Evaluation of Brain Stresses during Car Crashes using the SAE Baja Racecar Test Vehicle

Xiaorui Shangguan, Haoyang Yan, Dr. Roberto Cammino, Dr. Aiman Shibli, Andre Santos, Bruno Santos, Daniel Santos, Luciano Oliveira, Andre Luiz Tavares, Shenon Silva de Souza

Illinois Institute of Technology, Illinois 60616

Abstract: *This report describes the result of a research project focused on driver's brain damage evaluation during front impact of the Baja SAE race car to a wall. Two kinds of situation were considered in this analysis: a driver with and without a seat belt. The goal of this project is to check the amount of stress absorbed by the brain during impact and evaluate the role of the seat belt during impact. The analysis consists of a dynamic simulation of an impact of a car frame on a wall by using Finite Element Analysis (FEA) method. Models were meshed by using HyperMesh (a FEA pre-processing software). After finishing modeling, results were calculated and analyzed by using the Abaqus/Explicit (a computer aided engineering program) explicit solver. Results focus on the stresses, also will include energy, velocity, acceleration and displacements experienced by the following elements of model: brain, neck, dummy body and car frame. The results obtained from the analysis were displayed through charts.*

Keywords: *Baja SAE race car, Crash Simulation, Impact, Human Brain, Stress Distribution*

1. Introduction

The Baja SAE is an intercollegiate design competition run by the Society of Automotive Engineers (SAE). The Baja SAE racecar (Fig 2), is designed and built for off-road racing under extreme off-road condition, and it should be rear wheel driven. The car has to be driven by a single person and has to be safe.

This research tries to add a brain model (Fig 1) to the crash dummy, the material for brain is Gel, the most similar material with real brain. In order to evaluate what happens to the brain during a crash. We also, check to see how the brain is affected by the use of seat belt during impact, as opposed to not having a seat belt.

The Finite Element Analysis method is mainly used in this research. It is a method to approximately predict the reaction of a product in real world with applied boundary conditions. We used Abaqus/Explicit for these simulations.

Figure 1. Brain model snapshot.

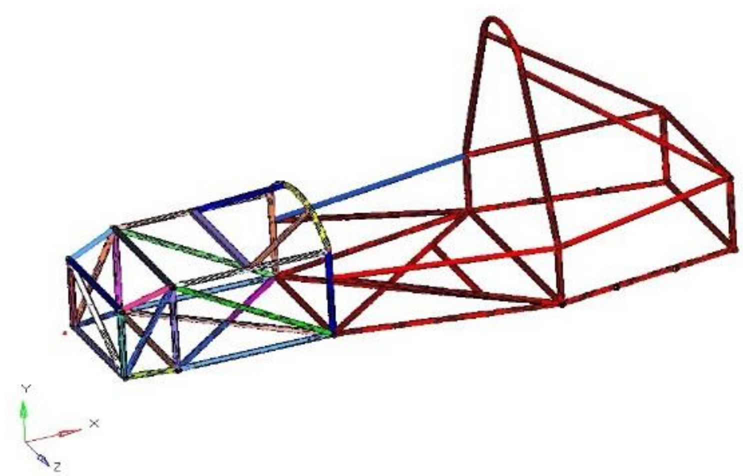


Figure 2. Baja SAE race car frame model.

2. Methods

Three main steps were followed in this research

2.1 Preprocessing

The software used in the preprocessing part was HyperMesh. The meshed models are shown in Figures 3 and 4.

2.2 Processing

After finishing the preprocessing step, the mesh was exported as an Abaqus/Explicit input file. Assigning material properties (as shown in Table 1) to the elements was also completed in this step. Material properties used, include density, density, Young's Modulus, Poisson's Ratio, Yield and Ultimate Stresses. Six different materials were used in this research. The properties of most of the materials were found through an online database (MatWeb.com).

Table 1: Material Properties.

