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CAD MODELLING AND STUDY ON RUPD (REAR UNDERRUN PROTECTION DEVICE) STRENGTH THROUGH FEM ANALYSIS: A COMPARATIVE STUDY USING SOLID WORKS AND ANSYS SOFTWARE

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Abstract: The World Health Organization reports that road traffic accidents remain a global epidemic, tragically claiming 1.35 million lives yearly. One significant contributor to this alarming statistic is collisions involving cars and heavy trucks. Innovative safety measures, such as Rear Underrun Protection Devices (RUPDs), must be developed and implemented to address this issue. This study evaluated a new RUPD design based on the Indian Automotive Standard of RUPD regulations. This study used 3D-CAD modelling and Finite Element Analysis (FEA) to create a robust RUPD design that could withstand collision forces. Through FEA simulations, we discovered that the RUPD had excellent energy absorption capabilities and reduced deformation during impacts. The 3D-CAD design of this new RUPD emphasises the crucial role RUPDs play in enhancing road safety. SolidWorks CAD modelling and FEM analysis techniques using SolidWorks Simulation & Ansys Software are potent tools for optimising RUPD performance & strength parameters based on deformation for given loading and boundary conditions, setting a benchmark for future research and development efforts in road safety.

Keywords: Road safety, Rear Underrun Protection Devices (RUPDs), CAD modelling, Finite Element Analysis (FEA), SolidWorks, ANSYS, Automotive safety.

1. Introduction

This study aims to develop, analyse, and evaluate a new RUPD based on the Indian Automotive Standard of RUPD regulations (IS 14812-2005) to enhance crashworthiness and reduce passenger compartment intrusion during heavy truck accidents. The researchers utilised 3D-CAD modelling and Finite Element Analysis (FEA) using industry-standard software, such as SolidWorks and ANSYS, to create and evaluate the RUPD design. A sturdy RUPD design was developed through CAD modelling to withstand collision forces. FEA simulations were then conducted to assess the performance and effectiveness of the RUPD in various impact scenarios. The results of the FEM analysis showed that the new RUPD design was superior, with excellent energy absorption capabilities and reduced deformation during impacts. Additionally, the integration of an Under-run protection bar facilitated seamless bumper-to-bumper contact between smaller and larger vehicles, significantly reducing the risk of fatalities and severe injuries to car occupants. These findings underscore the vital role of RUPDs in improving road safety. Using SolidWorks and ANSYS software in CAD modelling and FEM analysis provides valuable insights into RUPD performance and crashworthiness, leading to improved safety standards in the automotive industry.

2. Introduction to Rear Underrun Protection Devices (RUPDs)

Rear Underrun Protection Devices (RUPDs) are critical in mitigating the risks associated with collisions involving cars and heavy trucks. These devices are designed to prevent smaller vehicles from sliding underneath the rear of larger commercial trucks during accidents. The World Health Organization (WHO) reports that road traffic accidents claim a staggering number of lives globally each year, and collisions with heavy trucks contribute significantly to this toll. The severity of such accidents is often exacerbated by the lack of adequate protective measures, leading to devastating consequences for occupants of smaller vehicles.

