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Dynamic Response Analysis of Frontal Crash on Vehicle Against Lighting Column Using FEM

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Abstract: A collision between a car and a rigid object on the street, such as an electrical pole or lighting column, may pose a major risk to the the car driver and passengers. It is critical to investigate the collision of a vehicle with a rigid body, particularly the deformation of the vehicle's frontal region against a lighting column at various speeds. In this study, the deformation and dynamic response of the vehicle's frontal area are calculated and analyzed using the ANSYS finite element approach. According to the numerical analysis of frontal impact, a speed of 80 km/h results in a total deformation of 0.0713 m, while a velocity of 120 km/h results in a total deformation of 0.10218 m. When the vehicle is traveling at a higher speed, the lighting column causes additional deformation to the frontal region of the vehicle. Because of the significant internal energy generated during a collision, the car absorbs more impact energy than the lighting column due to the aluminium alloy's material properties.

Keywords: Crash, vehicle, lighting column, finite element method

1. Introduction

Numerous advancements have been made in recent years to help reduce the number of fatalities caused by fatal car accidents. Numerous attentions have been focused on the crashworthiness and road safety of vehicles. To increase crashworthiness, many vehicles incorporate lighter materials that can absorb forces during an impact, thereby reducing the risk of injury to human. Modern car manufacturers include numerous road safety devices and features in their vehicles. Frontal collisions have drew considerable attention from researchers and engineers seeking to improve the safety, as they account for approximately 50% – 70% of car accidents in developed countries [1].

There are numerous conditions that affect the frontal structure in car accidents. Several of them include the collision with another vehicle, a rigid wall, or other objects on the street [2-3]. There are numerous static objects along the street, particularly in urban areas, such as signposts, electrical poles, and lighting columns. The lighting column is constructed of structural steel and is primarily clad in aluminium to prevent corrosion. When a fast moving vehicle collides with a static object, such as a lighting column, the impact can be severe. If a vehicle collides with a lighting column, the remainder of the impact forces are absorbed by the vehicle's frontal parts. As a result, this situation presents a significant risk of injury and death to passengers.

The deformation of the vehicle's frontal parts can be determined using the Finite Element Method (FEM) by simulating the response and condition between the contacts. Both dynamic reaction and behaviours of the deformation of the vehicle frontal sections and lighting column can be determined at different collision speed (e.g. low, medium, and high speed).

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1.1 Car Crash Analysis

A car accident analysis is determined using a simulation that replicates a virtual car crash that can be used to determine and examine the level of safety of the vehicle and its passengers [4]. Computerized Aided Parametric Design (CAD) software is used to develop the problem model with detailed geometry, which is then transferred to a Finite Element Method (FEM) for preprocessing, solution, and post-processing. The FEM's output will next be interpreted in terms of various boundary conditions. Crash safety tests are carried out under a variety of conditions, including different types of collisions, different angles, different sides, and utilising different objects or other vehicles. Frontal impact crash tests, frontal offset crash tests, side impact crash tests, and rollover crash tests are the most prevalent types of crash tests.

1.2 Material of Car Crash Analysis

There are many materials that can be used in a crash analysis of vehicle components. Ambati et al. [5] uses aluminium AA5182 for the hood, door, founder and the wheel housing. Table 1 shows the material properties of aluminium AA5182 (aluminium alloy). Another study by Byeong Sam et al. [6] stimulates frontal analysis by using two distinct materials in the vehicle frame. Bhaskar et al. [7] used materials from Table 1 to design and analyse a car bumper based on material properties and strength. Aluminium is the most commonly used material for car bumpers due to its high energy absorption. However, in the bending test, aluminium is also the stiffest material, despite being the second best in terms of energy absorption.

