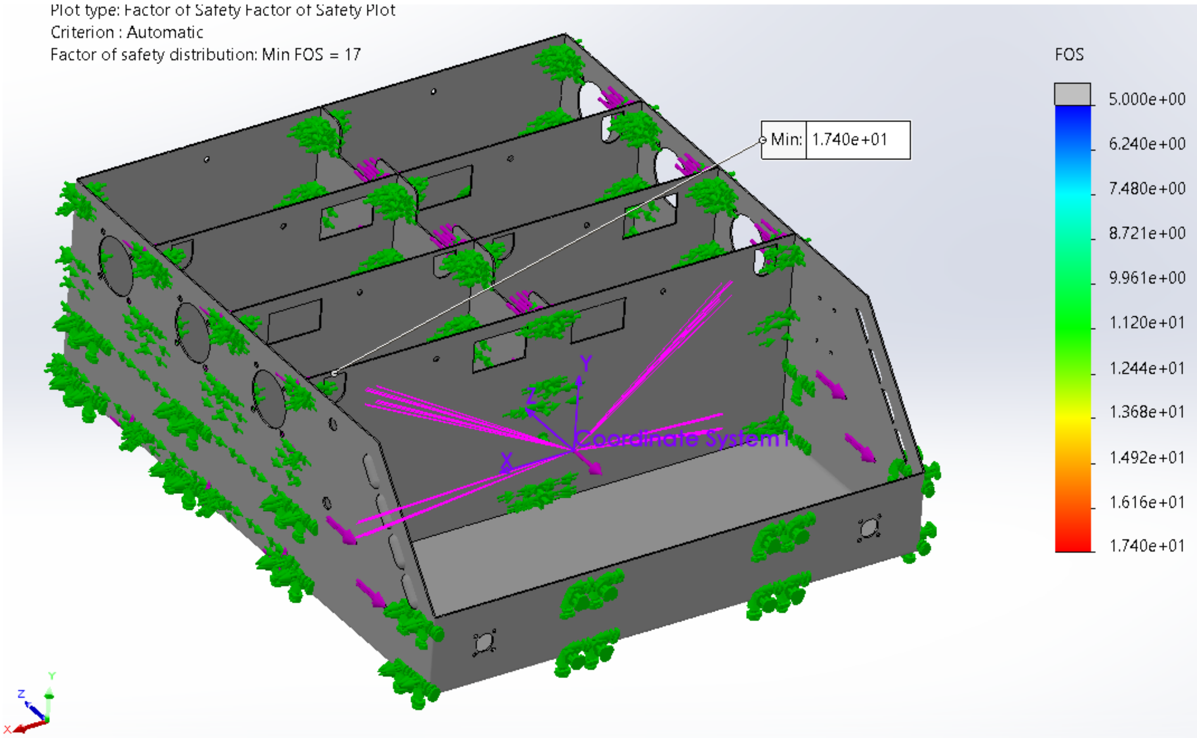

Figure 3.48: Longitudinal test FOS Plot (in positive z-direction)

Vertical Tests

Figures 3.49-3.52 shows the vertical tests in the positive y-axis direction, while Figures 3.53-3.56 shows the vertical tests in the positive y-axis direction.

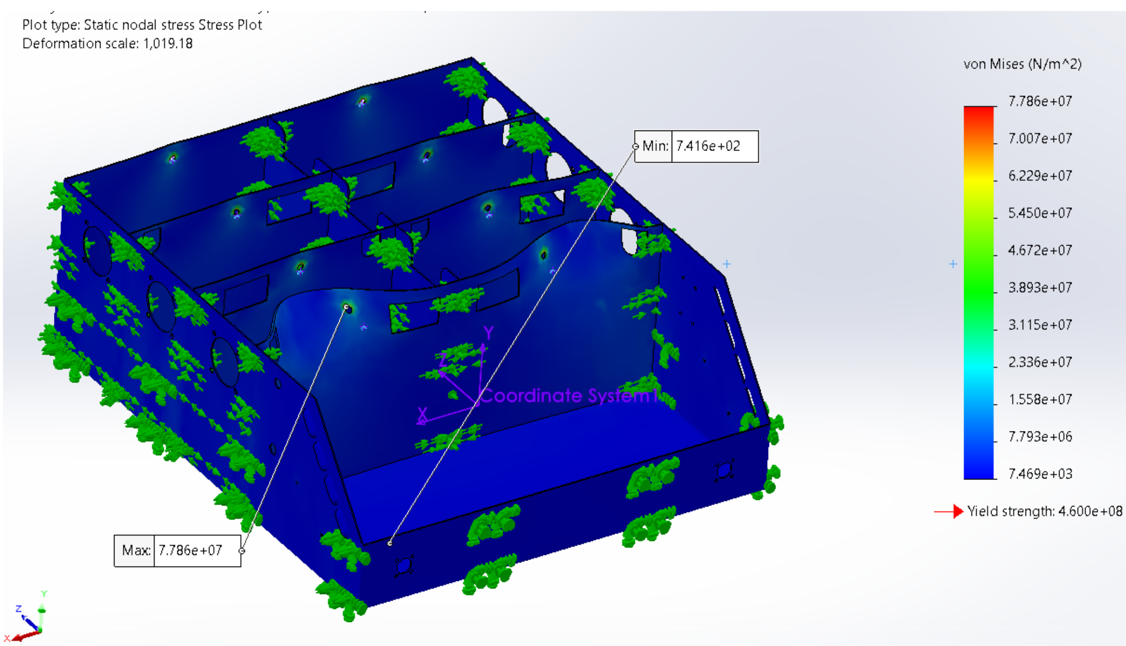

Figure 3.49: Vertical test Stress Plot (in positive y-direction)

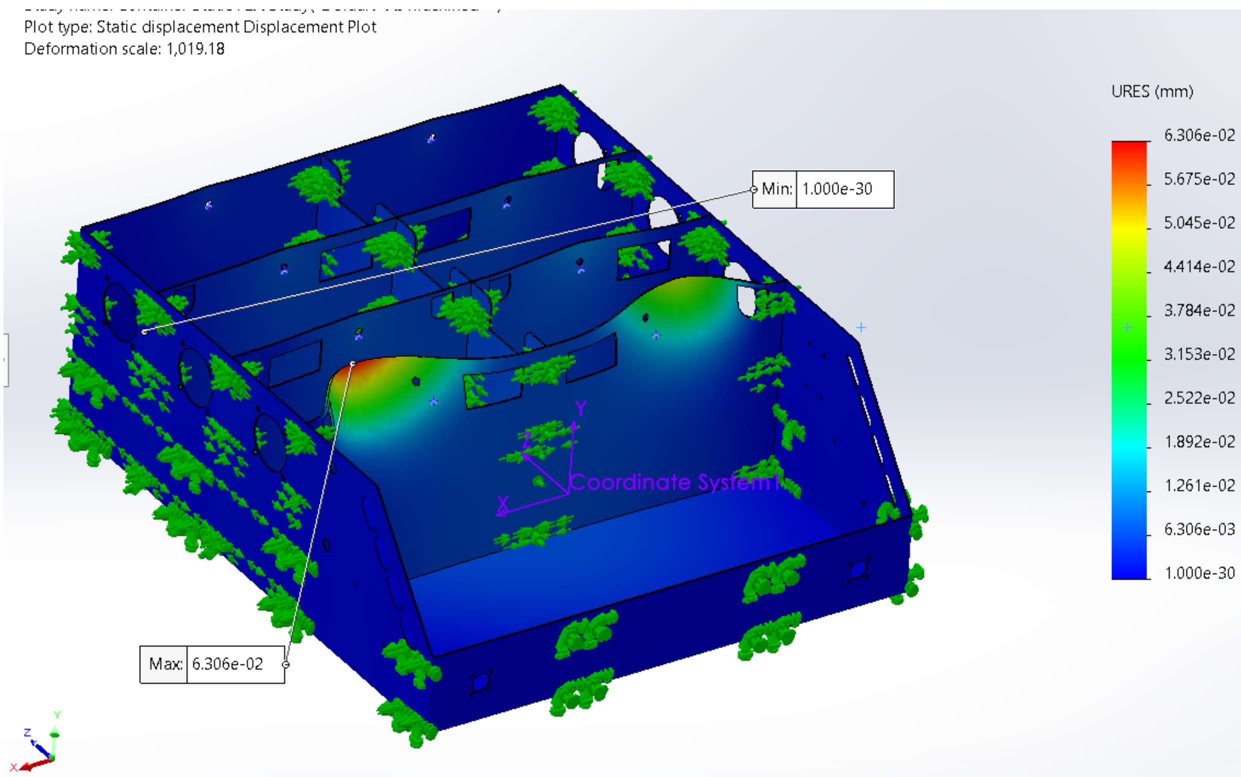

Figure 3.50: Vertical test Displacement Plot (in positive y-direction)

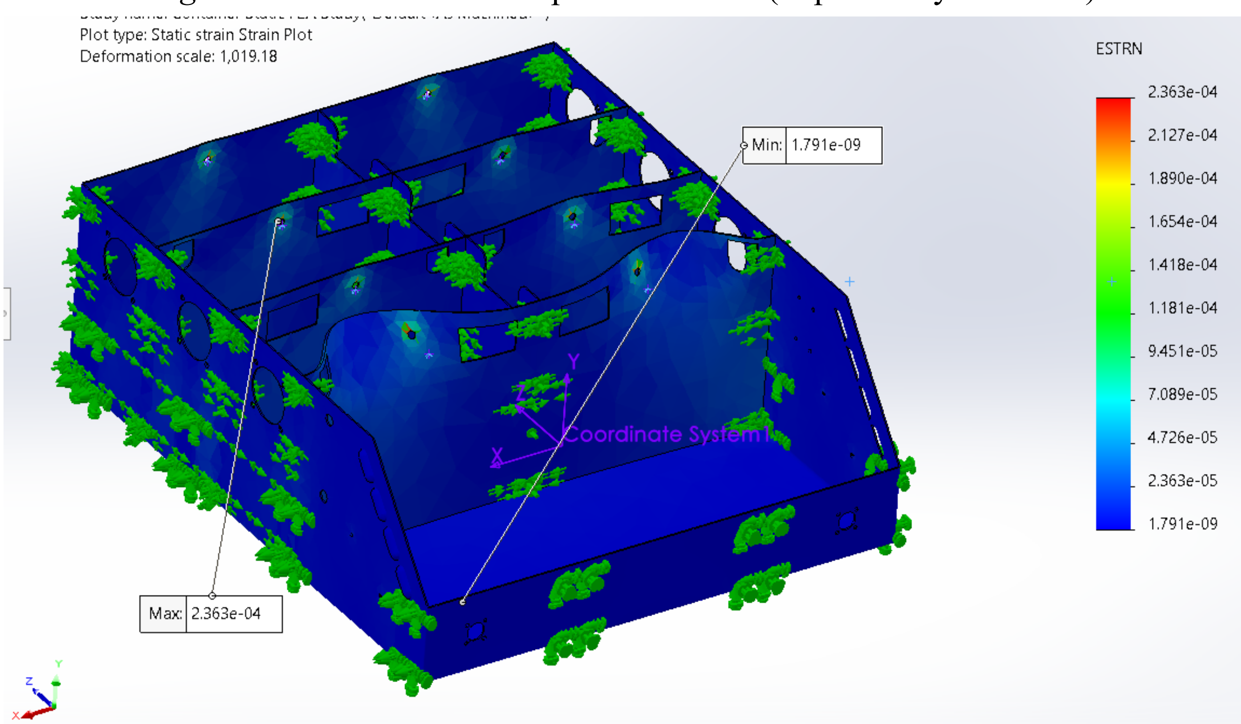

Figure 3.51: Vertical test Strain Plot (in positive y-direction)

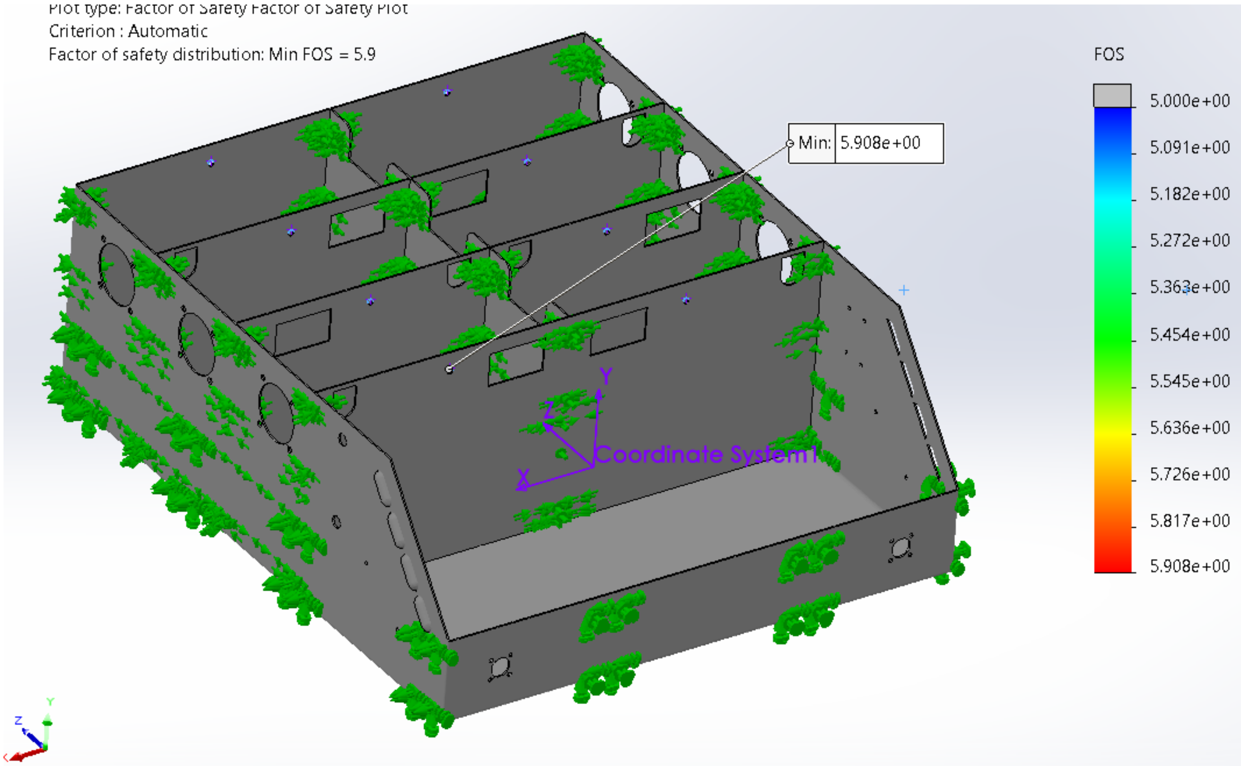

Figure 3.52: Vertical test FOS Plot (in positive y-direction)

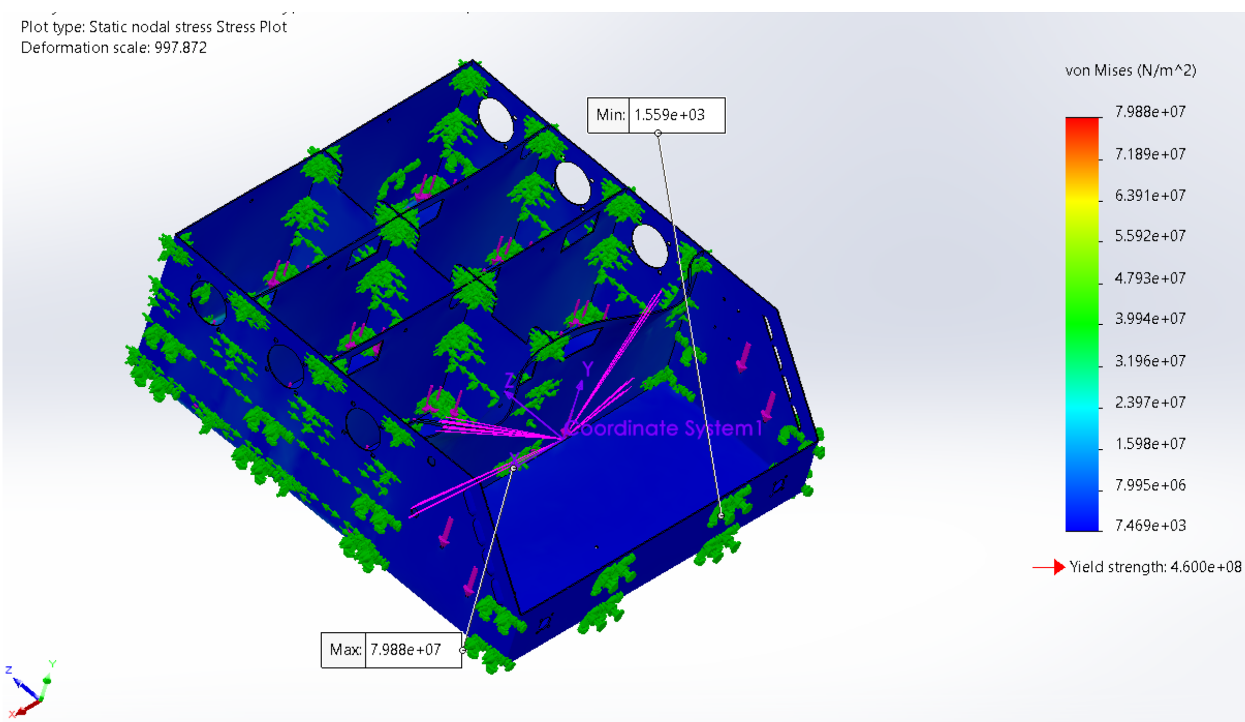

Figure 3.53: Vertical test Stress Plot (in negative y-direction)