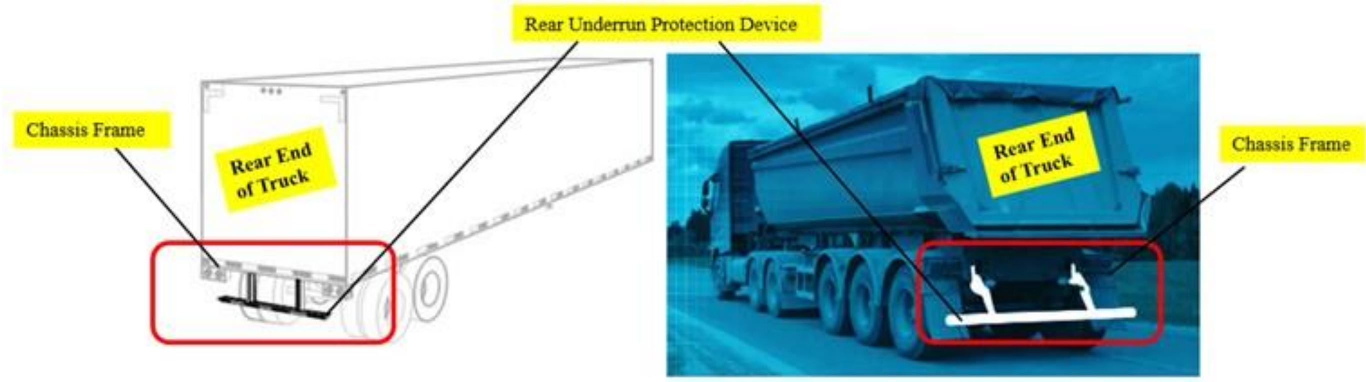

Figure 1. Schematic of Rear Underrun Protection Device (RUPD)
(The images are sourced from the internet and belong to the owners of the respective online content publishers.)

Underrun collisions between cars and heavy trucks can have catastrophic outcomes, including severe injuries and fatalities. Thus, regulatory bodies across the globe have devised and mandated Rear Underrun Protection Devices (RUPDs) to tackle this problem. These devices, usually affixed to the back of heavy trucks, serve as a barrier preventing smaller vehicles from going underneath during collisions. By absorbing the impact energy and redirecting forces, RUPDs help minimise the injuries' severity and avoid intrusion into the passenger compartment. The significance of RUPDs lies in their potential to save lives and prevent life-altering injuries. They provide an additional layer of protection for occupants of smaller vehicles. They are especially crucial in reducing the risk of head and neck injuries, among the most severe and life-threatening consequences of such accidents, as demonstrated in Figure 2.

Road Under Protection Devices (RUPDs) play a vital role in improving overall road safety. By setting safety standards and crashworthiness requirements, RUPDs help to advance safety regulations in the automotive industry. They also encourage vehicle manufacturers to prioritise innovative safety features in their designs. Thanks to advancements in technology and engineering, RUPDs have become more robust and effective in recent years. Computer-Aided Design (CAD) and Finite Element Analysis (FEA) techniques have optimised their performance. These modelling and analysis tools allow researchers and engineers to simulate and evaluate the behaviour of RUPDs in different impact scenarios, resulting in the development of more robust and efficient designs.

Figure 2. Possible Crash at Rear Underrun Protection Device (RUPD)
(The images are sourced from the internet and belong to the owners of the respective online content publishers.)

3. Literature Review

Heavy commercial vehicles come with under-run protection devices (UPD) to enhance the safety of passengers in smaller vehicles. These UPDs are classified as RUPD, SUPD, and FUPD, which stand for rear under-run protection devices, side under-run protection devices, and front under-run protection devices, respectively. Several papers on this topic have been reviewed to gain a better understanding. Here are some of the findings,

The study conducted by George Joseph et al. aimed to design a device for protecting against rear under-ride accidents. A quasi-static test assessed the guard's strength and energy absorption capacity subjected to applied loads. The constrained and boundary conditions utilised in the study were adequate. Approximately six designs were examined, and simulations were run to evaluate the efficacy of each guard. The resulting data was plotted for analysis.[6]

Prakash Kumar Sen, Shailendra Kumar Bohidar, et al. have found that head-on collisions often result in serious accidents that can be fatal for drivers. To improve car safety, it is recommended that heavy trucks be equipped with Front Under-run Protection

Devices (FUPD). Trucks with FUPD can reduce car driver fatalities by 40%. In India, trucks must have FUPD to meet safety regulations and protect against under-running of passenger cars. The required code for Front Under-run Protection Devices is IS 14812:2005. [7]

Kaustubh Joshi et al. emphasise the use of Rear Under-run Protection Devices (RUPD) and adherence to the IS 14812:2005 regulation to ensure trucks meet safety requirements and prevent the running of passenger cars. His RUPD design limits the maximum displacement of the RUPD bar to 50mm and plastic strain.[4]

After the extensive literature review and referring to the standard for RUPD design, the CAD Model is developed and analysed for its strength and optimised thickness based on the FEM results.

