

DYNAMIC_STRESS- STRAIN_ANALYSIS_REPORT_ LWG_1810351

by William Groom

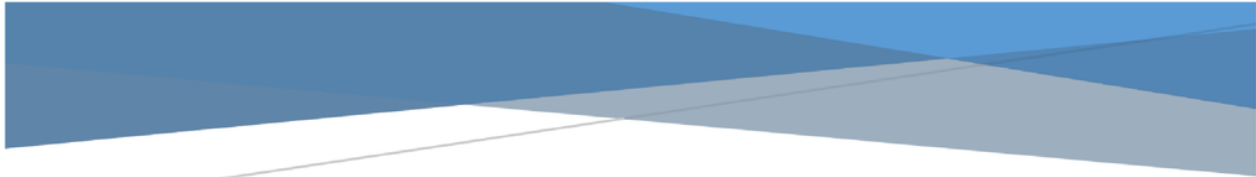
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DYNAMIC STRESS/STRAIN ANALYSIS

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Abstract

Four ballistic impact simulations were carried out using material properties of aluminum for the impact plate and four different projectile velocities designed to replicate in service, rifle calibers were used. Direct and Shear stress events were identified and analysed in order to gain a greater understanding of dynamic impact stresses upon a medium.

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2 Introduction

An ABAQUS simulation was used to assess the direct and tensile stress functions of an aluminium plate when impacted by a projectile at varying speeds. A range of projectile velocities were selected in order to simulate rifle calibre bullets from in service weapon systems. Direct stress with regards to compression and tension as well as shear stress in different directions were compared at various points within each simulation. Projectile velocities were also compared throughout each simulation. Basic elastic, plastic and density properties for the aluminium plate were used (reference here).

2.1 Background theory

Tensile stress is predominantly a stretching force most commonly explained through hanging a weight from a string. The string is under tensile stress from the weight, and will stretch slightly as a result. In order to calculate the tensile stresses in a system such as this the following formula is used.

$$\sigma = \frac{FORCE}{AREA} = Nm^2 \text{ OR } Pa$$

Compressive stress is the opposite of tensile as it is a stress that leads to a smaller volume of material rather than the elongation effect of tensile stress.

Young's modulus is the mechanism that explains the stiffness of an object, for example young's modulus of steel is $2 \times 10^{11} Pa$ or 200 GPa.

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Young's modulus = $E = \sigma/\epsilon$

Young's modulus is also used to describe the elastic region of a material with regards to materials stress/strain graph. See Figure 1

Slope of elastic region = E

The elastic region of a given material is determined as the region in which the material will deform under loading but, when the force is removed, will return to its original state. The plastic region follows the elastic and is determined as the point at which a material will deform permanently when the load or force is removed.

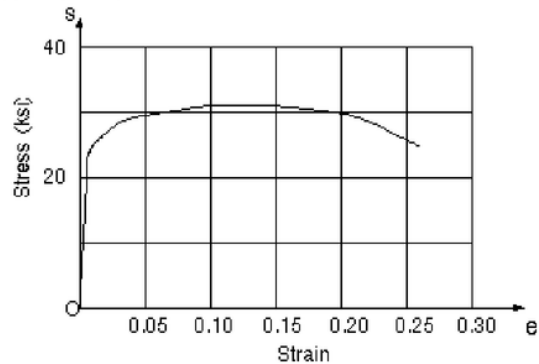


Figure 4. Stress-strain diagram for aluminum in tension.

Figure 1-Aluminium Stress/Strain Graph [1]

3 Test method

An ABAQUS simulation was supplied for the purposes of the experiment. This was a basic ballistic impact model using a plate fixed in space from its edges and a non-deformable projectile shaped to represent a bullet. The plate was given the same material properties as aluminium [2], this was done through the properties drop down menu and selecting the materials manager icon on the tool bar. Density, elastic and plastic parameters were set for the plate to replicate a standard form of aluminium Figure 4, Figure 5. The projectile was assigned a velocity per simulation through the Load drop down menu, the predefined fields file path and adjusting V3 accordingly Figure 6.

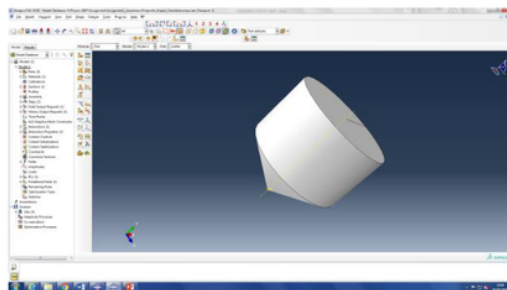


Figure 2-ABAQUS_Projectile

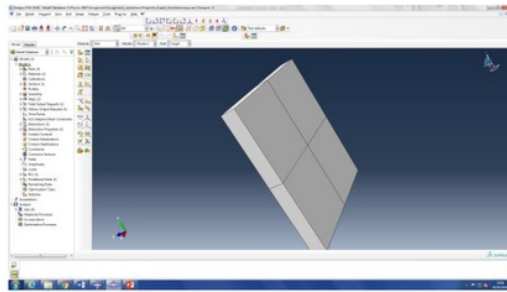


Figure 3-ABAQUS_Plate

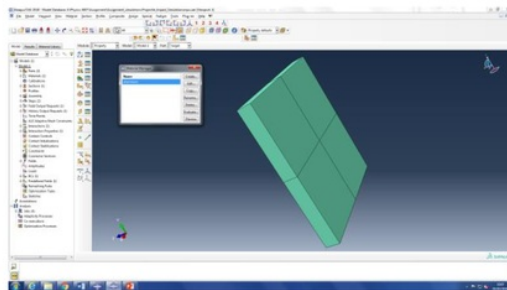


Figure 4-ABAQUS_Material Properties

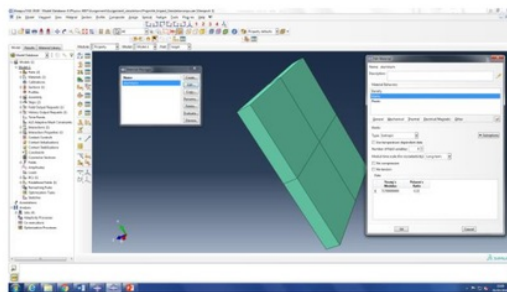


Figure 5-ABAQUS_Youngs Modulus

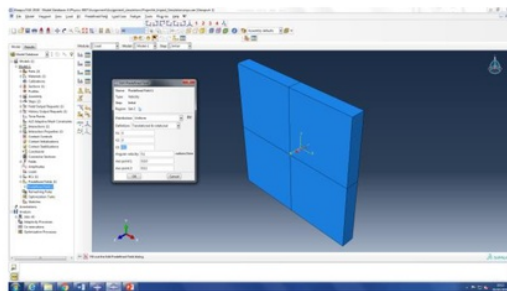


Figure 6-ABAQUS_Projectile Velocity

The simulation was run and the completed results examined, a cut through of the plate was required in order to fully visualise the internal events of the simulation. This was carried out using the cut

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manager icon within the visualisation drop down menu. This menu is required to view the completed simulation. Figure 7

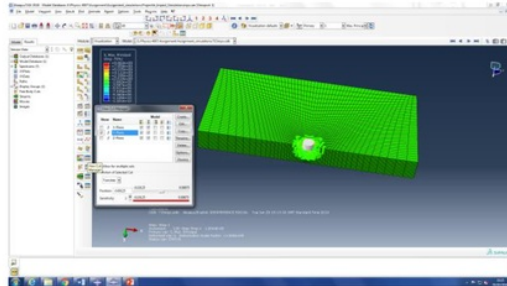


Figure 7-ABAQUS_Cut Manager

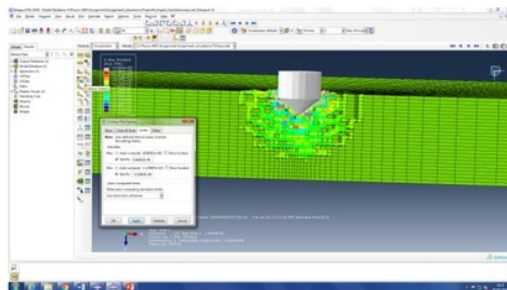


Figure 8-ABAQUS_Scaling

In order to fully understand the forces within the simulation the scaling factor of the plate required changing, this was done through the contour options icon, selecting the limits tab and adjusting the min/max values until a good contrast is achieved. Negative values represent compression and positive tension. This tab also allows the changing of colour mapping.

Projectile velocity was also recorded and graphed for each simulation carried out. This was done by first selecting the Create XY data icon in the visualisation drop down and ensuring the OBD field Output option is selected. Figure 9-ABAQUS_Projectile Velocity 1

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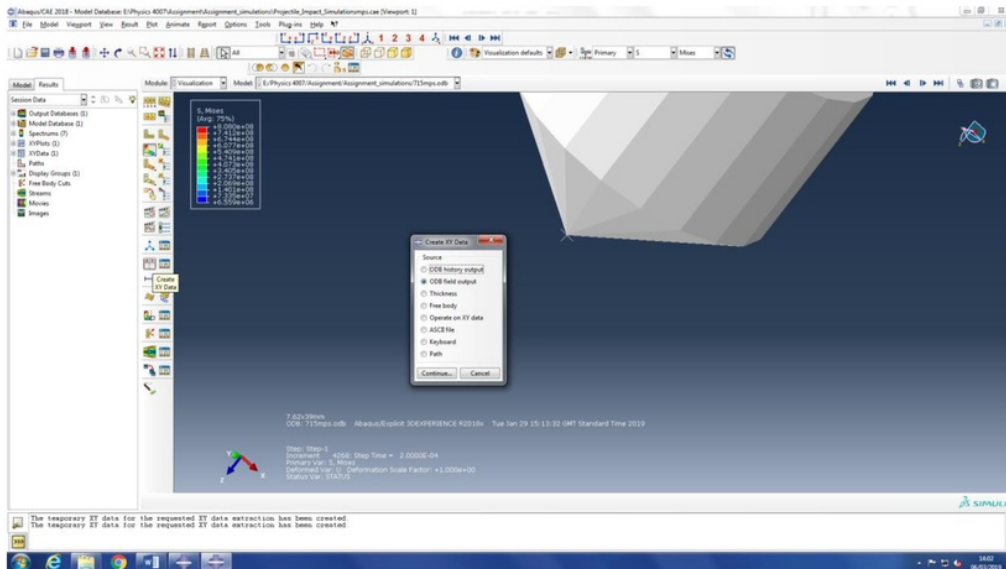


Figure 9-ABAQUS_Projectile Velocity 1

Select unique nodal from the pop up box and scroll down to spatial velocity, select magnitude and then move on to the elements/nodes tab within the pop up box. Figure 10-ABAQUS_Projectile Velocity 2

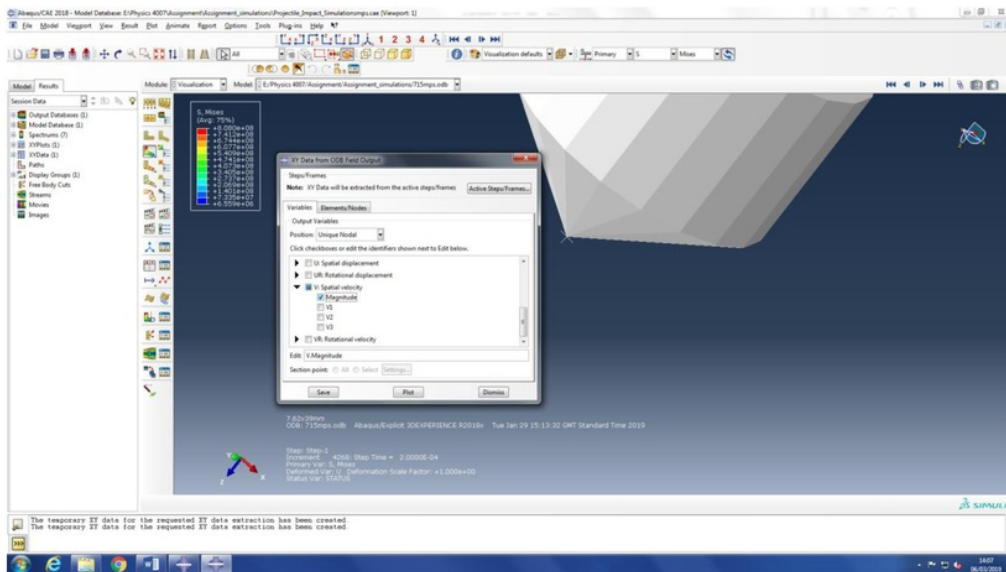


Figure 10-ABAQUS_Projectile Velocity 2

Ensure the tip of the projectile is selected, this will display a red dot on the node. Select the edit selection button and then Plot, Figure 11-ABAQUS_Projectile Velocity 3. This will then produce a velocity over time graph of which ever node was selected Figure 12-ABAQUS_Projectile Velocity 4.

