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Finite Element Analysis of Rear Underrun Protection Device during

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Abstract: The rear underrun protection devices (RUPDs) during collisions are the main subject of the abstract's finite element analysis. Heavy vehicles must have rear underrun protection devices installed to stop passenger cars from sliding beneath them in the event of a rear-end collision. RUPD designs that are poor frequently cause fatal injuries in such accidents. This analysis uses numerical simulations and experimental tests to assess the effectiveness of RUPDs. The review identifies areas for improvement and looks at different research techniques used to evaluate RUPDs during car-to-heavy truck rear impacts. Discussions also include crash velocities, various car frontal crash test scales, and the ability of various RUPD designs to absorb energy. It also can be concluded that the higher the impact velocity, the higher the reaction force. The best performance of the RUPD is the New Design, which absorbed 12 kJ, 19 kJ, and 30 kJ for 12.5 m/s, 15.0 m/s, and 17.5 m/s, respectively.

Keywords: Finite Element Analysis, Rear Underrun, RUPD.

1. Introduction

Accidents between trucks and passenger cars are common in mixed-traffic environments [1]. Research done by [2] stated that because of the significant differences in mass and structural stiffness and incompatible geometries, the car's crash structure and occupant restraint systems frequently fail to function correctly, resulting in even more severe damage to the car's deformation and severe injury to the occupants in a malignant rear under-run collision. Thus, the installation of a rear underrun protection device is a must on trucks. According to related domestic and foreign reality, numerous types of equipment exist in the domestic and international markets, such as the rear under-run barrier and so on. However, there is some problem with the design of the rear under-run protection device. Firstly, the Design of the rear under-run protection device is not sufficient to absorb energy to minimise accident severity during the collision. Next, the design follows all the regulations stated by The United Nations.

2. Research Methodology

Methodology is a method used to complete a research study properly to ensure that the research runs smoothly. This study primarily concerns observing the impacted condition and finite element analysis on rear-underrun protection devices. This chapter provided an analysis of the research

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methodology, emphasising the theoretical conceptual foundation and elaborating on the objective, strengths, and weaknesses. The research methodology is outlined in Figure 1 to create an overview of how the research study was conducted. Finite Element Analysis (FEA) software and Computer Aided Design (CAD) software play important roles during this research. This research uses ANSYS to stimulate crash simulation and interpret the data for FEA. Other than that, SOLIDWORK2021 is used to construct a geometrical model of the Rear-Underrun Protection Device (RUPD).