4. METHODOLOGY

ECE's R58 standard sets the regulations for RUPDs. The Indian law, IS 14812 – 2005 (shown in Figure 3), is based on this standard. To meet the criteria, the RUPD device must be strong enough to withstand forces applied parallel to the vehicle's length and be attached to the chassis side members (or equivalent components) while in service. This can be achieved by ensuring that, during and after the application of force, the horizontal distance between the rear of the device and the back of the vehicle does not exceed 400mm at any of the points P1, P2, and P3.

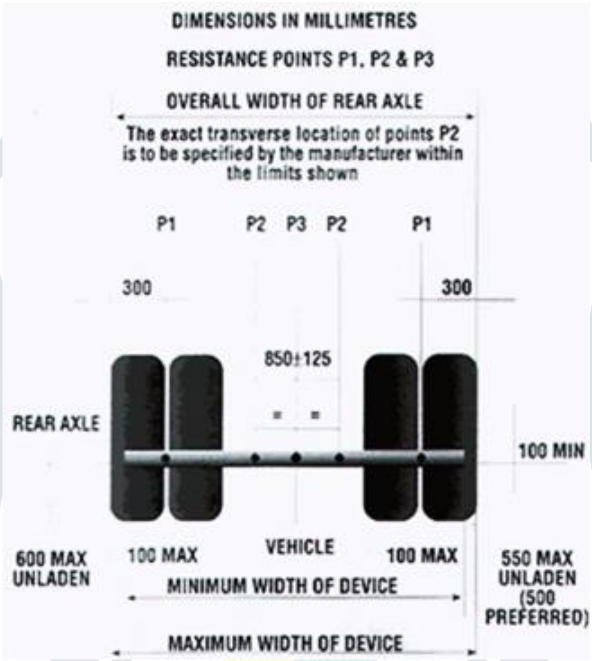

Figure 3. Indian Automotive Standard of RUPD (IS 14812-2005)

This study used a 'C' channel instead of a thin cylinder tube to design the rear under-run protection device (RUPD) based on the Indian Automotive Standard of RUPD (IS 14812-2005), as shown in Figure 3. This modification was made to comply with regulations that aim to improve strength and reduce deformation. First, a 3D CAD model was created. Then, FEM studies were conducted to evaluate strength parameters and optimise thickness.

5. CAD MODELLING AND DESIGNING THE RUPD IN THE SOLIDWORKS MODELLING SOFTWARE

This study has designed and modelled RUPD according to Indian Automotive Standard IS 14812-2005, using the SolidWorks part, as shown in Figure 4.

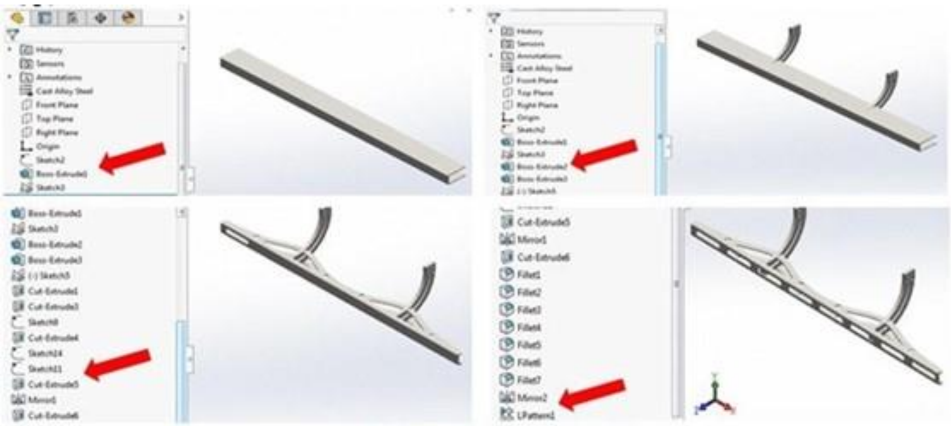

Figure 4. 3D-CAD Model creation using SolidWorks Software

In the initial design of RUPD, we used many slots in the arm and body of the RUPD to keep the weight of RUPD as low as possible; we want to verify the deformation of the RUPD with minimum self-weight, as shown in Figure 5.