Table 1 - Material properties of car component and vehicle frame

Material	Density(kg/m^3)	Young Modulus (GPa)	Poisson's Ratio
Aluminium AA5182	2.65	69.6	0.33
Aluminium A6061-T6	2.7	70.5	0.33
Steel	7.85	210	0.30

1.3 Vehicles Frontal Impact

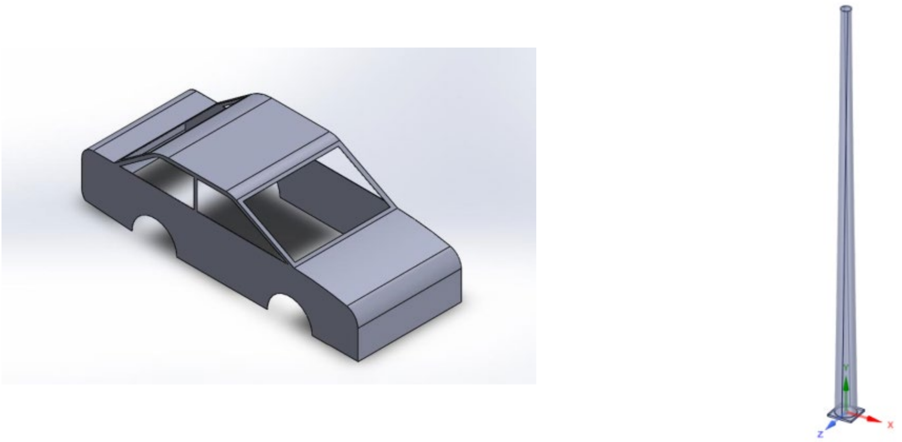
Frontal impact on a vehicle can occur in a variety of situations, including a car colliding with a pedestrian, a car colliding with a heavy goods vehicle (HGV), or a vehicle colliding with static objects [8]. Frontal impact happens when the entire front structure of the vehicle collides with another object, such as another vehicle or a rigid wall, at a specific speed. During a high-speed accident, the impact forces can create very large impact forces and deformation on the frontal structure region of vehicles. According to Abdel-Nasser [9], the front structure must be able to withstand the impact forces during the impact. Simulations of the human body's dynamic response during a frontal collision demonstrate that the occupant slides forward at a speed of 55 m/s. Even if passengers are wearing seatbelts, the high impact during a frontal accident at medium speed reveals that the rest forces absorbed by the front structure might pose a significant risk to the person. According to Teng Tso Liang et al. [10], the effectiveness of the safety belt can protect the occupant in a frontal impact condition, based on the simulation. The safety belt, on the other hand, restrains the upper torso and upper thigh but does not prevent the neck and head parts from moving forward. According to a physical frontal test conducted by the Australasian New Car Assessment Program (ANCAP), frontal impacts account for 60% of catastrophic crashes.

1.4 Finite Element Method (FEM)

The finite element method (FEM) or finite element analysis (FEA) is a computational or numerical method used in engineering and mathematical physics to generate approximate solutions to boundary value problems [11]. This method can be used to solve problems with complex geometry, loads, and material properties where an analytical solution cannot be found. The finite element method solves a problem by formulating the problem into a system of simultaneous algebra equations [12]. FEM programmes follow a typical three-step process. The first step is pre-processing, which involves generating data input, followed by solution, which involves calculating the case study, and finally post-processing, which involves generating the solution's result [13].

2. Methodology

In this study, SolidWorks was used to generate a geometric model of the vehicle and lighting column, as well as to assemble both parts by mating the front part of the vehicle and the face of the lighting column until they were fully defined. After importing the "igs or stl" files into ANSYS FEM software, both assembled pieces can be analysed for deformation after a crash at various speeds. The model's dimension is a real-life dimension that can be obtained in the company catalogue. The vehicle model in this study is based on the external car body structure rather than the actual internal components of the car engine. The vehicle's geometry model is shown in Figure 1(a). The dimensions of the vehicle are based on the actual car dimensions, which is the Toyota Camry, with a dimension of 4916 x 1445 x 1866 mm. The lighting column has a 6 m height, which is the standard for lighting columns, and a 350 mm diameter, which was derived from an existing dimension. The material for the lighting column is assigned after the model is finished. The lighting column produced with SolidWorks software is shown in Figure 1(b).