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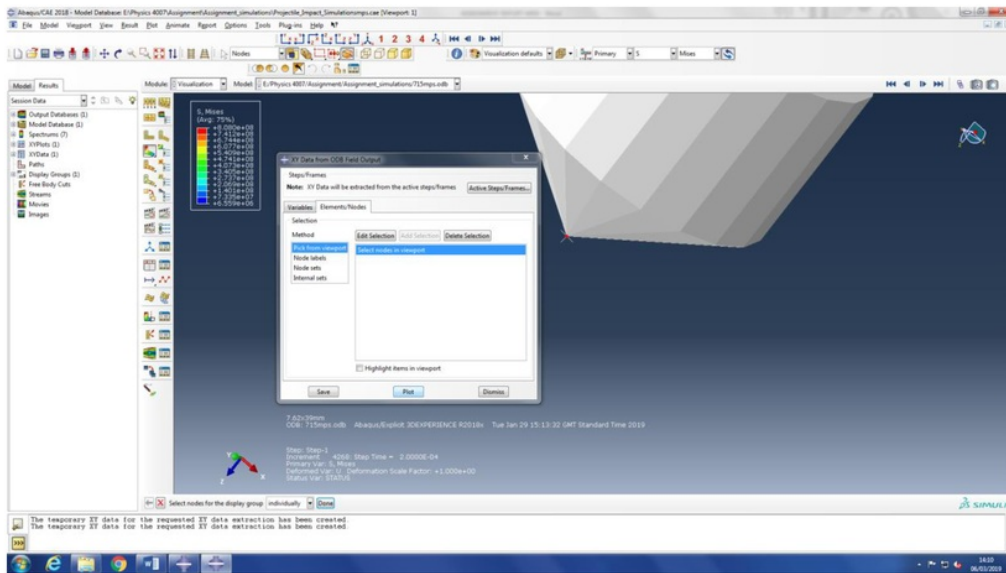


Figure 11-ABAQUS_Projectile Velocity 3

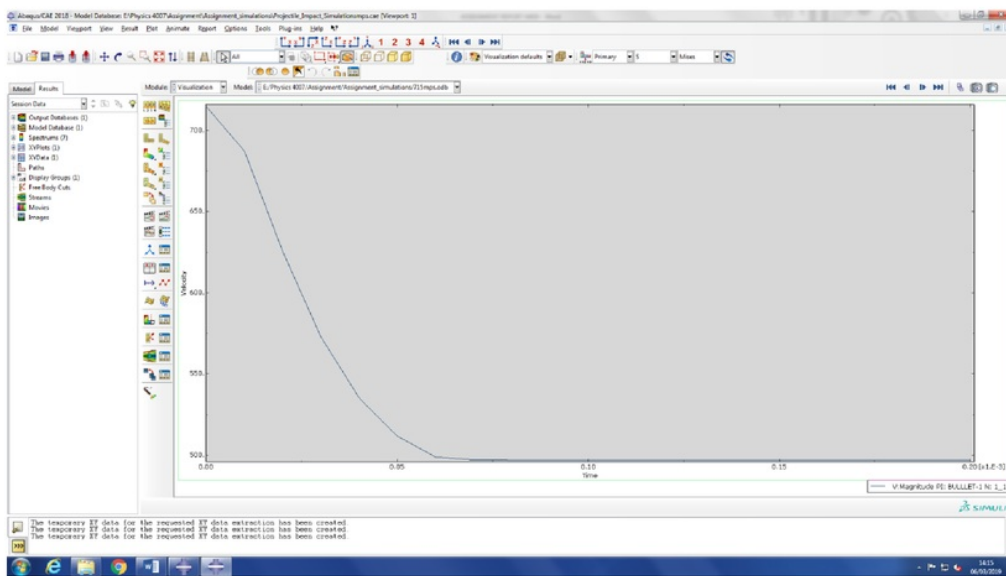


Figure 12-ABAQUS_Projectile Velocity 4

4 Results

Four simulations were conducted in order to represent a variety of commonly used rifle-calibre bullet velocities. The bullet velocities simulated were, 922mps (5.56x45mm NATO) [3], 838mps (7.62x51mm NATO) [3], 715mps (7.62x39mm (7.62 Russian)) [4] and 862mps (7.62x54r) [5]. It was assumed that the difference in bullet mass, geometry and composition did not affect the results as the simulation was designed to represent the effects of changing velocities upon a medium and not these additional variables. The plate thickness was 200mm with a bullet weight of 30g and a cross section of 4mm.

4.1 Data

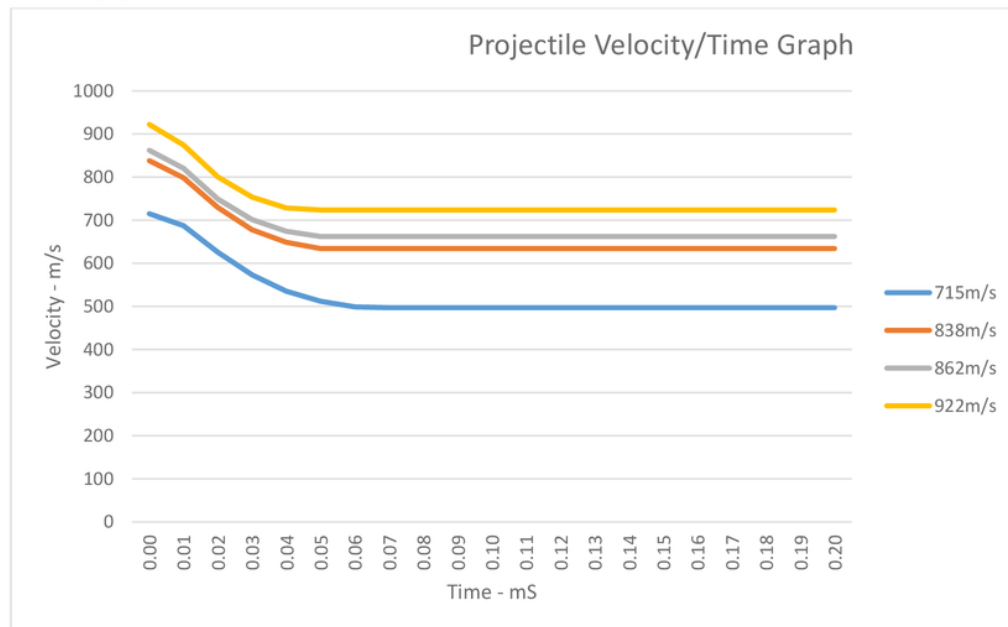


Figure 13_Projectile Velocity/Time Graph

Table 1-Projectile Velocity Table of Results

Simulation	Initial Velocity	End Velocity	Velocity lost	Percentage lost
5.56x45mm	922	723	199	21.5835
7.62x54mm	863	661	202	23.4067
7.62x51	838	634	204	24.3437
7.62x39mm	715	496	219	30.6294

In all the simulations the projectile successfully penetrated the aluminium plate and lost a similar amount of energy. This is evidence of plate performance maintaining constant parameters as

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expected of a modelled simulation. Every simulation displayed spalling events following the projectiles exit from the back side of the plate, this is evidence of large tension events in the plate.

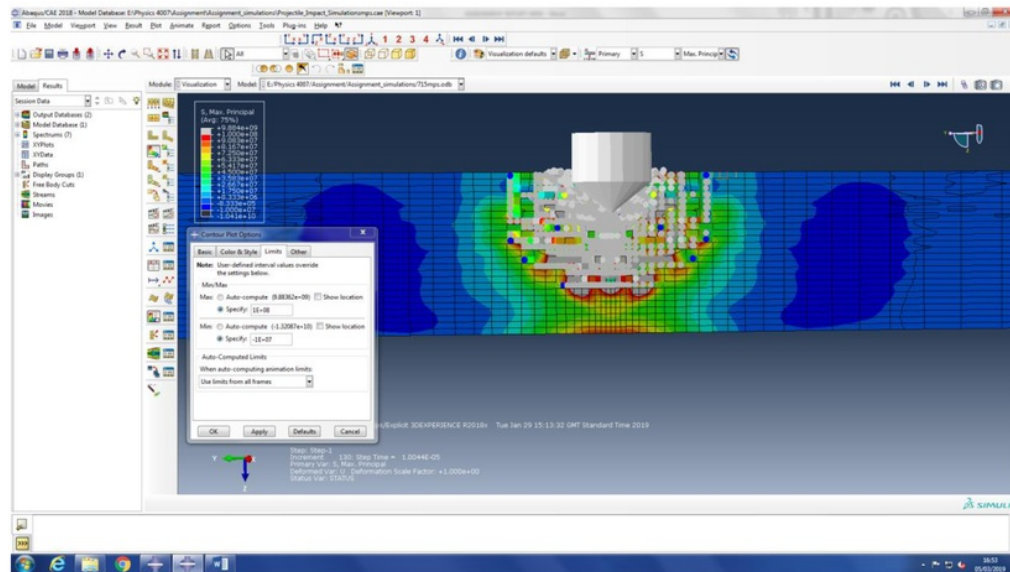


Figure 14-715m/s_1.0044E-05_Max Principle

In Figure 14-715m/s_1.0044E-05_Max Principle, events were visible with high tensile stress waves emitting away from the projectile's point of impact, these were measured to be 9.884 GPa. Lesser magnitude, but still comparatively high-pressure, reflecting tensile waves were present coming from the back side of the plate where the pressure was measured to be 81.67 – 90.83 MPa. Compression events were also visible radiating away from the high tensile zones measured to be around 1MPa. This suggests greater tensile stress is present at this point in the simulation.

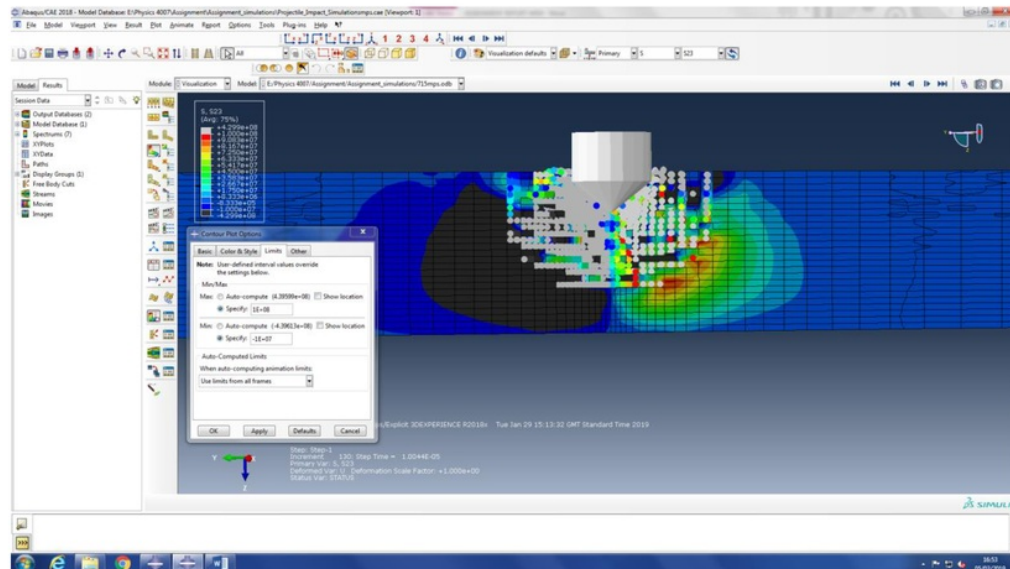


Figure 15-715m/s_1.0044E-05_S23

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Figure 15-715m/s_1.0044E-05_S23 shows shear stresses were present however, these events are comparatively small (6.087 GPa) when compared to direct and tensile stresses present at the same time point in Figure 14-715m/s_1.0044E-05_Max Principle. Shear stress events were moving away from the projectile impact point at an angle that suggest origin around the projectiles angled edges.

