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Investigation On the Effect of the Rear Under-Run Protective Device of Heavy Vehicle Using Finite Element Simulation

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Abstract: In rear-end collisions with other vehicles, such as trucks; the crashworthiness of the rear under-run protective device of the truck directly affects the safety of the occupants of the vehicle. Rear-end crashes between cars and trucks result in a significant number of fatalities and serious injuries, which makes them a major public safety problem. This research paper is to study the effect of the collision of rear under-run protective device of truck and its damage behavior when it is collide with cylinder. RUPD beam and cylinder collisions will investigate using the finite element method and will be simulated in ABAQUS/CAE software. The entire structure of rear under-run protective device has been designed in ABAQUS/CAE according to the actual parameters on the real rear under-run protective device beam. Steel material is applied for the whole RUPD beam structure and mass of cylinder is 115 Kg. The predefined field feature was used to apply the velocity to the cylinder-shaped impactor with 80 km/h and the load for cylinder is 5000N. According to the data acquired for force against time, the force reaches a maximum value of 580kN and with a displacement value of 100.052mm at time 0.02, the beam displacement value also reached its maximum level. The data reveals that the amount of energy absorbed increased significantly from time 0.006 to 0.02, peaking at time 0.02, when it reached a value of 2831.067 J. The RUPD beam's ability to absorb more energy demonstrates that its design is more crashworthy and capable of providing a good performance when colliding with the cylinder.

Keywords: Crashworthiness , Rear Under-Run Protective Device, Rear-End Crash, Failure Behaviour

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1. Introduction

Ministry of transportation Malaysia stated that the number of road traffic accident is increased by 3.1 percent for the last decade and rear-end collision is one of the main contributors of road traffic accidents in Malaysia [1]. According to [2] rear end collision causes 75.8 percent of casualties involving passengers in car and 58.8 percent in truck. Other than that, the minor injuries that causes by rear end collision are also concerning for both type of vehicles which are 24.2 percent and 41.2 percent respectively. Rear-end collision is one of the most common types of car accidents. When the frontal area of vehicle A collides with the back half of vehicle B, a collision occurs. Rear-end collisions can happen as a result of a driver's inattention, intoxication, road issues, bad weather, and other factors. Carelessness is the most prevalent cause of rear-end crashes, which means that one of the driver's actions fell short of what a reasonable person would have done or not done in the circumstances that led to the accident.

The trend in Malaysia's death rates for motorcycle accidents during the early 1990s has contributed to an increase. Careless driving was the most frequent sort of driver error that caused fatal motorcycle accidents. It was evident that the number of motorcycle riders disobeying traffic lights had increased by around three times [3]. In order to further investigate the causes of motorcycle accidents in Malaysia, it is important to identify the factors that affect the likelihood of speeding behaviour.

1.1 Thin walled beam

Thin-walled beams are structural components with three separate dimensions of varied magnitudes: the thickness is thin in comparison to the cross-sectional dimensions, which are modest in turn in relation to the beam length. Thin-walled beams were used by civil engineers as frameworks, beams, and columns in the second half of the 19th century. Then, thin walled beam is also used by the aerospace, aeronautics, and turbomachinery industries. They are superior to conventional compact section beams in a number of ways [4]. Engineers have employed thin-walled beams in structural engineering for many years. The maximum thickness of a typical thin-walled item is 1.5 mm. Specific thin-walled beams are generally built using steels like S320 or S355 because thin-walled cross-sections are composed of sheet steel, which is typically stronger [5]. In the construction of bridges, commercial buildings, and warehouses, thin-walled beams are frequently used. Cost, weight economy, the need for new materials, and other factors all play a role in its expansion. Because of their low thickness-to-width ratio, thin-walled structural components are very effective [6].

1.2 Thin Walled Beam as Under-Run Bar

Thin-walled beams are also used to make under-run bars in addition to the vehicle body frame. Under-run bars are often mounted at a truck's front, side, and rear. The purpose of the front under-run bar is to both absorb force during collision and prevent smaller vehicles from colliding with the truck from the rear. The side under-run bar prevents any car or person from colliding with the trucks and getting crushed. Rear under-run protection device (RUPD) is designed to reduce the severity of injuries sustained by passengers in passenger cars in collisions with large commercial vehicles (HGVs) [7]. A cross member beam and support members make up the rear-end under-run bar (usually two pieces). The majority of RUPDs are welded or screwed into the frame of the vehicle. Depending on the user's needs, the RUPD can be fixed or adjustable (e.g., foldable, slidable, and foldable-slidable) [8].