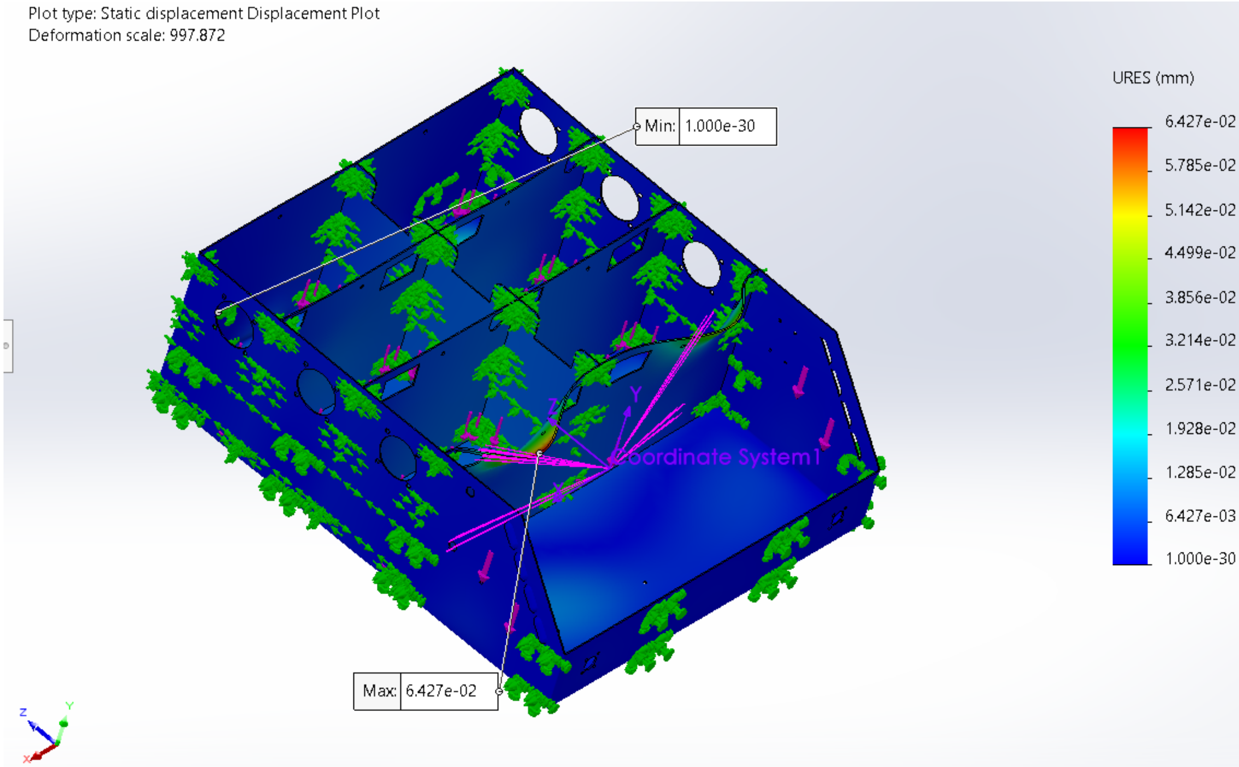

Figure 3.54: Vertical Test Displacement Plot (in negative y-direction)

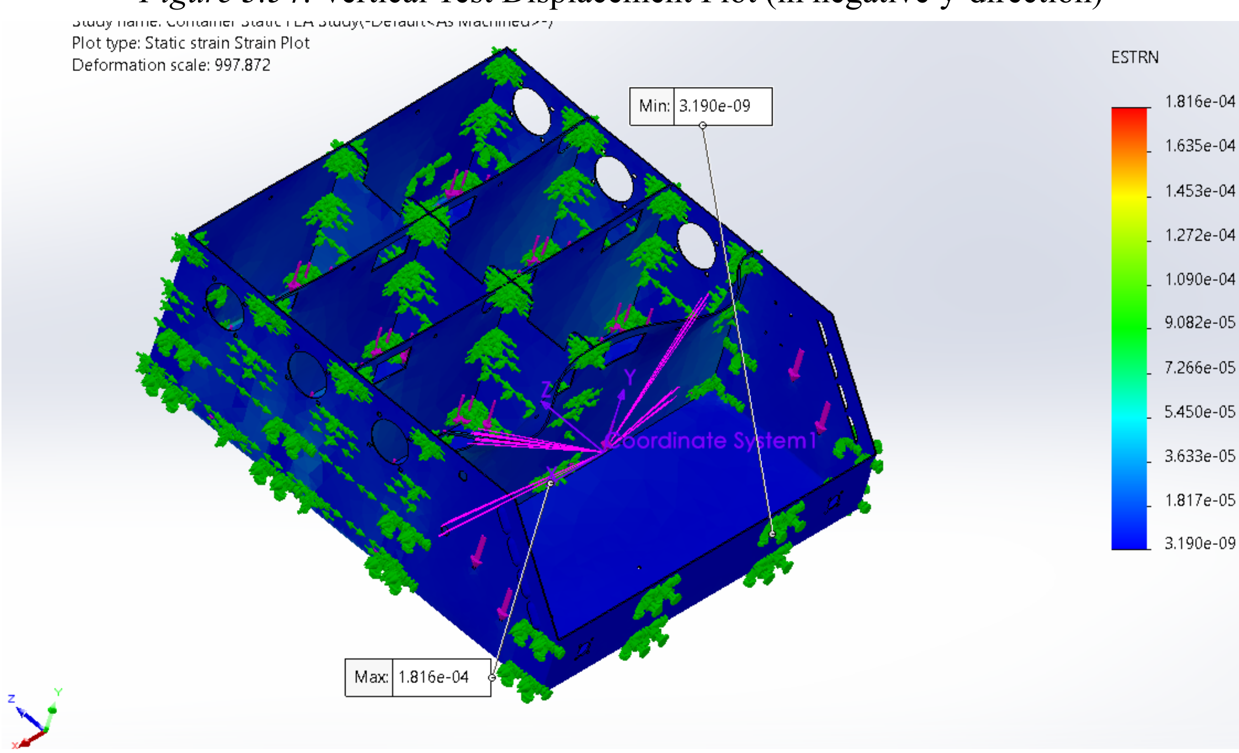

Figure 3.55: Vertical Test Strain Plot (in negative y-direction)

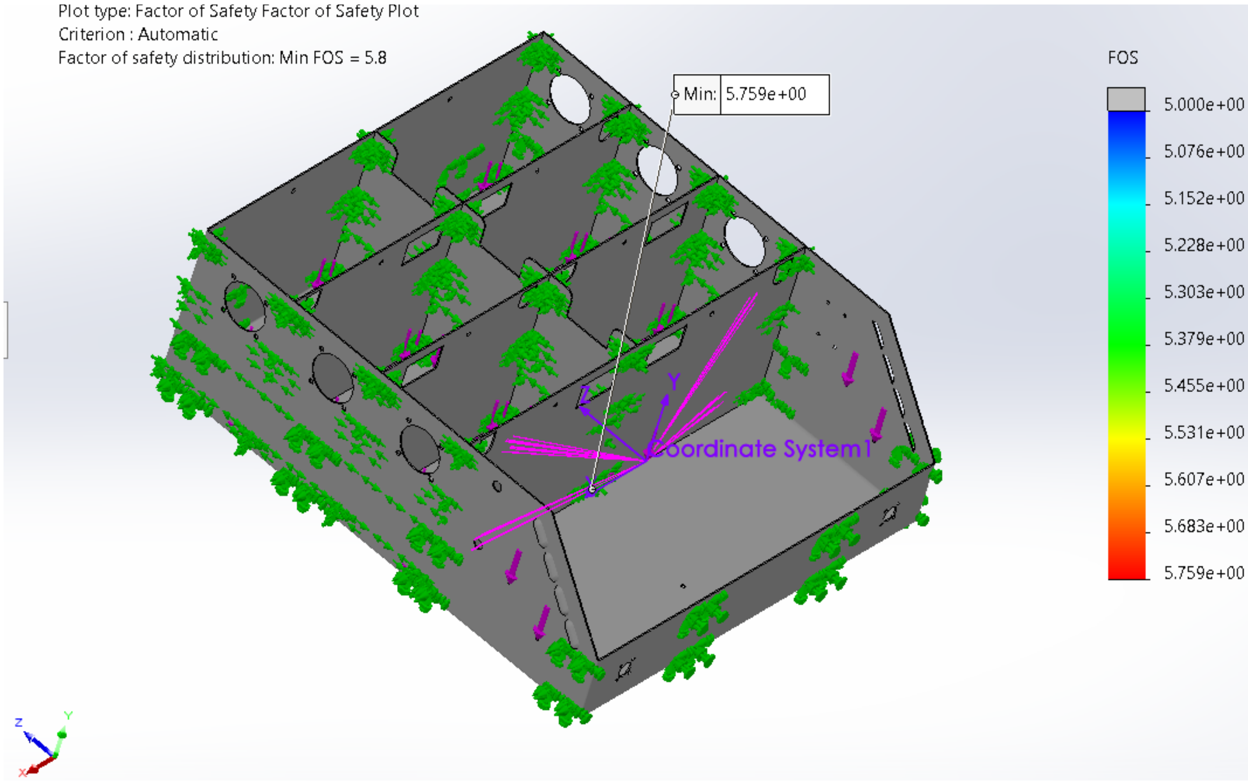

Figure 3.56: Vertical Test FOS Plot (in negative y-direction)

Combined Load Test

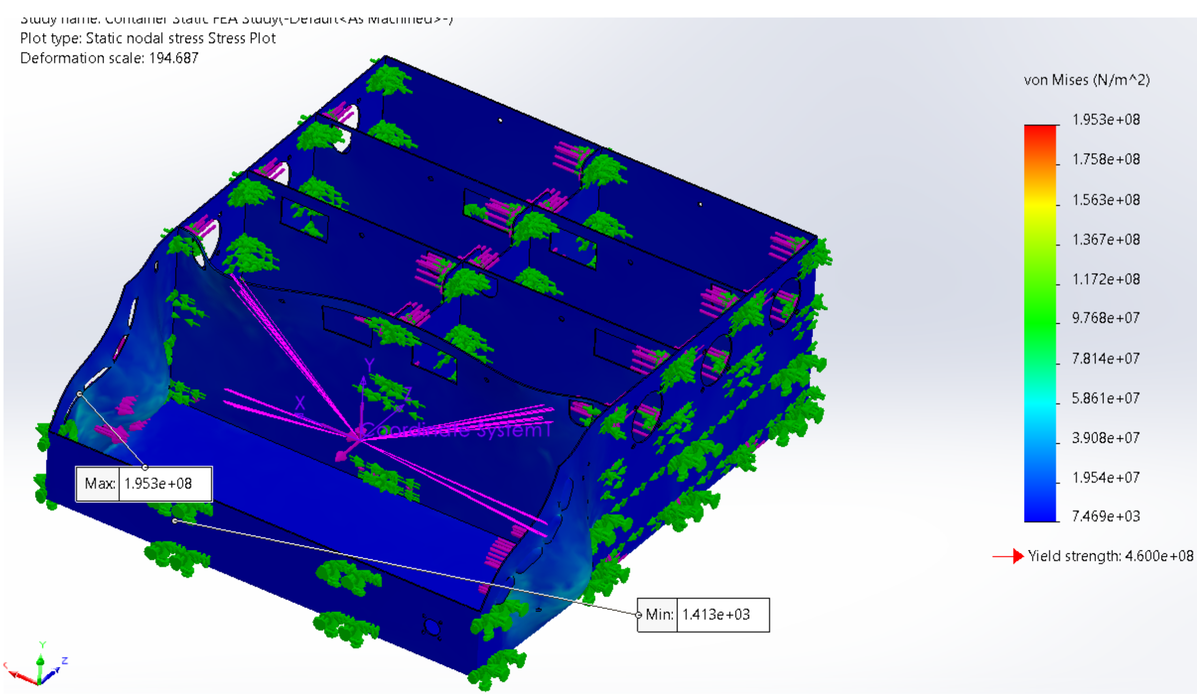

Figure 3.57: Combined Load Tests Stress Plot (-ve axis directions)

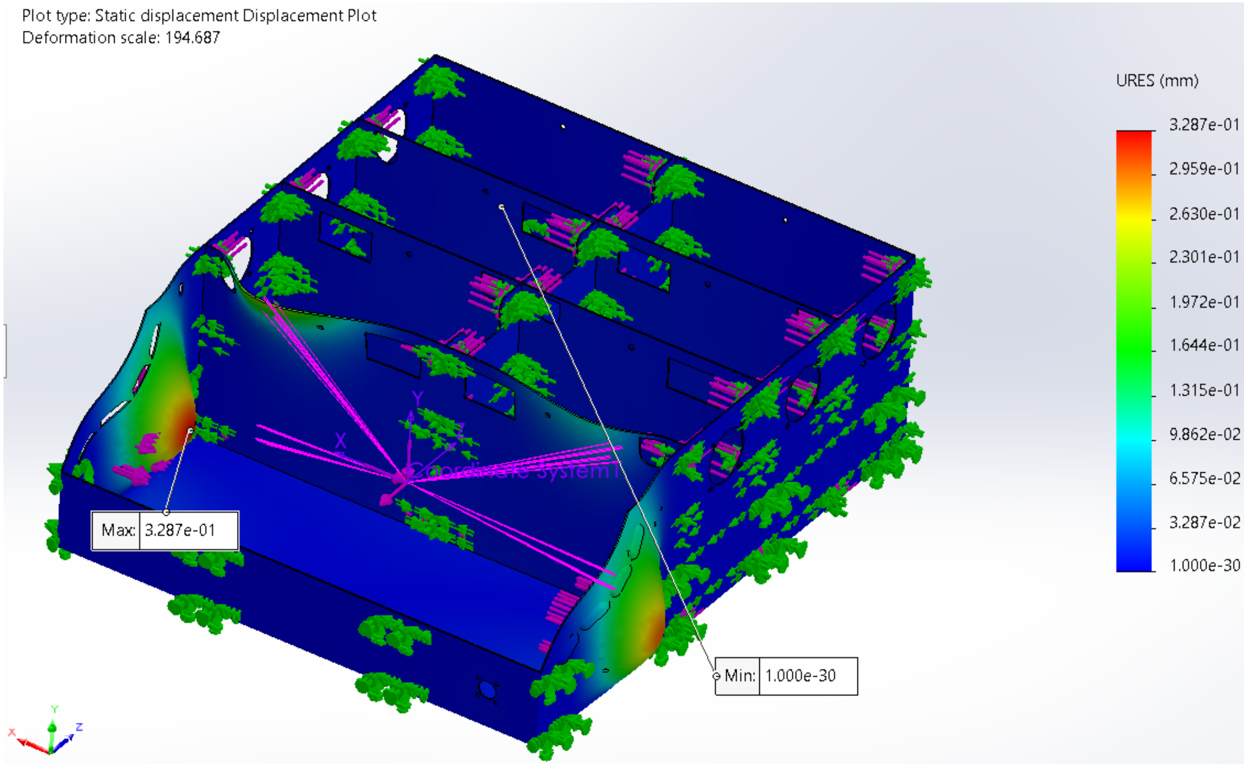

Figure 3.58: Combined Load Tests Displacement Plot (-ve axis directions)

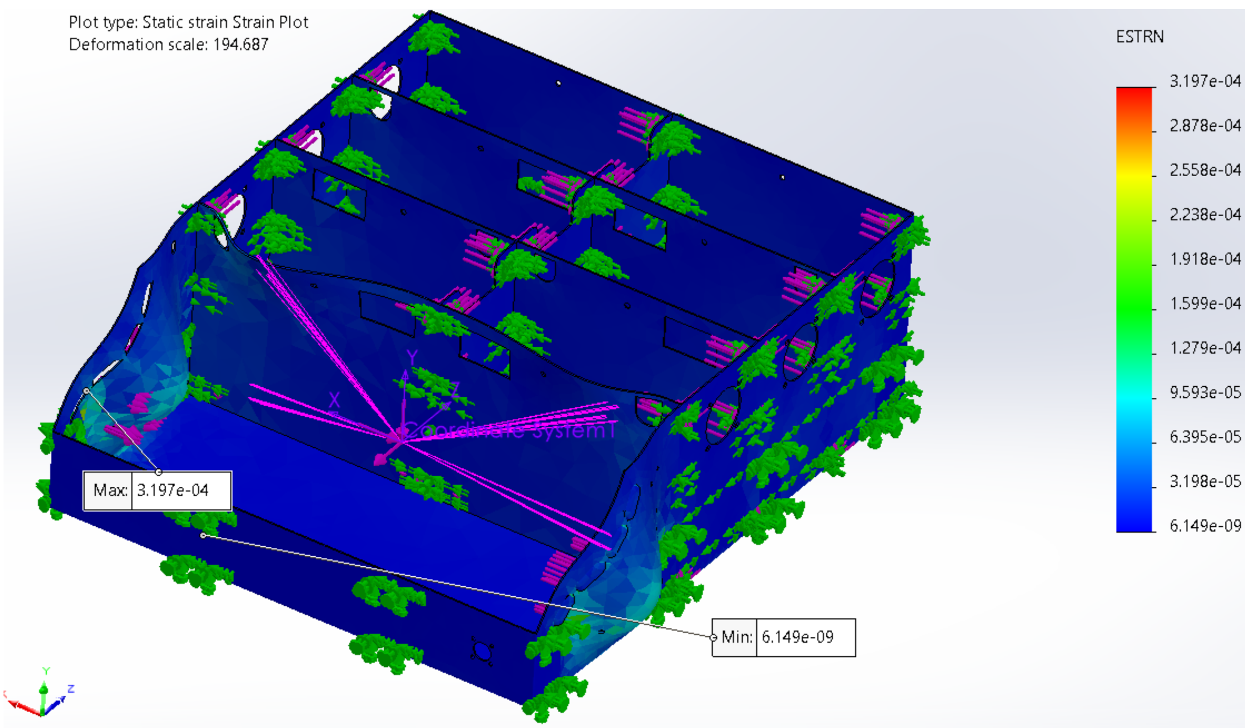

Figure 3.59: Combined Load Tests Strain Plot (-ve axis directions)