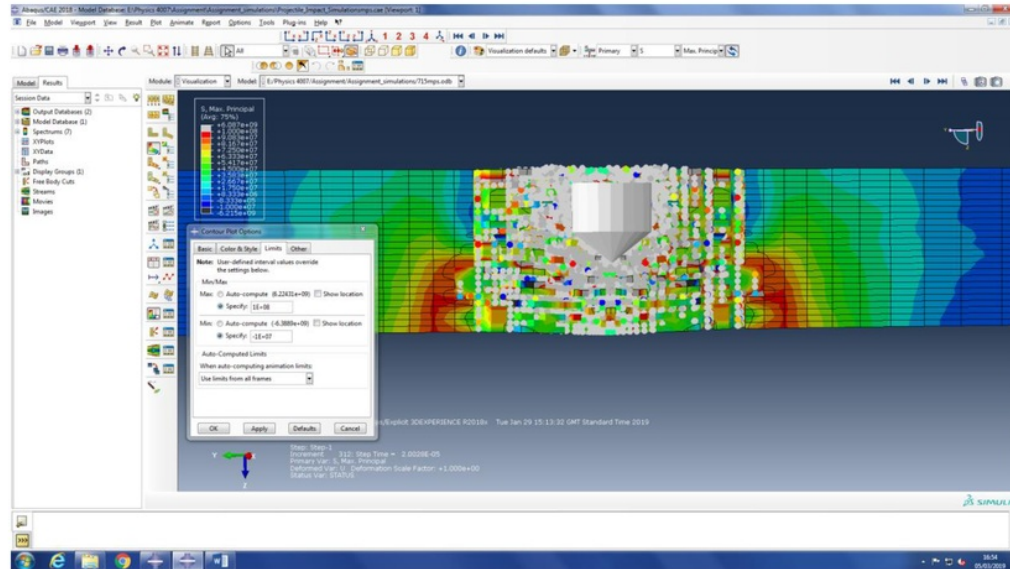


Figure 16-715m/s_2.0028E-05_Max Principle

Figure 16-715m/s_2.0028E-05_Max Principle clearly displays high tensile events. These were visible on all sides of the projectile, denoted by the grey colour chart of the simulation, and were measured to be at least 6.087 GPa. Reflective tensile events were visible radiating away from the back side of the plate and were measured to be ranging from 100Mpa to 45MPa, denoted by the red to green banding depicted. Compression events, denoted by the blue colouring, were present leading the tensile zones and most notably to the sides of the projectile entry point. These were measured to be 10MPa.

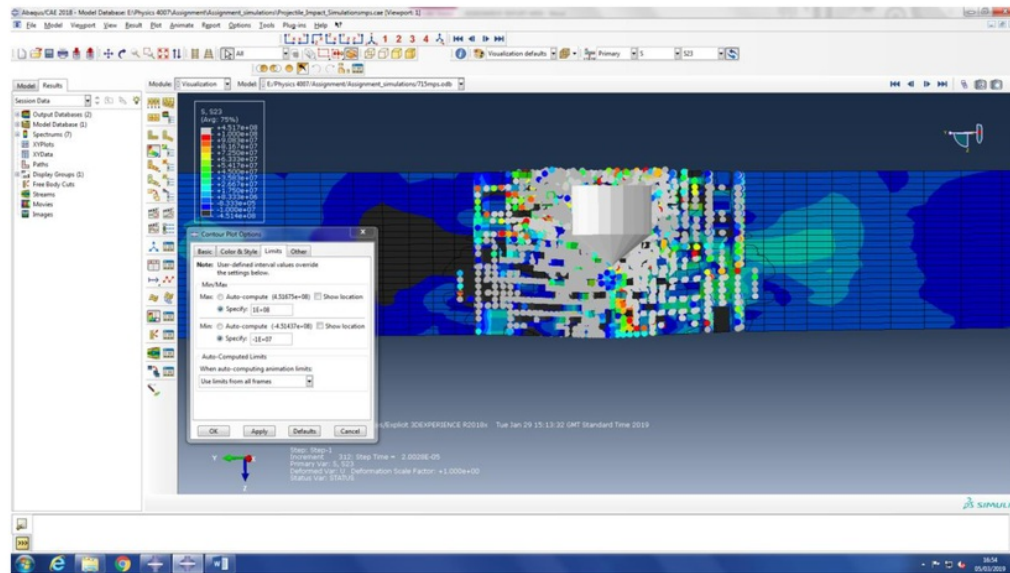


Figure 17-715m/s_2.0028E-05_S23

Shear stress is visible in Figure 17-715m/s_2.0028E-05_S23 as denoted by the black and light blue banding radiating away from the projectile impact region. These events were comparatively small when compared to Figure 16-715m/s_2.0028E-05_Max Principle and were measured to be 8.333MPa -451.4MPa.

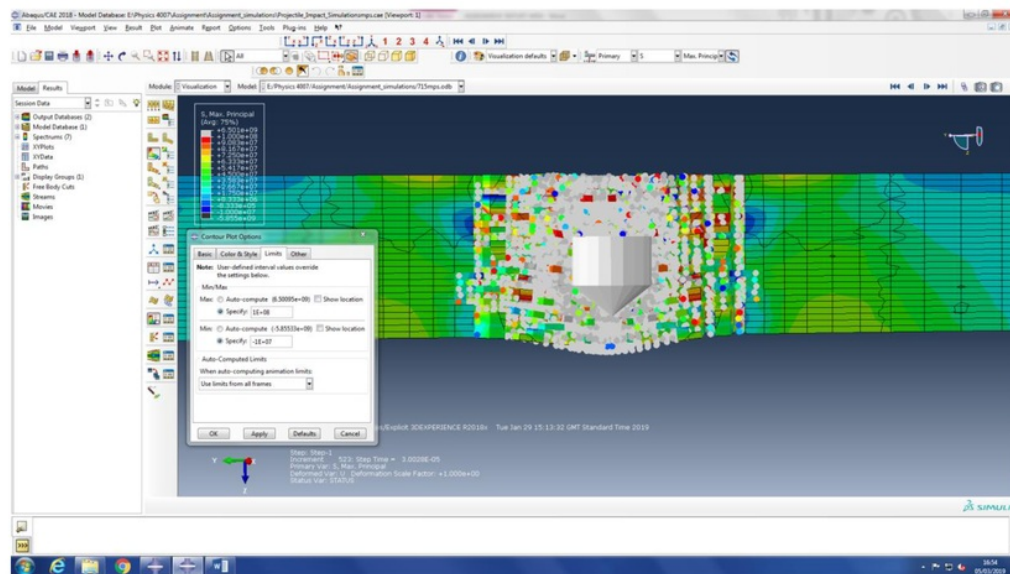


Figure 18-715m/s_3.0028E-05_Max Principle

Figure 18-715m/s_3.0028E-05_Max Principle depicts the first evidence of “bulging” of the back side of the aluminium plate. This event indicates the surpassing of the plates yield stress value which was set to be 350MPa, this was further supported through the saturating tensile events still clearly dominant with a measured pressure of 6.5GPa radiating outwards from the projectile. Tensile waves

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were also present radiating from the top and back side of the plate, denoted by the green and yellow colouring on the simulation. These were measured to be 63MPa and suggest a weakening of the reflective wave when compared to Figure 16-715m/s_2.0028E-05_Max Principle with a pressure of around 100MPa.

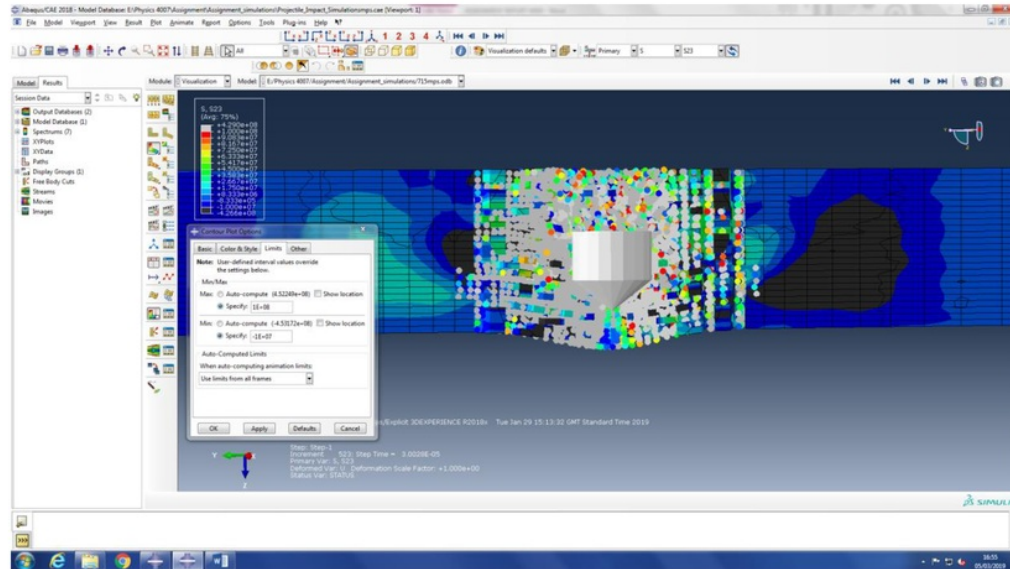


Figure 19-715m/s_3.0028E-05_S23

Figure 19-715m/s_3.0028E-05_S23 depicts a switch in regions when compared to Figure 17-715m/s_2.0028E-05_S23. This is present in the swapping of positive and negative pressure regions. Figure 17 shows negative pressure events on the left side of the plate whereas Figure 19 shows this effect to be on the right. This indicates evidence of a rippling shear stress event radiating from the projectile impact region.

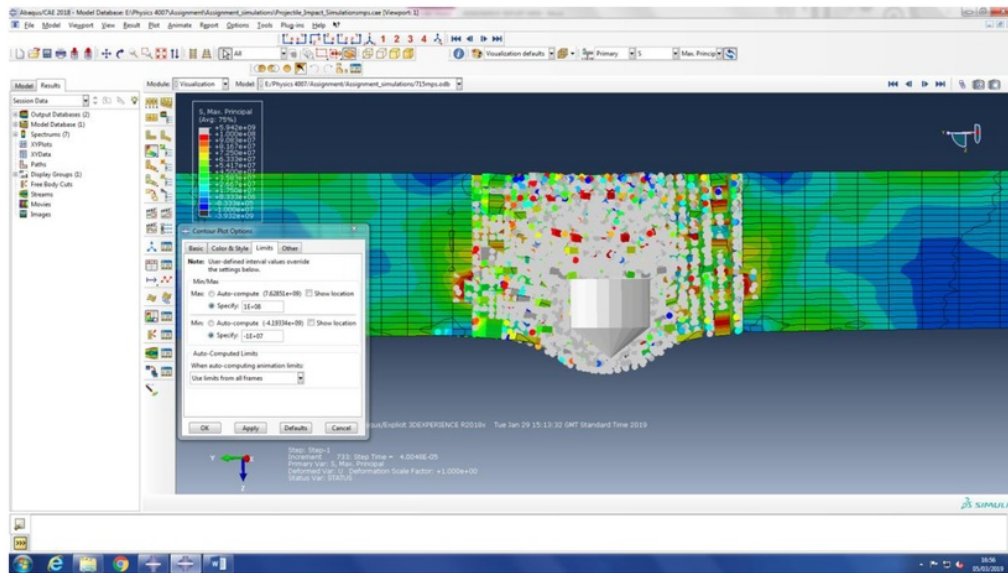


Figure 20-715m/s_4.0048E-05_Max Principle

Figure 20-715m/s_4.0048E-05_Max PrincipleError! Reference source not found. depicts further bulging of the backside of the plate, indicating complete penetration of the plate was likely. High tensile stress was still dominant, surrounding the projectile and measured to be 5.9GPa. Similar magnitude tensile waves are present radiating out from the projectile. Regions of tensile events ahead of these radiating waves were measured to be 45MPa and appear to be part of the plates rippling motion indicated by the tension and compression wave interactions.