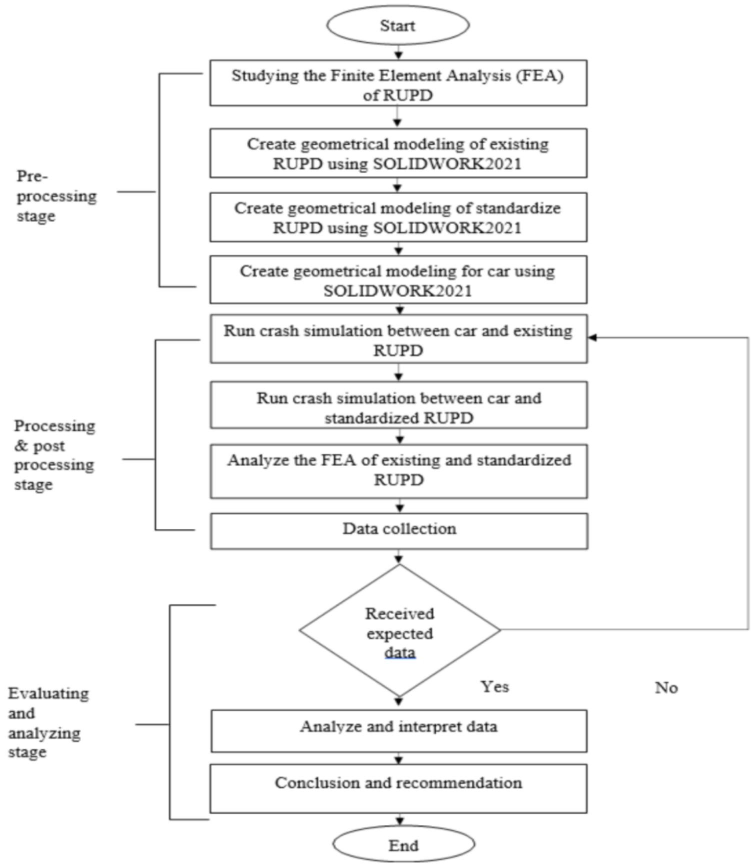


Figure 1: General research flowchart

Geometrical modelling for the existing RUPD, standardised RUPD and car is created using SOLIDWORK2021 software. The dimensions of the current RUPD design are taken on the road. For the standardised RUPD, dimensions were obtained from [3]. An explicit dynamic program was created to address the dynamic problem. The ANSYS software's explicit dynamic simulation solution is ideal for simulating short-term physical events that can cause material damage or failure. Such events are frequently expensive or difficult to test experimentally. To investigate the performance and failure behaviour of the RUPD when subjected to a crash, the commercial ANSYS Workbench 2022 R2 Mechanical-Explicit Dynamics (ANSYS AUTODYN PrepPost) was used.

For the software to produce reliable and accurate results, it is crucial to select the material properties and their accurate input. It's critical to consult relevant material data, consider the unique properties of the materials being modelled, and consider the specific properties needed for a given analysis because they may vary. Geometry describes the digital representation of a real-world system or object that serves as the foundation for simulation or analysis. It includes the analysed elements' dimensions, proportions, and spatial configuration. The car was assigned a rigid body; meanwhile, the RUPD was assigned a flexible. Mesh creation is the process of separating discrete elements from a continuous geometric model. It is a crucial step in numerical simulations and FEA because it enables the approximate solution of mathematical equations on a discretised domain and the approximation of physical behaviour. Based on the simulation, the end time of crash simulation between the car and RUPD is 0.2 s [3]. After this value has been assigned, other settings are automatically generated by ANSYS. The end time specifies the total time required to complete the impacting the rigid RUPD. The truck chassis is fixed, and the recommended speed of the car model is assumed to be 45, 54, and 63 km/h before colliding with the RUPD assembly [3]. All impact velocity selections were assigned to the car in the negative x-direction towards the RUPD to obtain the simulation solution. Before arriving at the solution, all these velocities were converted into meters per second. All designs considered in this paper is represented as in Figure 2.