Property	AISI 1020	Al	Bone	Gel	Plastic	Belt
Density(10^{-3}g/mm^3)	7.87	1.15	1.5	1.06	1.15	1.18
Young's Modulus (Mpa)	186000	350000	5000	1	2300	700
Poisson's Ratio	0.29	0.33	0.3	0.5	0.3	0.3
Yield Stress (Mpa)	320	277				
Ultimate Stress(Mpa)	450	347				

Boundary (fix the rigid body before the racecar frame) and initial conditions (the impact velocity is 27mm/ms or 100km/h for whole racecar in different situations) were applied in this step as well, since this paper focus on the difference with belt and without belt situations, so the velocity and simulation step time (6ms) were chosen for reducing analyzing time.

In addition, mass scaling was also defined in this part. Mass scaling is often used in Abaqus/Explicit for computational efficiency. A mass scaling of about 5% is used in this simulation. Other important information such as contact and output results were also defined in this part.

2.3 Post processing

The next step is the post-processing part (Fig 5), which is mostly about analyzing results. The Abaqus Viewer was the software used for this part. The stresses, energy, velocity, acceleration and displacements experienced by the various parts of the model were mainly analyzed in this part.

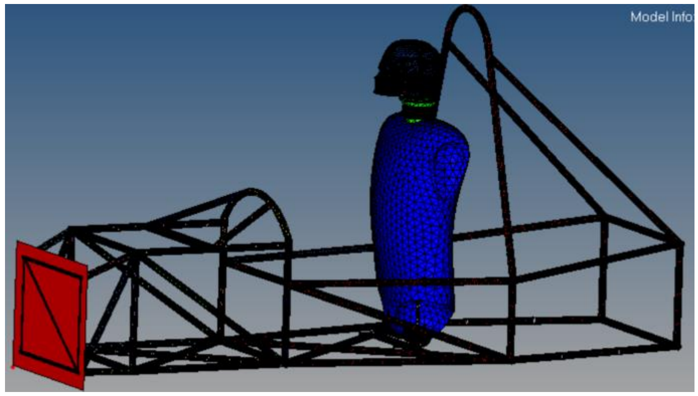


Figure 3. Assembled model.

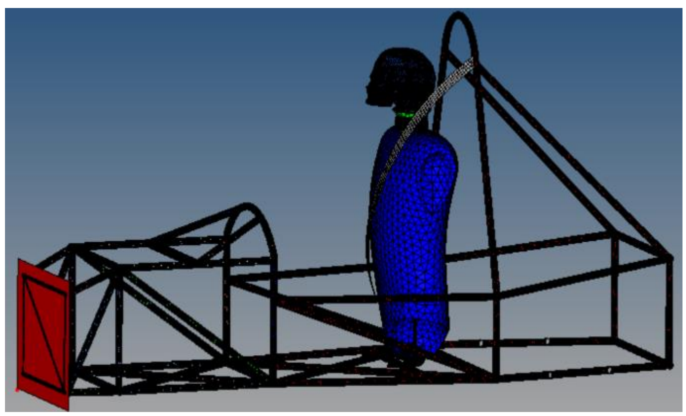


Figure 4. Assembled model with seat belt.

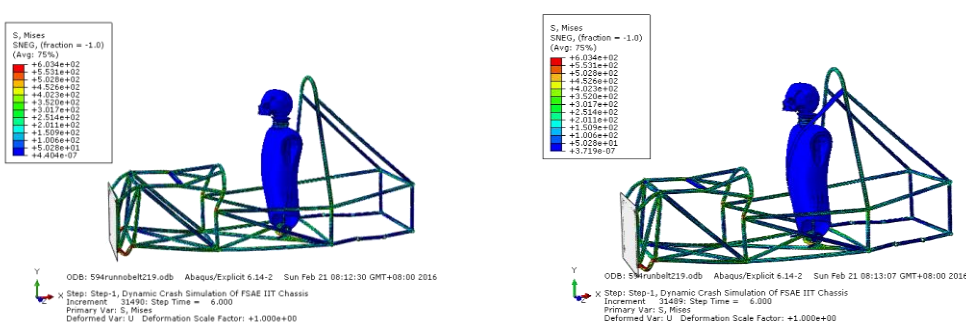
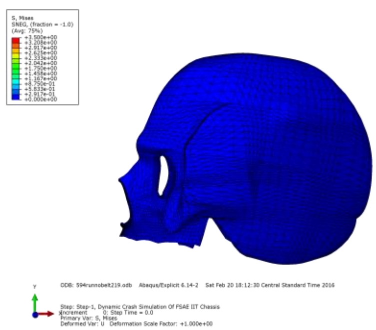


Figure 5. Simulation results without belt & with belt.