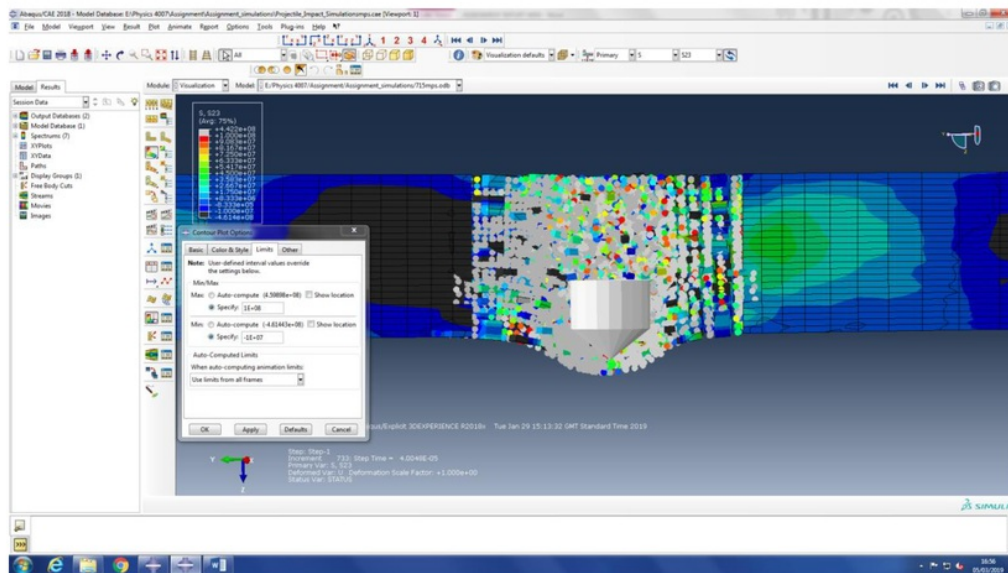


Figure 21-715m/s_4.0048E-05_S23

Figure 21-715m/s_4.0048E-05_S23 further supports the theory of plate ripple as described for Figure 19-715m/s_3.0028E-05_S23.

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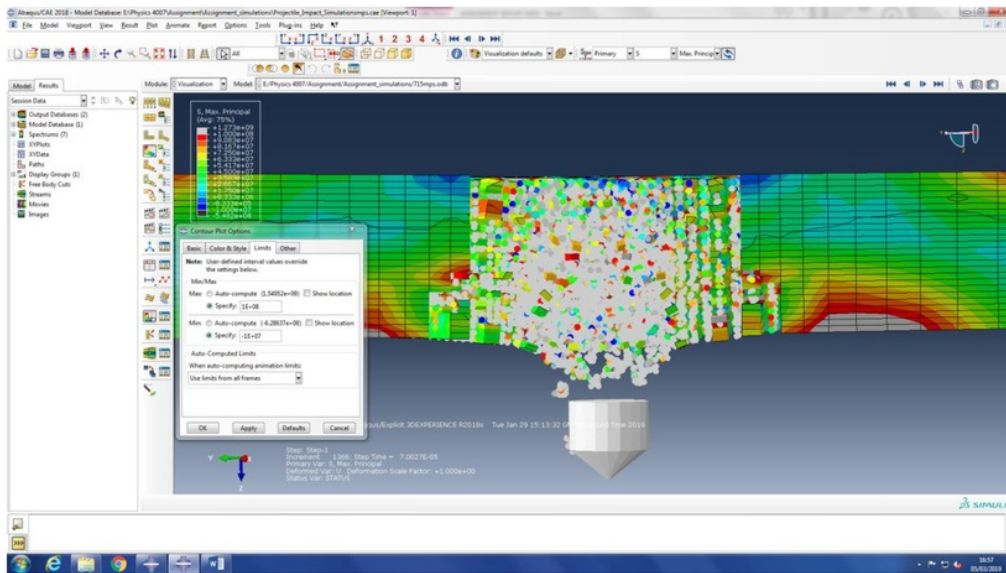


Figure 22-715m/s_7.0027E-05_Max Principle-Spalling

Figure 22-715m/s_7.0027E-05_Max Principle-Spalling clearly depicts spalling events as indicated by the separation of plate particles from the main body. This is indication of high-tension events due to the force required to separate the plate material in this manner.

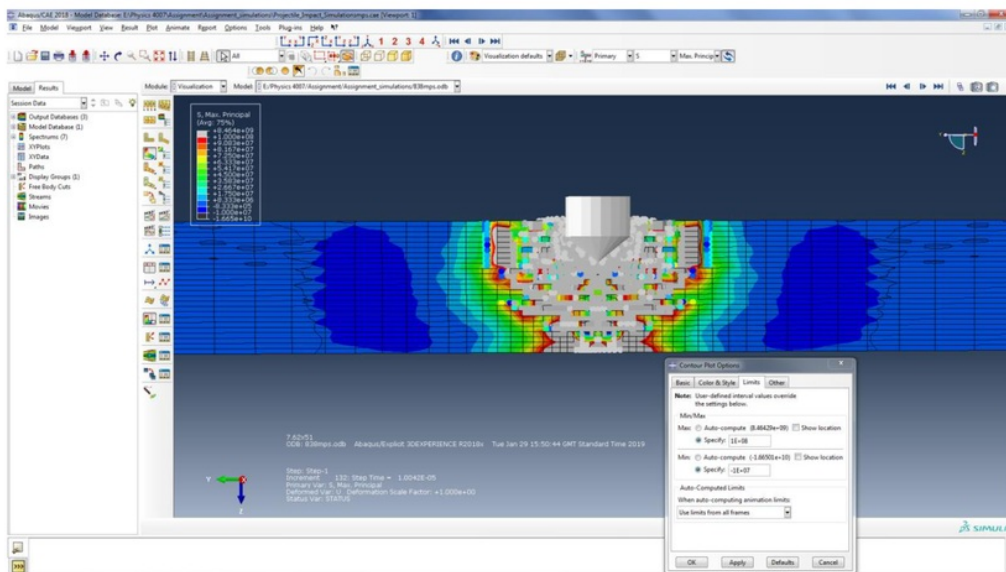


Figure 23-838m/s_1.0042E-05_Max Principle

Dominant, high pressure tensile events were present upon projectile impact with the plate and shown in Figure 23-838m/s_1.0042E-05_Max Principle. Pressures of 8.464GPa were measured within structures radiating away from the projectile. These radiating structures impacted the back side of

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the plate and were beginning to reflect back into the plate. Compressive events were present radiating away from the high tensile zones, these were measured to be 833KPa.

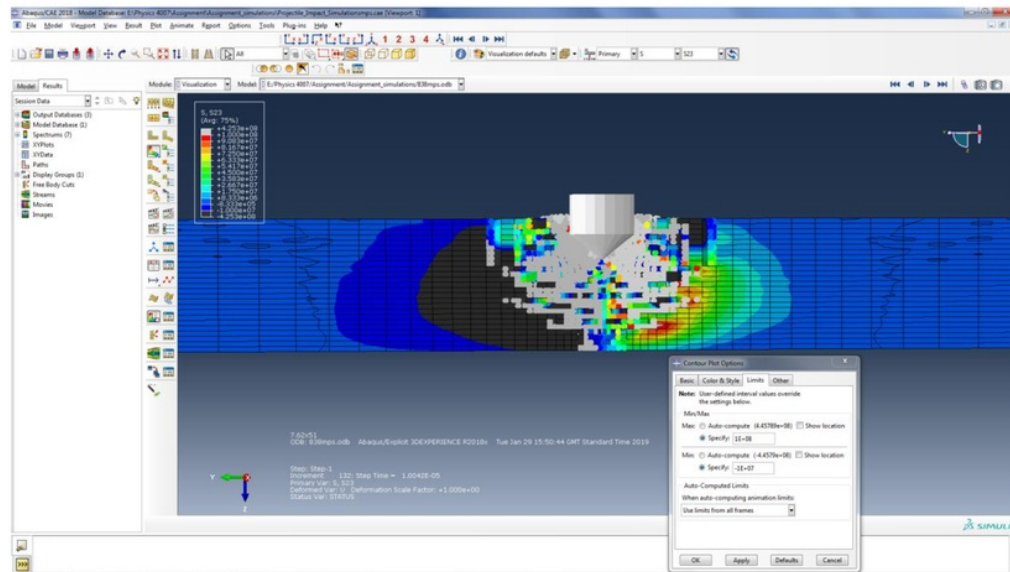


Figure 24-838m/s_1.0024E-05_S23

Figure 24-838m/s_1.0024E-05_S23 clearly depicts equal and opposite shear stress events. These structures were visible radiating away from the projectile upon impacting the plate, and were measured to be 425MPa in opposite directions.

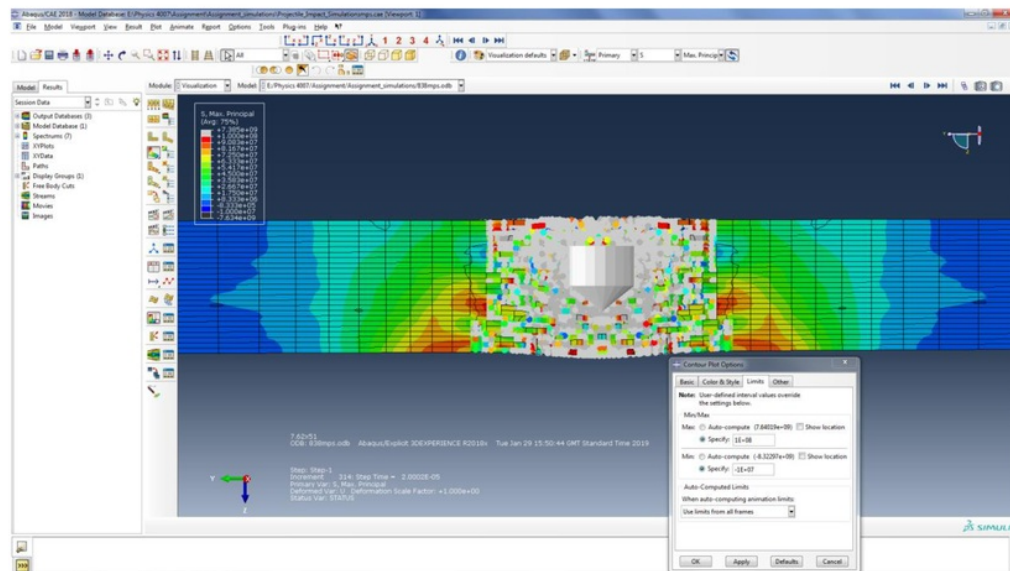


Figure 25-838m/s_2.0002E-05_Max Principle

Figure 25-838m/s_2.0002E-05_Max Principle depicts radiating tensile waves originating from the back side of the plate, denoted by the red and orange zones and measured to be 100MPa.

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Compression event structures were present at the leading edge of the tensile structures indicating the plate moving in one, outward, direction.