(a) (b)

Fig. 1 - Geometry model; (a) vehicle, (b) lighting column

ANSYS Workbench is used with Design Modeler as a finite element analysis (FEA) tool. The software can be used for performing structural, thermal, and electromagnetic analyses. The Design Modeler is a platform for creating and modifying geometry in preparation for ANSYS Workbench analysis. While SpaceClaim is a multipurpose 3D modelling application that can provide a cost-effective solution, it also eliminates geometry problems with various 3D CAD operations and reduces the time it takes to simplify the model. The geometric model of the car and the lighting column assembly is shown in Figure 2.

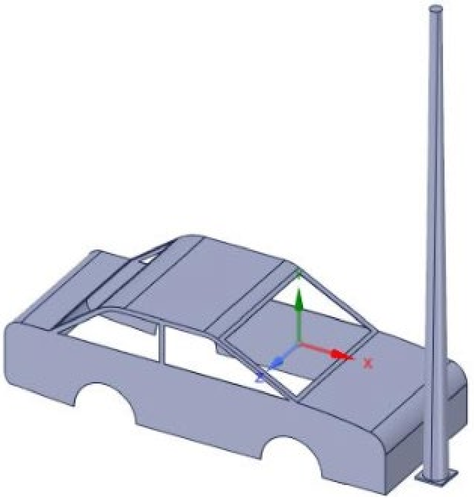


Fig. 2 - Geometry model of assembled vehicle and lighting column

3. Result and Discussion

3.1 Meshing of Model

Meshing aids in the solution of a problem by dividing the domain into multiple parts, each of which represents an element. Figure 3 depicts the finished mesh of the models. Because the front deformation is the one that has to be observed, the meshing is more detailed at the front area of the vehicle to produce an accurate result. According to the software's statistics, the total number of elements generated for the entire model is 17,816. The vehicle has a total of 10,282 elements, while the lighting column has 7,534. The frontal area of the vehicle, which is the bumper, and the contact area are specified by a smaller element size, which is 0.005 m. This is to ensure that the mesh at the frontal section of the vehicle face has greater details. The size of the element on the vehicle's other sides has been set at 1.2 metres. The CPU time can be lowered by applying course meshing on the other faces of the vehicle and reducing the number of possible meshes.