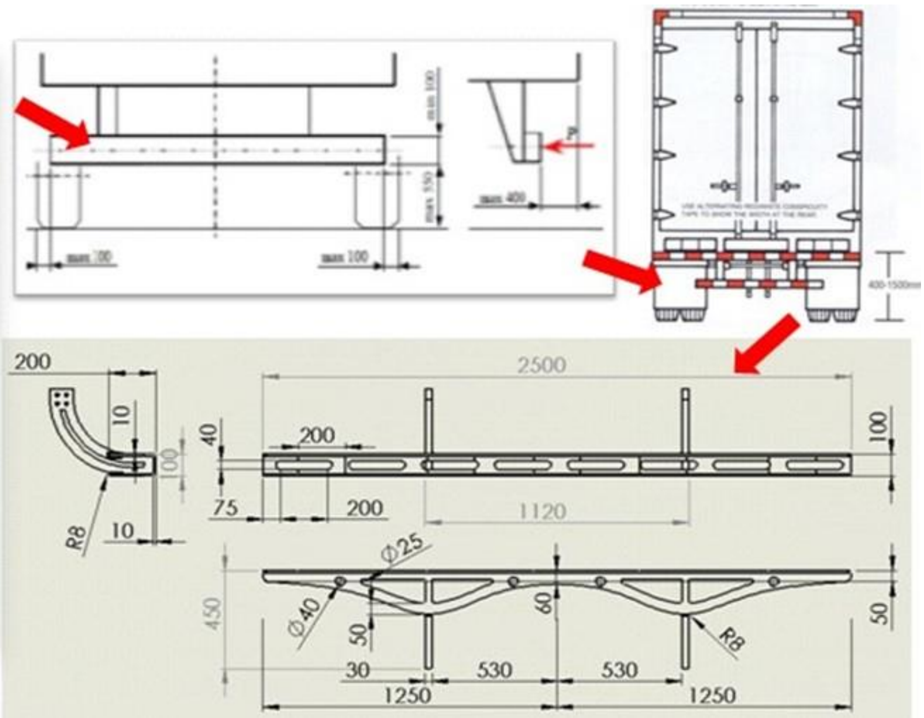

Figure 5. RUPD with slots for low-weight

6. STATIC ANALYSIS OF RUPD IN BOTH SOLIDWORKS AND ANSYS SOFTWARE

Assuming the mass of a car is 2000kg (maximum), and it travels with an acceleration of ten m/s2, From Newton‟ 's law, F = m X a. Hence, F= 2000 X 10 = 20000N, considering the car running with a force of 20KN.

- As we know, the arm of the RUPD is fixed to the truck's chassis. This study has assumed the same boundary condition that the component is selected.
- As per the Indian Automotive Standard of RUPD (IS 14812-2005), there are three points, namely P1, P2 & P3, indicated in Figure. 3; We have to analyse the impact at both sides and centre impact of the car on RUPD
- This study used the SolidWorks simulation static analysis and validated the results by comparing the values in ANSYS software for similar boundary, material and loading conditions (20KN) with corresponding mesh elements.
- For the study, we have selected Alloy steel as the material as it has an economical strength-to-weight ratio.

The properties of Alloy Steel are given below in Table.1

Table 1. Material properties

Density	7700 kg/m^3
Poisson's ratio	0.28
Young‟s modulus	210000 N/mm^2

6.1 CAD Modelling & Design changes to minimise the deformation & increase energy absorption

Table 2. below reflects that the deformation is around 4.3mm (RUPD Design 1. With Slots); now, we want to increase the energy absorption and decrease the possible deformation of RUPD.

- This study reduced the number of slots in the second run, and the arm was made solid to give more strength. The design changes are shown in Figure 6 below.
- The areas marked in red colour in Figure 6 below clearly indicate the design changes made to the RUPD
- As we added material to fill the slots in RUPD to make it stronger, This study wants to see the simulation results for the modified design.
- Similar boundary, material and loading condition (20KN) with corresponding mesh elements as in the initial case.