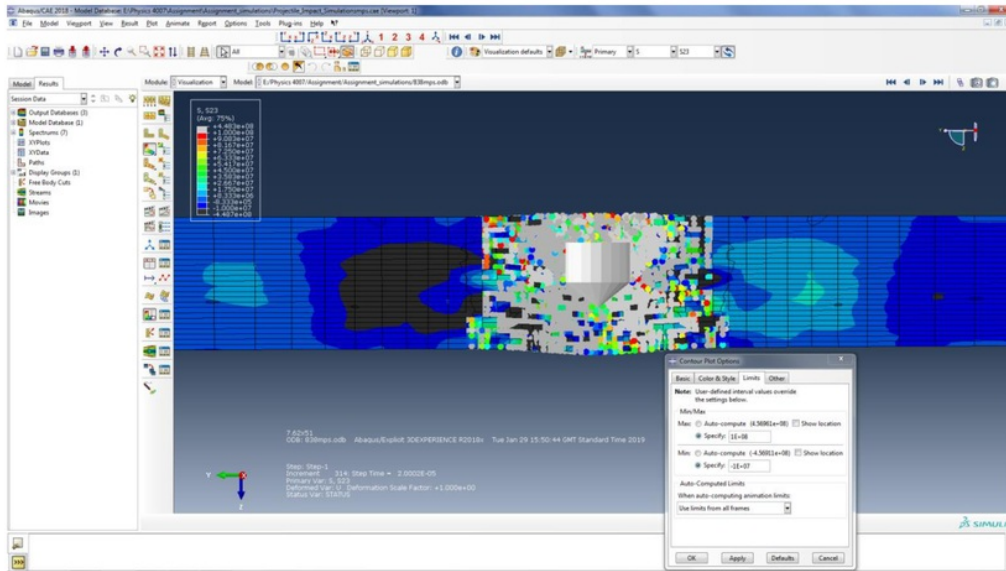


Figure 26-838m/s_2.0002E-05_S23

Figure 26-838m/s_2.0002E-05_S23 depicts expanding equal and opposite shear stress structures radiating away from the projectile impact region. These structures were measured to be 448MPa

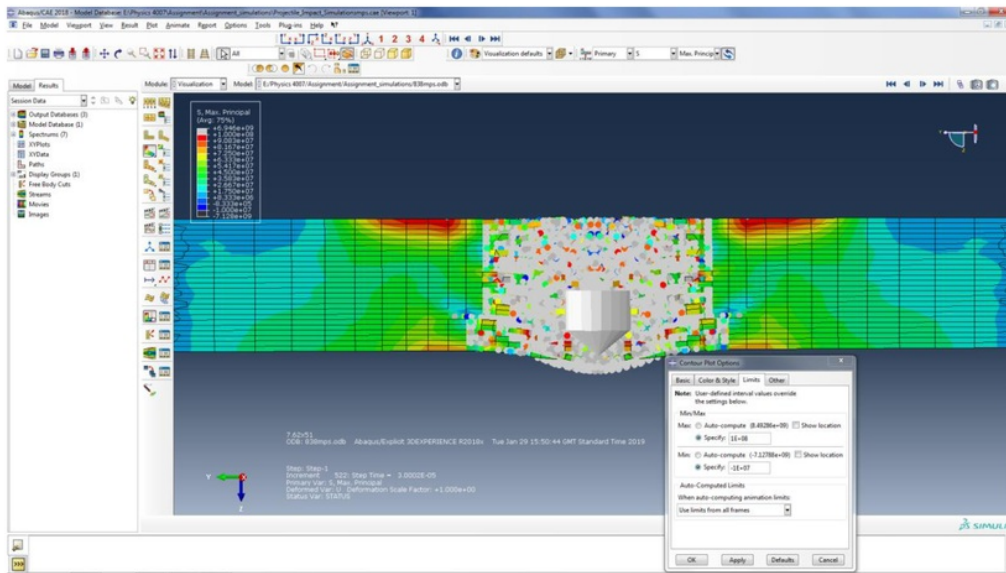


Figure 27-838m/s_3.0002E-05_Max Principle

Figure 27-838m/s_3.0002E-05_Max Principle depicts high tensile loading still present surrounding the projectile with significant bulging of the back side of the plate. High tensile events were present at the top on the plate next to the projectile impact region, these measured at 100MPa and indicate a plate ripple effect due to their appearance at 3.0E-05Seconds into the simulation.

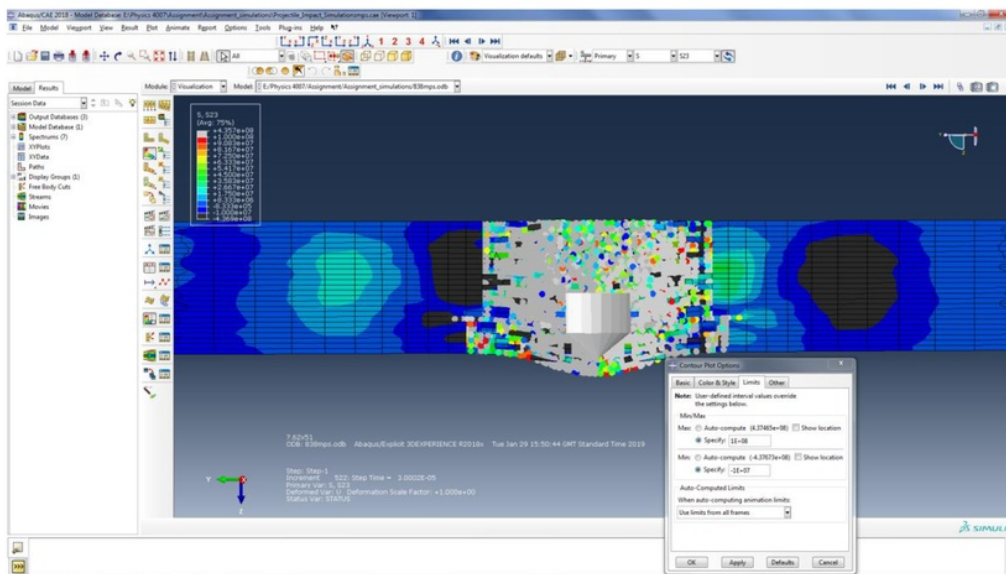


Figure 28-838m/s_3.0003E-05_S23

Figure 28-838m/s_3.0003E-05_S23 depicts first indication of plate ripple due to the change in shear stress regions. These areas appear to have gone from positive to negative when compared with Figure 26-838m/s_2.0002E-05_S23.

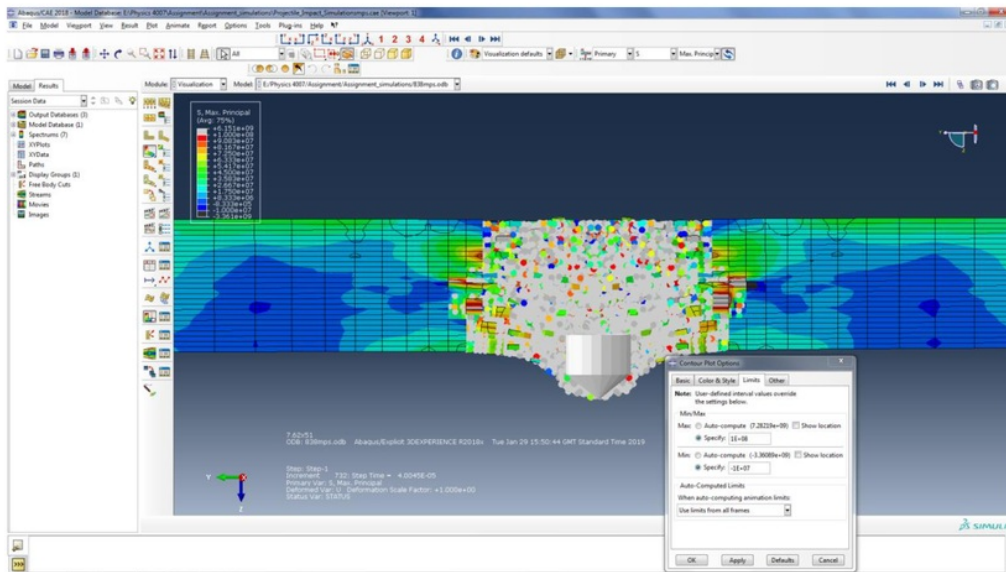


Figure 29-838m/s_4.0045E-05_Max Principle

Figure 29-838m/s_4.0045E-05_Max Principle depicts the projectile exiting the plate and high tensile loading is still present surrounding the projectile. These were measured to be 6GPa.

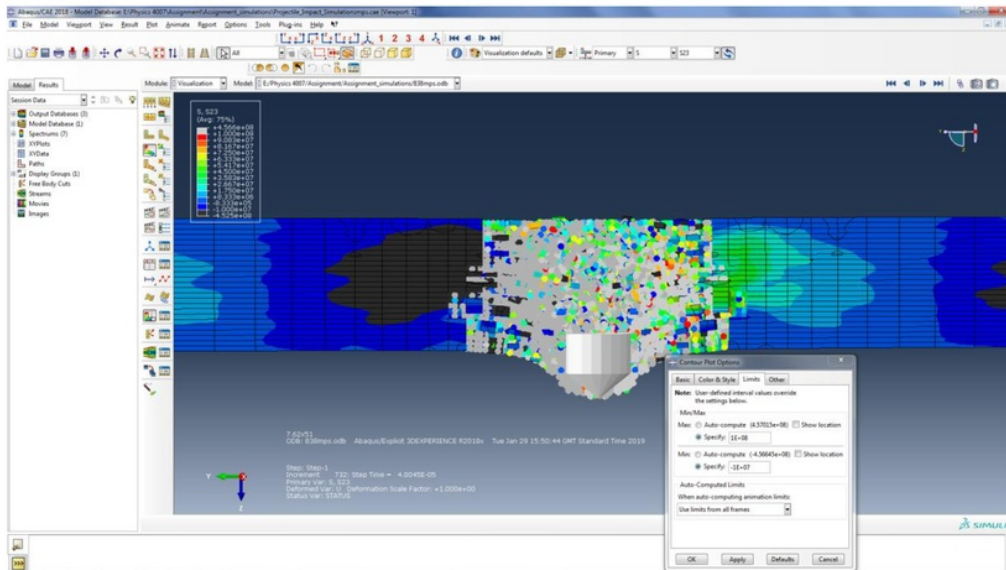


Figure 30-838m/s_4.0045E-05_S23

Figure 30-838m/s_4.0045E-05_S23 depicts further evidence of plate ripple as indicated by the change in pressure radiating away from the projectile impact region.

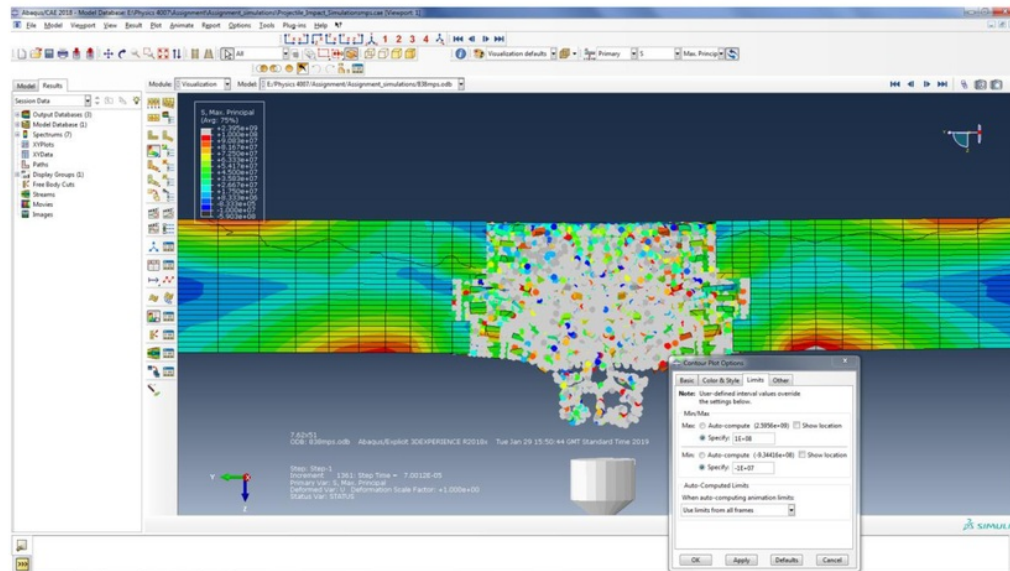


Figure 31-838m/s_7.0012E-05_Max Principle-Spalling

Figure 31-838m/s_7.0012E-05_Max Principle-Spalling – indicates a large spalling event following the projectile path. High compression structures were present on the backside of the plate, radiating upwards. This is further evidence of plate ripple as Figure 27-838m/s_3.0002E-05_Max Principle depicts similar events at the top of the plate.

Simulations 838, 863 and 922 all display very similar results to simulation 715 as shown in Figure 23-838m/s_1.0042E-0_Max Principle through to Figure 49-922m/s_4.0032E-05_S23. All final time points show spalling as a result of extreme tensile stress loading.

