IMPACT ANALYSIS OF A BAJA ROLL CAGE

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HAVE APPROVED THIS THESIS

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BY

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ABSTRACT

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This paper provides the simulation analysis of a Baja SAE roll cage and its reaction to different collision situations. Although there are other factors that go into the study of a car collision test, this study will emphasize the importance of the vehicle structure. With the focus on minimal deflection and stress, the study will consist of multiple impact scenarios such as frontal impact, side impact, and a rollover test.

The roll cage provided in this study is a welded tubular 4130 Chromoly steel frame. To identify the reliability and safety of the vehicle, the simulations were done through ANSYS CAE from a series of assumptions and calculated forces. The chassis design incorporated in this study is from the 2022 CSULB SAE Chapter Baja car – modeled in Solidworks. In addition to the impact analysis, a modal analysis was defined here to help the SAE Baja team improve their design for the 2023 Baja vehicle.

ACKNOWLEDGEMENTS

I would like to thank the 2018-2020 Baja SAE team at California State University, Long Beach. In particular, this extensive research and simulation analysis could not be one without the help of Fernando Martinez Saldana.

To my mother and aunt which have been my number one supporters. And to my grandparents - forever in my memory.

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INTRODUCTION

The Importance of Crash Testing

Over the past 50 years, cars have gotten safer due to the importance of vehicle occupant safety. The first vehicle models have been recognized as “death boxes of metal” because vehicle safety was not the priority of vehicle manufacturers. That is until 1970, when the United States government formed the National Highway Transportation Safety Administration which introduced the first “Federal Motor Vehicle Safety Standard ". These new requirements limited car manufacturers on the design of the vehicle. That is, until the adoption of modern technology in the 1980s. Vehicle manufacturers would then be able to digitize their designs and simulate crash behavior without the expense of physical prototypes (Donut Media, 2018). [1]

This modern technology introduced a widespread adoption of crumple zones. The crumple zone is usually located in the front and rear of a vehicle, and it is designed to crush during a collision. These crumple zones allow the vehicle to withstand higher impulse forces than a fighter jet without injuring its occupants (Henry Reich, 2015). [2]

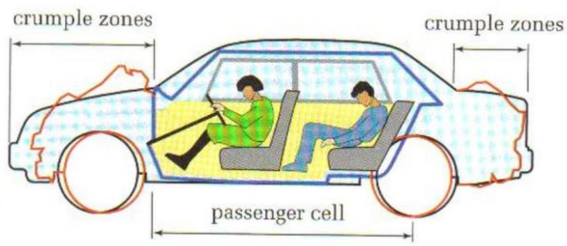

Figure 1. Vehicle crumple zones.

The Physics of a car crash

Most cars today convert chemical energy from the engine's combustion into kinetic energy to move the car. Once the vehicle is in motion, a vehicle is designed to stop by using the brakes which dissipates the energy through heat. However, in the case of a collision, the energy of the moving vehicle dissipates by the deformation of the metal (Henry Reich, 2015).

The impact force of a collision is related to the change of the vehicle acceleration over a period of time. For example, when approaching a stop sign, smooth braking is allowed by decelerating for a longer period of time, rather than waiting on the last few inches to apply the brakes. However, a car collision cannot be compared to a normal stop sign scenario; thus, car manufacturers have developed the crumple zone to allow an extended period of time before the vehicle approaches a complete stop.

BACKGROUND

The Society of Automotive Engineers

The Society of Automotive Engineers has the vision to lead the connection and education of mobility professionals to enable clean, safe, and accessible mobility solutions (SAE, 2022). [3] To prepare the engineers of the future, the Society of Automotive Engineers (SAE) has developed a series of competitions under the Collegiate Design Series (CDS). The Baja SAE is one of the CDS competitions where students are challenged to develop an all-terrain vehicle (ATV) prototype with a focus on reliability, ease of serviceability, and project budgeting. All of the vehicles in this competition are built around a structural steel tube frame/roll cage. Under Article 3 – Roll Cage Section B.3.1. – Objective of the *Baja SAE rule book* (2021), "The purpose of the roll cage is to maintain a minimum space surrounding the driver. The cage must be designed and fabricated to prevent any failure of the cage's integrity during normal operation or during a collision or rollover" (p. 25) Thus, before fabrication is dictated, it is highly recommended to test the integrity of the structure. Because the competition promotes the adequate use of budgeting, a finite element analysis of the vehicle roll cage is used to avoid the cost of prototyping.