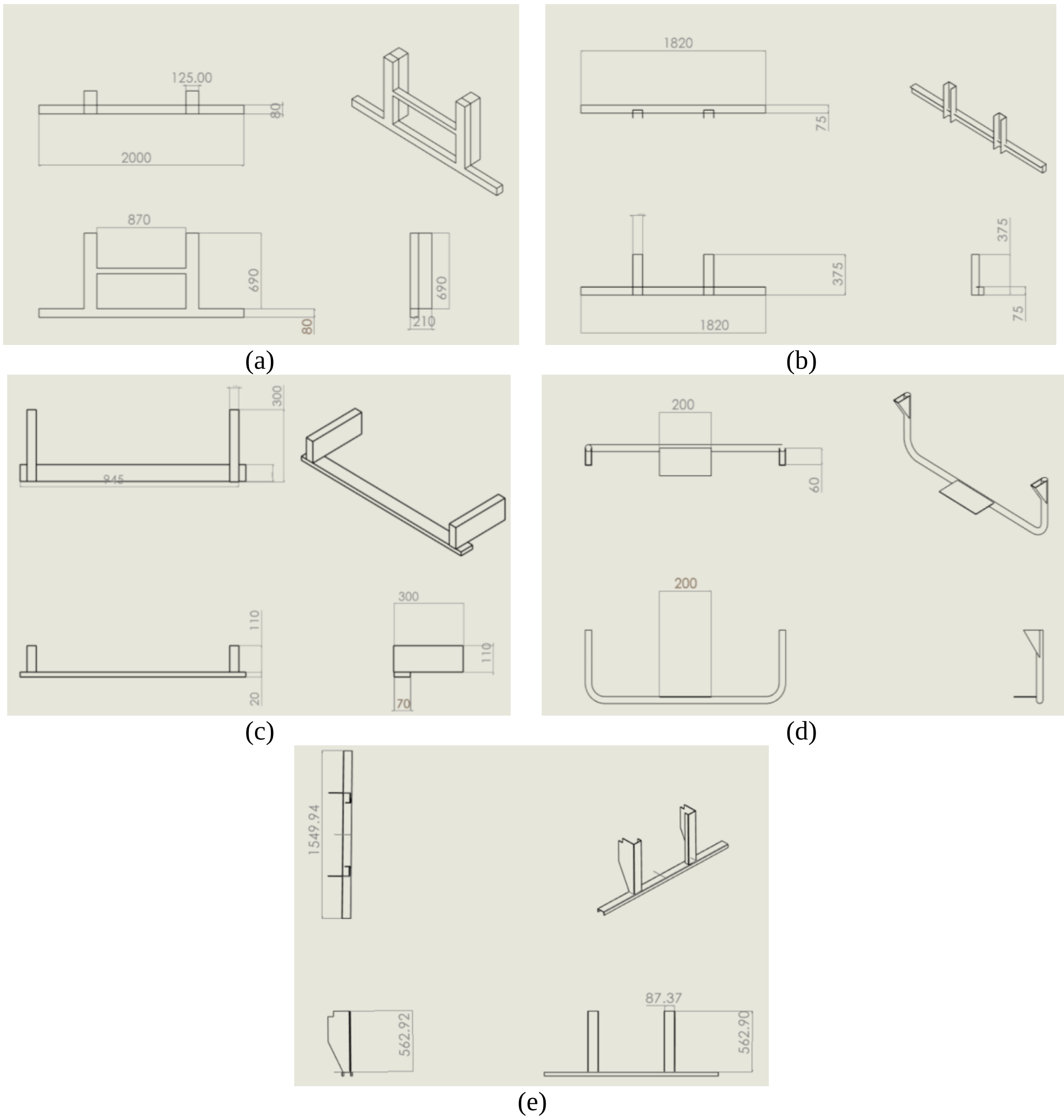


Figure 2: Projection views, (a) RUPD 1, (b) RUPD 2, (c) RUPD 3, (d) RUPD 4 and (e) Standard design

3. Results and Discussion

The study’s results are presented in the result section. Along with any measurements or statistical analyses performed, it includes a description of the data gathered and examined. The raw data, graphs, charts, or tables that illustrate the study's findings are presented in the results section. On the other hand, the discussion is interpreting and explaining the findings. Figures 3 (a) and 3 (b) show a new design of RUPD for this study. To fulfil this study's objective, a new RUPD design was designed. All the criteria of a good RUPD were implemented in this design. Firstly, the location of installation. The new design of RUPD was installed at the rear of the lorry or truck. The allowable distance from the RUPD is 400 mm from the ground. Regarding FMVSS223/224, 560 mm is the maximum height from above. RUPD needs special constructional features to perform as intended. Therefore, it is crucial to position the RUPD correctly; the RUPD's performance is determined by its ground clearance and distance from the truck to prevent a collision with the truck or trailer [4]. The ground clearance of the truck should never exceed 500 mm, preferably close to 400 mm, to maximise the energy absorption capacity of the car's front structure and to prevent the "wedge effect" (where the car front would slide under the RUPD and hit the truck's bodywork) [5] as in Tables 1 and 2.