2. Materials and Methods

The development of innovative, competitive, and energy-efficient products is critical for success on global markets for heavily impacted sectors like the automotive industry. A large reduction in vehicle weight is required, in addition to the development of improved or innovative powertrain designs. The choice of certain materials and material combinations is heavily influenced by the cost aim and, as a result, the vehicle's target market segment.

2.1 Steel

As a result of rising demands for passenger safety, vehicle performance, and fuel efficiency, there has been fierce competition between the steel and low density metal industries during the previous decade. The steel industry's reaction to the new problems has been a quick development of greater strength steels known as Advanced High Strength Steels. When compared to traditional steel grades, these steels have better formability and crashworthiness [9].

High-strength steels, ultra-high-strength steels, and advanced high-strength steels have been created expressly to meet the needs of the automobile industry. These new steel grades have already demonstrated their superiority in meeting the requirements for automotive materials, including durability, strength, stiffness, strong crash energy absorption and acoustic qualities, low production cost in large quantities, and recycling potential [10].

Steels with yield strengths ranging from 210 to 550 MPa are classified as HSS. Yield strengths of ultra-high strength steels (UHSS) exceed 550 MPa. Interstitial free (IF), bake hardenable (BH), carbon-manganese (C-Mn), and high strength low alloy (HSLA) steels are among the HSS grades. Table I shows typical HSS mechanical characteristics [10].

Table 1: Typical high strength steel grade mechanical properties

Product	Yield strength, MPa	Tensile strength, MPa	Elongation, %
HSS, hot rolled	310-462	380-558	26-28
HSS, cold rolled	303-370	372-445	26-27
HSLA	300-420	384-500	27-36

2.2 Methods

An explicit dynamic is a feature that addresses the dynamic problem. ABAQUS/CAE 20.1 finite element software's explicit dynamic simulation solution is appropriate for simulating short-term physical events that can result in material damage or failure. The cylinder will represent as impactor that will collide with protective device for the truck barrier in the case of collision impact. As initial data for simulation, the material's mechanical properties, part geometry requirements, and other tools were supplied. To provide a smooth change in the output, fine-meshing is conducted around the model's impact zone. This aids in the model's performance improvement. A set of mechanical qualities of the geometry of the rear under-run protective device can also be characterised as mechanical behaviour. Steel material is applied for the whole RUPD beam structure. For properties of the cylinder, mass inertia has been applied and using the mass inertia value of a scooter as a reference. Tables 1.2 show the properties steel used in this study, as well as other material properties that were changed for a section of the model’s components, as determined by the mechanical behaviour that was required**.**

Table 2: Properties of steel for RUPD beam

Mechanical Behaviour	Properties	Steel
Density, ρ		7.8E-09 gm^{-3}
Elastic	Young’s Modulus, E	210000 Pa
	Poisson’s Ratio,	0.3
	Yield Stress 1	750
Plastic	Yield Stress 2	800
	Yield Stress 3	820

Yield Stress 4	839
Yield Stress 5	890
Yield Stress 6	920
Yield Stress 7	950
Yield Stress 8	1120
Plastic Strain 1	0
Plastic Strain 2	0.01
Plastic strain 3	0.02
Plastic Strain 4	0.1
Plastic Strain 5	0.16
Plastic Strain 6	0.42
Plastic Strain 7	1
Plastic Strain 8	4.2

Table 3: Damage properties for RUPD beam

Fracture Strain	Stress Triaxiality	Strain Rate	Damage Evolution
1	0	30	0.022
0.6	0.39	30	

3. Results and Discussion

3.1 Effect of collision on rear under-run protective device

Rear under-run protective device of truck will crumble after collide with the cylinder. This effect happens due to the force that applies by the cylinder toward the rear truck's barrier by the certain load. The structure of the rear under-run protective device design plays an important role in the impact of collisions in real situations. The diagram below shows the collision effect that occurs on the rear under-run protective device when it collides with the cylinder.

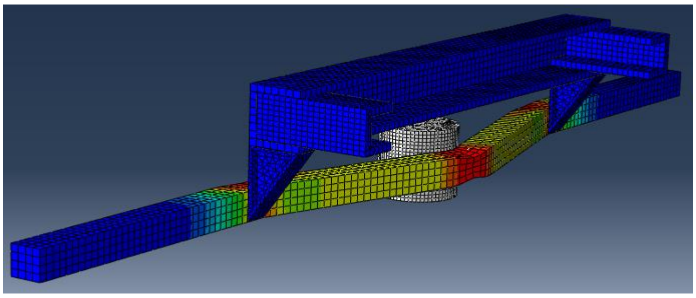

Figure 1: Impact on rear protective device

From the diagram above, the form of bending that occurs in the rear under-run protective device beam only occurs in the middle of the entire rear under-run protective device structure. This is because the beam has a support structure that can help avoid the effects of a severe collision from the impactor. As mention before, the area of the beam that collides directly with the cylinder turns red because that area is the area that receives the most force from the impactor. Apart from the middle section of the beam that collides with the cylinder, the area of the beam that being fixed to the support of the rear truck's barrier also turns red after the collision because that area receives resistance force from the support beam.