The Finite Element Method

The Finite Element Method is a numerical method of solving partial differential equations: an equation that relates a function with its rate of change. The motor vehicle frame, also known as a chassis, is described under the finite element method as a beam structure element analysis because of the complexity of the structure, the use of ANSYS CAE software will be used to conduct the FEA of the chassis under different loading factors. The scenarios considered in this test will be taken as inspiration from the Insurance Institute for Highway Safety rating tests.

The Insurance Institute for Highway Safety (IIHS)

The IIHS Is a nonprofit scientific organization that works towards "reducing deaths, injuries and property damage from motor vehicle crashes through research and evaluation." The organization evaluates vehicles under different collision scenarios to then develop a safety rating. The IIHS test is not mandatory by law, but vehicle manufacturers are required to ensure the safety of the driver (Heffner, 2020). [4] According to the IIHS test overview website page (2022), the IIHS considers six different tests to identify crash safety: "moderate overlap front, driver-side small overlap front, passenger-side small overlap front, side, roof strength, and head restraints & seats." This study will use the test mentioned here as an inspiration to ensure the roll cage of the Baja SAE vehicle is structurally safe.

Scenarios in this test

The following scenarios are considered to analyse the deformation and stress concentration of a Baja SAE chassis model.

1. Front Impact Test
2. Side Imact Test
3. Roll Over Test
4. Front Bump Test
5. Modal Analysis

<u>Defining The Chassis</u>

The chassis structure is made out of 2 different steel tube members: a primary and a secondary. These members in conjunction are used to describe the entire roll cage. For the composure of this study, the members will be identified in this section to distinguish primary members from secondary members.

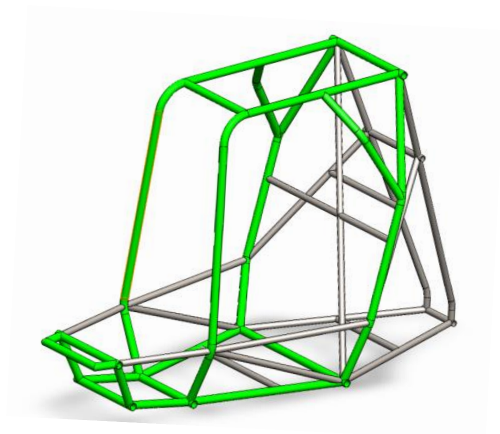

Figure 2. Roll Cage, Primary members (colored in green)

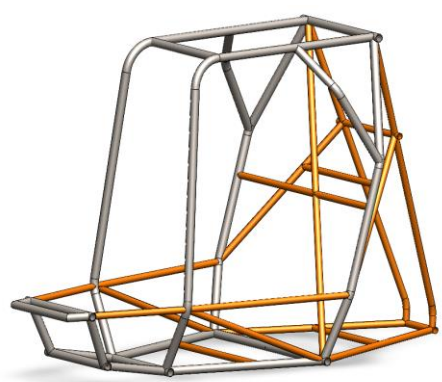

Figure 3. Roll Cage, Seconary members (colored in orange)

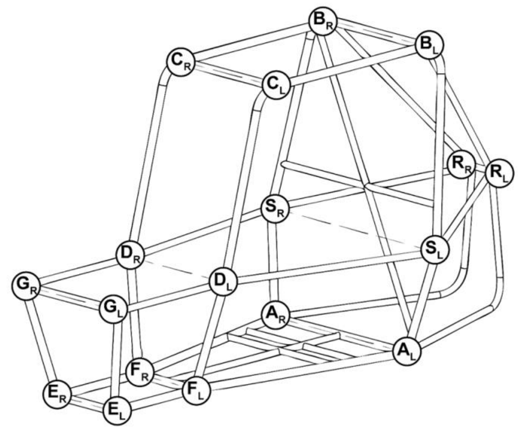

Figure 4. Roll Cage named points/nodes

FRONT IMPACT TEST

The IIHS considers the front impact test “the most common type of crash resulting in fatalities”. [IIHS, 2022] The IIHS conducts three diferent collision scenarios: “moderate overlap test, driver-side small overlap test and passenger-side small overlap test.”