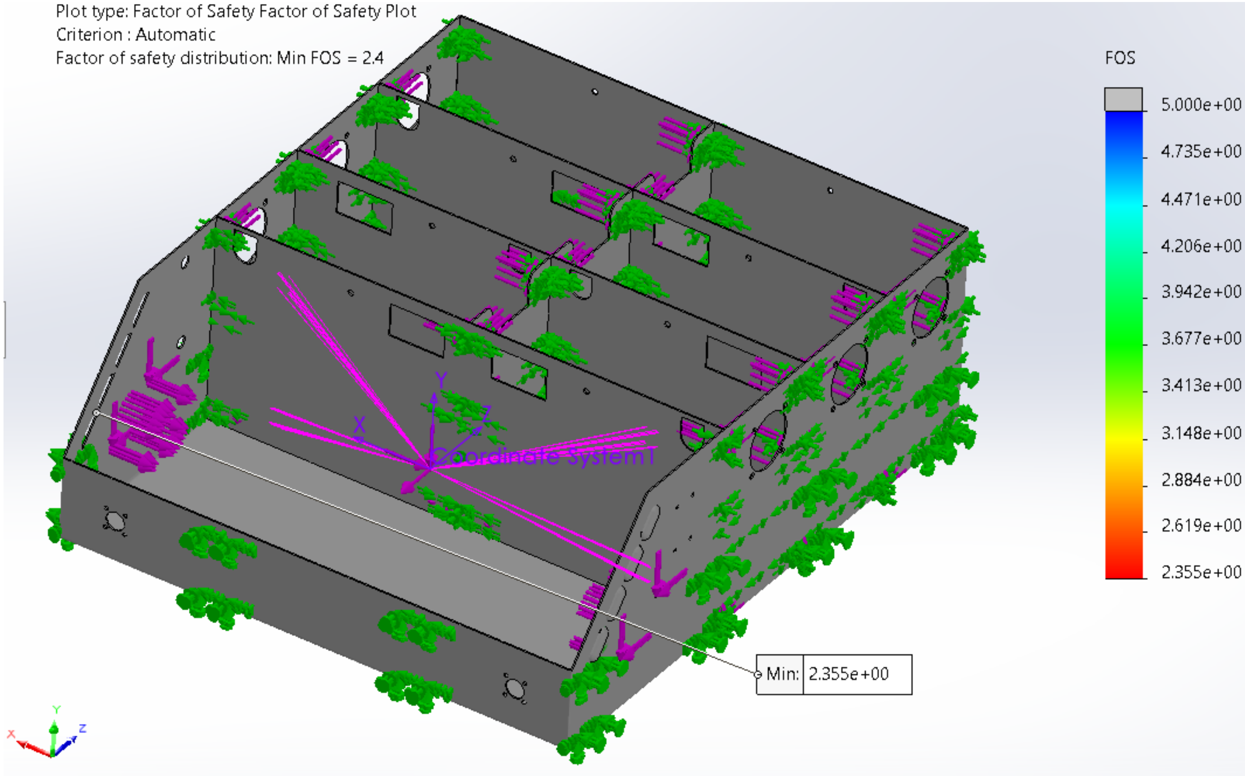

Figure 3.60: Combined Load Tests FOS Plot (-ve axis directions)

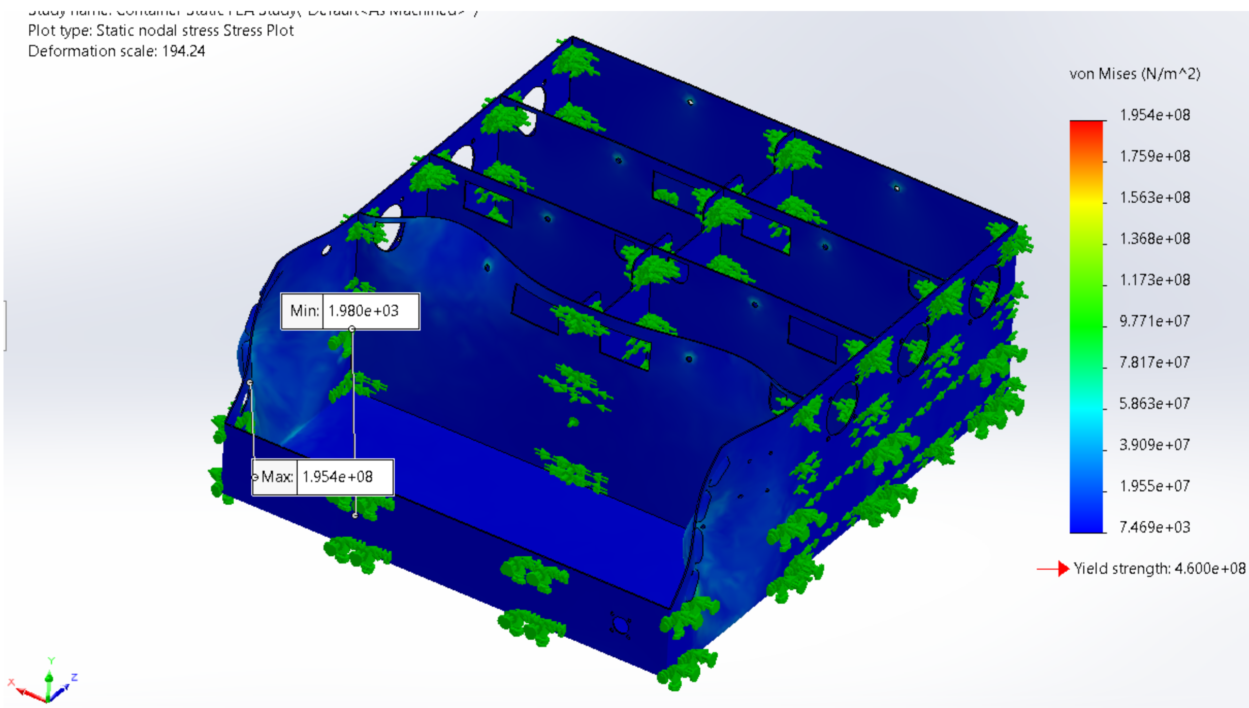

Figure 3.61: Combined Load Tests Stress Plot (+ve axis directions)

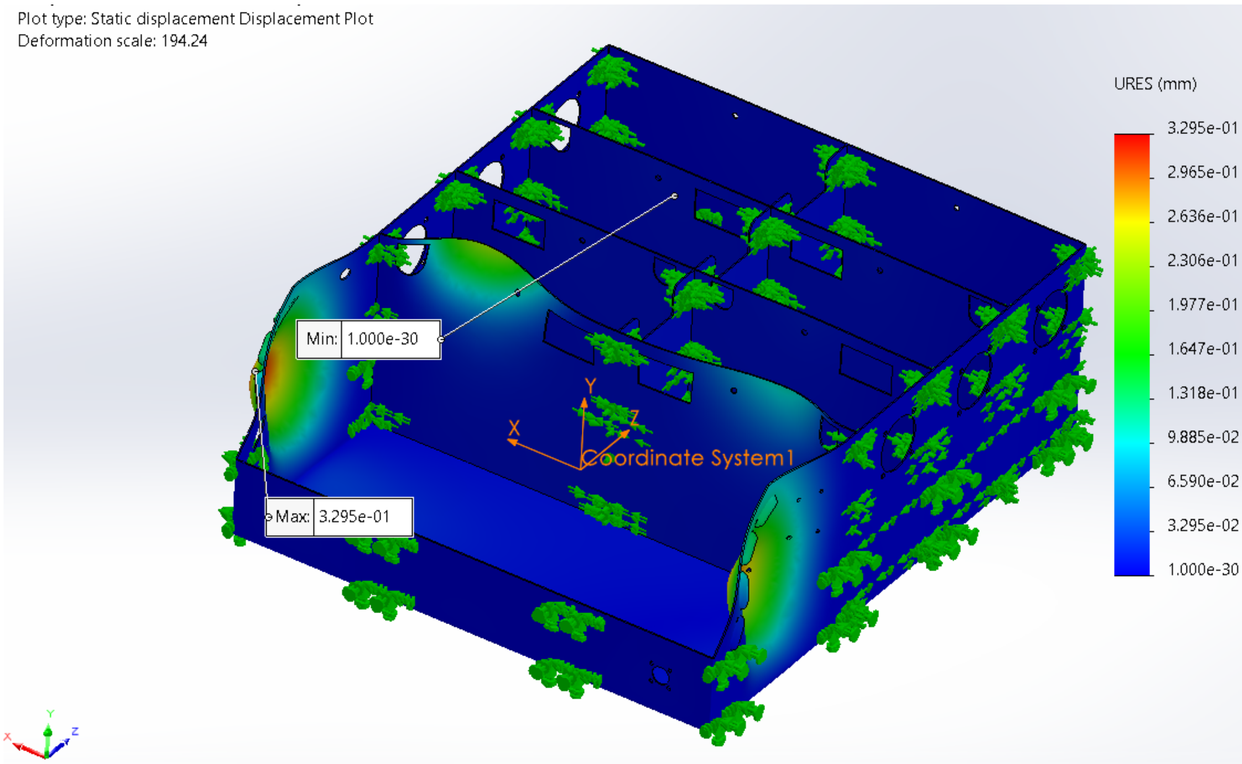

Figure 3.62: Combined Load Tests Displacement Plot (+ve axis directions)

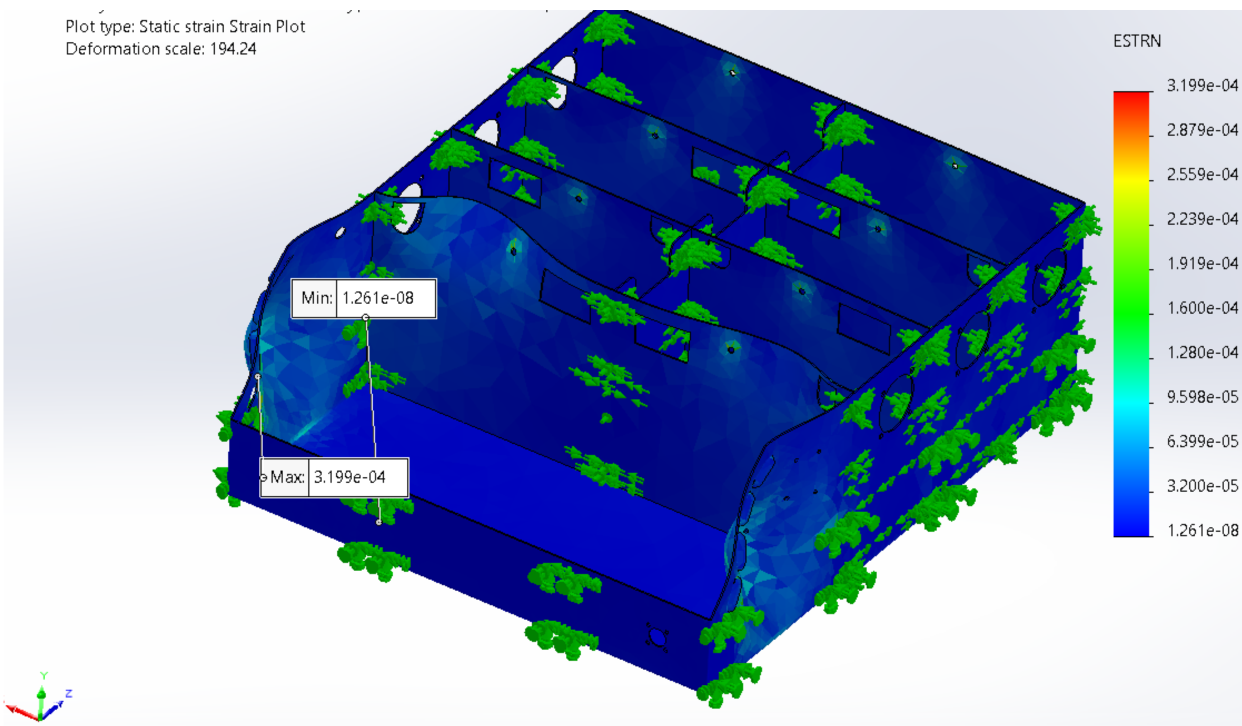

Figure 3.63: Combined Load Tests Strain Plot (+ve axis directions)

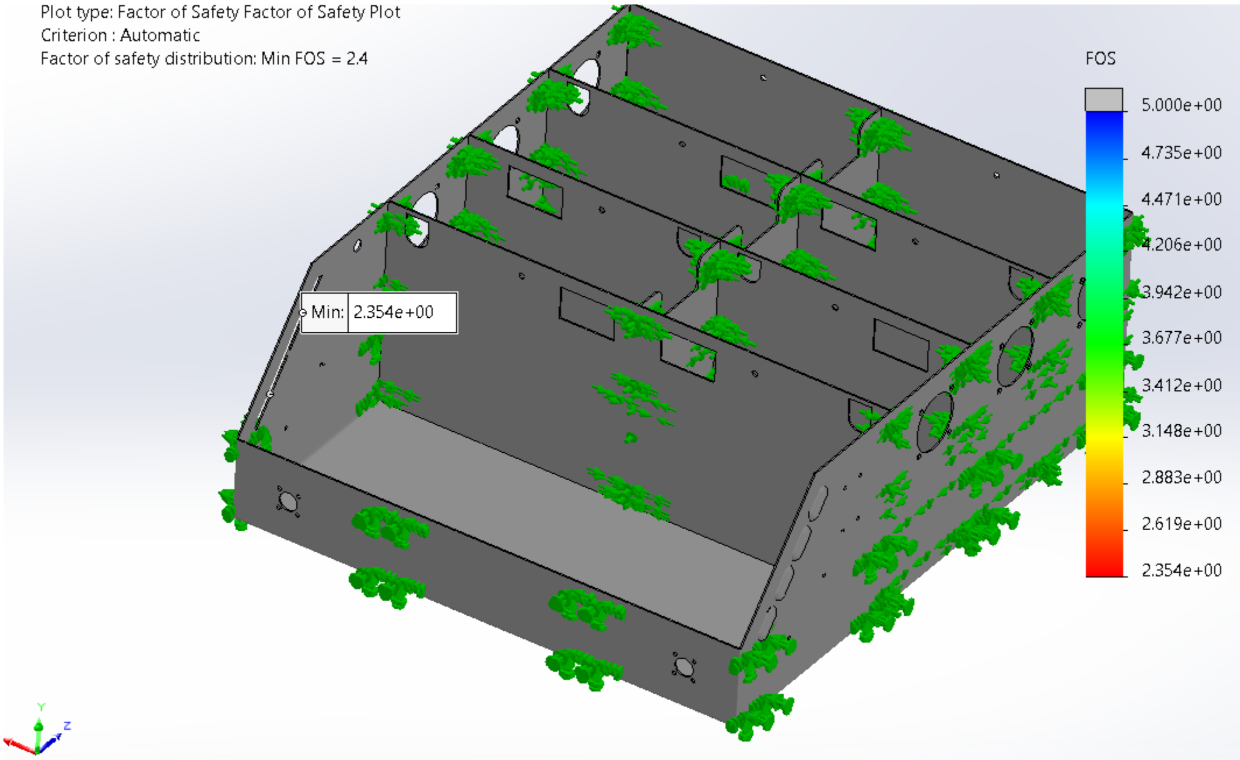

Figure 3.64: Combined Load Tests FOS Plot (+ve axis directions)

Lid FEA

A lid for the accumulator container was conducted, and its Finite Element Analysis was also conducted, as per the rulebook. The load cases performed were the same as the These tests were done in 1020 only, as the 4130 tests were seen to be redundant, as the lid was assumed to be plenty strong with 1020 as the material, despite having similar load case restraints applied to the lid.

Setup

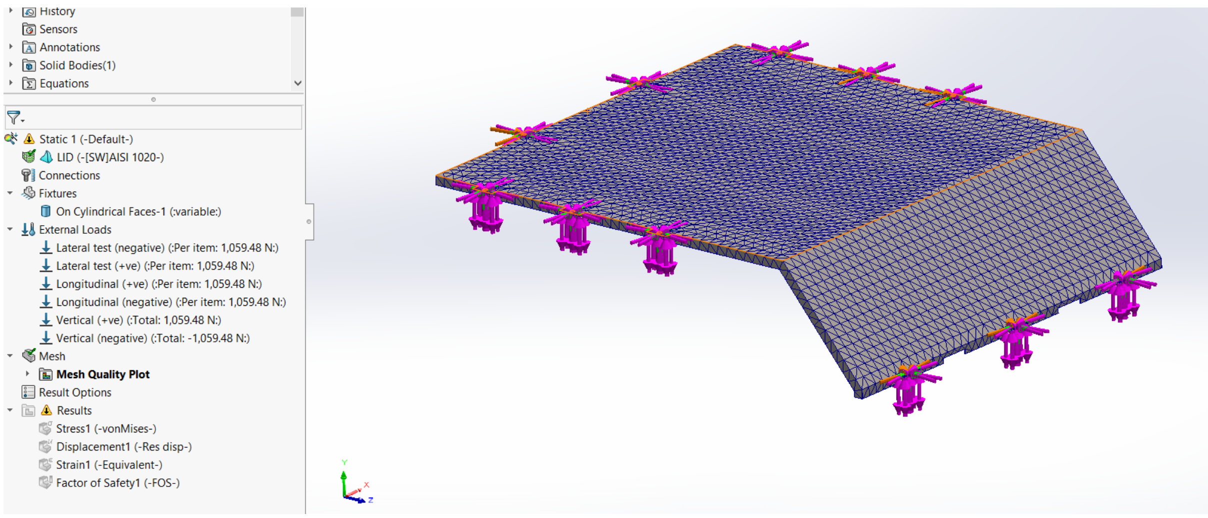

Figure 3.65: FEA Static Test for Accumulator Container Lid

The “Split Line” function was made to implement surface areas where each of the forces would act upon, which includes mainly the mounting tabs for the lid itself, as well as the mounting holes for the bolts that hold the lid to the accumulator.