Table 1: Mechanical properties of RUPD (steel) [3]

Density (kg/m^3)	7850
Modulus of Elasticity (MPa)	200
Poisson’s Ratio	0.3

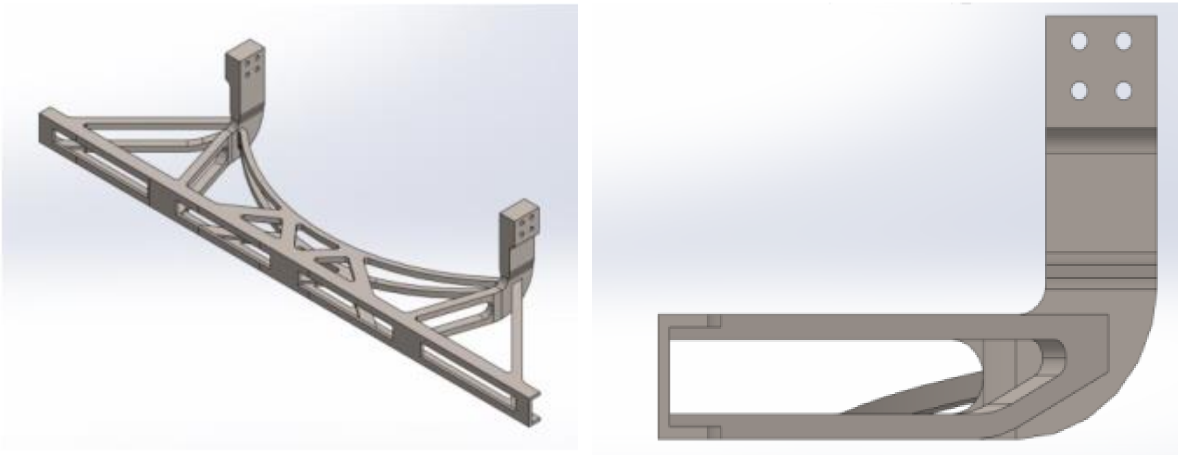
Table 2: Geometry definition of RUPD and car

	RUPD	Car
Stiffness behaviour	Flexible	Rigid
Body interaction	Frictionless	Frictionless

Next, cross member beam and support member joined together as whole structure. It comprises support members (typically two pieces) and a cross-member beam. In the event of a rear-end collision with a truck or trailer, the primary goal of the rear underrun protective device is to reduce injuries to the smaller vehicle's occupants, particularly a passenger car [4]. The Collection data of reaction force was collected to perform analysis on each RUPD. All the graphs represent force against displacement for a specific impact velocity of 12.5 m/s, 15.0 m/s and 17.5 m/s. Based on Figure 4, the maximum value of force is 180 kN, which occurs at 0.25 m for 17.5 m/s. The highest magnitude for 12.0 m/s is 170 kN, which occurs at 0.25 m. For 12.5 m/s, the highest value of force is 160 kN. The car started to crash into the RUPD at 0.15 m and stopped at 0.3 m approximately for 12.5 m/s, 15.0 m/s and 17.5 m/s. Figure 4 shows the graph of force against displacement for 12.5 m/s, 15.0 m/s and 17.5 m/s for design 2. Collision occurs at 12.5 m/s, 15.0 m/s and 17.5 m/s at 0.2 m. Maximum reaction force magnitude for 12.5 m/s, 15.0 m/s and 17.5 m/s are 35 kN, 53 kN and 70 kN, respectively. Collision is completed at 0.7 m for 12.5 m/s, 1.4 m for 15.0 m/s and 1.2 m for 17.5 m/s. Next, Figure 4 shows the graph force against displacement for Design 3. The highest magnitude of force is 40 kN, which occurs at 0.45 m for 17.5 m/s, while 35 kN, 30 kN for 12.5 m/s and 15.0 m/s, respectively. The collision finished at 0.7 m for 15.0 m/s and 17.5 m/s; meanwhile, for 12.5 m/s, the collision finished at 0.6 m. The car started to crash into the RUPD at 0.2 m for 12.5 m/s, 15.0 m/s and 17.5 m/s.

Figure 4 (d) shows a reaction force versus displacement graph for Design 4. The crash started at 0.1 m for 12.5 m/s, 15.0 m/s and 17.5 m/s. The maximum reaction force values for 12.5 m/s, 15.0 m/s and 17.5 m/s are 70 kN, 80 kN, and 160 kN, respectively and suddenly decreased to zero value, then fluctuated until the end of the collision. The collision for 12.5 m/s, 15.0 m/s and 17.5 m/s stop at 0.25 m, 0.4 m, and 0.45 m respectively. Then, Based on Figure 4 (e), the maximum magnitude of force for 12.5 m/s, 15.0 m/s, and 17.5 does not have a big difference, which are 172 kN, 173 kN and 173 kN, respectively. The car started to crash into RUPD at 0.2 m. For 12.5 m/s, the force value fluctuates drastically towards the end, but for 15.0 m/s and 17.5 m/s, the force magnitude increases slightly towards the end.