Figure 5. Moderate overlap frontal test (courtesy of the IIHS.org website)

In this study, the front impact test considers the vehicle travelling at full speed and colliding against a rigid wall. Two scenarios will be consiered for the front impact test: 1. Frontal impact no overlap, and 2. Frontal impact overlap. The second scenario is given under the circumstance that the driver attempts to avoid a collision but is unable to do so resulting in a moderate overlap crash. The first scenario is under the assumption that the driver has no reaction and thus crashes face forward onto a fixed wall.

Scenario 1. Frontal Impact – No Overlap Test

A fixed support is set at the node points A_L, S_L, A_R, and S_R. This constraint is set to consider only the reaction the members who are surrounding the driver.

The reaction force is calculated based on the assumption that the crash will deform the vehicle by 6 inches by the time the vehicle comes at rest.

$$F = \frac{1}{2d} m V^2 \qquad \text{(equation 1)}$$

For
m = 800lbs
V = 35 miles/hour
d = 6 inches

$$F = \frac{1}{2\left(6[in] \cdot \left(\frac{1[mile]}{63360[in]}\right)\right)} (800\ [lbs]) \left(35\ \left[\frac{mile}{hour}\right] \cdot \left(\frac{1\ [hour]}{3600\ [s]}\right)\right)^2$$

$$F = 400\ lb_f$$

A force of 400 lb_f is defined at the GLC member (member from node G_L and G_R) as shown in Figure 6.

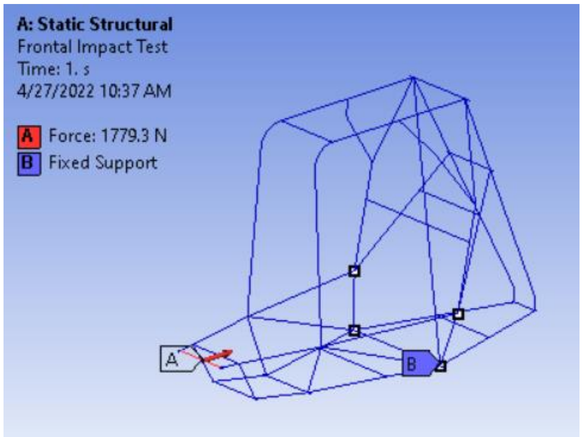

Figure 6. Structural analysis set-up, Frontal Impact, Scenario 1

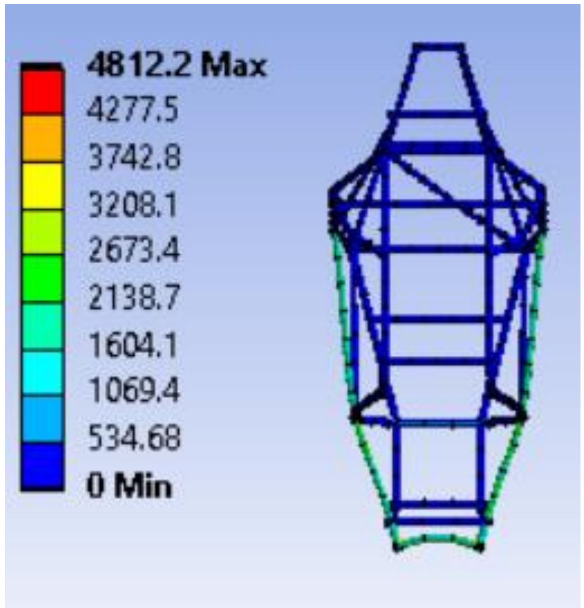

Figure 7. Frontal Impact, No Overlap, Stress Diagram (top view)

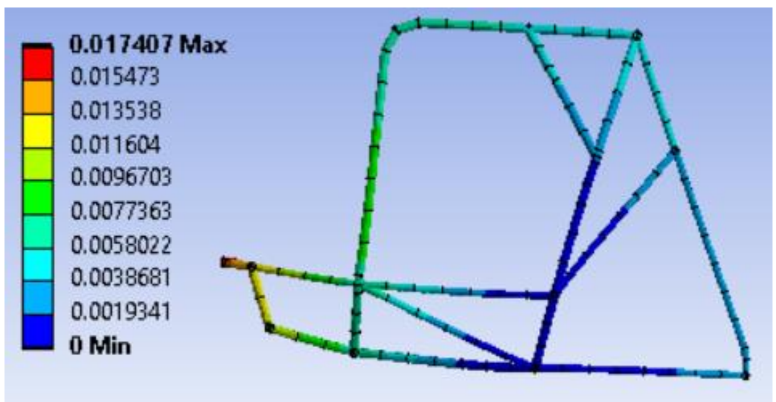

Figure 8. Frontal Impact, No Overlap, Deformation (side View)

<u>Scenario 2. Frontal Impact – Moderate Overlap Test</u>

The set up for scenario 2 is quite similar to scenario 1. The only difference is that the scope selection is on a node rather than on a member. The node selected for the force is G_R to simulate a moderate crash on the right side of the driver.