Lateral Tests

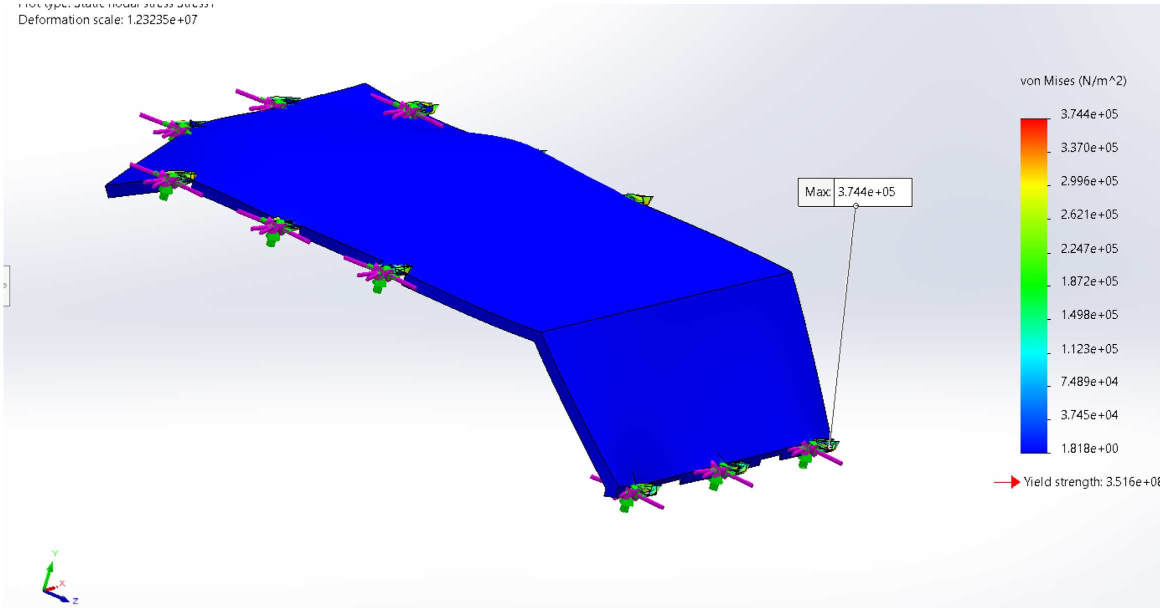

Figure 3.66: Lateral Test Stress Plot (+ve direction)

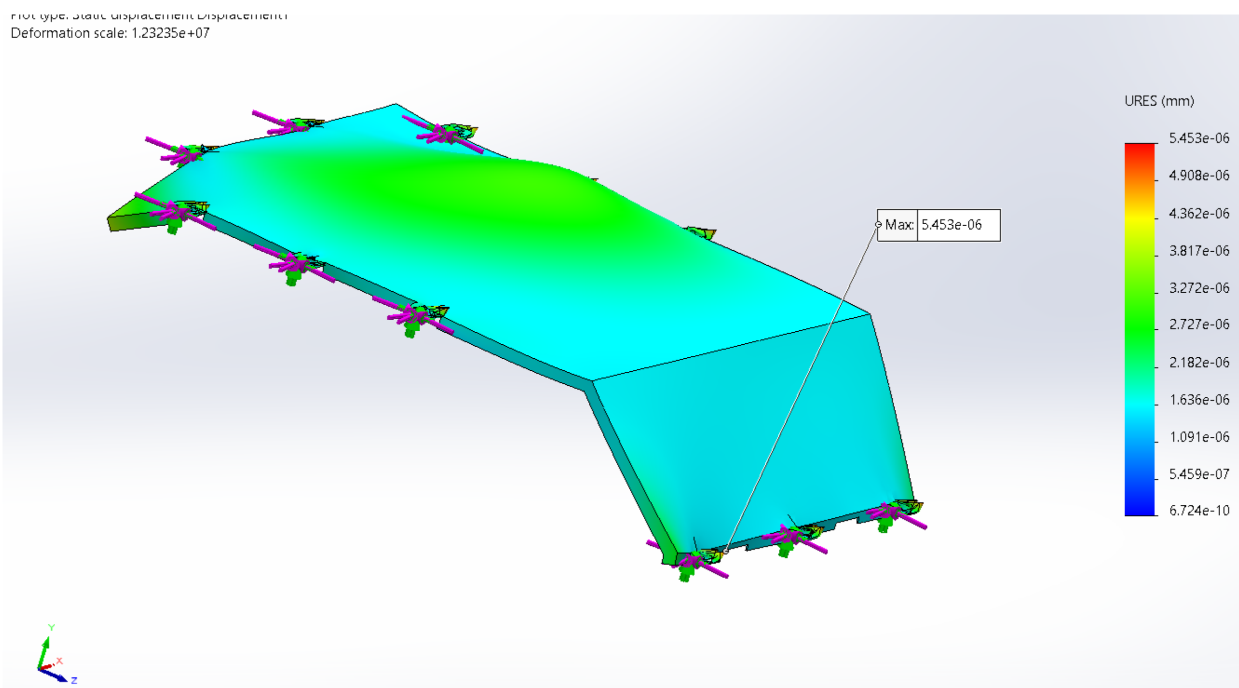

Figure 3.67: Lateral Test Displacement Plot (+ve direction)

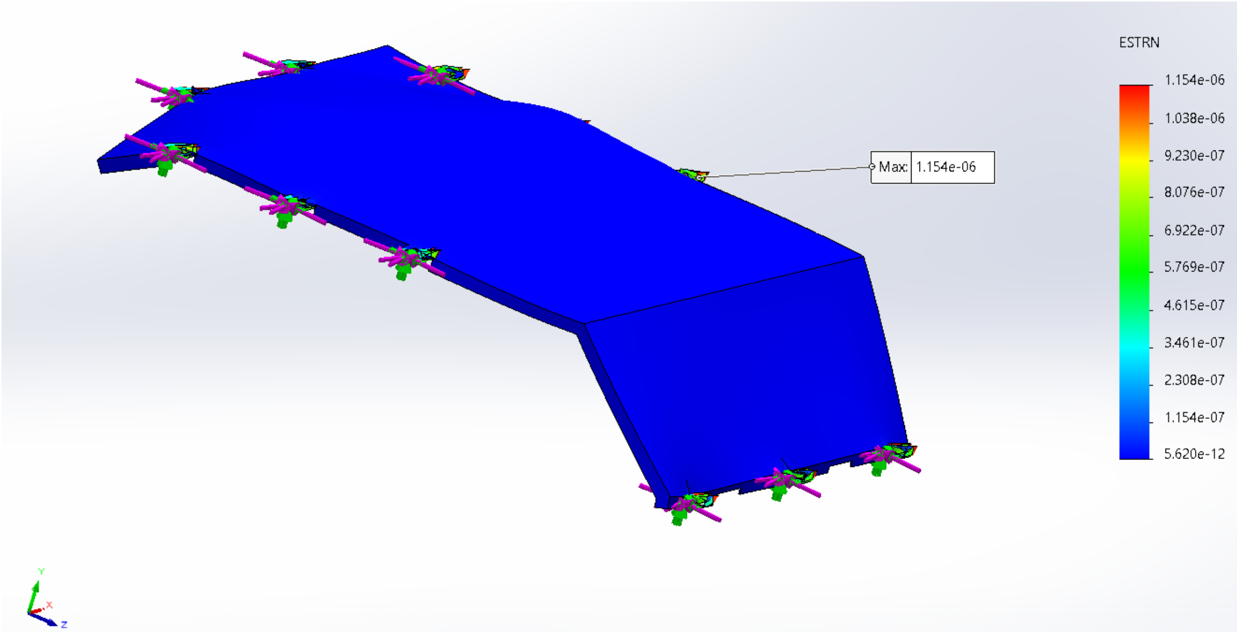

Figure 3.68: Lateral Test Strain Plot (+ve direction)

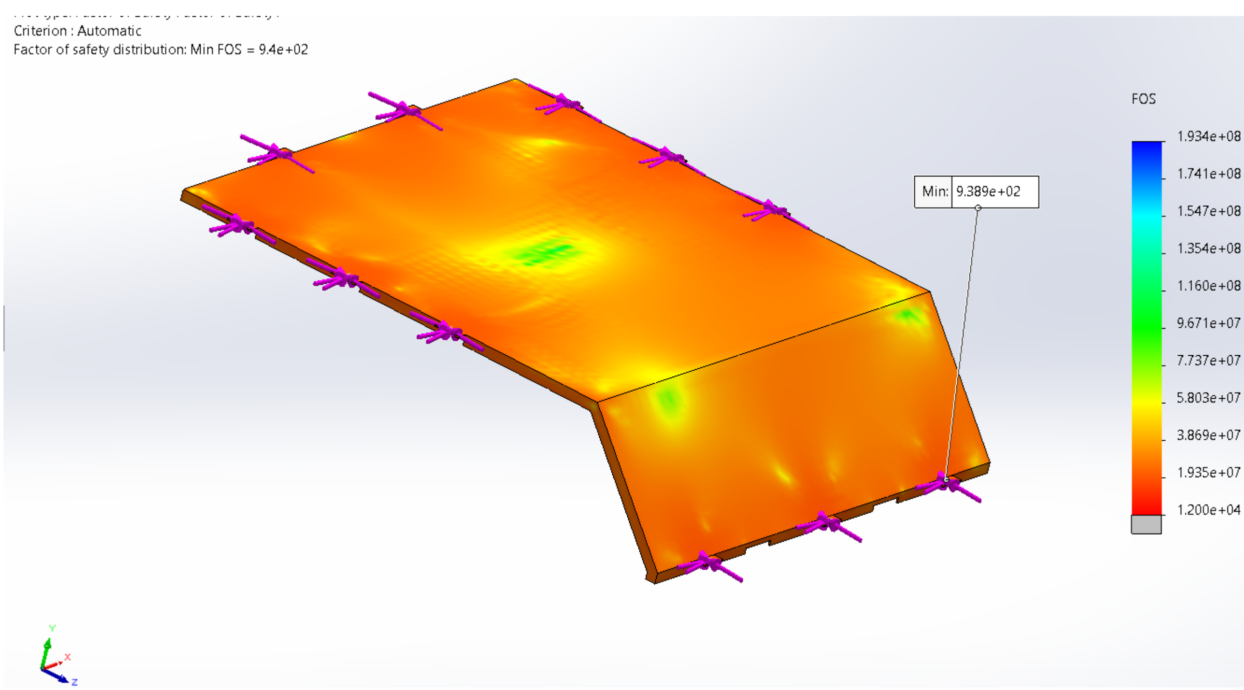

Figure 3.69: Lateral Test FOS Plot (+ve direction)

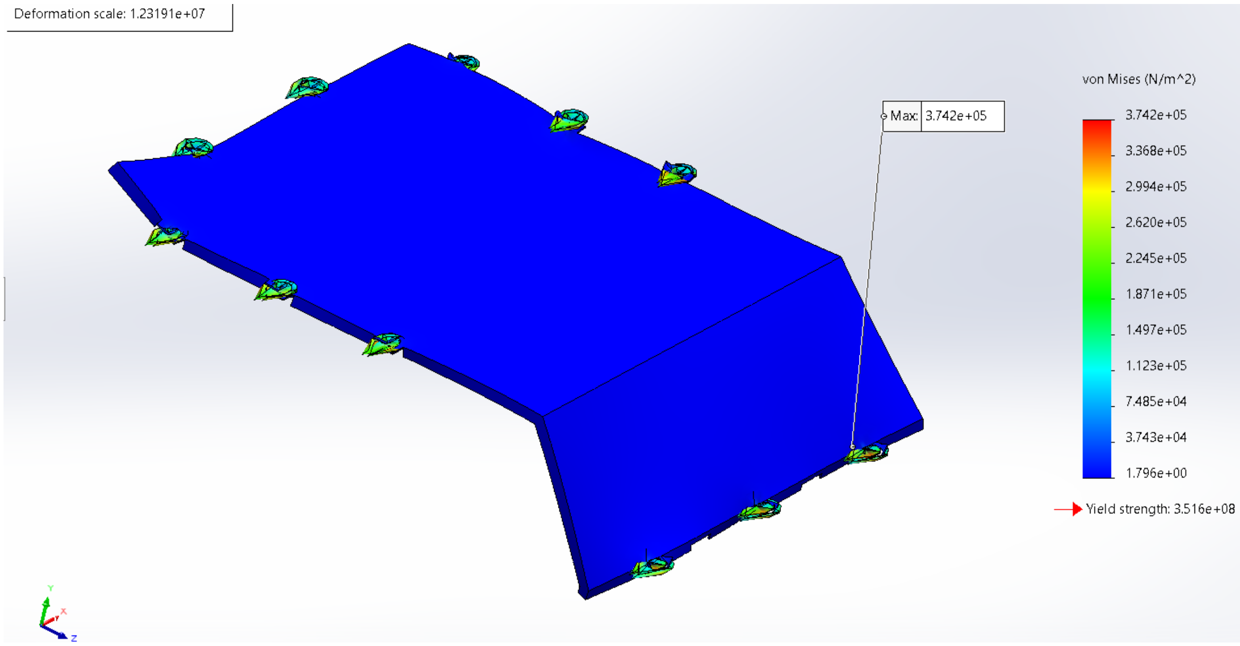

Figure 3.70: Lateral Test Stress Plot (-ve direction)

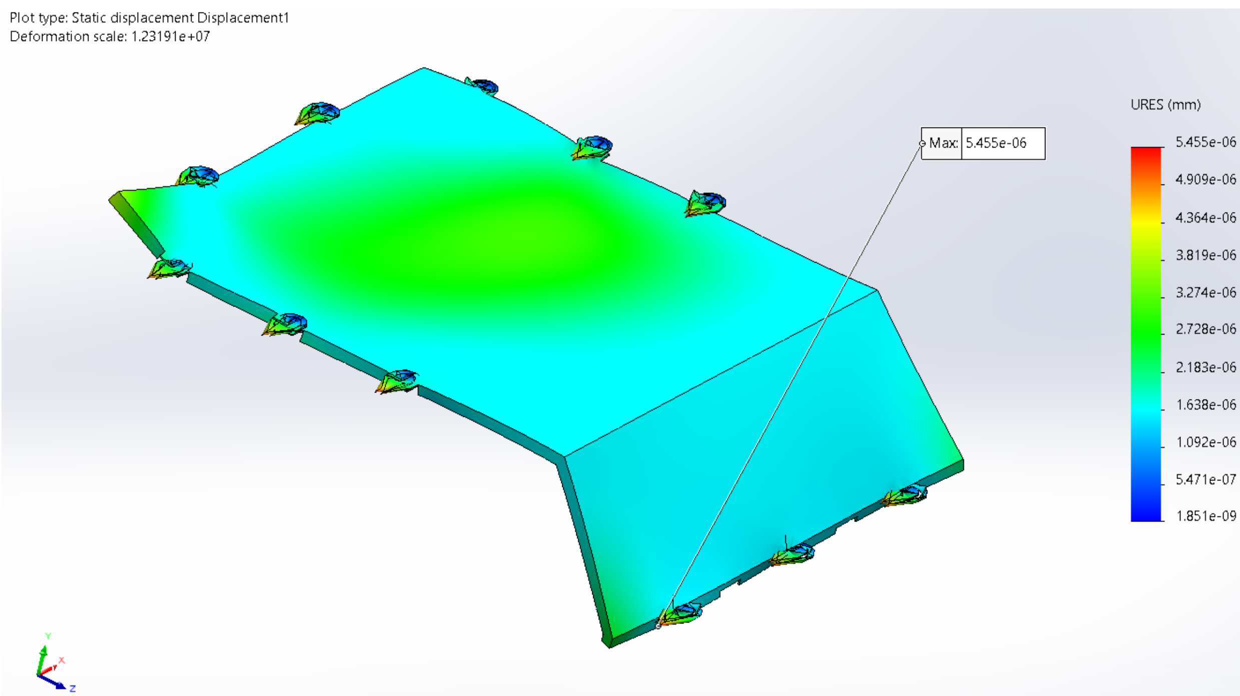

Figure 3.71: Lateral Test Displacement Plot (-ve direction)

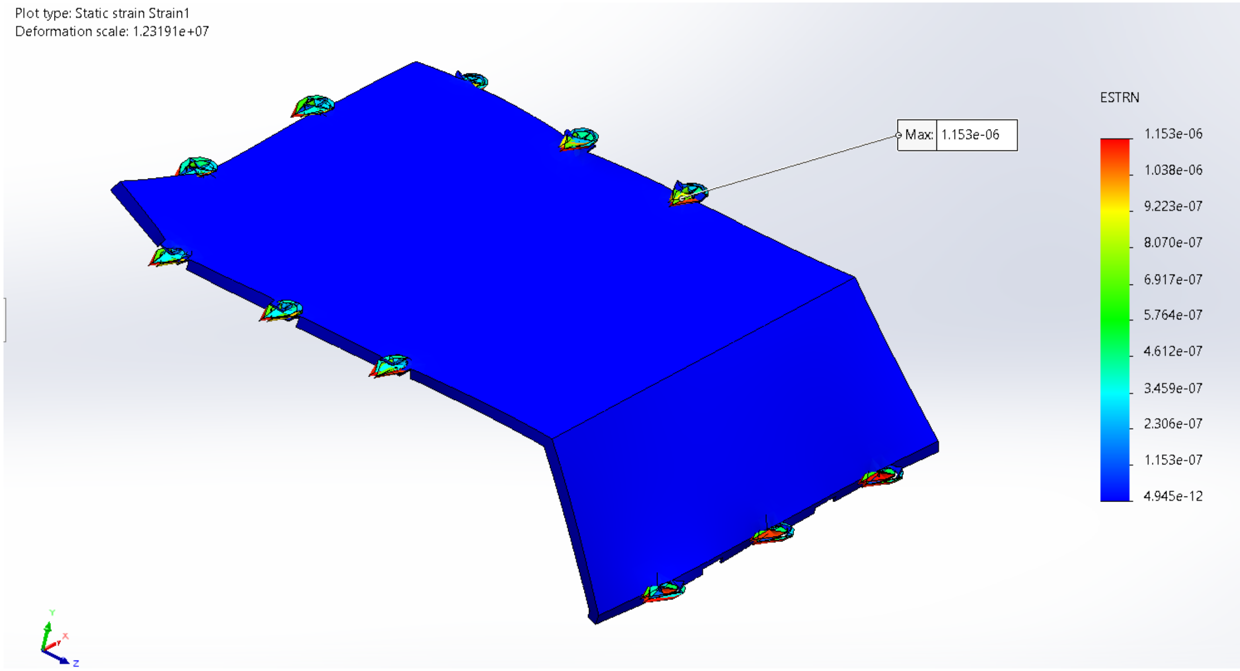

Figure 3.72: Lateral Test Strain Plot (-ve direction)