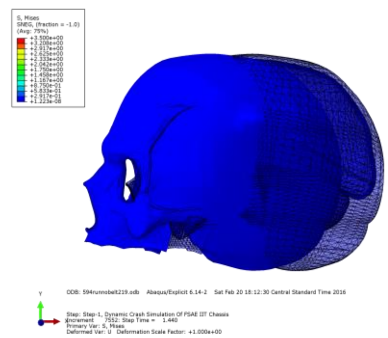
3. Results

For the results presentation, all data for the case without seat belt will be shown, and a comparison of results of cases with and without the seat belt would also be made in this part.

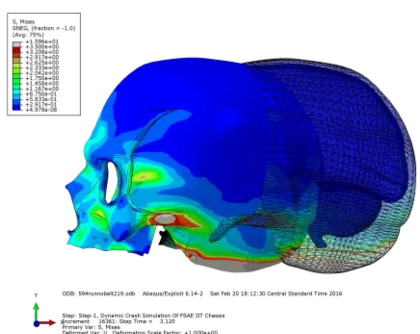
A sequence of deformation snapshots (Fig 6, 7) during impact is shown in the following Figures.



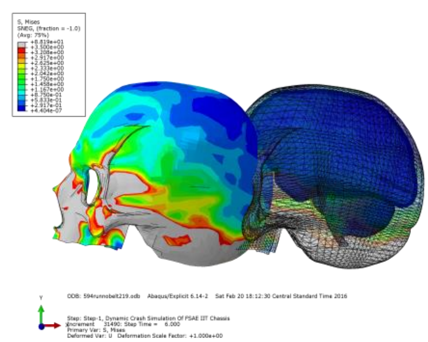
(a) Head simulation at 0ms.



(b) Head simulation at 1.4ms.

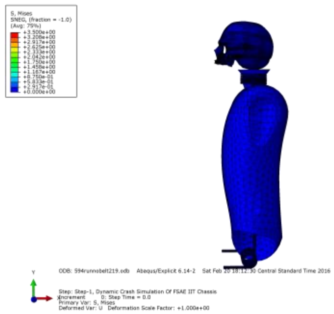


(c) Head simulation at 3.1ms.

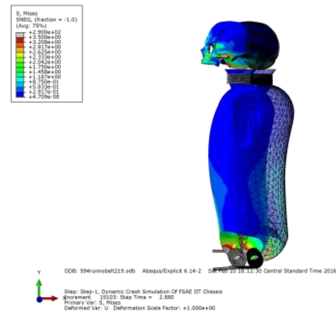


(d) Head simulation at 6ms.

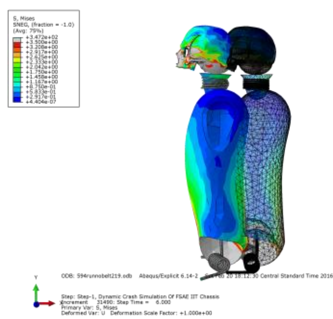
Figure 6. Head swing with impact.



(a) Body simulation at 0ms.



(b) Body simulation at 2.8ms.



(c) Body simulation at 6ms.

Figure 7. Body swing with impact.

3.1 Displacement

Displacement of the brain is measured and shown in the following figures, it's increased with the time. (Fig 8, 9).