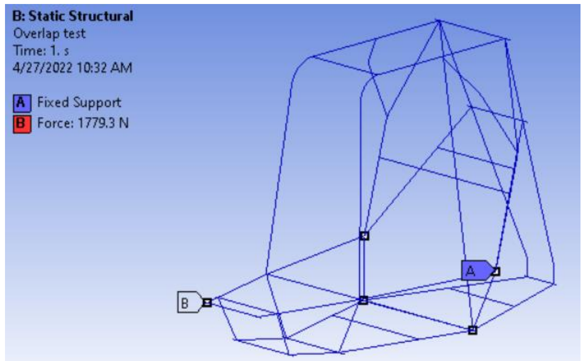

Figure 9. Structural analysis set-up, Frontal Impact Scenario 2

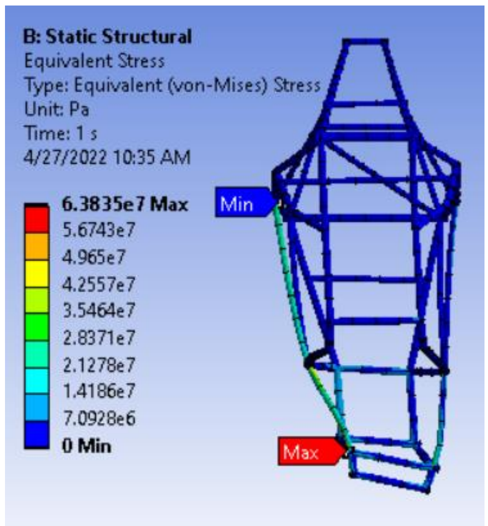

Figure 10. Frontal Impact – Overlap, Von Mises (Top view)

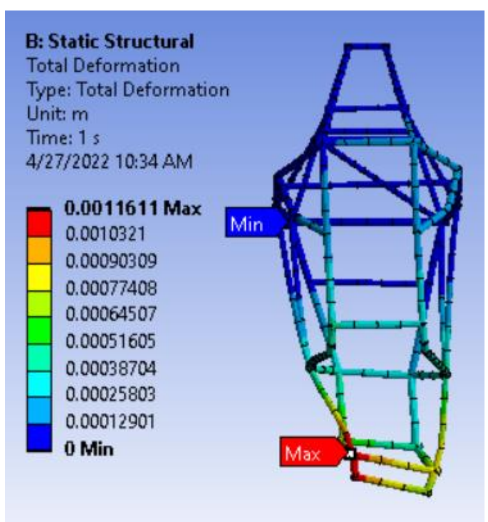

Figure 11. Frontal Impact – Overlap, Deformation (Top view)

SIDE IMPACT TEST

The side impact test considers a crash of another vehicle onto the side of the roll cage. Accounting "for about a quarter of passenger vehicle occupant deaths in the US", the side impact test puts the driver at a more risk compared to the frontal impact test. From the structure of the chassis, the driver is inches a part from the SIM members. Thus, it would not take much deformation to cause a collision between the driver and objects outside the vehicle. This scenario will consider a collision from another Baja SAE vehicle with the same velocity and mass.

The simulation set-up has a fixed support at the opposite side of the impact at nodes S_R, A_R, F_R, and D_R. Thus:

For:
m = 800lbs
V = 35 miles/hour
d = 6 inches

$$F = \frac{1}{2\left(3[in] \cdot \left(\frac{1[mile]}{63360[in]}\right)\right)}(800\ [lbs])\left(35\ \left[\frac{mile}{hour}\right] \cdot \left(\frac{1\ [hour]}{3600\ [s]}\right)\right)^2$$