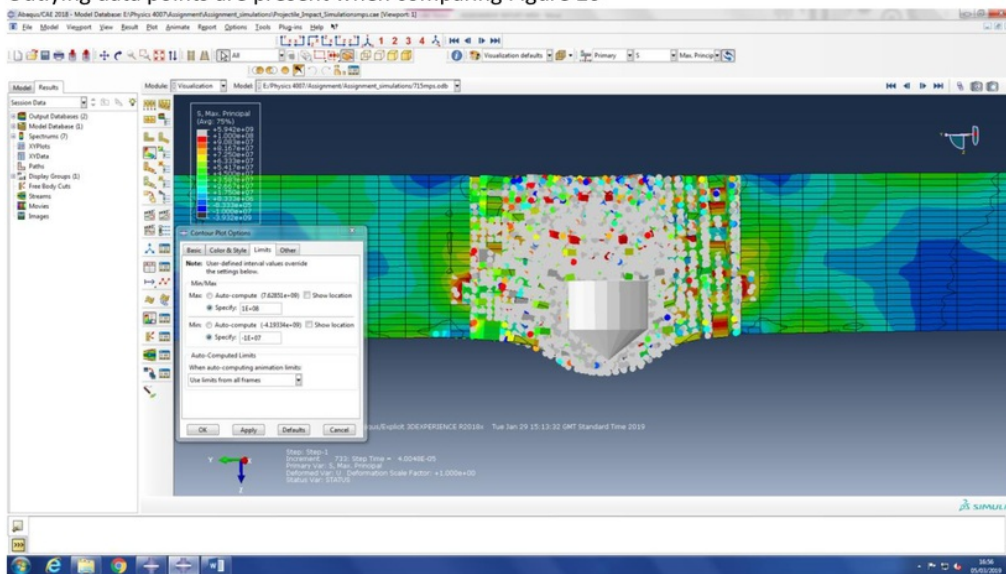
Table 2-Simulation Max Pressures, depicts the maximum pressures present in both direct and shear stress plains for each simulation figure.

Simulation Velocity	Max Principle – tensile stress – E+09	23 – shear stress – E+08
715		
	9.844	4.229
	6.087	4.517
	6.501	4.290
	5.942	4.422
	1.273	
838		
	8.464	4.253
	7.385	4.483
	6.946	4.357
	6.151	4.566
	2.395	
863		
	8.142	4.278

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	8.177	4.374
	6.319	4.452
	8.034	4.530
	1.242	
922		
	8.854	4.295
	7.488	4.494
	7.538	4.599
	9.209	4.502
	2.510	

Outlying data points are present when comparing Figure 20



, Figure 29 Figure 29-838m/s_4.0045E-05_Max Principle, Figure 39 and Figure 48 as shown in the fourth row of each simulation velocity in Table 2-Simulation Max Pressures. The non linier peaks of 8.03Gpa for simulation 3 (863m/s) and 9.209GPa present in simulation 4 (922m/s) were saturating tensile event structures in line with what might be expected when spalling events first occur. These high peak tensile pressures were the driving force behind the mesh separation of the plate.

An additional simulation was carried out in order to investigate the outlying pressure measured in Figure 48. This simulation had an edited Tmax time base which was adjusted from 200μs to 100μs.

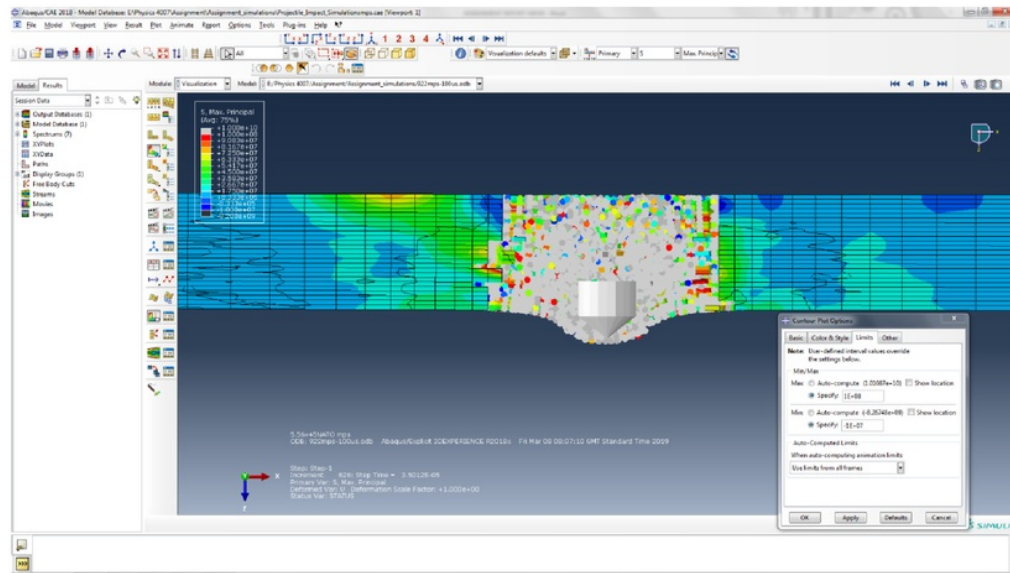


Figure 32-922m/s_3.5012E-05_Tmax=100us

Figure 32-922m/s_3.5012E-05_Tmax=100us clearly depicts a high tensile pressure event measured to be 10GPa. This provided further evidence of the building of high tension region in the back side of the plate, leading to spalling becoming visible at further points in time within the simulation. This is the initial “tearing” of the back side of the plate.

5 Conclusion

All simulations carried out successfully penetrated the aluminium plate, creating spalling events concurrent with high exit energy when compared with the relatively low yield strength selected for the aluminium (350MPa).

While the decelerations appear to be the same, in the order of 200m/s, the percentage loss ranged from 22% for the 922m/s simulation, to 31% for the 715m/s simulation. This highlights that while the same energy is required to successfully penetrate the plate, this energy requirement will effect slower moving projectiles more.

All simulations carried out for this experiment display similar features at each time point selected for analysis. This was expected due to the relatively soft aluminium replicated on the plate and the similar velocities chosen for each projectile.

6 Recommendations

- A wider range of projectile velocities should be simulated in order to fully interrogate the aluminium plate properties.
- A range of different aluminium plate properties should be simulated with the same velocities as used in this work, to fully interrogate the projectile velocity effects on target.

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- A more accurate representation of real world projectiles could be experimented with, namely projectile deformation. This would be achieved through meshing the projectile.
- The projectile could be designed to better geometrically represent real world bullets.
- More nodes
- Tighter time scales

7 References

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2 [https://www.researchgate.net/post/What_values_are_to_be_taken_for_yield_strength_and_pla](https://www.researchgate.net/post/What_values_are_to_be_taken_for_yield_strength_and_plastic_strain_for_aluminium_in_plasticity_section_of_material_property_in_Abaqus)
] [stic_strain_for_aluminium_in_plasticity_section_of_material_property_in_Abaqus](https://www.researchgate.net/post/What_values_are_to_be_taken_for_yield_strength_and_plastic_strain_for_aluminium_in_plasticity_section_of_material_property_in_Abaqus). [Accessed
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]

8 Appendix

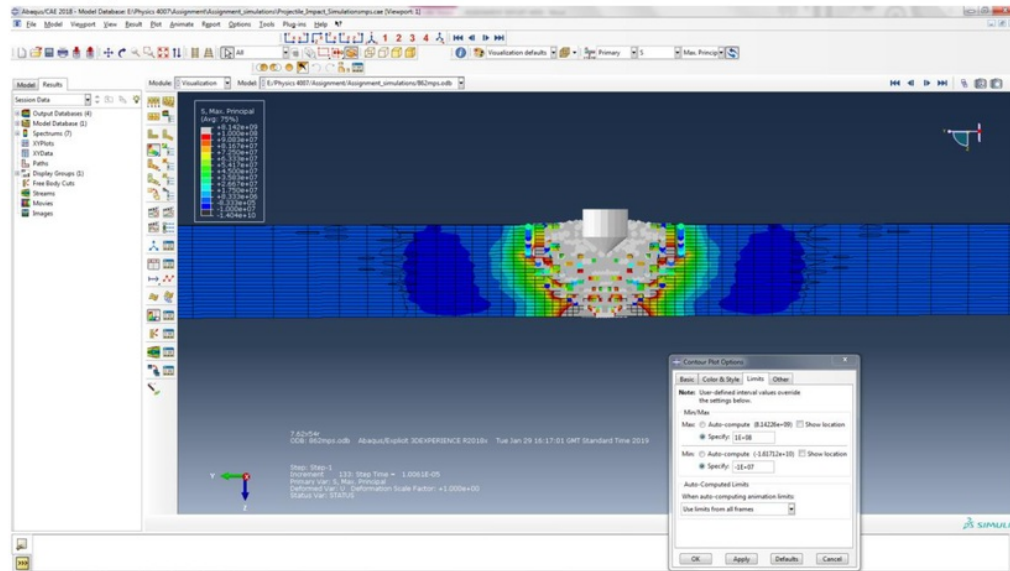


Figure 33-863m/s_1.0061E-05_Max Principle

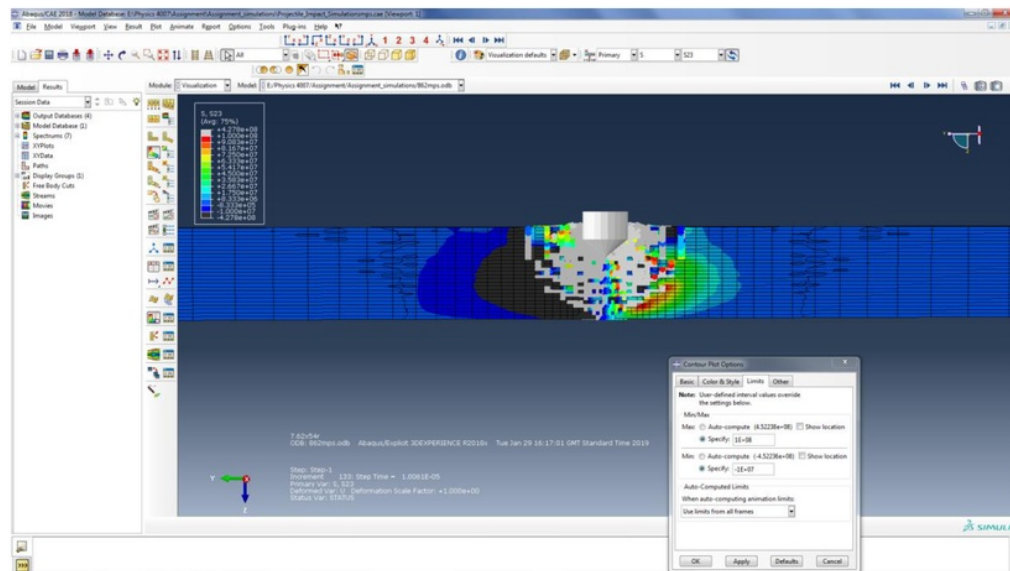


Figure 34-862m/s_1.0061E-05_S23

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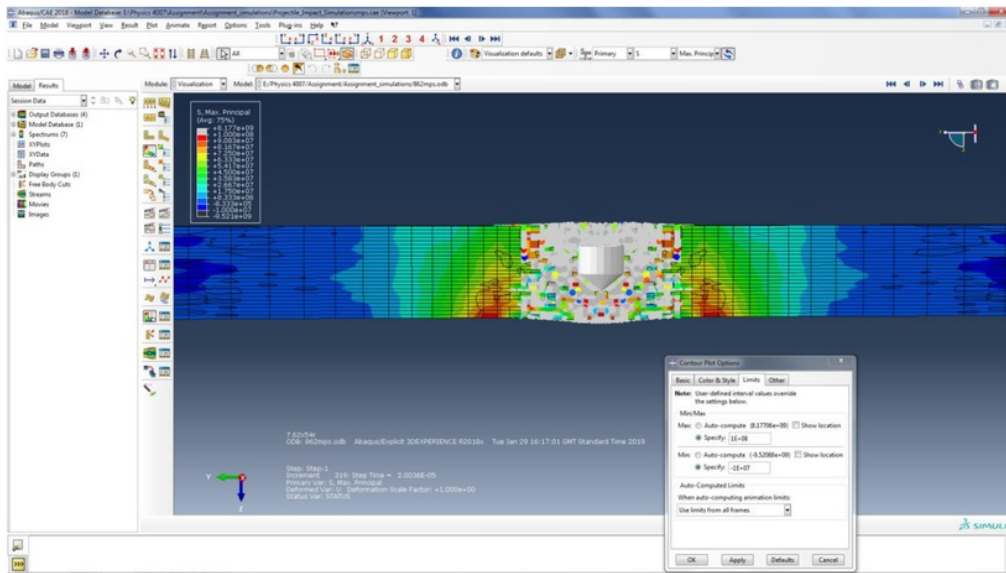