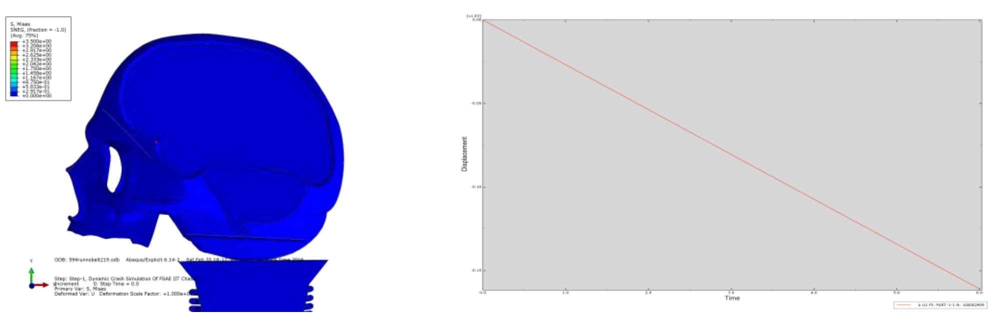
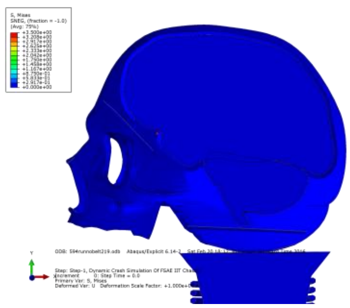


Figure 8. Highlighted node used to output displacement.

Figure 9. Displacement distribution without seat belt for the node from Figure 8

3.2 Velocity & Acceleration

Velocity and acceleration of a point on the brain is shown in following figures (Fig 10, 11, 12). Velocity increased rapidly in car moving direction after 3.7ms.



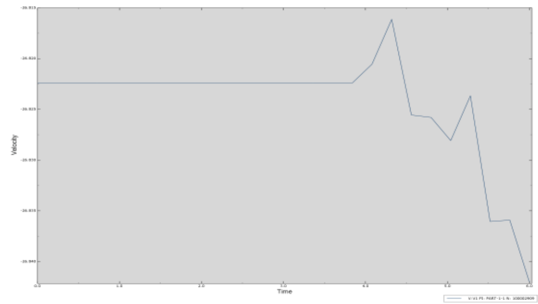


Figure 10. Highlighted Node used to output velocity.

Figure 11. Velocity distribution without seat belt at the node from Figure 10.

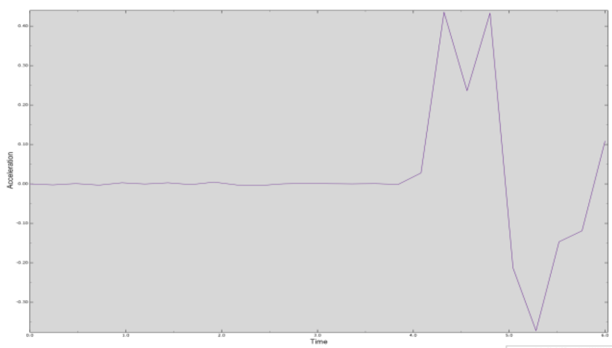


Figure 12. Acceleration distribution on the brain, without seat belt.

3.3 Kinetic energy

The Kinetic Energy of the system is also recorded (Fig 13). The Kinetic Energy is decreased during whole process.

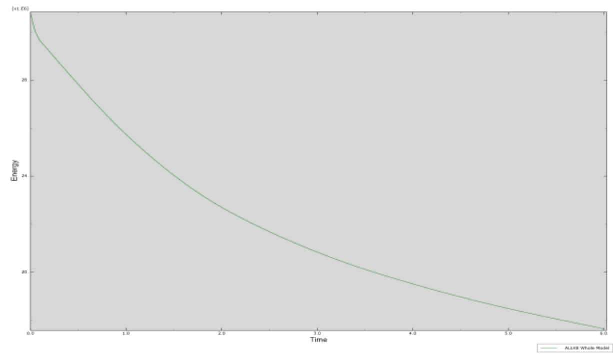


Figure 13. Kinetic energy distribution without seat belt.

3.4 Stress

The material for brain is Gel, the most similar material with real brain. Stress is extracted on a brain element (Fig 14, 16) and we focus on the Mises Stress. The Stress distribution increased very fast to a maximum value begin with 4ms (Fig 15), then starts to increase in opposite direction rapidly because of the function of spring in the bottom. Also, most of the stress distribute on the temporal lobe of brain.