$$F = 800\ lb_f$$

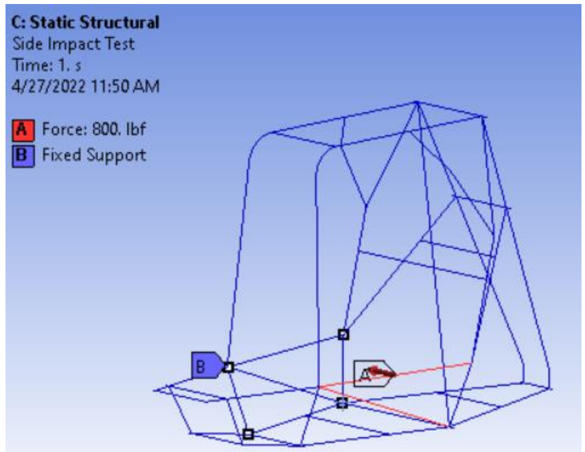

Figure 12. Structural analysis set-up, side impact

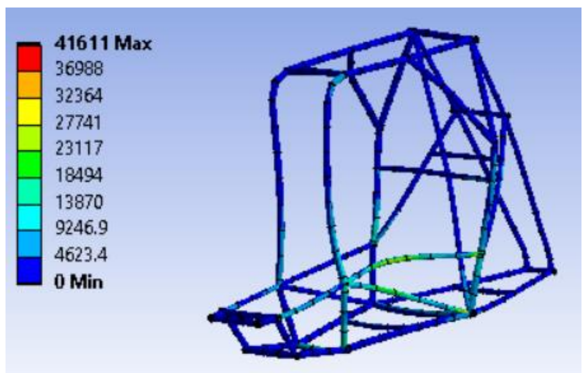

Figure 13. Side Impact, Von Mises

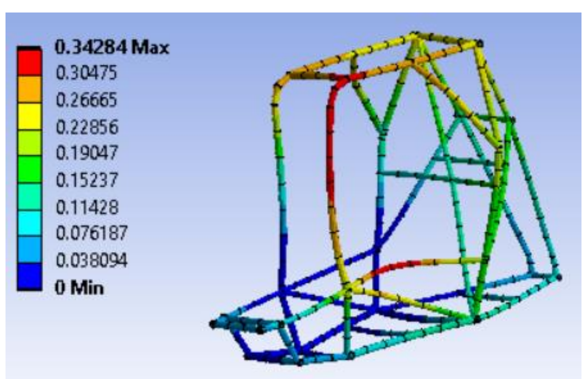

Figure 14. Side Impact, Deformation

ROLL OVER TEST

A roll over test is performed to identify the “roof” strength of the vehicle. This simulation is very important for the Baja vehicle due to the high roll over probability it has from the steep hills and rocky terrain it endeavours.

The roll over test simulation is set up under static conditions. A fixed support is set at the lowest most points of the floor skid plate as shown below (fig. 14).

The force is set at the very top of the roll cage: above the driver. The force is set to F = 25,760 lb_f. Given a mass = 800 lbs, and an acceleration due to gravity of 32.2 ft/s^2, using Newton’s second law of motion,