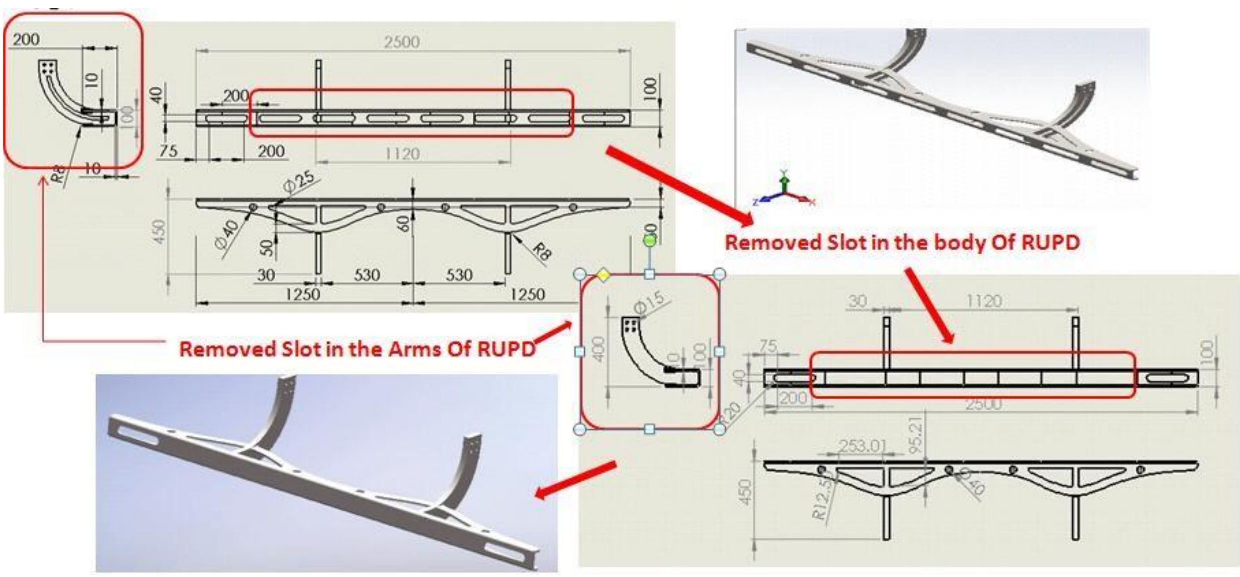

Figure 6. Design modification by removing the slots in RUPD

6.2 Results and Discussions

Below, Figure 7 shows the analysis of modified RUPD for centre impact at point P3 in SolidWorks Simulation & ANSYS software.

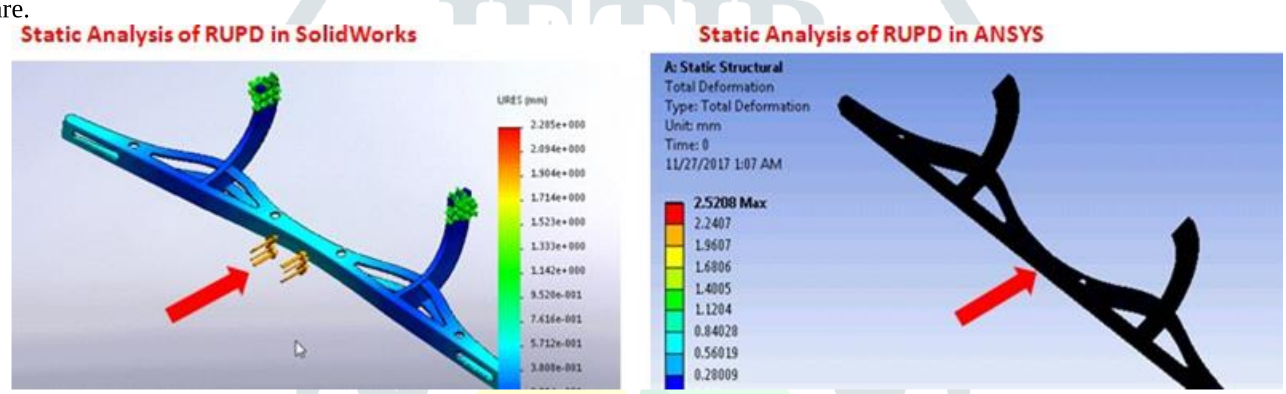

Figure 7. Simulation of modified RUPD for centre impact at point P3

With the given loading and boundary condition, the RUPD with 10mm ‘C’ Chanel model is subjected to static analysis, and results are tabulated as shown in Table.2