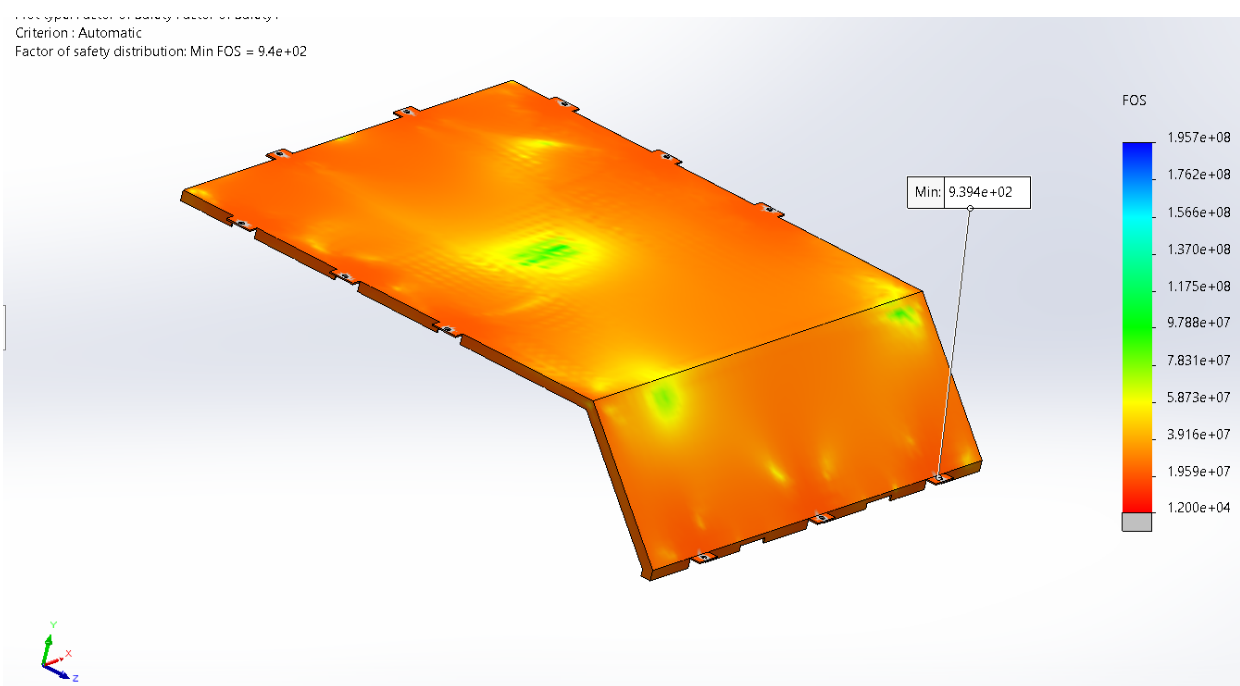

Figure 3.73: Lateral Test FOS Plot (-ve direction)

Longitudinal Tests

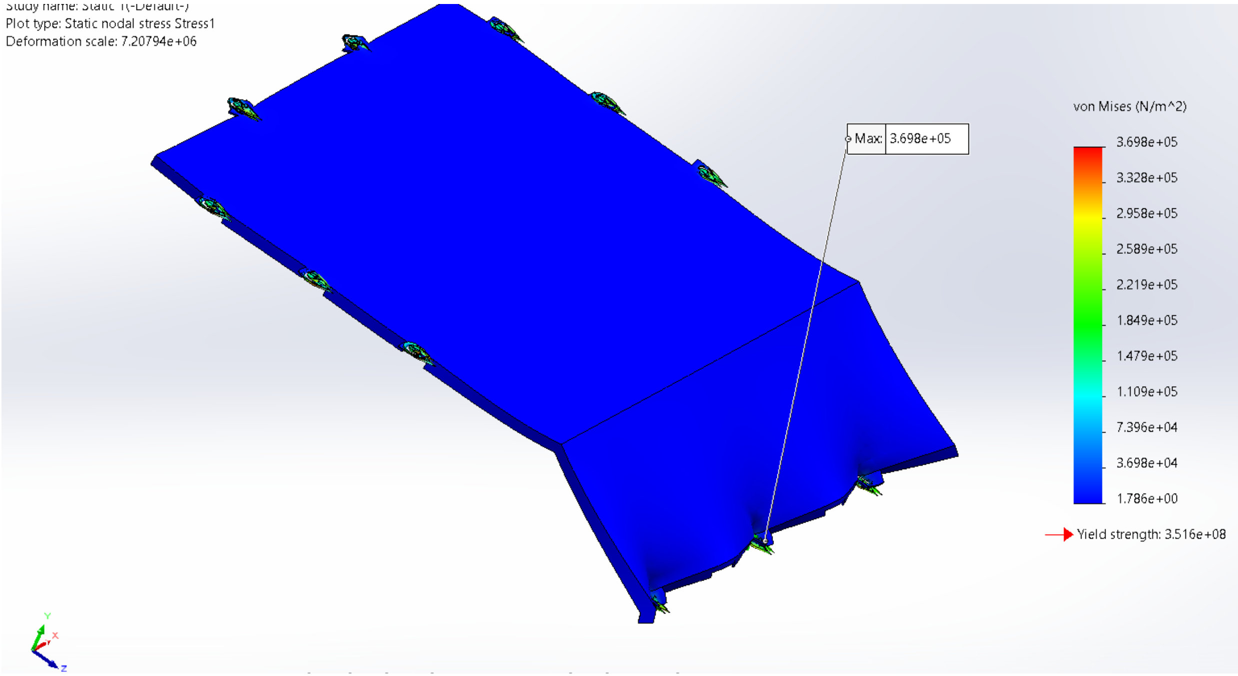

Figure 3.74: Longitudinal Test Stress Plot (+ve direction)

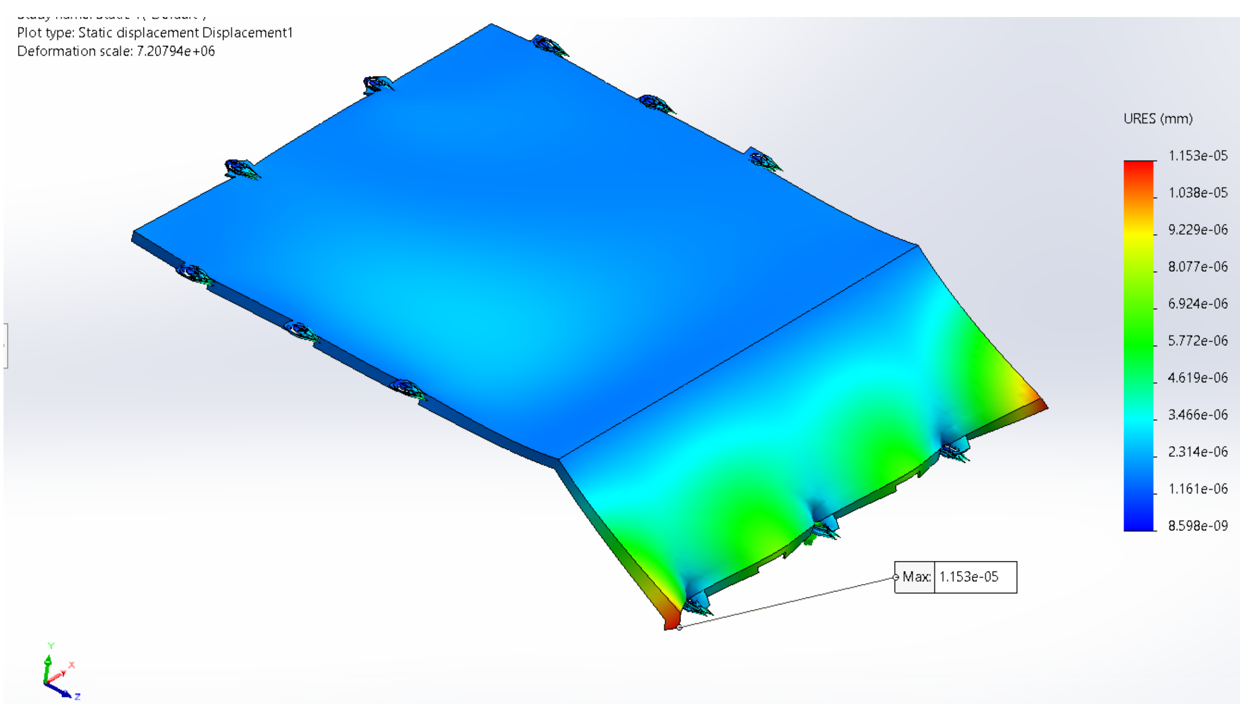

Figure 3.75: Longitudinal Test Displacement Plot (+ve direction)

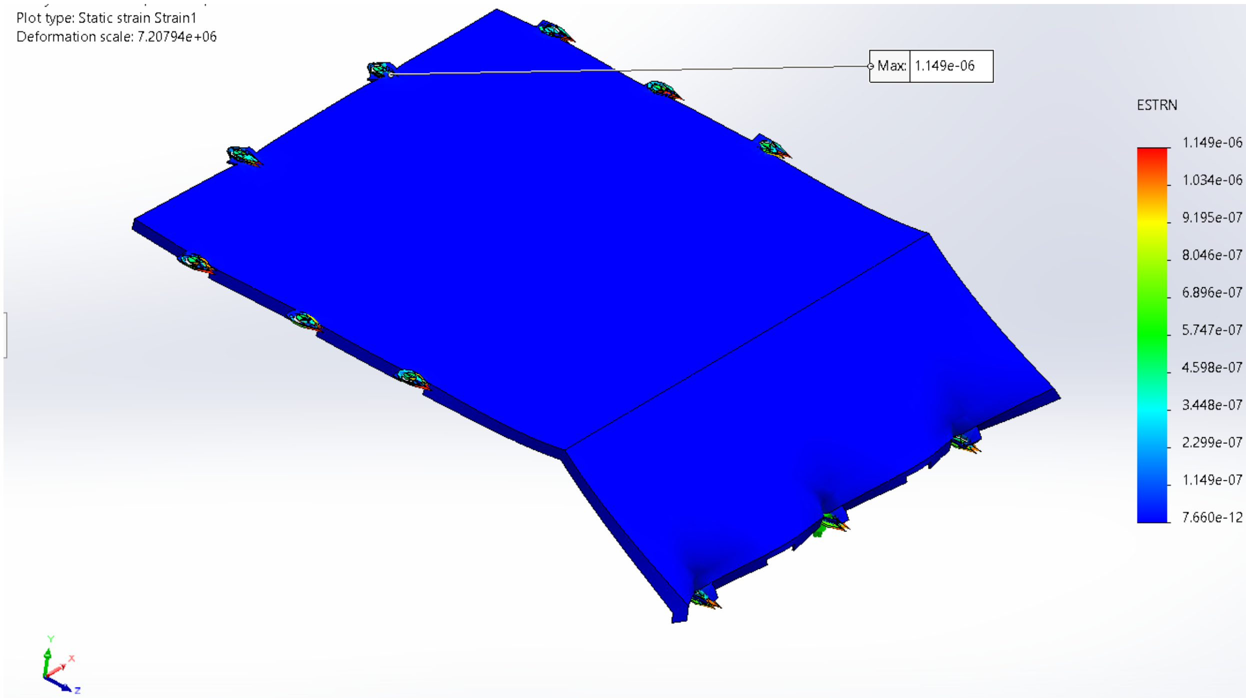

Figure 3.76: Longitudinal Tests Strain Plot (+ve direction)

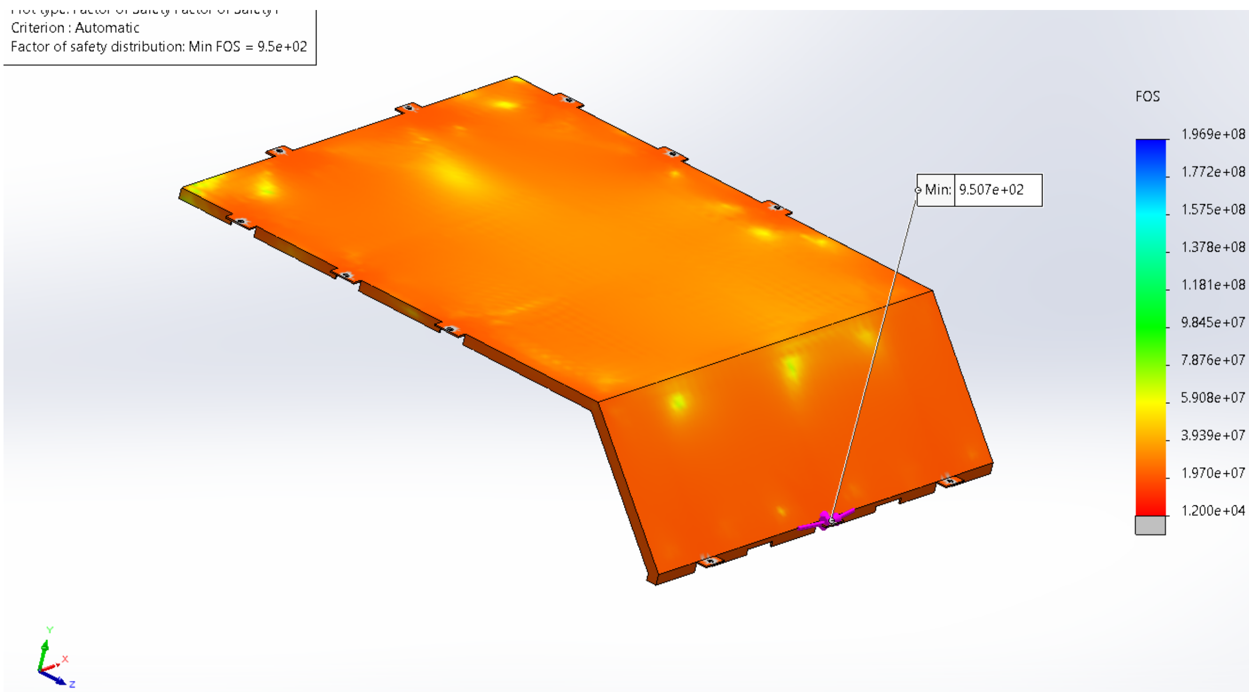

Figure 3.77: Longitudinal Tests FOS Plot (+ve direction)

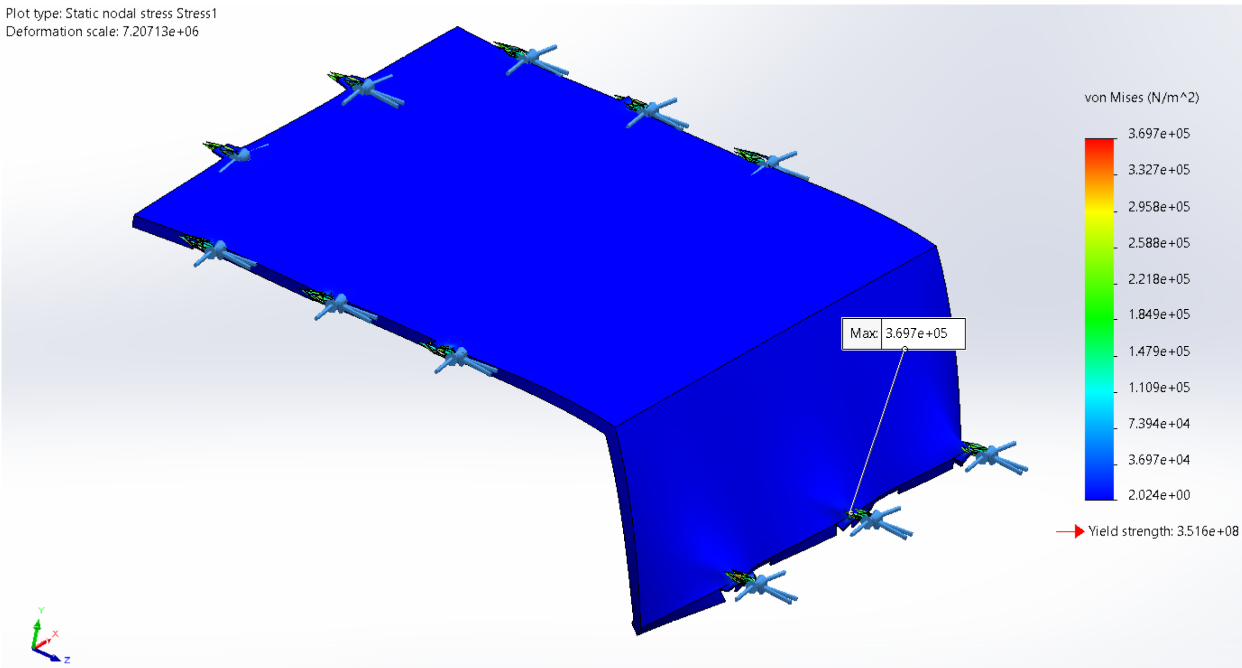

Figure 3.78: Longitudinal Tests Stress Plot (-ve direction)