$$F = 800[lb_m] * 32.2\left[\frac{ft}{s^2}\right], \qquad F = 25{,}760\ lb_f$$

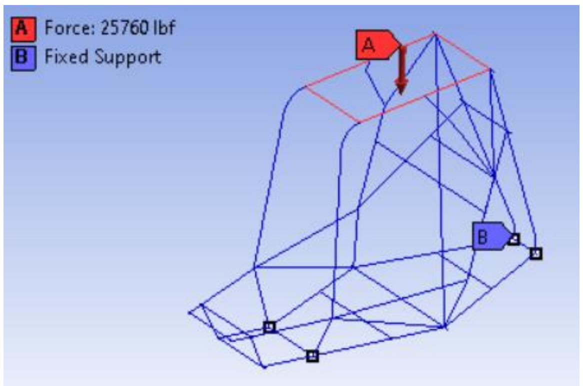

Figure 15. Structural analysis set-up, roll over

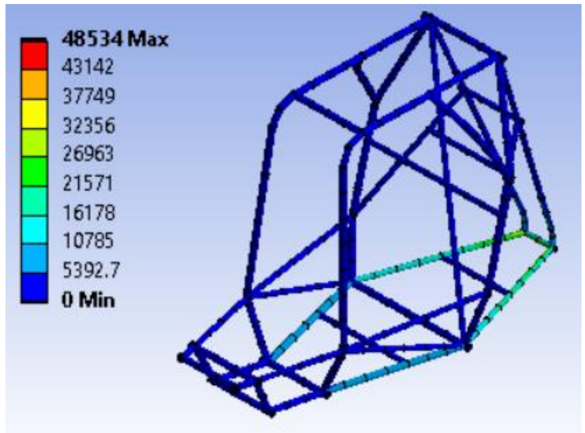

Figure 16. Roll Over, Deformation

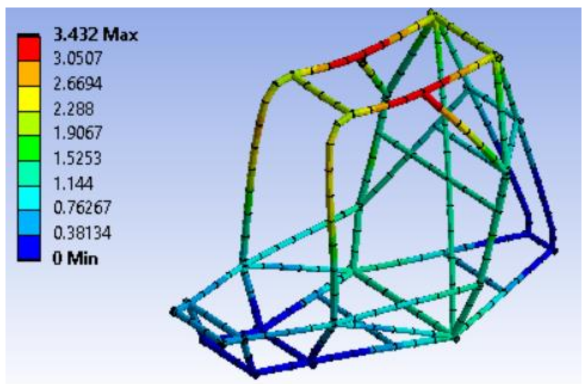

Figure 17. Roll Over, Von Mises

REAR IMPACT TEST

The rear impact test considers a collision from a secondary vehicle. The simulated vehicle is assumed to be at rest while a secondary vehicle crashes while travelling at full speed. The force value is the same one used for the front impact test – no overlap.

The set-up is also very similar to the frontal impact test. The roll cage is fixed at the extreme position of the passenger cabin as seen in figure 17.

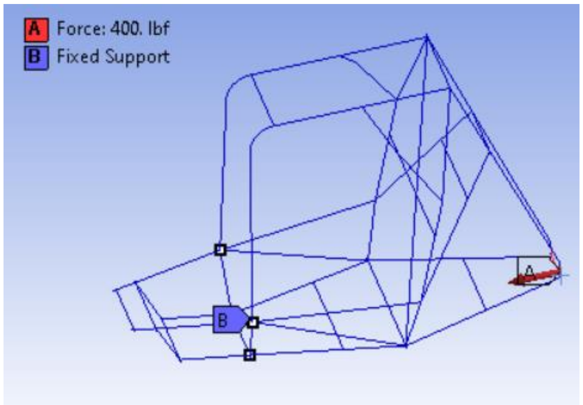

Figure 18. Structural analysis set-up, Rear Impact

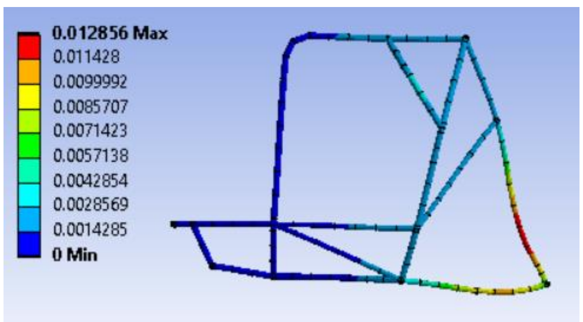

Figure 19. Rear Impact, Deformation

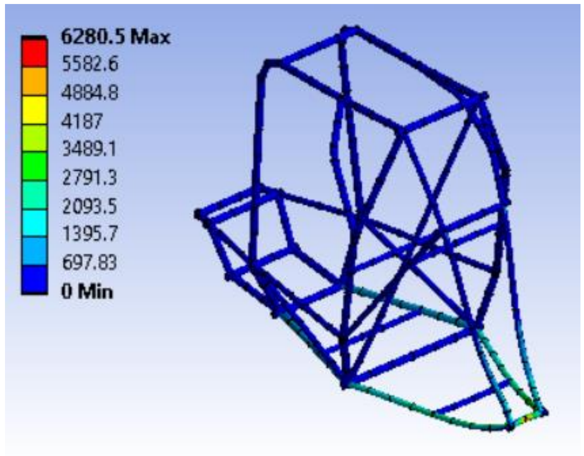

Figure 20. Rear Impact, Von Mises

CONCLUSION

In comparison with the earlier models of cars, the technology available today has advance the safety features of the automobile available in the market. Although it is not the only factor in vehicle safety, the structure of a vehicle play's a major role when reducing the risk of passenger injury during a collision. Deformation is suitable in crumple zones because of the allowed dissipation of energy; however, a vehicle must ensure the driver's safety cell is untouched. Because collisions can occur at any time, it is important to consider all of the possibilities of a car crash.

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