After that, from Figure 4 (f), it can be concluded that 17.5 m/s has the highest value of force, which is 80 kN. The second highest magnitude of force is 60 kN at 1.0 m for 15.0 m/s, followed by 30 kN for 12.5 m/s. The collision between the car and RUPD finished at 15.0 m/s and 17.5 m/s between 1.0 and 1.5 m meanwhile for 12.5 m/s at 1.5 m. The magnitude of force for 12.5 m/s and 15.0 m/s decreased gradually towards the end, but for 17.5 m/s, the magnitude of force decreased drastically. All the RUPD shows the same trend: the higher the velocity impact, the higher the value of maximum reaction force. Under different sliding velocities, the impact forces did not significantly alter. But as the sliding velocity increased, the friction force also did. This suggests that both impact velocity and sliding velocity affect the amplitude of friction force, with impact velocity having a greater influence on impact force than sliding velocity [6]. Other than that, all the graphs produce poorly curved graphs because the value of reaction force increases and decreases randomly. The sudden decrease is an indicator of the failure design resistance during the intrusion; meanwhile, the increase and sudden decrease also happen because the reaction force magnitude is attributed to the rigid behaviour of the RUPD [3].



(a) (b)

Figure 3: New design (a) Isometric and (b) Side views

To evaluate the impact performance of RUPD, a graph of reaction force against displacement is important. The energy absorbed by the RUPD during the collision, which is directly related to the impact performance of the RUPD, can be observed by calculating the area under the graph between reaction force and displacement. Figure 5 shows the graph of energy absorption for 12.5 m/s. The lowest magnitude of energy absorption is 5 kJ, which occurred at Design 4. Meanwhile, the new design absorbed the highest energy magnitude, 12 kJ. For 15.0 m/s, the new design is also the best to absorb a large amount of energy, which is 19 kJ. The lowest magnitude of energy absorbed, which is 5 kJ, occurs at Design 1 and Design 4 for 15.0 m/s. Based on Figure 5, a new design absorbed the highest energy absorption value, which is 30 kJ energy, and Design 3 absorbed the lowest energy value, which is 6 kJ. The difference in the energy absorption value happened because of the difference in the design of the protective beam on the RUPD. The protective beam's design enables the RUPD to work by absorbing impact energy. Since the protective beam's profile greatly impacts how well the RUPD absorbs energy, 18 different protective beam cross-section profiles are looked at. Different designs of the protective beam are listed according to their cross-section profiles to achieve the subfunction of absorbing impact energy. These include the box, square, and tubular sections and three additional combined models, including the double box, Lip-channel, and tubular-C-channel sections. The result is the generation of 72 potential RUPD solutions derived from the product of the alternative potential number of each sub-function [7]. Finally, it can be concluded that New Design is the best structure for RUPD, and it can be proved by the amount of energy it can absorb. The higher the energy absorption, the higher the impact performance of the RUPD. So, it can decrease severity when a rear collision happens between the car and the rear of the heavy goods vehicle.