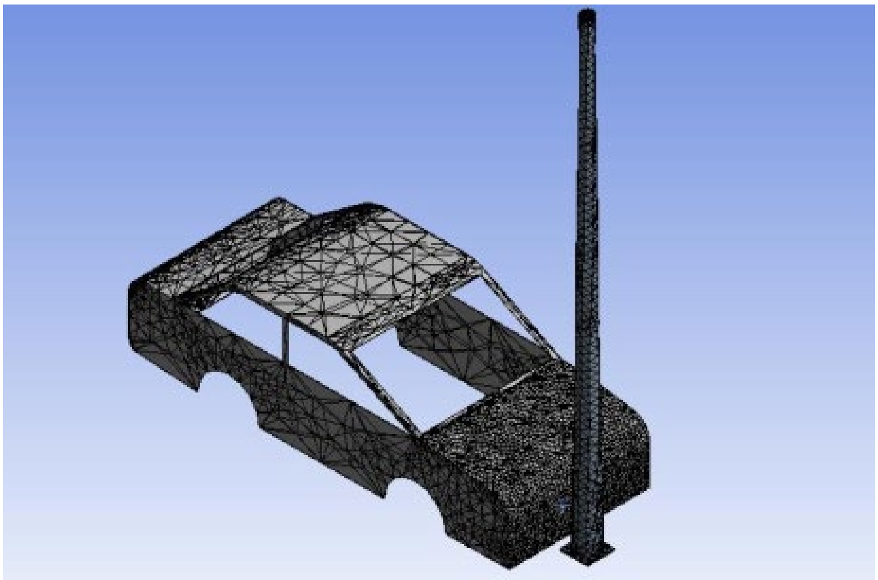


Fig. 3 - The meshing of geometry model assembly

3.2 Discussion and Observation

The vehicle is constructed of aluminium alloy, while the lighting column is made of structural steel. Table 2 shows the material properties of the materials used for the analysis. The vehicle body is deployed at speeds of 80 and 120 kilometres per hour. The lighting column's bottom base is assumed to be a fixed support, while the top is free to move. To ensure that the car is fixed in the y-direction, the vehicle body's displacement in the y-direction is set to 0 m at the bottom edges. The end time for the analysis is run up to 0.01 s for the whole analysis.

Table 2 - Material properties of the model

Material	Density(kg/m^3)	Young Modulus (GPa)	Poisson's Ratio
Aluminium Alloy NL	2.77	69	0.33
Structure Steel NL	7.85	200	0.30

Total deformation is calculated as the vector sum of all directional displacements of the system and represents the overall deformations caused by stresses on the model. The deformation of the vehicle's frontal area, which includes the bumper and contact area, must be determined. The deformation is visualised by the system after the collision of the frontal area of the vehicle against the lighting column. The displacement of the system in a given direction and along a certain axis (in this case, the x-axis) is referred to as directional deformation. The equivalent (von – Mises) stress is a value that used to determine whether the given material will yield or fracture. A material will yield when the stress of the material under load is equal to or greater than the yield limit of the specified material under tension.

3.3 Deformation Result at Velocity of 80 km/h

Figure 4 depicts the total deformation between the vehicle's frontal areas and the lighting column following the collision. A velocity of 22.22 m/s (80 km/h) is applied to the vehicle body in the initial condition. According to the results in Figure 5 and Table 3, deformation increases as internal energy increases and kinetic energy decreases. The deformation is at its maximum when the internal energy is at its peak because of the collision of the car against the lighting column. When the car begins to bounce back in the second stage, the deformation decreases. Based on the results in Table 3, the maximum deformation over time at the velocity of 80 km/h is 0.071373 m or 71.373 mm, as shown in Figure 4. The maximum deformation over time is increasing when the velocity of the vehicle is increased. The high velocity of the vehicle makes the internal energy increase thus the deformation at the frontal part more severe. This circumstance has a good agreement with the study conducted by Yong Han et al. [14] in which vehicle impact velocity influence the human kinematics and injury severity.