Figure 35-862m/s_2.0036E_05-Max Principle

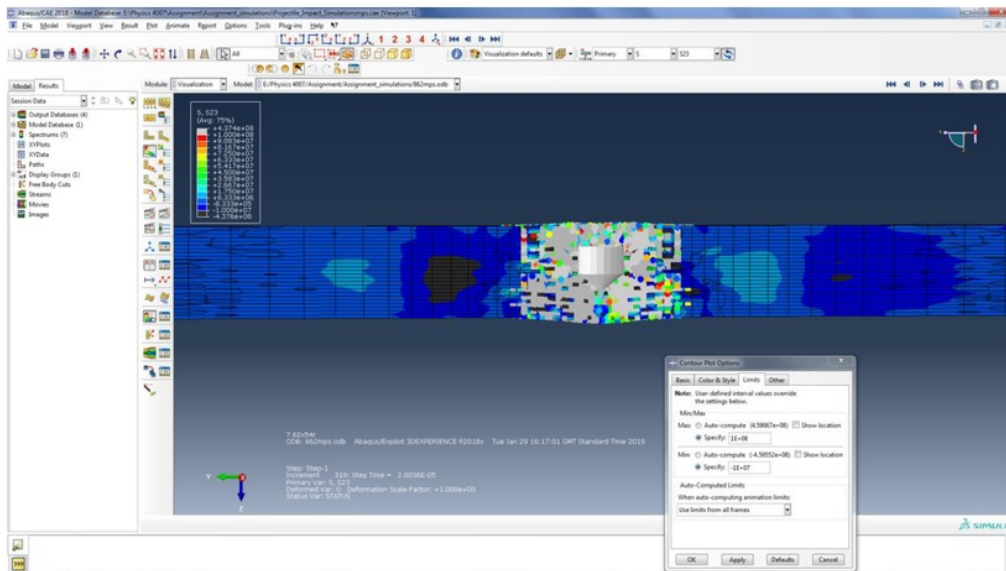


Figure 36-862m/s_2.0036E-05_S23

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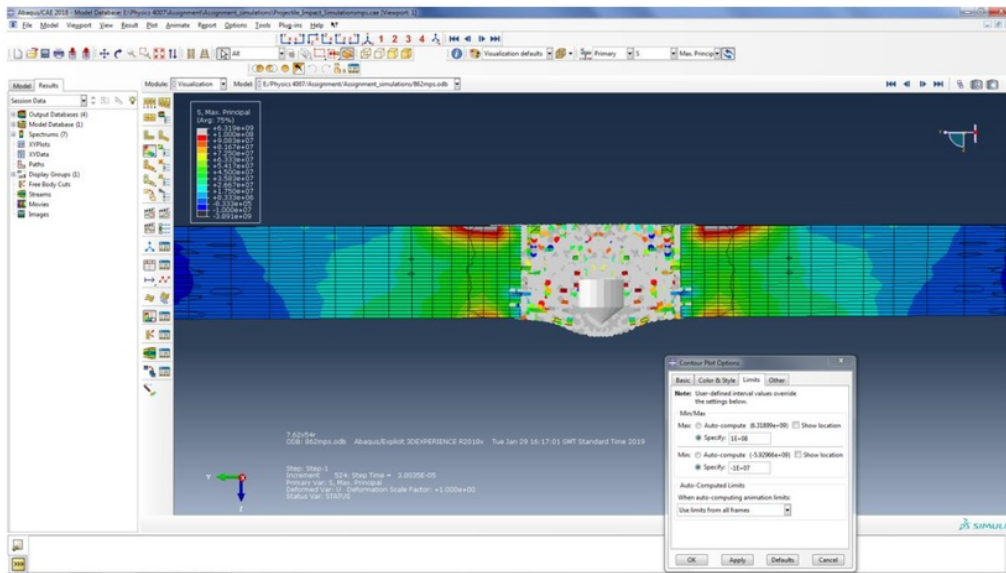


Figure 37-862m/s_3.0035E-05_Max Principle

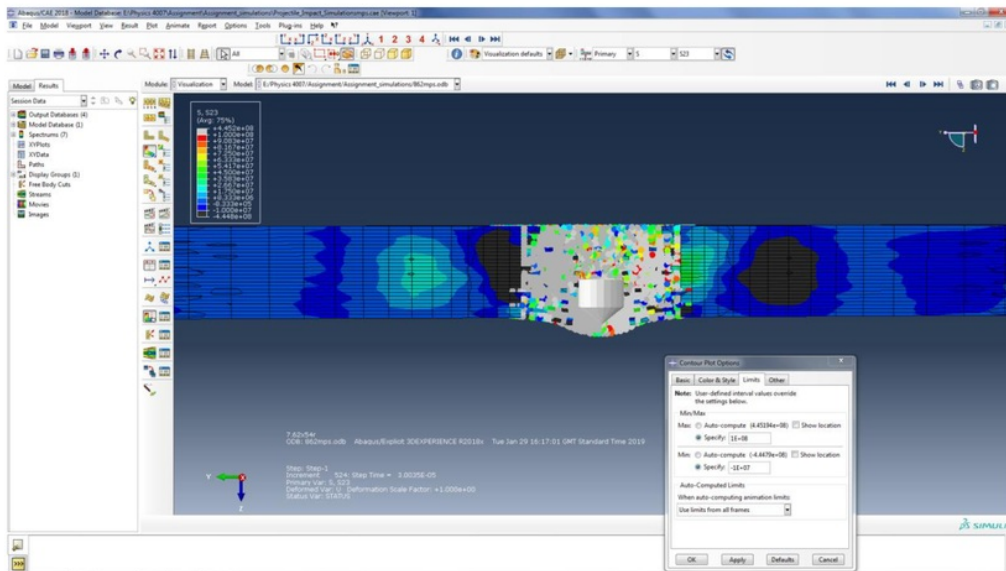


Figure 38-862m/s_3.0035E-05_S23

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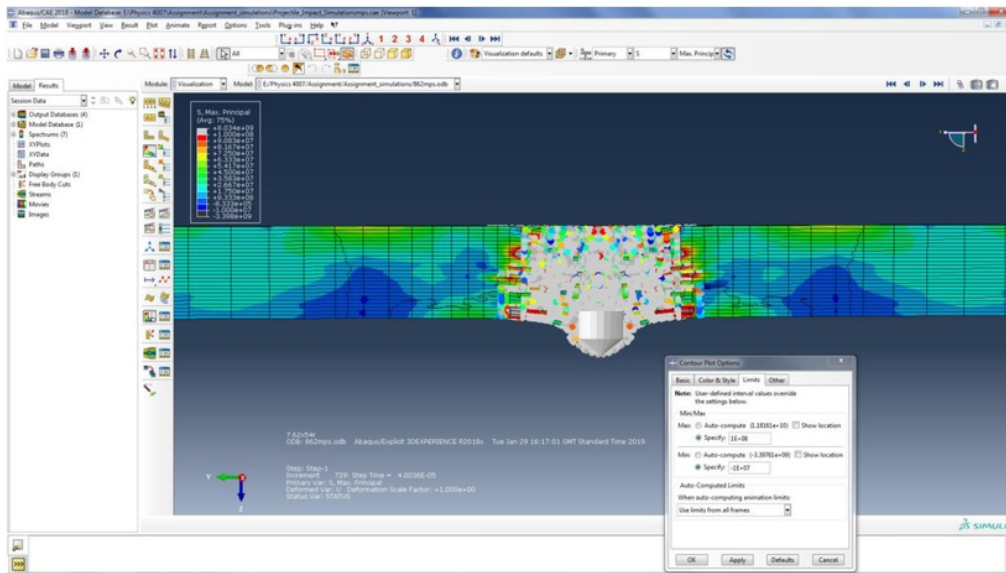


Figure 39-862m/s_4.0036E-05_Max Principle

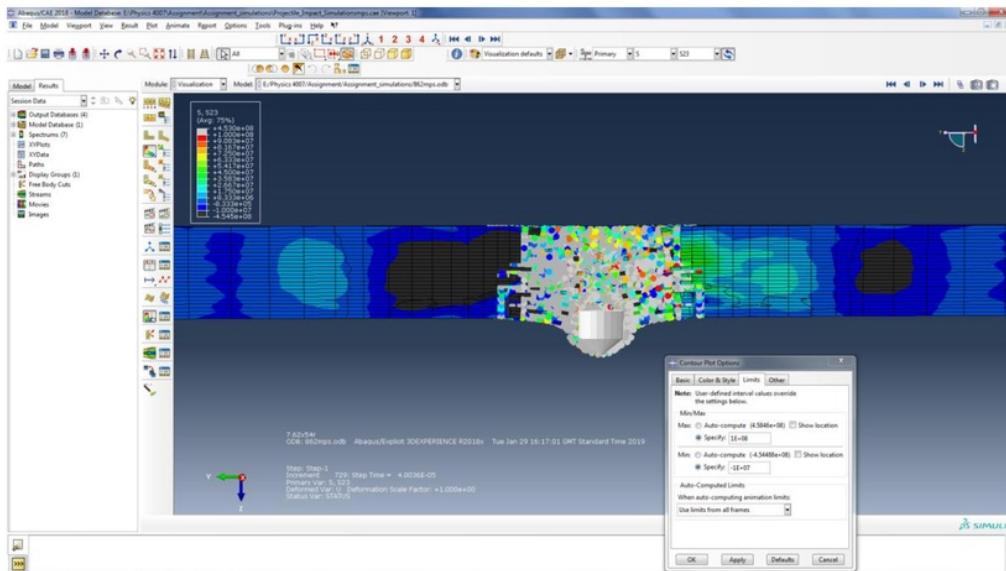


Figure 40-862m/s_4.0036E-05_S23

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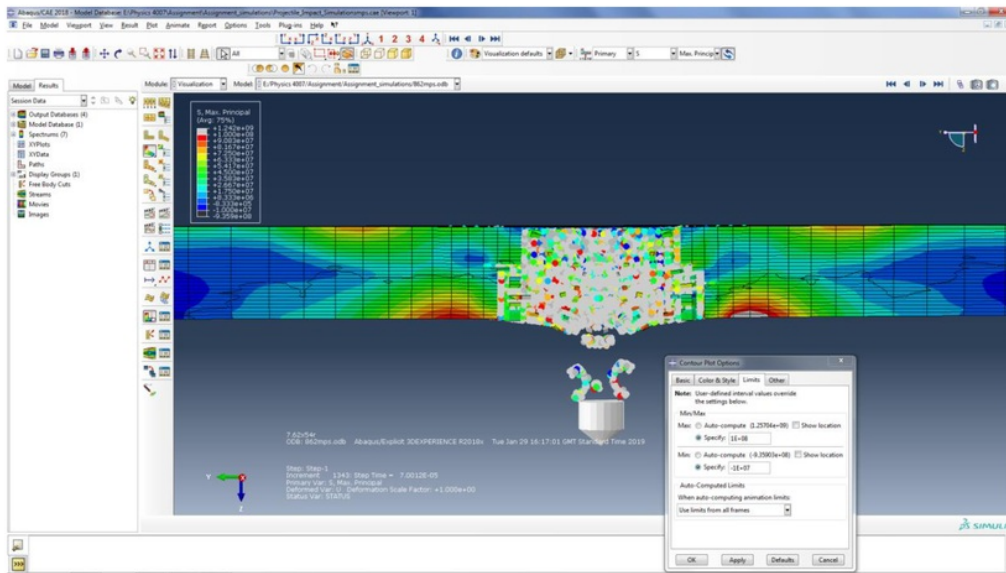
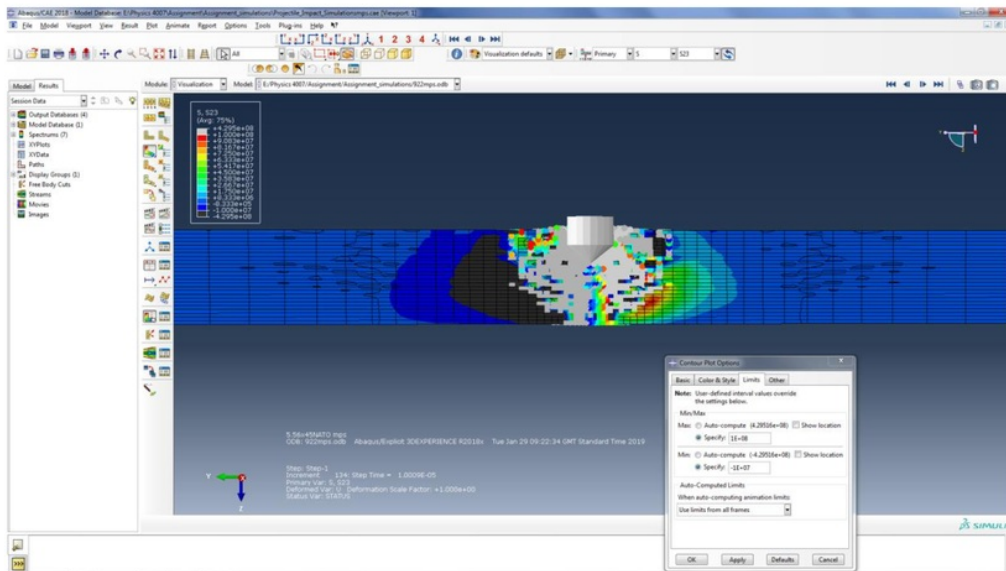
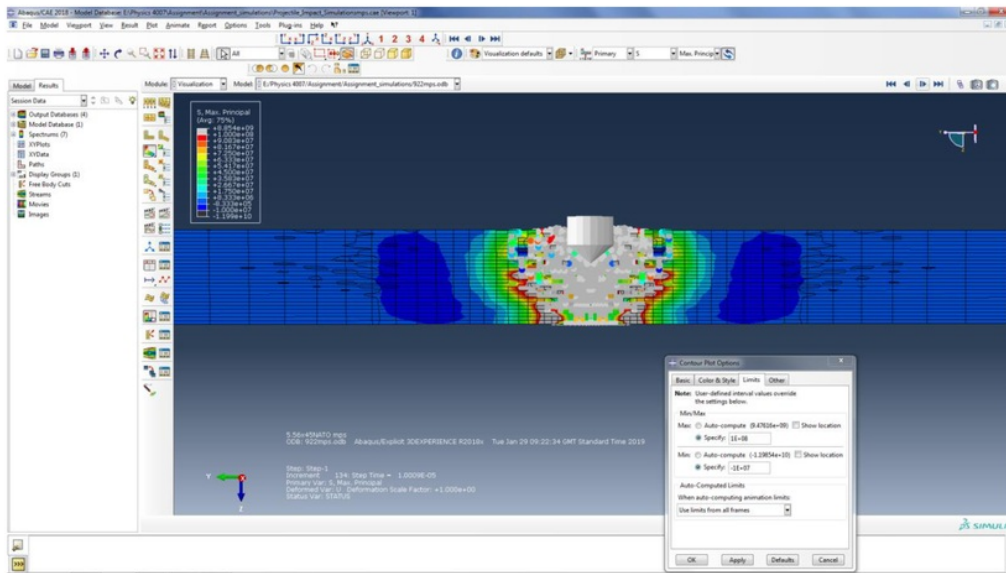