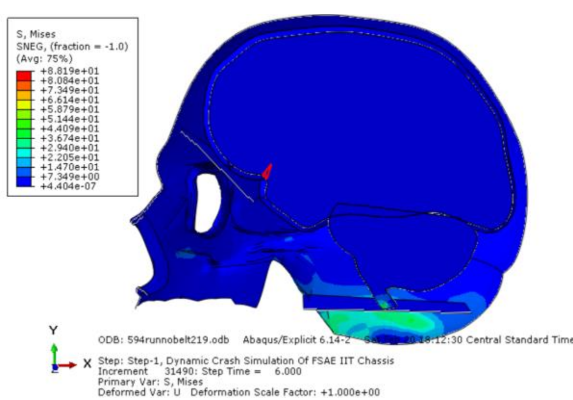


Figure 14. Element used to output stress.

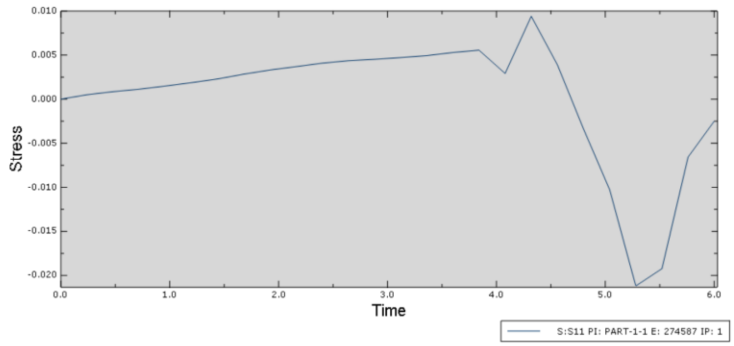


Figure 15. Stress distribution without seat belt.

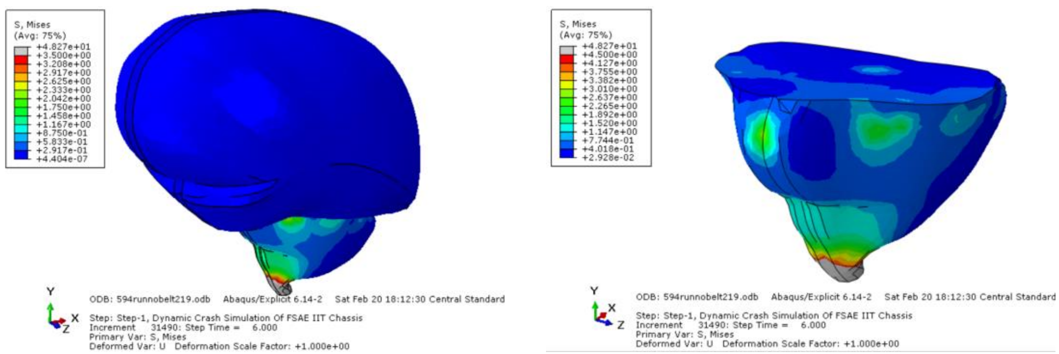
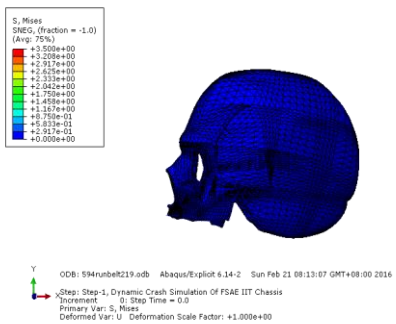


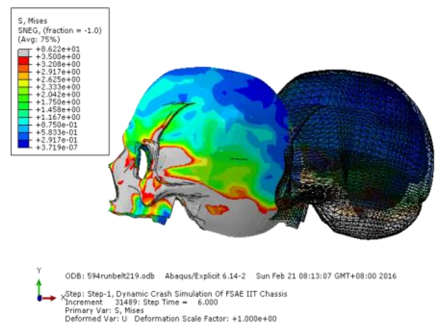
Figure 16. Stress contour in 6s.

4. Discussion

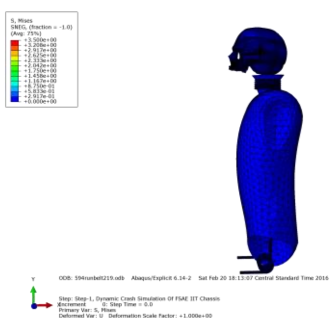
Results are now presented for the case of impact with the driver using a seat belt with the same velocity of 27mm/ms in no belt situation. A simulation of same impact process with the belt on human body is simulated the results are discussed below (Fig 17).