3.2 Energy absorption

The results of energy absorption for the collision between the cylinder and the RUPD beam can be seen in the table below. The velocity of the cylinder that collides with the RUPD beam in this simulation has been set at 80km/h.

Table 4: Table of energy absorption

Time (s)	Force (N)	Displacement (mm)	Energy Absorption (J)
0	0	0	0
0.001	0	5.00024	0
0.002	208856	10.0004	1044.589
0.003	275778	15.0032	1379.648
0.004	175927	20.0059	879.661
0.005	168814	25.0035	843.664
0.006	189030	30.0011	944.819
0.007	203101	35	1015.139
0.008	230513	39.9975	1152
0.009	255503	44.9951	1277.067
0.01	277409	49.994	1386.559
0.011	305336	54.9916	1525.947
0.012	342318	59.9892	1710.99
0.013	389292	64.9881	1945.778
0.014	433852	69.9857	2168.218
0.015	466542	74.9833	2333.386
0.016	488337	79.9886	2446.788
0.017	537319	85.0042	2695.353
0.018	550348	90.0212	2760.71
0.019	564475	95.0368	2831.067
0.02	580528	100.052	

The data obtained from the simulation shows that the amount of energy absorbed by the RUPD beam is increasing with increasing time. At time 0.002 to 0.003, the amount of energy absorbed by the RUPD beam increased from 0 to 1044.589 J and 1379.648 J respectively. However, the total energy absorb slightly decreased at time 0.004 and 0.005 to 879.661 J and 843.664 J respectively. Then, at time 0.006 to 0.02, the results of the data show that the amount of energy absorbed continued to record a significant increase and reached a maximum value of 2831.067 J at time 0.02. With the increase in the amount of energy absorption by the RUPD beam shows that the design of the RUPD beam is able to provide a good performance when colliding with the cylinder and has better crashworthiness. The energy absorption graph can be seen in the picture below.

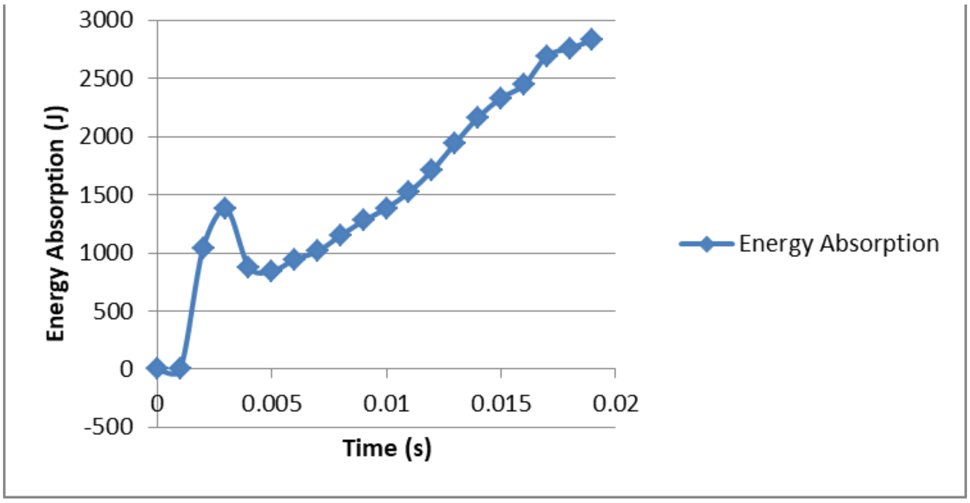

Figure 2: Graph of energy absorption against time

4. Conclusion

In conclusion, the finite element method (FEM) static analysis method employed for this study is beneficial because it simulates examining a real product. The cost of utilizing just a computer and a few other supplies to complete this procedure is likewise not significant. So, before creating a real product, the majority of engineers will employ this technique. The main purpose of this study is to observe and test the impact of collisions on rear under-run protective device on heavy vehicles. The impact of the collision between the beam and the cylinder can be seen in the simulation that was successfully produced in ABAQUS/CAE software. With the results of the findings and the data successfully obtained, it can be concluded that the objective in this study was successfully achieved where the results from the simulation clearly show the impact of the collision that occurred on the rear under-run protective device of the truck.

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