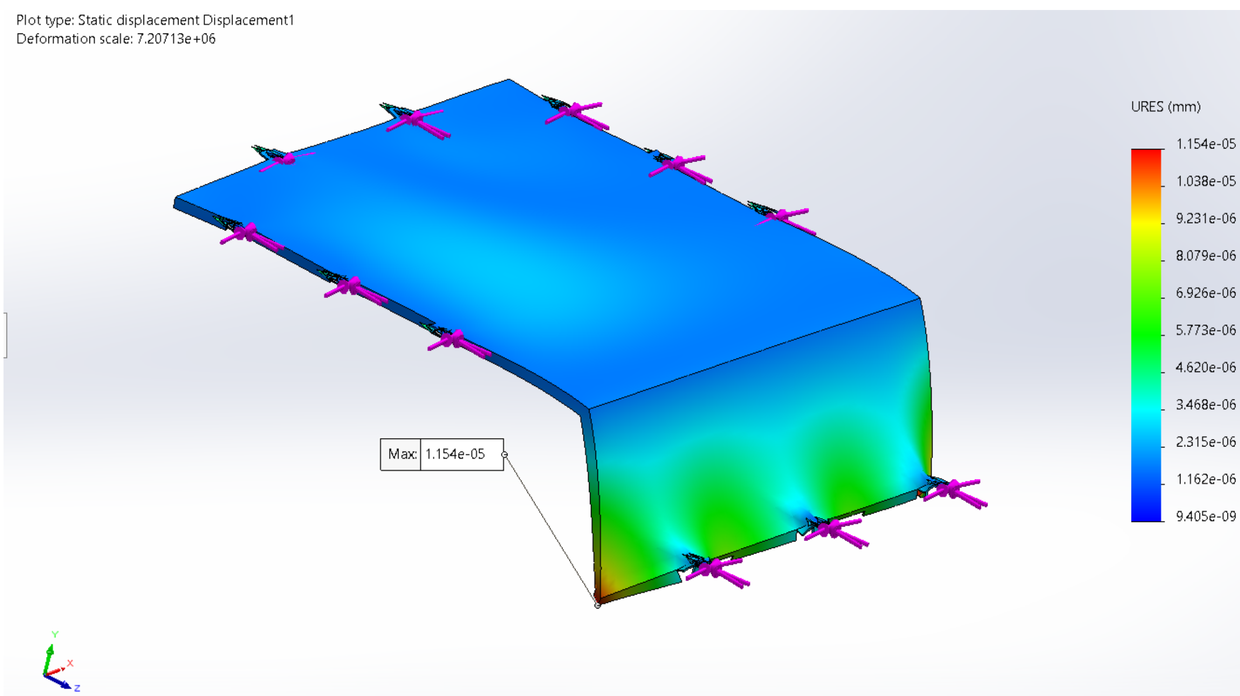

Figure 3.79: Longitudinal Tests Displacement Plot (-ve direction)

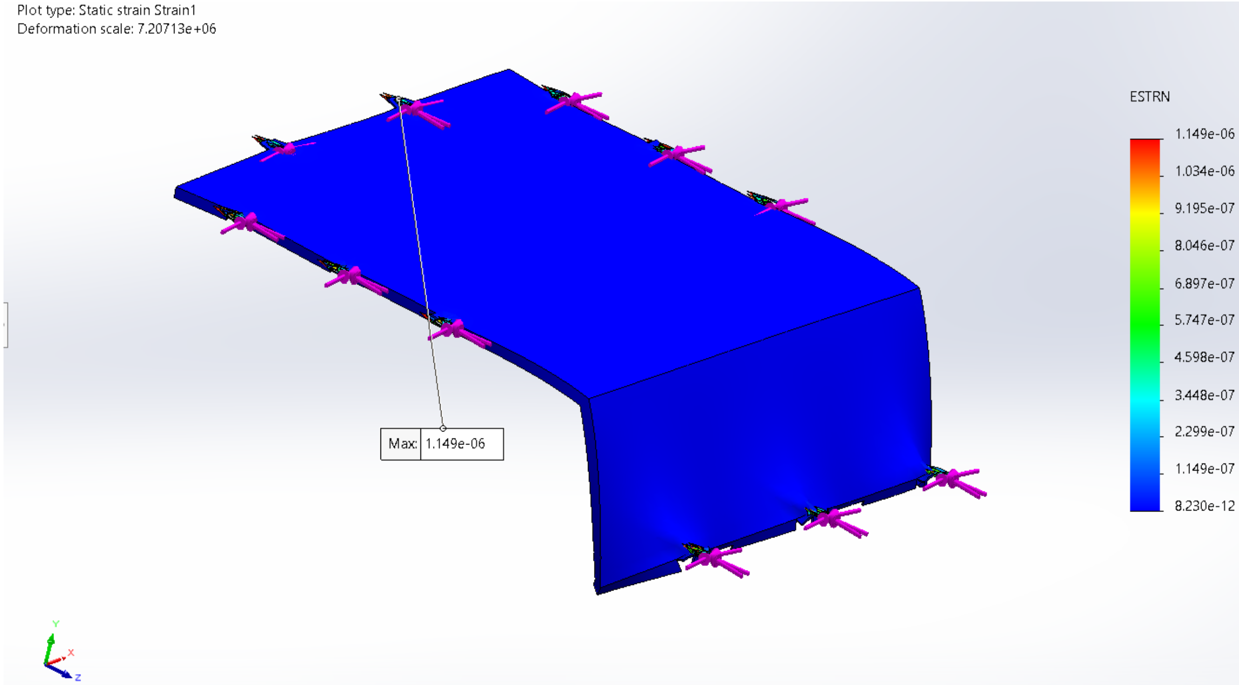

Figure 3.80: Longitudinal Tests Strain Plot (-ve direction)

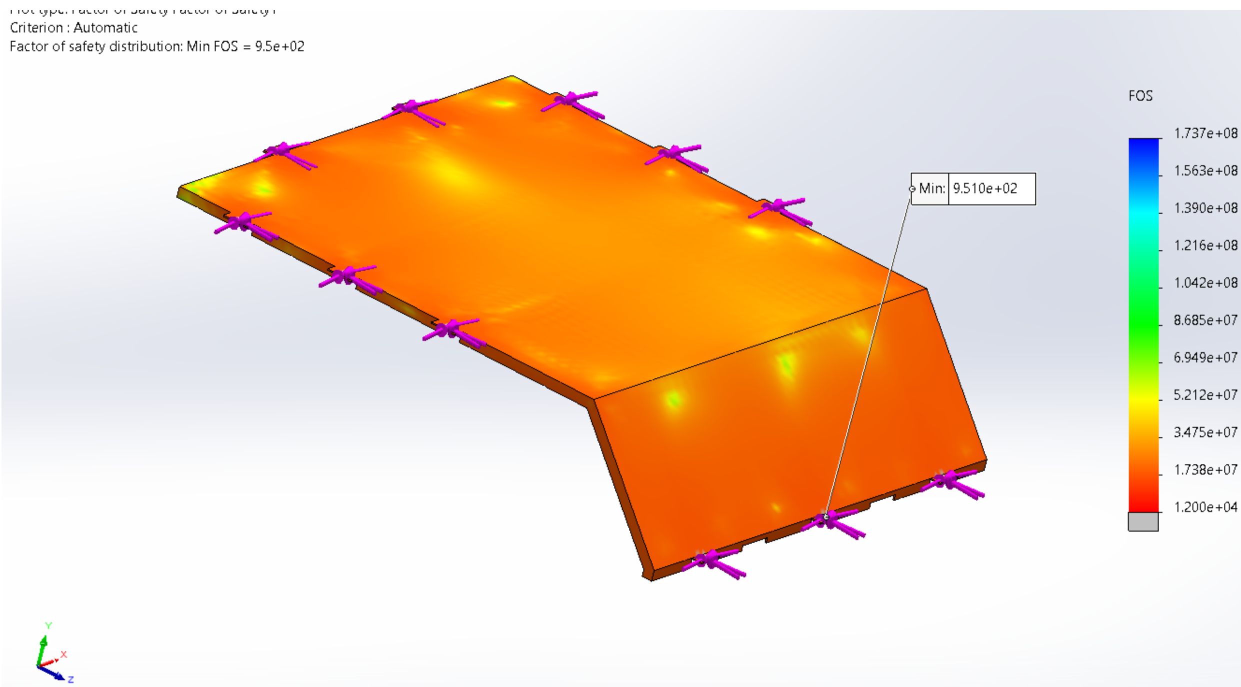

Figure 3.81: Longitudinal Tests FOS Plot (-ve direction)

Vertical Tests

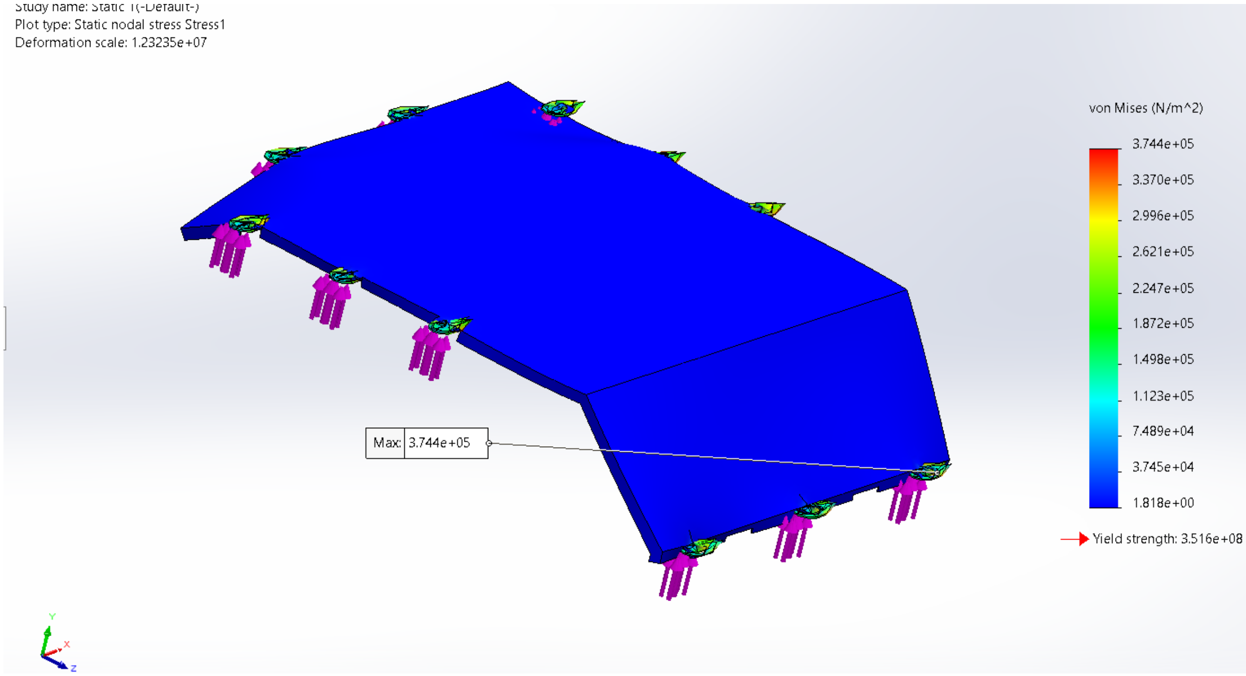

Figure 3.82: Vertical Tests Stress Plot (+ve direction)

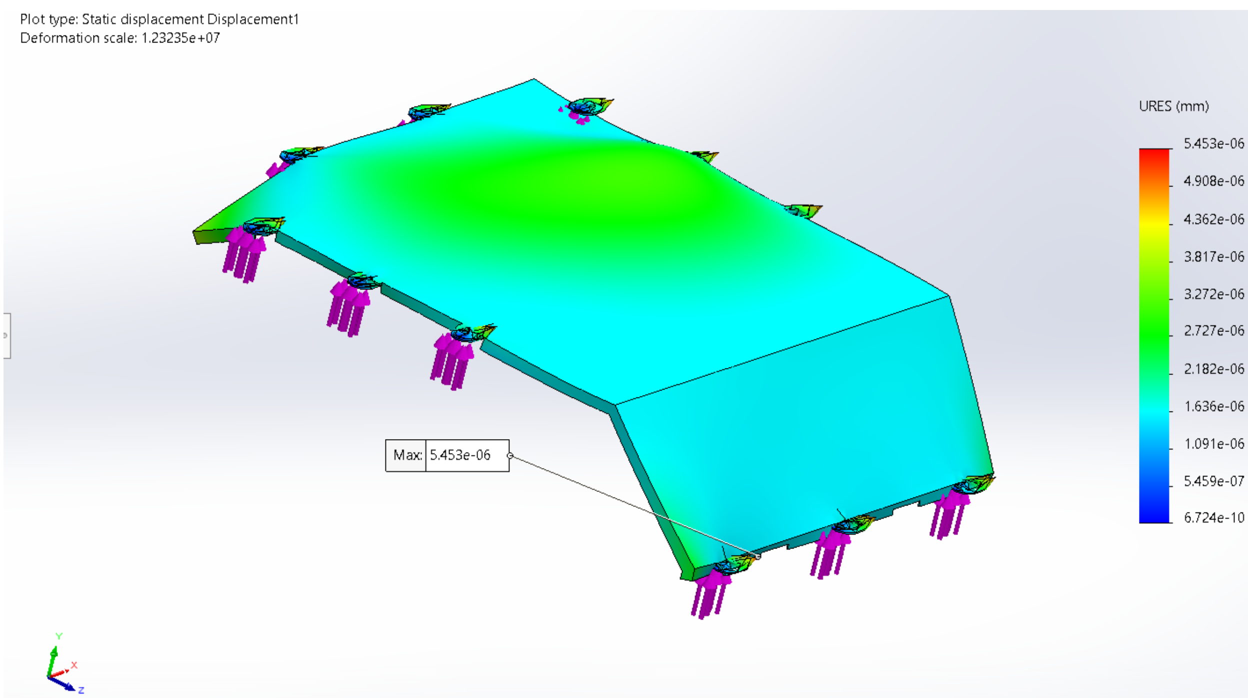

Figure 3.83: Vertical Tests Displacement Plot (+ve direction)

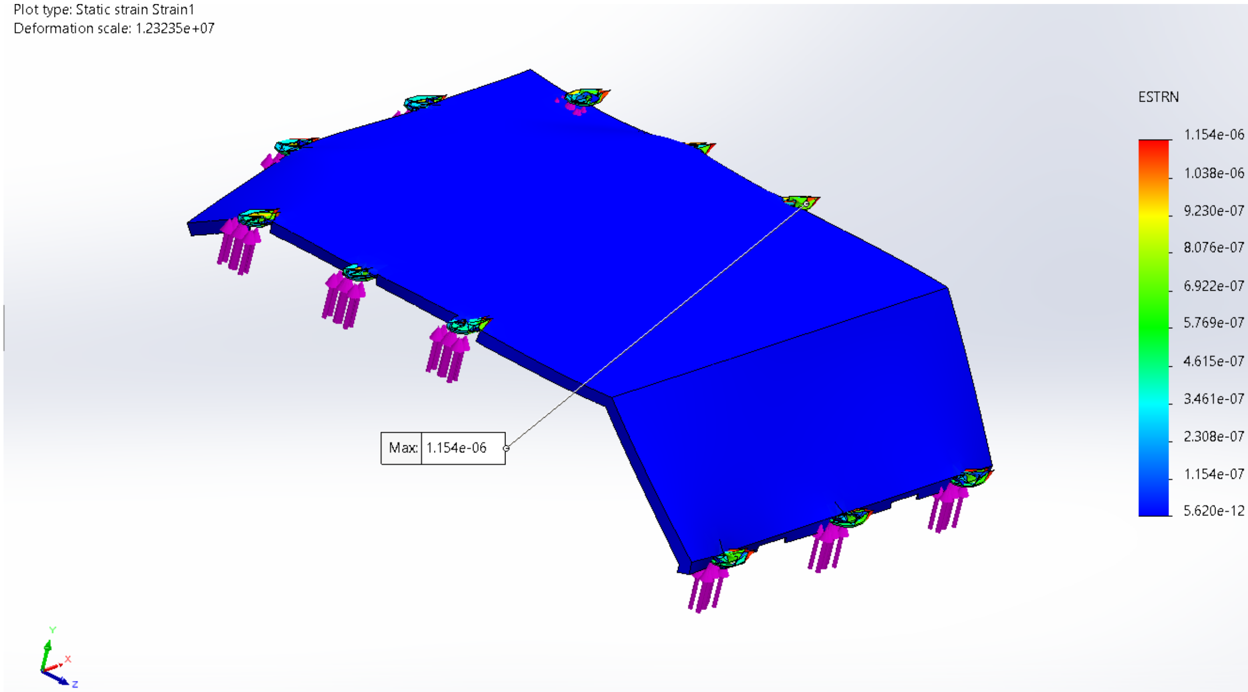

Figure 3.84: Vertical Test Strain Plot (+ve direction)