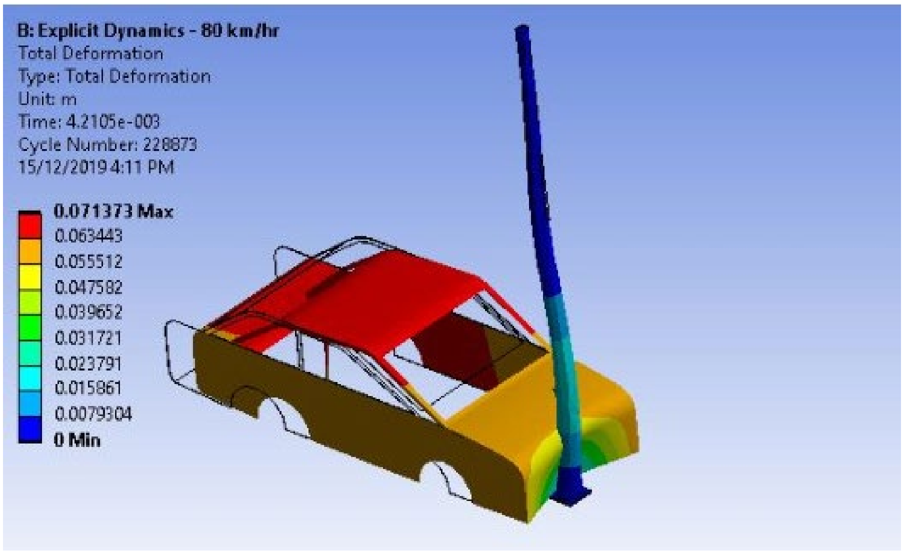


Fig. 4 - Deformation of vehicle and lighting column at 80 km/h

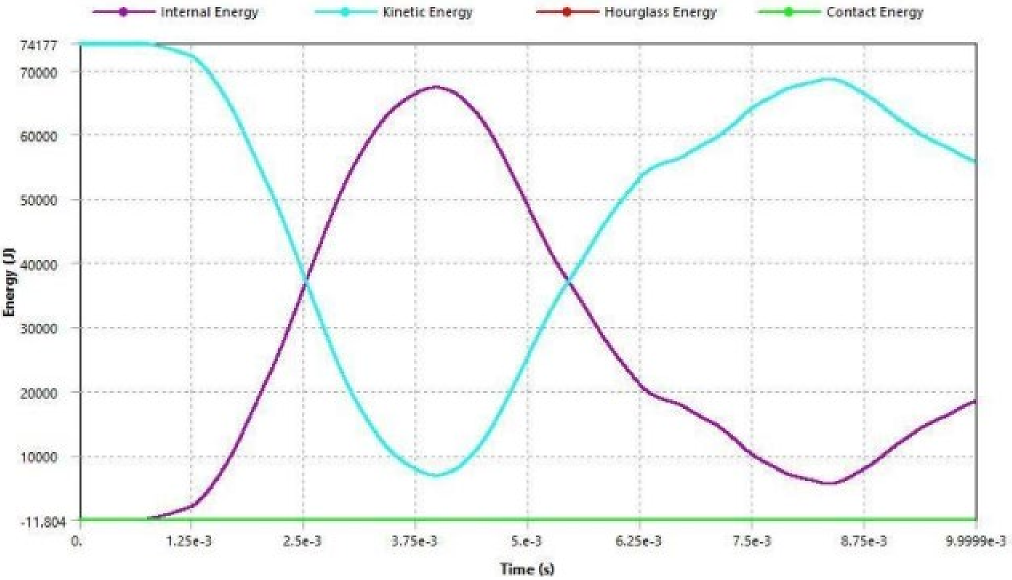


Fig. 5 - Impact energy profile at velocity of 80km/h

Table 3 - Solution result of crash impact at velocity 80 km/h and 120 km/h

Description	Total Deformation (m)	Maximum Deformation (m)	Equivalent (Von-Mises) Stress (Pa)
Velocity = 80 km/h			
Maximum value over time	7.1373×10^{-2}	7.1137×10^{-2}	2.3311×10^{9}
Minimum value over time	0	-6.5503×10^{-2}	0
Velocity = 120 km/h			
Maximum value over time	0.10218	9.4166×10^{-2}	3.5306×10^{9}
Minimum value over time	0	-0.10142	0

The vehicle's internal energy begins to build when it collides with the lighting column, as seen in Figure 5. The internal energy of the vehicle begins to decrease as it begins to bounce back. The kinetic energy drops during the collision with the lighting column and begins to grow after the bounce back from the lighting column. The collision of the vehicle against the lighting column can be seen when the internal energy is at its maximum and the kinetic energy is at its minimum. This is because the car receives the most impact energy during the crash, resulting in the highest internal energy.

3.4 Deformation Result at Velocity of 120 km/h

Figure 6 depicts the total deformation of the car following impact with the lighting column at a speed of 120 km/h. The initial condition of the analysis is a velocity of 120 km/h applied to the vehicle's body. Figure 7 shows the analysis' energy vs. time graph. As the vehicle collides with the lighting column, its internal energy begins to rise. The internal energy of the vehicle begins to decrease as it begins to bounce back. The collision of the vehicle against the lighting column can be seen when the internal energy is at its maximum and the kinetic energy is at its minimum. This is because the car receives the most impact energy during the crash, resulting in the highest internal energy. The kinetic energy is decreasing because the vehicle stops during the impact against the lighting column.