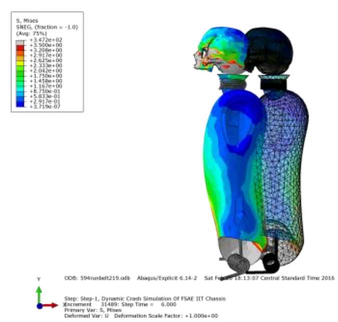
(a) Head simulation in 0ms.



(b) Head simulation in 6ms.



(c) Body simulation in 0ms.

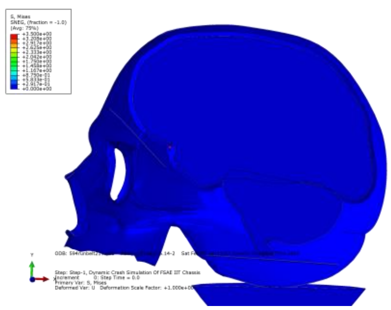


(d) Body simulation in 6ms.

Figure 17. Head & Body swing with impact.

4.1 Displacement

Displacement profiles are very similar to the case without the seat belt (Fig 18, 19, 20).



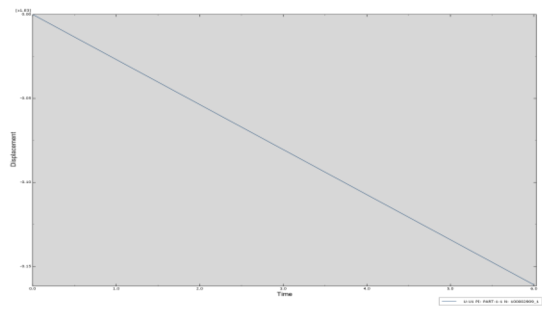


Figure 18. Highlighted node used to output data.

Figure 19. Displacement distribution with seat belt for the node from Figure 18.

4.2 Velocity & Acceleration

Similar velocity profiles are observed. However, velocity are overall lower because of belt protection (Fig 20, 21).

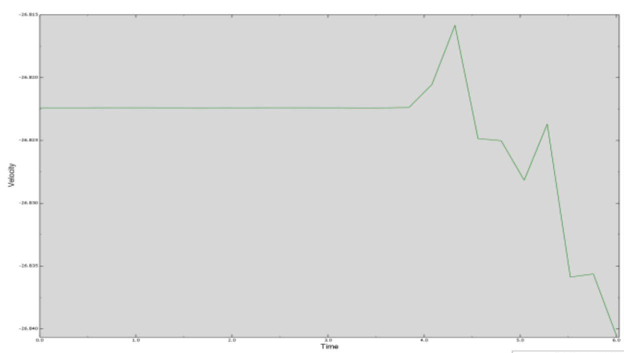


Figure 20. Velocity distribution with seat belt.

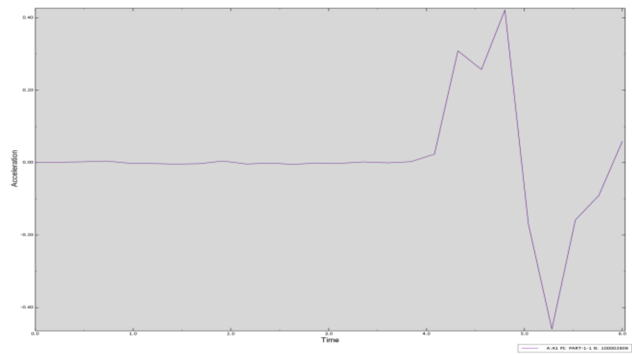


Figure 21. Acceleration distribution with seat belt.

4.3 Kinetic energy

The energy is almost the same as the case without the seat belt, given the energy is driven by the vehicle (Fig 22).