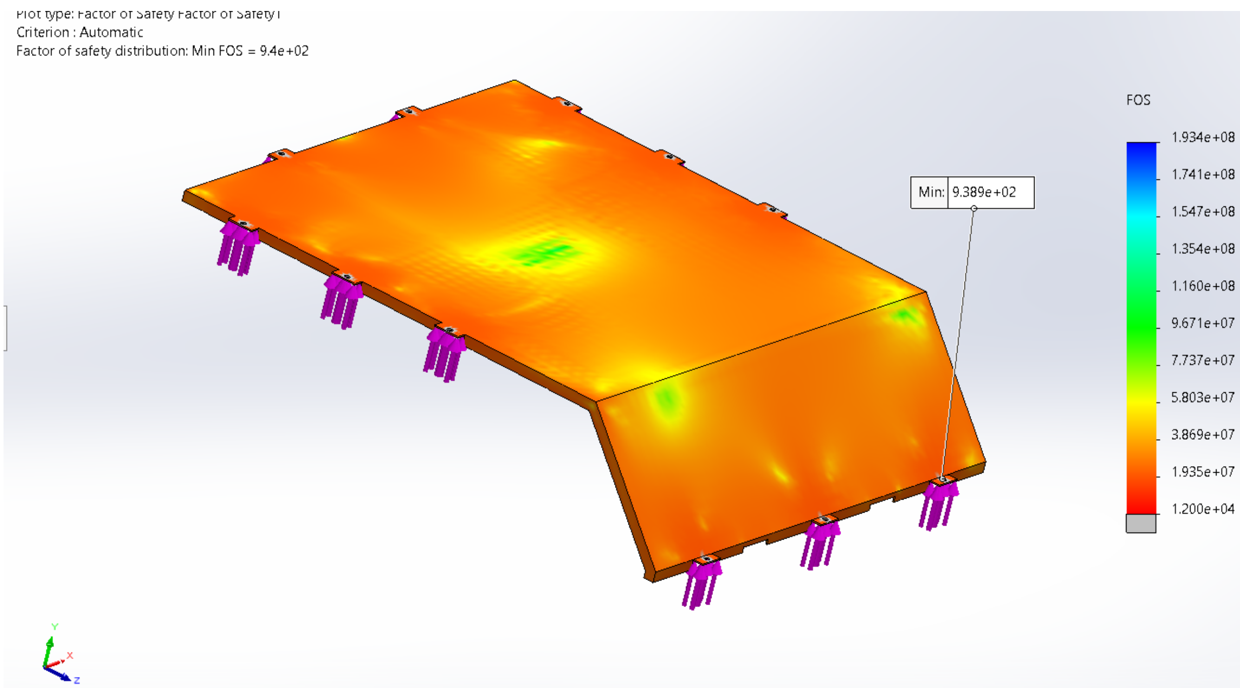

Figure 3.85: Vertical Test Strain Plot (+ve direction)

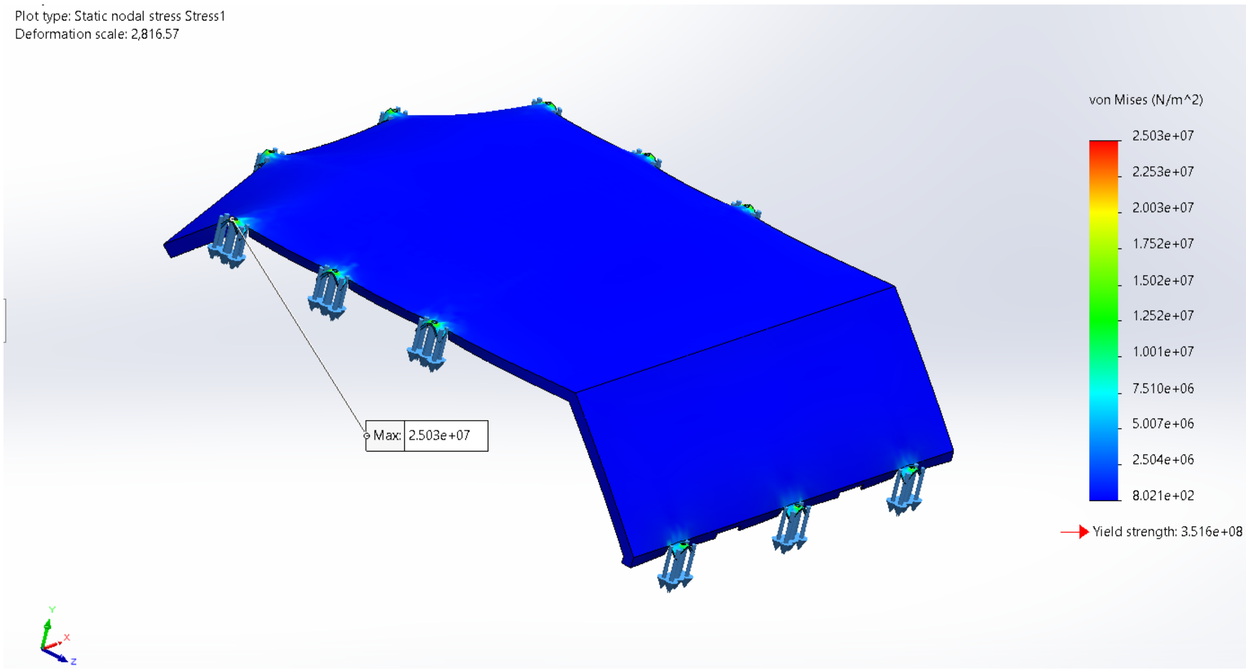

Figure 3.86: Vertical Test Stress Plot (-ve direction)

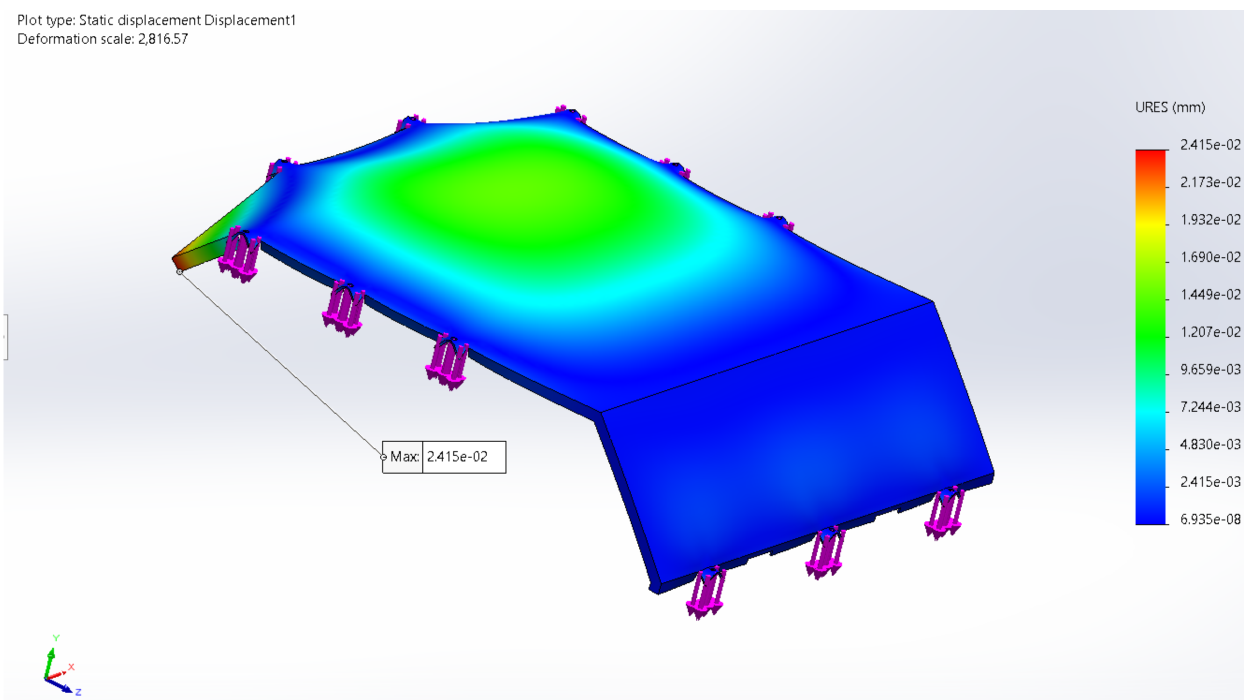

Figure 3.87: Vertical Test Displacement Plot (-ve direction)

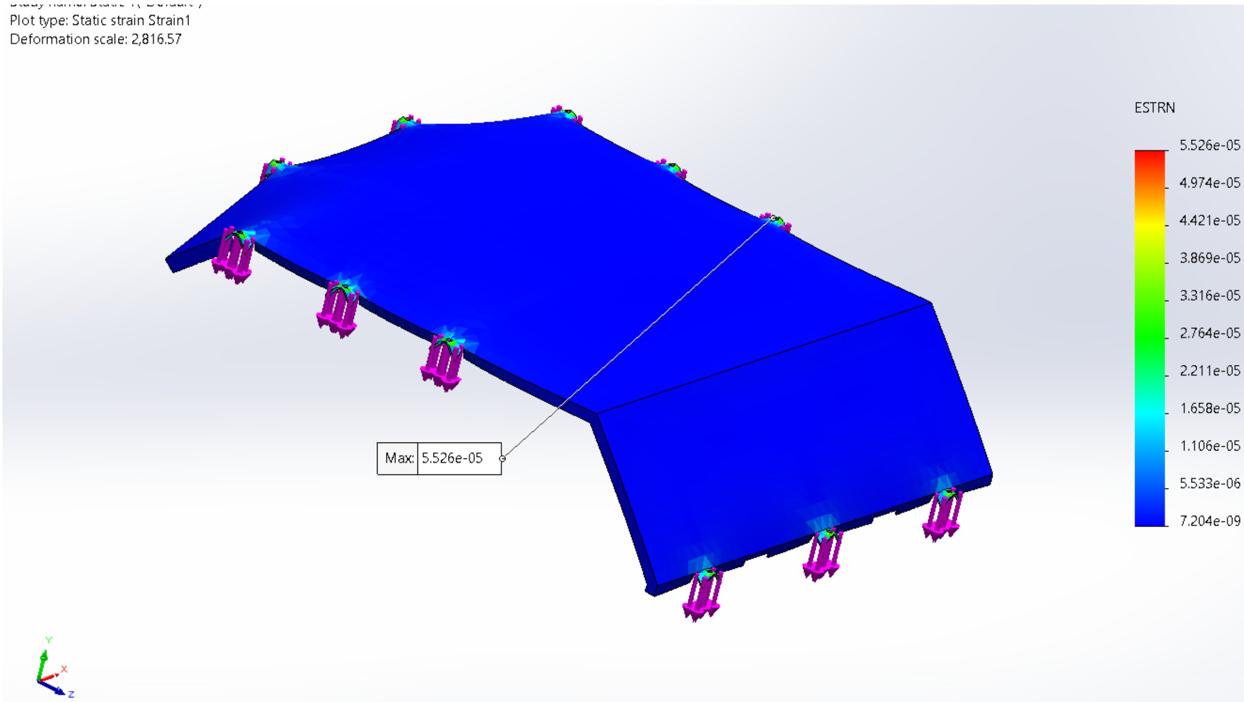

Figure 3.88: Vertical Test Strain Plot (-ve direction)

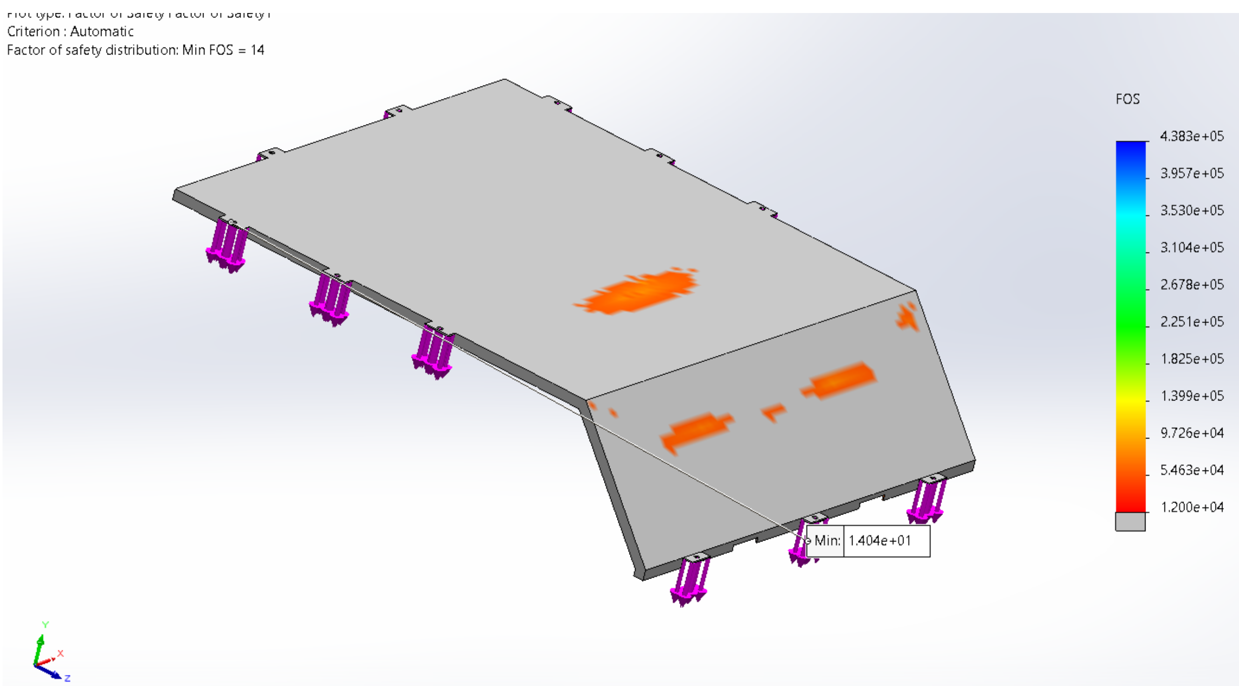

Figure 3.89: Vertical Test FOS Plot (-ve direction)

Combined Load Tests

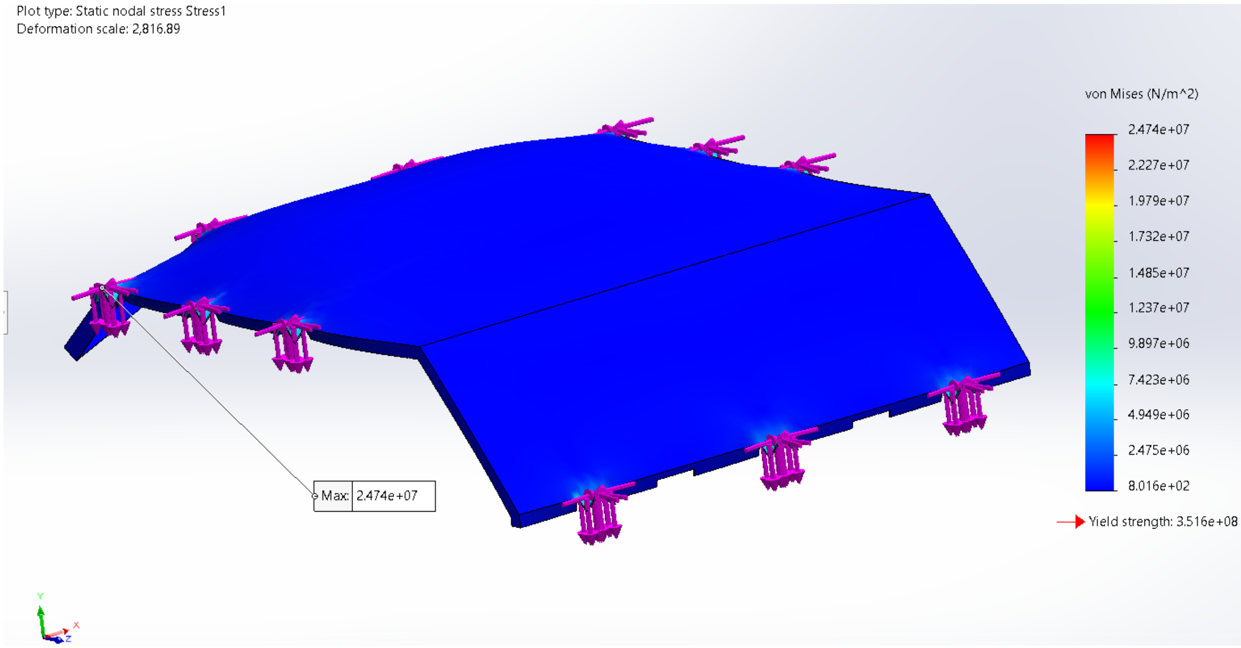

Figure 3.90: Combined Load Test Stress Plot (-ve directions)

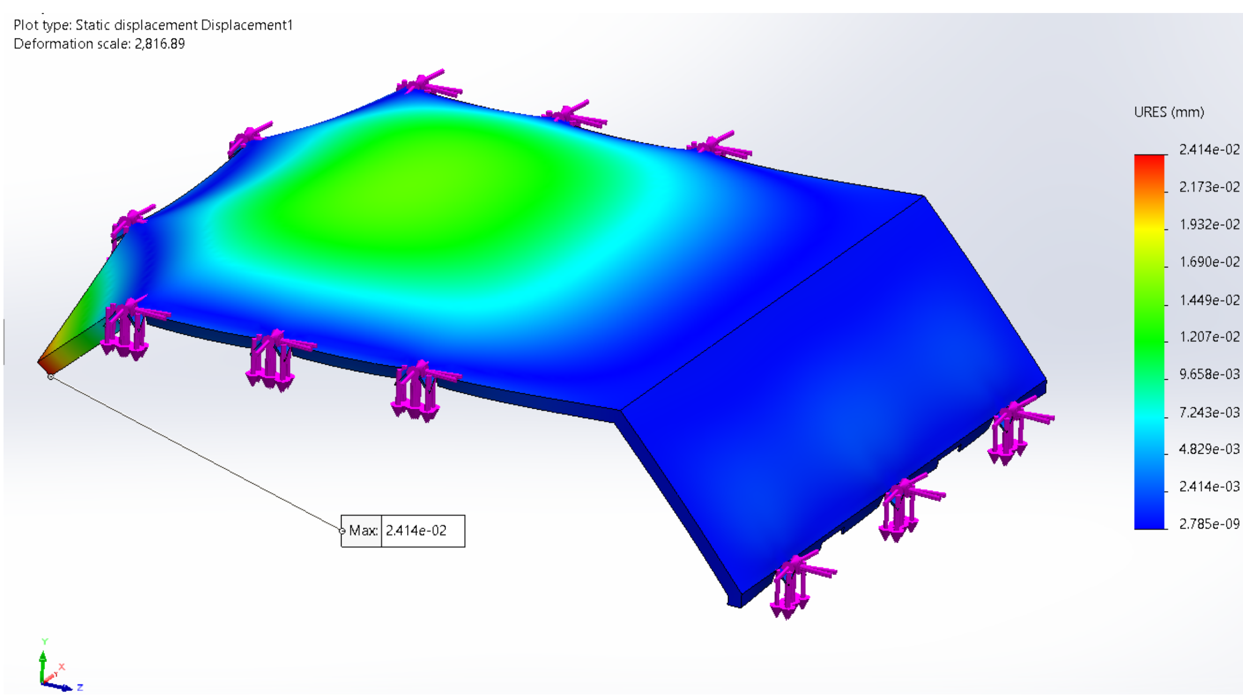

Figure 3.91: Combined Load Test Displacement Plot (-ve directions)