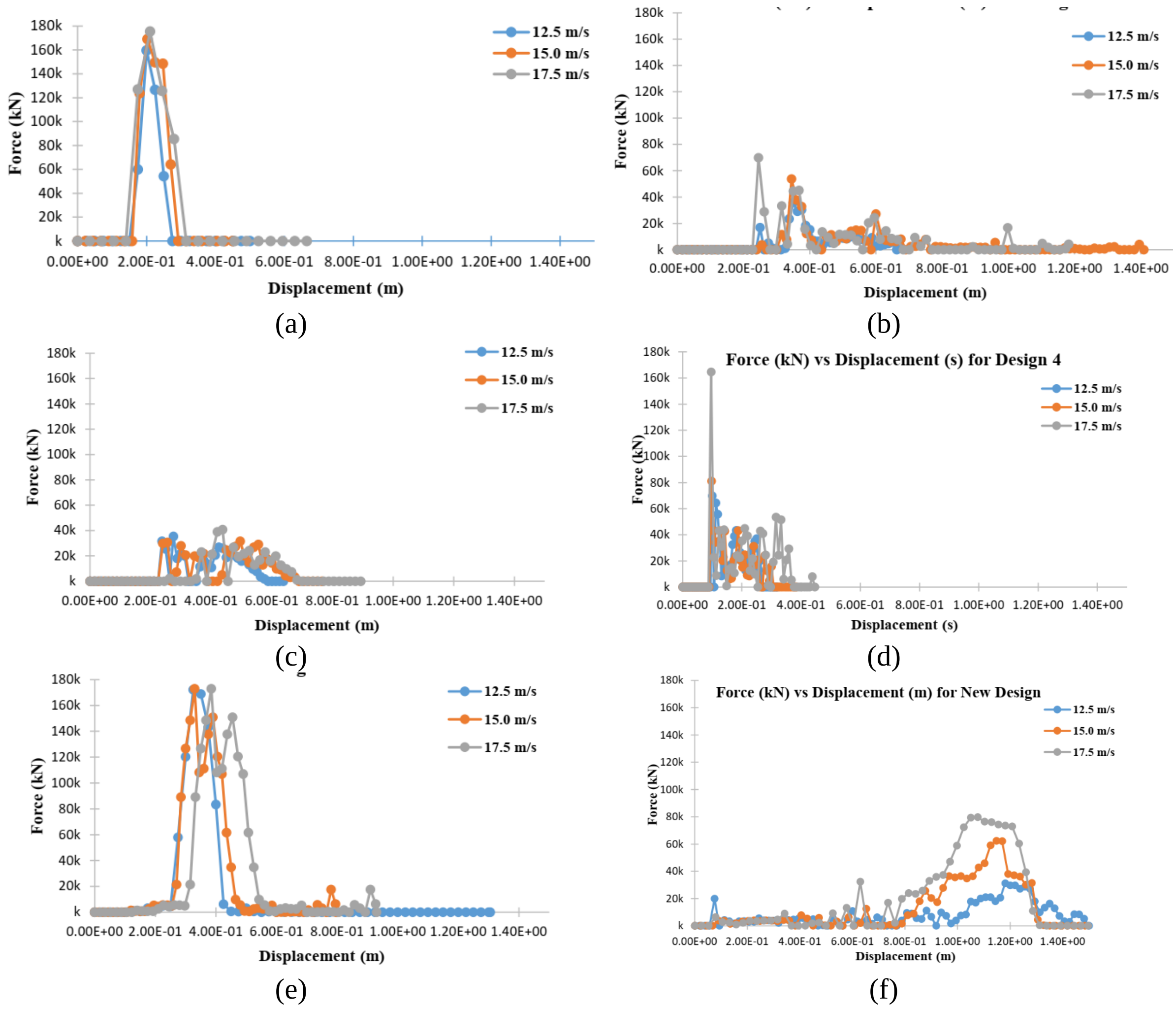


Figure 4: Force versus displacement of (a) RUPD 1, (b) RUPD 2, (c) RUPD 3, (d) RUPD 4, and (e) Standard design

The percentage error of total energy absorption for standardised design was calculated for validation purposes. Table 3 shows the comparison in terms of energy absorption. The percentage errors for 45 km/h, 54 km/h, and 63 km/h are 73.05 %, 59.14 %, and 45.63 %, respectively. The difference in values of total energy absorption occurs due to some factor. Firstly, the size of meshing. In engineering and scientific research, meshing is a critical step in numerical simulation and computational modelling. The computational domain is broken down into smaller components, such as triangles or quadrilaterals in 2D, tetrahedra, or hexahedra in 3D. No specific mesh sizing is mentioned in the research; thus, the simulation result differs from the research. Next, geometrical modelling of the car. In the journal, the Toyota Yaris was the model for the car that crashed into RUPD; meanwhile, in this study, the geometrical modelling of the car is simple compared to the journal's geometrical modelling of the car. Although the car was assigned as a rigid body, it plays a vital role in getting the precise value of the solution from the simulation.