Table 2. Comparison of simulation results

REAR UNDERRUN PROTECTION DEVICE (RUPD) with 10mm C Chanel	Design 1. With Slots		Design 2. Without Slots	
Parameters	***Mass (Kg)***	***Deformation (mm)***	***Mass (Kg)***	***Deformation (mm)***
1. SolidWorks static Simulation	62.156	4.303	70.7852	**2.285**
2. ANSYS Mechanical Static Analysis	62.145	4.2552	70.7642	**2.5208**

From the above Table.2, there is a decrease in the deformation value, and this modified design holds good for more energy absorption. Deformation for side impact for the modified RUPD at points P1 & P2 is shown in Figure 8, resulting in deformation **of 6.877mm.**

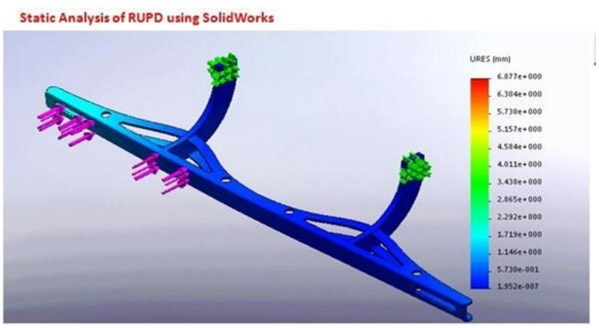

Figure. 8 Side impact for the modified RUPD for centre impact at points P1 & P2

So now, by finalising this modified design, to study the impact of the thickness of the 'C' section on the strength parameters of RUPD, a design study was carried out as follows.

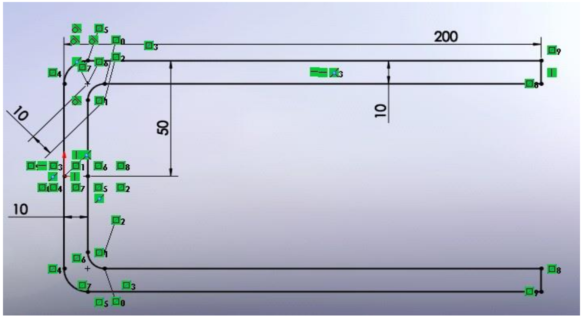

Figure 9. Sketch of C section of RUPD with thickness 10mm

With the help of the CAD Design Study feature in SolidWorks software, and analysed the RUPD for similar boundary, material and loading conditions (20KN) with corresponding mesh elements as in the initial case, with a thickness of 'C' section of body as 10mm, 14mm, 18mm, a varying parameter as shown in Figure.9. The results of the Design Study is tabulated in Table.3, as shown below. The 14mm thickness of the C section yielded the optimum strength parameter with 20KN for centre impact for the modified RUPD at point P3, as shown in the Table.3

Table 3. Centre impact at point P3 with different thickness

Sl.No.	RUPD (Variation inThickness of "C" section)	Mass Of the RUPD in (KG)	Von Misses Stress in (MPa)	DisplacementIn (mm)	Strain in the member in (MPa)
1.	10 mm	70.7852	487.225	2.285	1.491e-003
2.	**14 mm**	**84.9464**	**447.648**	**1.938**	**1.38e-003**
3.	18 mm	92.5839	450.387	1.930	1.436e-003

A similar design study is carried out for side impact at points P1 and P2, as per standards in Figure 3. The Design Study results are tabulated in Table 4 as shown below; the 14mm thickness of the C section yielded the optimum strength parameter with 20KN for side impact for the modified RUPD at points P1 & P2 with different thicknesses.

Table 4. Centre impact at point P3 with different thickness

Sl. No.	RUPD (Variation inThickness of "C" section)	Mass Of theRUPD in Kg	Von Misses Stress in (MPa)	DisplacementIn (mm)	Strain in the member in (MPa)
1.	10 mm	70.7852	926.184	6.877	2.921e-003
2.	**14 mm**	**84.9464**	**881.028**	**6.233**	**2.829e-003**
3.	18 mm	92.5839	904.836	6.463	3.064e-003

6.3 Explicit Dynamic Analysis using ANSYS Mechanical Workbench

Specialised problems require advanced analysis tools to accurately predict the effect of design considerations on product or process behaviour. The ANSYS explicit dynamics enables us to capture the physics of short-duration events for products that undergo highly nonlinear, transient dynamic forces.