Figure 41-862m/s_7.0012E-05_Max Principle

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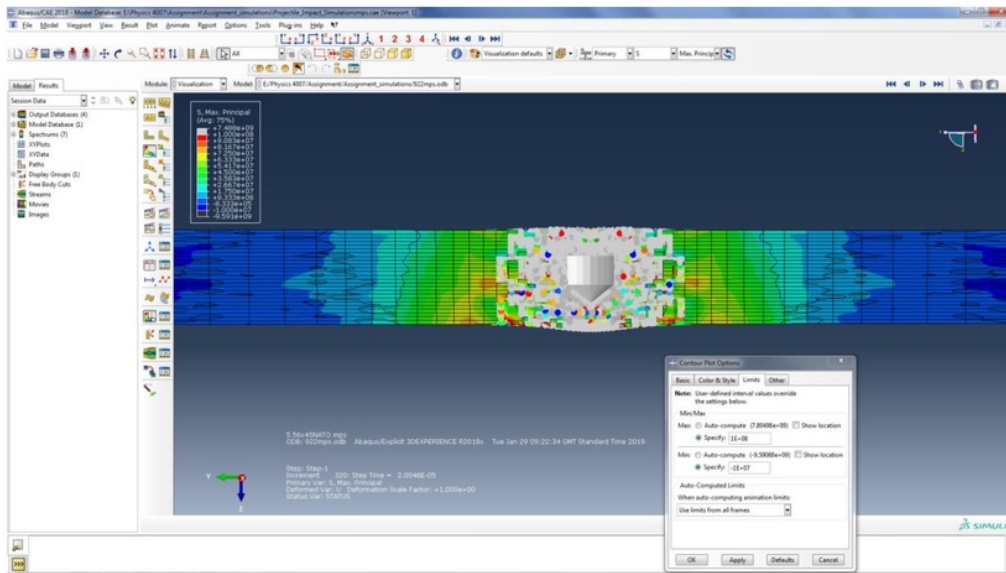


Figure 44-922m/s_2.0048E-05_Max Principle

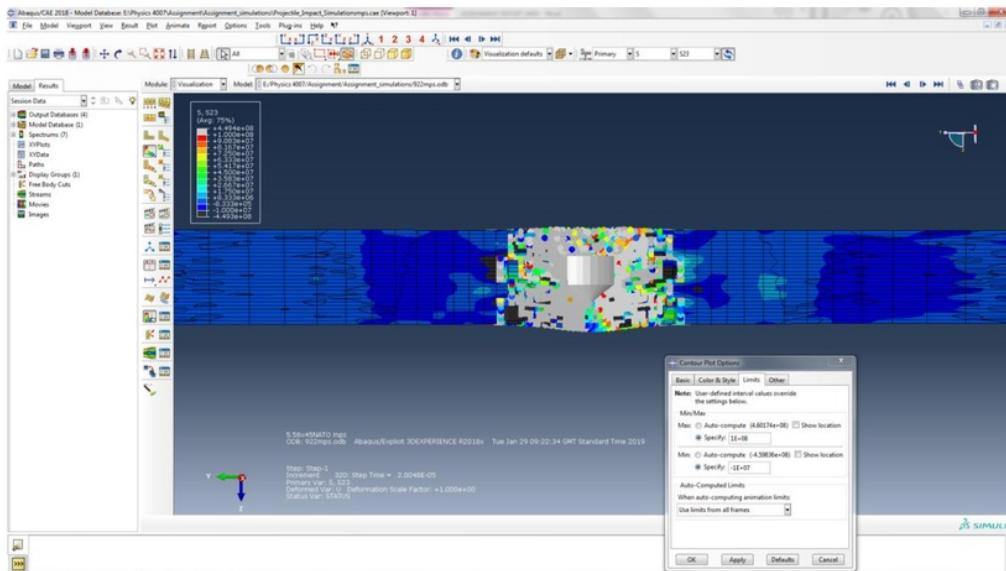


Figure 45-922m/s_2.0048E-05_S23

Figure 46-922m/s_3.0000E-05_Max Principle

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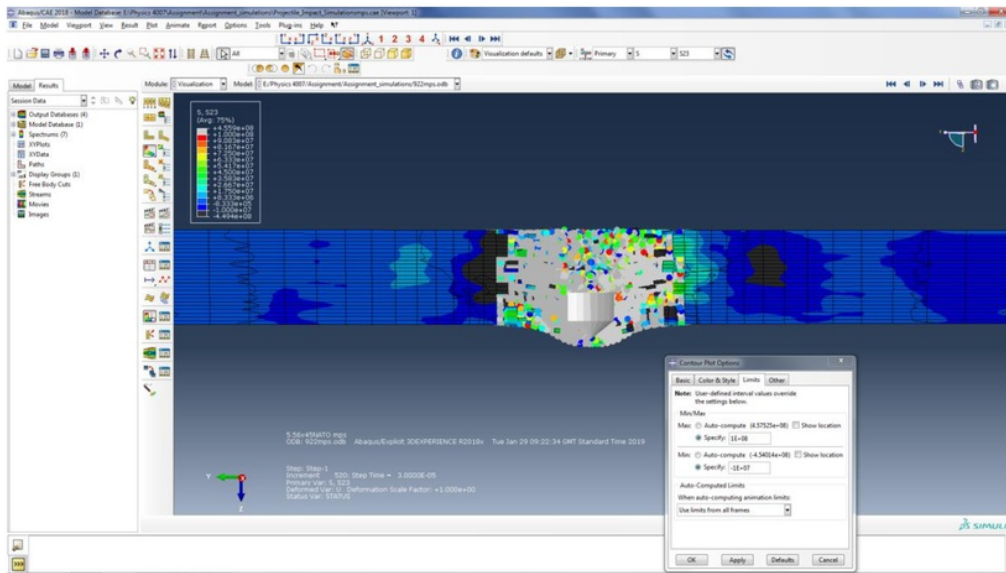


Figure 47-922m/s_3.0000E-05_S23

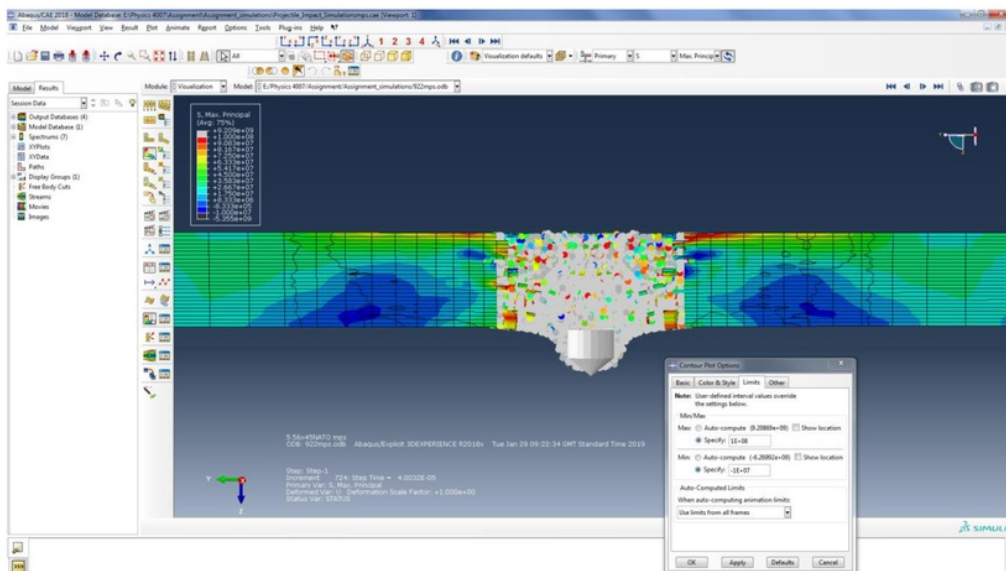


Figure 48-922m/s_4.0032E-05_Max Principle

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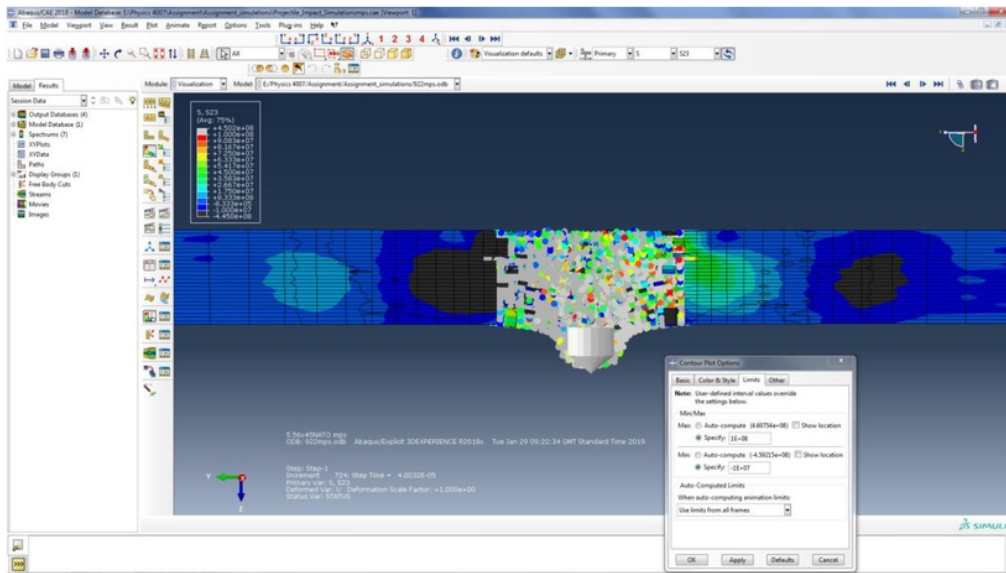


Figure 49-922m/s_4.0032E-05_S23

Table 2-Simulation Max Pressures