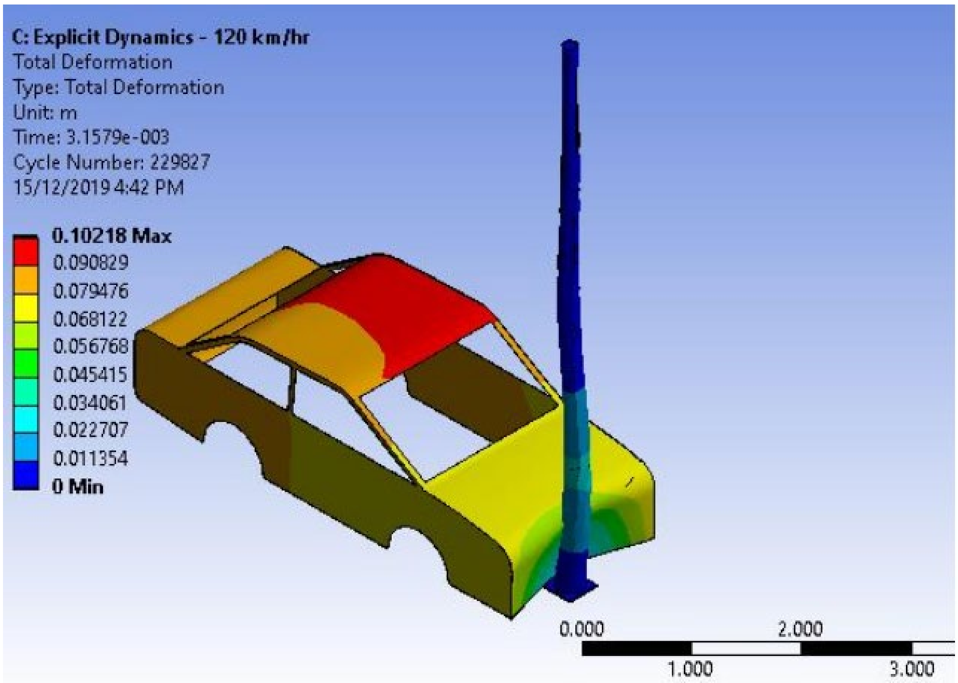


Fig. 6 - Deformation of vehicle and lighting column at 120 km/h

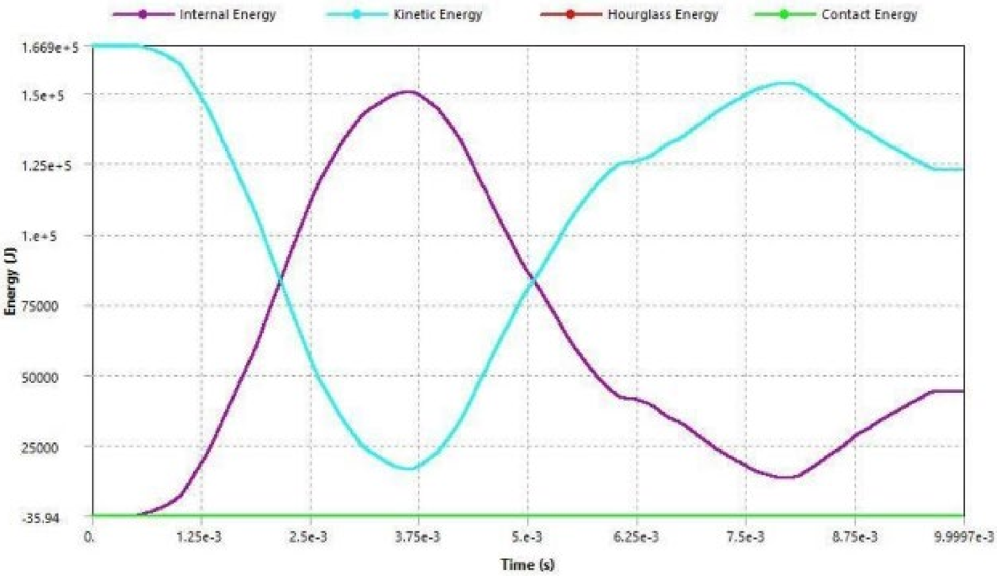


Fig. 7 - Impact energy profile at velocity of 120km/h

The two intersection points between internal and kinetic energy indicate the vehicle's contact with the lighting column. According to the energy graph in Figure 7, the collision between the vehicles and the lighting column begins at around 0.0019 seconds. The graph demonstrates that as the vehicle's velocity increases, the time before the vehicle collides with the lighting column decreases. The second stage occurs near the second intersecting line, at which point the vehicle begins to bounce back. The vehicle bounces back around 0.005 s at a velocity of 120 km/h. When the vehicle's velocity increases, the vehicle begins to bounce slightly faster.

Deflection occurs when a sufficient load is applied to the material that exceeds its yield strength, causing plastic deformation. The material returns to its original shape when the force is released, which is known as elastic deformation. This explains why the energy vs. time graph has two intersecting lines. The first intersection occurs when the material undergoes plastic deformation, while the second intersection occurs when the aluminium alloy undergoes elastic deformation.

3.5 Analysis on Equivalent (Von - Mises) Stress Result

The equivalent stress depicts the material behaviour of a vehicle's structure during a collision. Table 2 shows the properties of the material in consideration. Structural steel has four times the strength of aluminium alloy and has a higher density. The maximal stress occurs at the highest internal energy, according to Table 3. At an average speed of 80 km/h, the maximum stress is 2.3311 x 109 Pa. At a speed of 120 km/h, the maximum stress is 3.5306 x 109 Pa. The stress is increasing as the speed increases. It demonstrates that when velocity rises, the equivalent stress rises with it. Because structural steel is stronger than aluminium alloys, the result reveals that the material of aluminium alloys yields over time. When the stress is greater than the yield strength, which is 0.28 x 109 Pa, the aluminium alloy yields, causing deformation. All of the maximum stress readings revealed that the stress is greater than the aluminium alloy's yield strength.