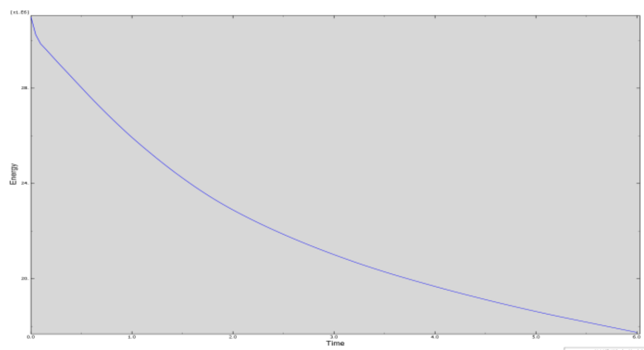


Figure 22. Kinetic energy distribution with seat belt.

4.4 Stress

When compared to temporal lobe of brain with no belt situation, the red color in temporal lobe here is deeper under same stress limitation, which means the stress is higher in same location by this situation. This shows that, while the seat belt would help the body and head from impacting the steering wheel, the brain stresses are higher due to the effect of the seat belt (Fig 24, 25).

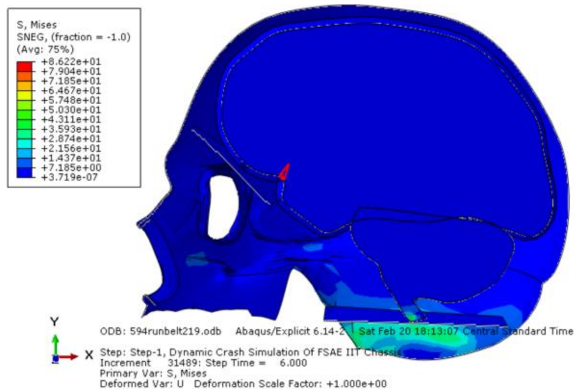


Figure 23. Highlighted element used to output data.

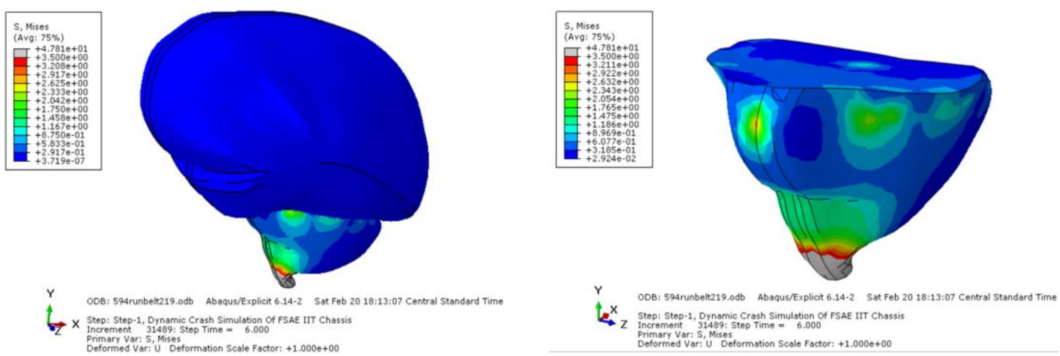


Figure 24. Stress contour in 6s.

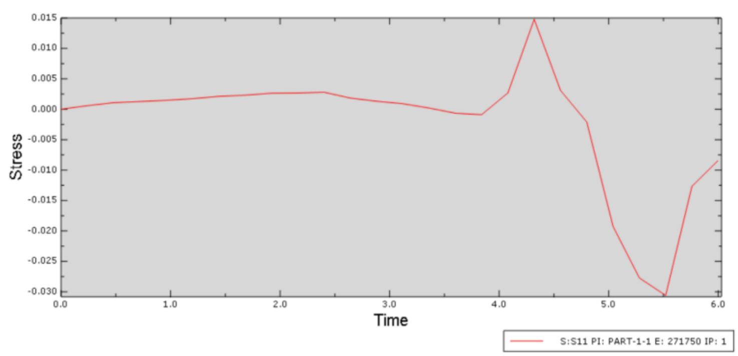


Figure 25. Stress distribution with seat belt.

5. Conclusion

By using the software Abaqus/Explicit, it was shown that further enhancement on a crash test dummy by using more detail in the model could be used, particularly at the brain level. This will help extract brain stresses during impact and enhance seat belt parameters to minimize brain stresses further, while at the same time preventing impact with the steering wheel.

6. References

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7. Acknowledgements

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