The Explicit Dynamic analysis on the original has been performed using ANSYS software for the 14mm RUPD model, as it has given satisfactory deformation concerning mass & thickness. The trial run of explicitly dynamic analysis has been carried out to check the stresses induced and the behaviour of the assembly. The force of 25KN was applied along the centre line (2500mm) of the C section body for 0.05 seconds. Results have shown the energy absorption from RUPD for centre and side impact is satisfactory. Below Figure.10, Figure.11 and Figure.12 show the energy dissipation results and plots for the centre impact at point P3 by a Car to RUPD.

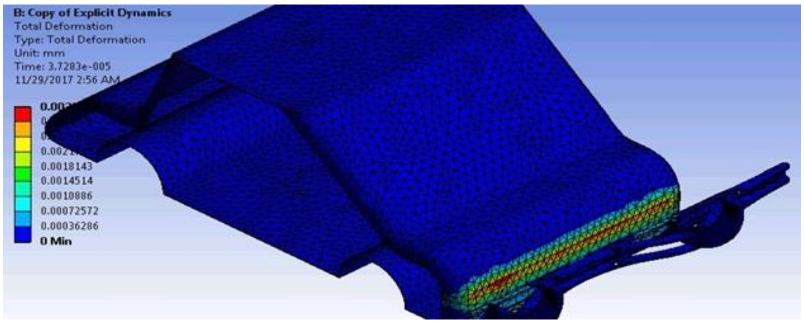

Figure 10. Centre impact at point P3 on RUPD with a CAR model

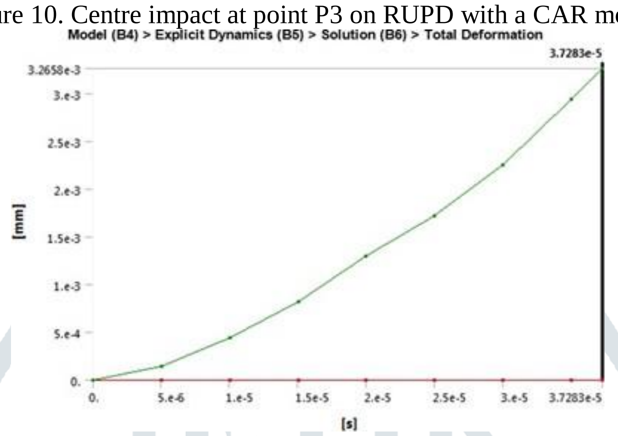

Figure 11.Deformation Vs Time in Sec plot for centre impact at point P3

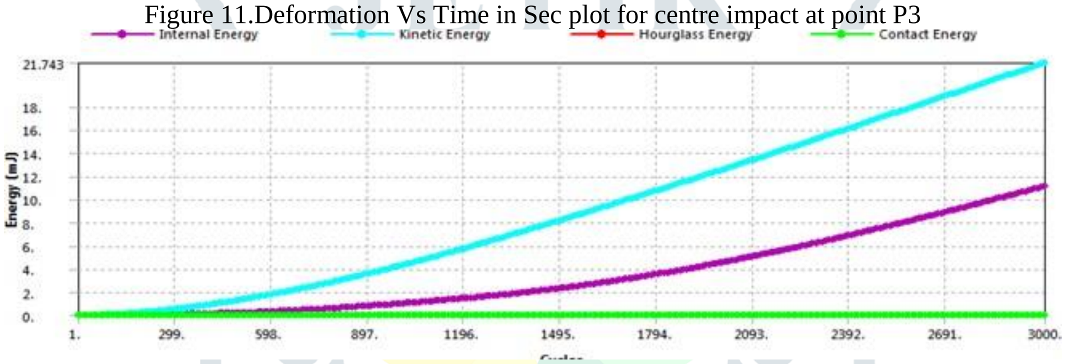

Figure 12. Energy in mJ vs. Number of cycles plot for centre impact at point P3

The same analysis is carried out on point P1 & P2; below, Figures 13, Figure.14 and Figure.15 shows the energy dissipation results and plots for the side impact at point P1 & P2 by a Car to RUPD.