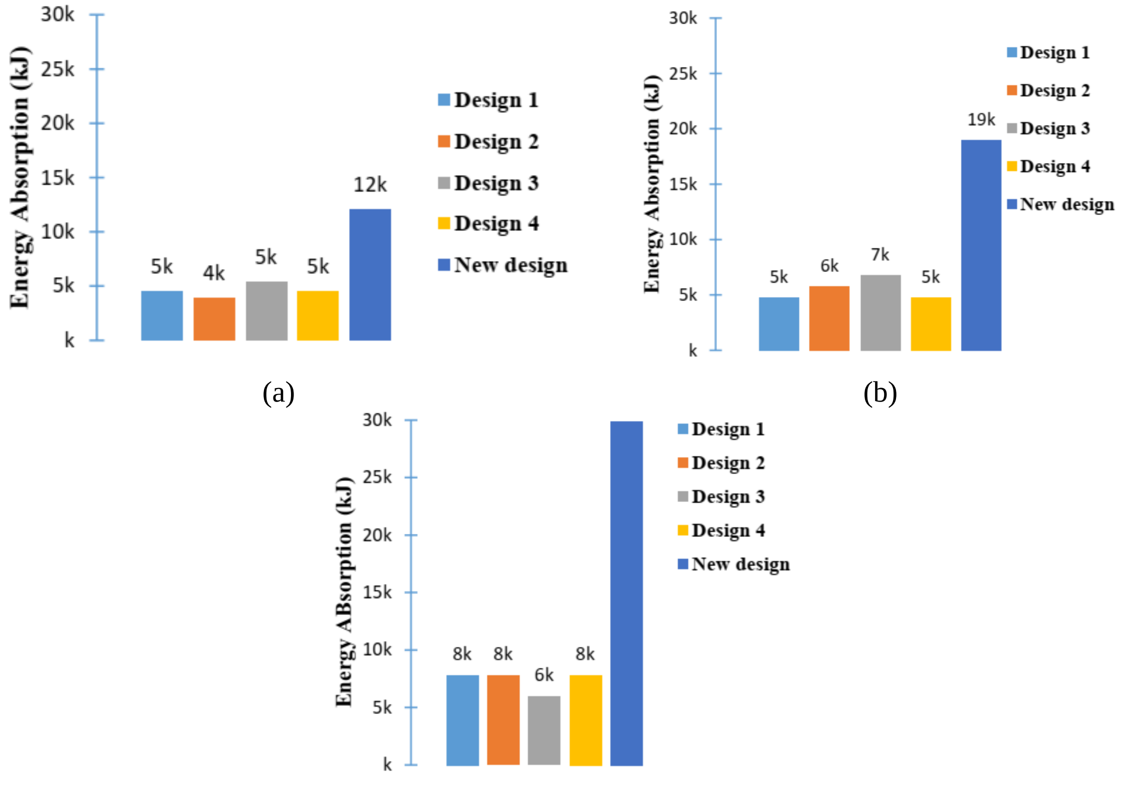


Figure 5: Energy absorption of different designs subjected to different velocities, (a) 12.5m/s, (b) 15.0 m/s, and (c) 17.5m/s

Table 3: Energy absorption comparison between LS-DYNA and ANSYS

	LS-DYNA	ANSYS
45 km/h	720 kJ	193 kJ
54 km/h	550 kJ	223 kJ
63 km/h	480 kJ	261 kJ

4. Conclusion

In conclusion, the finite element analysis of rear underrun protection devices has been conducted with three main objectives: to evaluate the impact performances of existing RUPD structures, design a new RUPD structure, and compare the impact performance between the existing design and the new design. The FEA approach has proven to be a valuable tool in achieving these objectives and has provided insights into the effectiveness and potential improvements of RUPD systems.

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