4. Conclusion

The response of the vehicle dynamics following a frontal collision with a rigid column has been tested and analyzed. The geometry of the both models is created using SolidWorks software and the assembly file is created using ANSYS SpaceClaim. Appropriate material and boundary conditions must be applied to the model before the deformation on the vehicle's frontal area can be estimated. Aluminium alloy is used in the vehicle model while structural steel is applied to lighting column model. The impact energy profile shows two stages of the collision. The first stage demonstrated the vehicle colliding with the lighting column, while the second stage showed the vehicle rebounding from the impact because of the elasticity of the materials. The internal energy surged following contact with the lighting column and decreased as it began to bounce back, according to the Impact energy profile results. Similarly, the kinetic energy of the vehicle drops after contact and increases as it is bounced back.

The time taken for the vehicle to collide with the lighting column grows in direct proportion to the vehicle's increased velocity, as seen in the energy vs. time graph. The graph of total and directional deformation vs time showed that deformation increases as internal energy increases. When internal energy is increased, the equivalent of von–Mises stress also increases. The deformation, stress and internal energy are increasing when the velocity is increasing. Because of the increased internal energy caused by the high stress, the deformation is more severe. As a conclusion, a vehicle that collides with rigid or static objects at high speed, pose a significant risk to the occupant. Safety measure such as the application of soft bumper should be installed in a vehicle to absorb impact energy during collision.

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