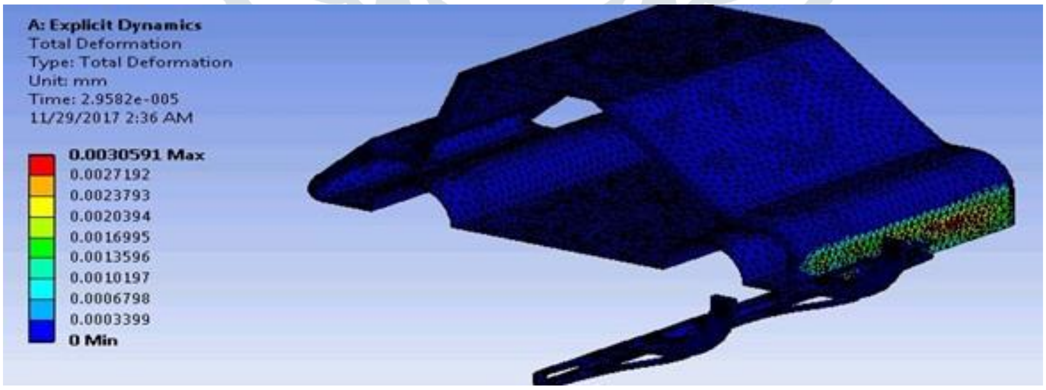

Figure 13. Side impact at points P1 P2 on RUPD with a CAR model

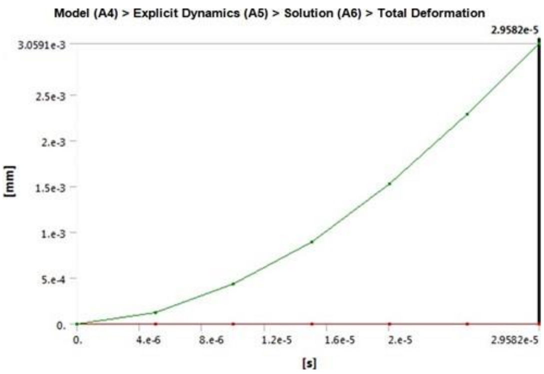

Figure 14. Deformation Vs Time in Sec plot for side impact at points P1, P2

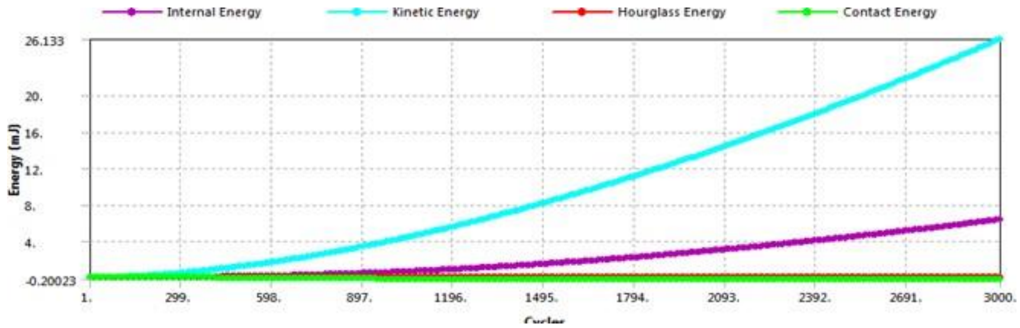

Figure 15.Energy in mJ vs. Number of cycles plot for side impact at points P1, P2,

7. Conclusion

Advanced 3D-CAD modelling and FEM software have revolutionised automotive and aerospace parts' design, optimisation, and simulation. This study confirms that all existing components can undergo design optimisation to reduce material costs and manufacturing time. In this CAD modelling and FEM study on RUPD, it was discovered that the results of the design study are presented in Table 3. The 14mm thickness of the C section provided the optimal strength parameter of 20KN for centre impact for the modified RUPD at point P3, as shown in Table 3. Additionally, the 14mm thickness of the C section yielded the optimal strength parameter of 20KN for side impact for the modified RUPD at points P1 and P2, with varying thicknesses.

8. Acknowledgement

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