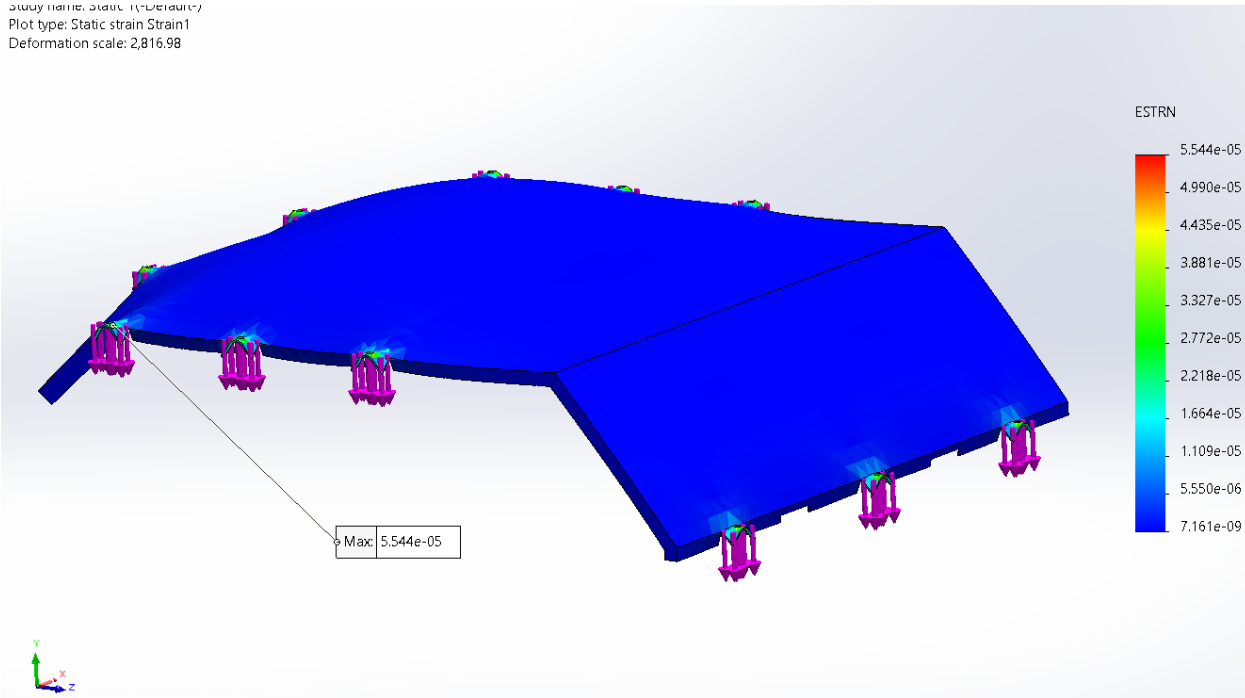

Figure 3.92: Combined Load Test Strain Plot (-ve directions)

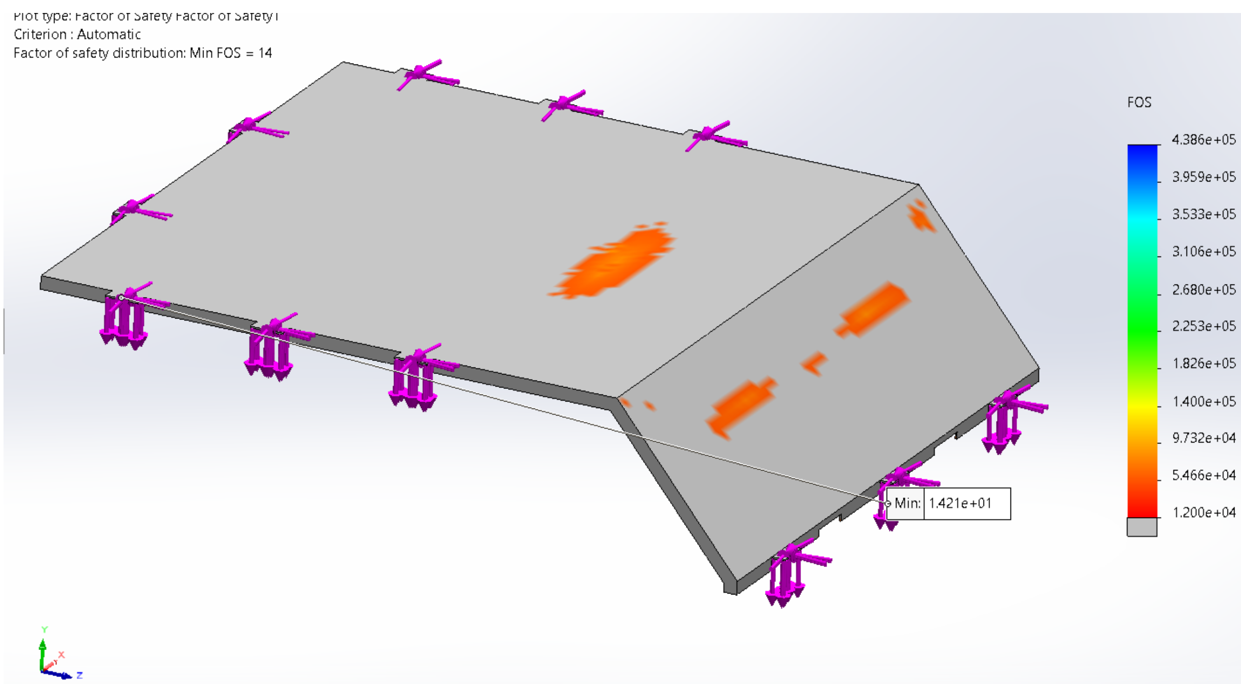

Figure 3.93: Combined Load Test FOS Plot (-ve directions)

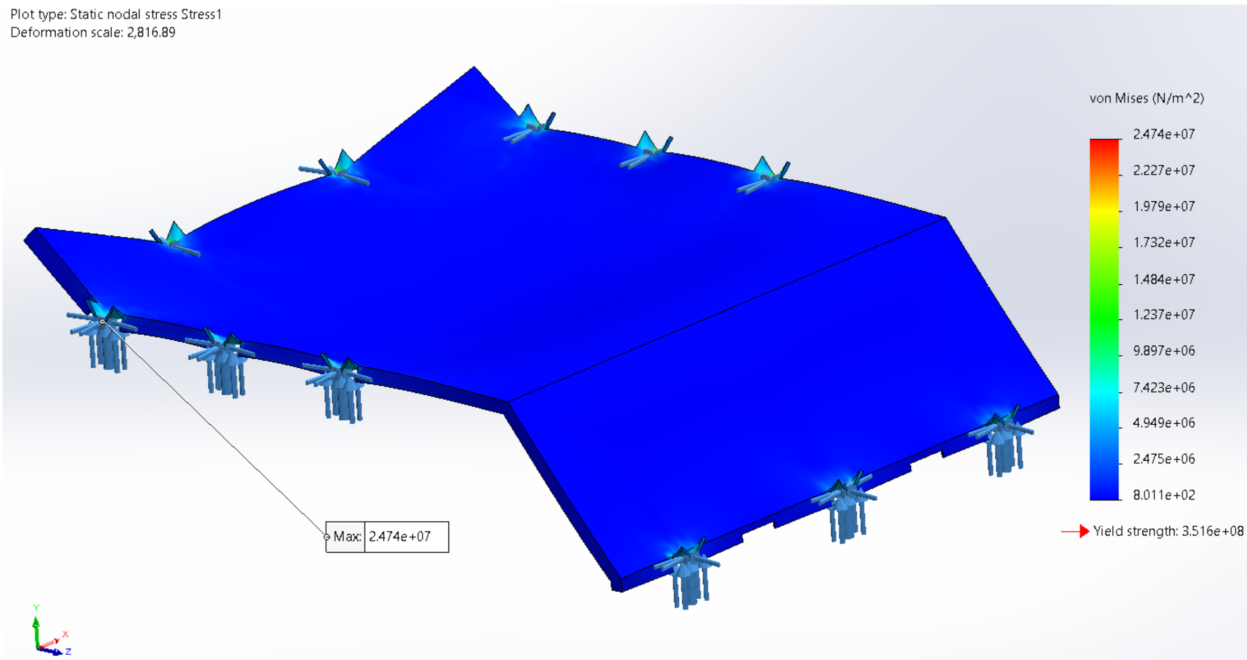

Figure 3.94: Combined Load Test Stress Plot (+ve directions)

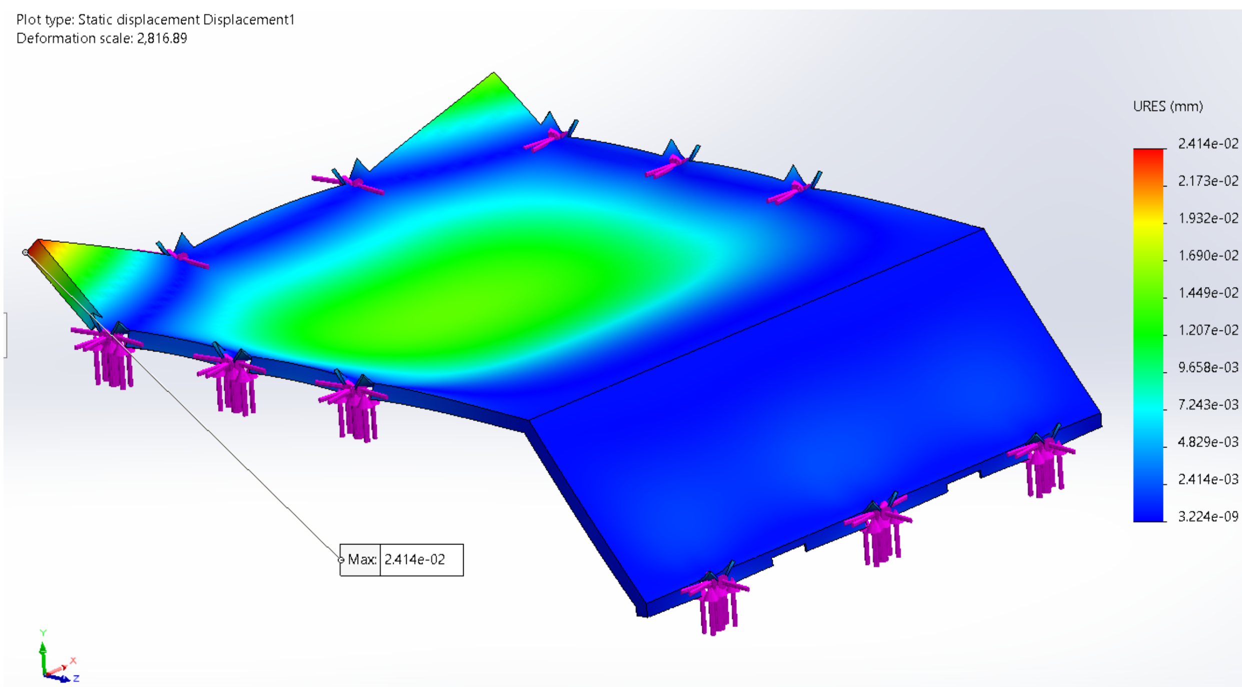

Figure 3.95: Combined Load Test Displacement Plot (+ve directions)

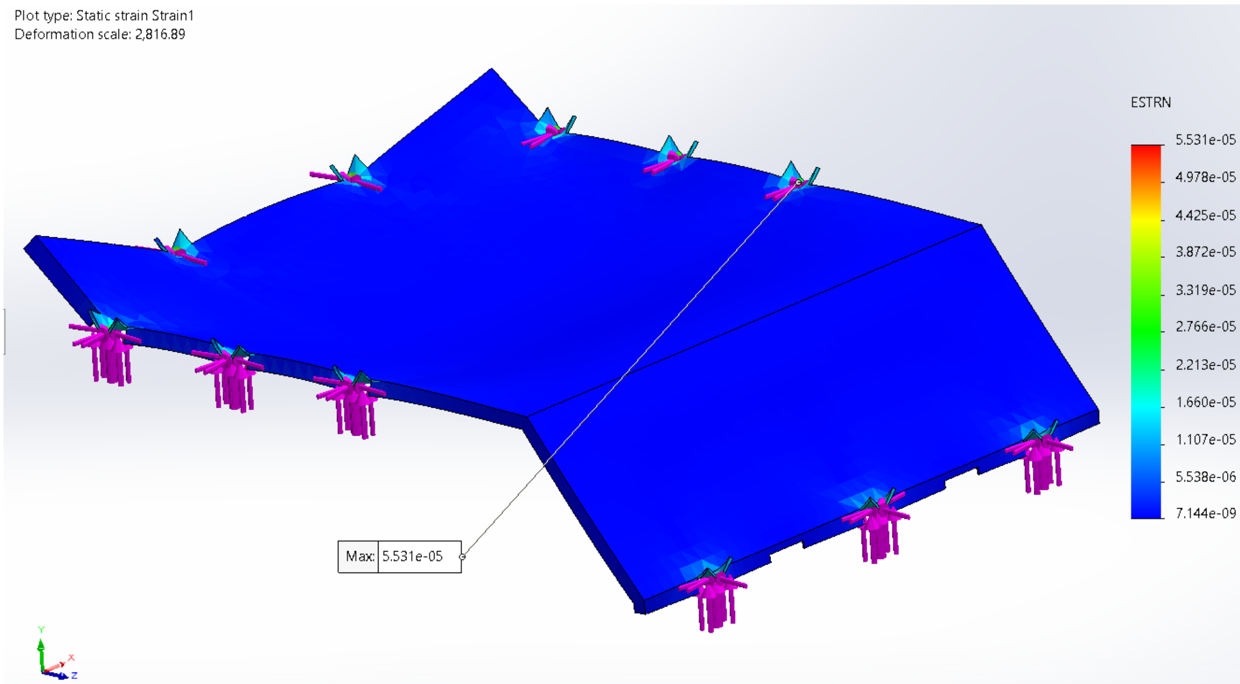

Figure 3.96: Combined Load Test Strain Plot (+ve directions)

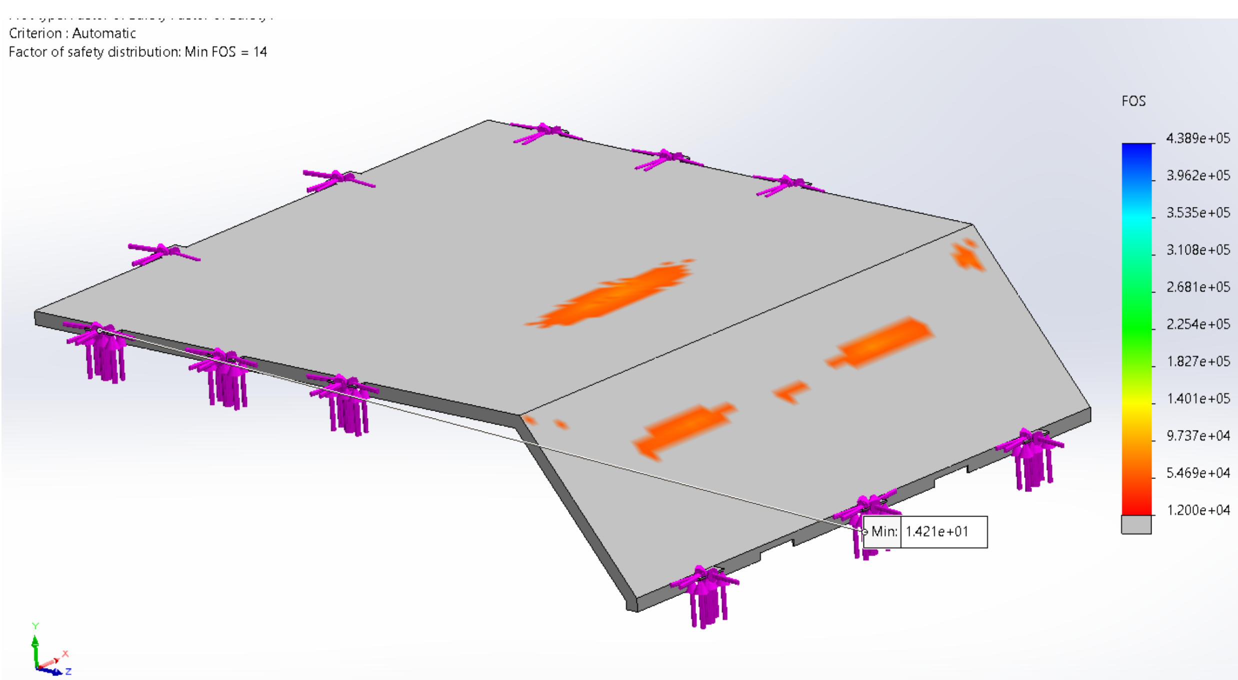

Figure 3.97: Combined Load Test FOS Plot (+ve directions)