RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING
e-ISSN: 2773-4765

RPMME

Vol. 5 No. 1 (2024) 180-191
https://publisher.uthm.edu.my/periodicals/index.php/rpmme

# Crash and Impact Analysis of Light Vehicle Against Traffic Light Pole

**Puvanithan Raguraman[1], Mohd Norihan Ibrahim [1*]**

[1] *Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), Batu Pahat, 86400, MALAYSIA*

*Corresponding Author: norihan@uthm.edu.my
DOI: https://doi.org/10.30880/rpmme.2024.05.01.020

**Article Info**

Received: 03 February 2024
Accepted: 06 July 2024
Available online: 15 September 2024

**Keywords**

Crash, Vehicle, Traffic Light Pole, Deformation, Speed, ANSYS

**Abstract**

When a car collides with a rigid object on the road, such as a traffic light pole or a lighting column, the occupants are put in grave danger. Collisions such as these could cause a major unfortunate to both vehicles, human and infrastructure. It will cost financially and pose harm to public or pedestrians as well. To better understand the impact dynamics of such collisions, a study was conducted on the crash and impact analysis of a light vehicle against a traffic light pole. The study focused on the deformation of the vehicle's frontal area against the traffic light pole at various speeds, which were classified into two categories, which is medium low speed and medium high speed. The study used ANSYS explicit dynamics finite element method to conduct the numerical analysis and simulation. The total deformation, equivalent Von-Mises stress, and directional deformation analysis provided detailed insights into the dynamic response of the vehicle and traffic light pole interaction. The results shows that when going at higher speeds, the traffic light pole caused additional deformation on the frontal region of the vehicle. Due to the material quality of the aluminium alloy, the car absorbed more impact energy than the traffic light poles due to the high internal energy released during the crash. The findings of this study can help improve the safety of vehicles and traffic light poles, reducing the financial cost and harm to the public or pedestrians caused by such collisions.

## 1. Introduction

Road traffic accidents are a significant issue worldwide, with millions of collisions occurring annually, resulting in numerous injuries and fatalities [1]. In urban and rural areas, the presence of lighting columns, traffic light poles, and signposts increases the likelihood of light vehicle collisions, which can have severe consequences for both vehicles and infrastructure. The International Federation of Red Cross and Red Crescent Societies has described the situation as a worsening global disaster that destroys lives and livelihoods, hampers development, and leaves millions in greater vulnerability [2].

The study addresses the varying degrees of deformation and impact forces generated during collisions between vehicles traveling from lower to higher speeds and stationary objects, such as traffic light poles. Analyzing the dynamic response of frontal crashes, as explored by Abdel-Nasser in 2013, focuses on the severe impact forces and potentially fatal risks posed to passengers. Abdel-Nasser's study delves into the damage severity on both vehicles and lighting columns, emphasizing the limited impact energy absorption capabilities of rigid lighting columns with high yield strength material [3]. The need to refine crash models for accurate predictions of

peak acceleration values during collisions with traffic light poles becomes evident. Additionally, insights from Ispas & Nastasoiu's 2017 study, involving four car-to-pole crash tests with varying years of car manufacture, highlight
the satisfactory performance of older car front ends despite less advanced materials and technology [4]. The findings emphasize the necessity of further studies utilizing a single car model to comprehensively analyze vehicle crashes against traffic light poles.

The focus of this study is on the crash and impact analysis of light vehicles against traffic light poles, which are common in urban areas and serve as essential safety infrastructure. The primary objective is to examine the dynamic behavior of light vehicles during frontal collisions with traffic light poles and to analyse the total deformation, equivalent Von- Mises stress and deformation pattern of light vehicles involved in collisions with traffic light poles. By conducting a numerical analysis using the Finite Element Analysis (FEA) method, this study aims to provide valuable insights into the dynamic response of the vehicle and traffic light pole interaction at various impact velocities.

This study offers significant insights into the risks involved in collisions between lightweight vehicles and traffic light poles at different speeds (low and high speed). By identifying the factors that influence the severity of such collisions, this study can guide the development of safety measures to reduce the associated risks. Additionally, the study helps in better understanding the dynamics and impact forces involved in collisions between lightweight vehicles and traffic light poles, aiding in designing improved safety features and crash mitigation strategies for vehicles. Lastly, the findings of this study can contribute to the development of new materials for traffic light poles that can better absorb impact forces during collisions, potentially reducing the severity of collisions and minimizing the risks to both vehicle occupants and pedestrians.

## 1.1 Finite Element Method (FEM)

Real-world crash tests might be difficult to carry out due to the need for proper facilities, precise measurement tools, effective data collecting techniques, qualified employees, and, of course, access to a vehicle [5]. As a result, rather than depending completely on real-world crash tests to approximate and comprehend the outcomes, it is reasonable to present a model of a collision and undertake an analysis. According to Venkatesh et al., 2022, the introduction of high-performance computers and crash simulation software has resulted in a change in perspective in the process [6]. Instead of relying primarily on experimental validations, computer simulations are being used to examine and evaluate designs during the safety design process. This integration enables a more thorough evaluation of the design's safety characteristics and lowers reliance on traditional experimental methods. Finite element methods are increasingly used to numerically address structural, hydrodynamic, and Multiphysics problems [7]. The Finite Element Method (FEM) is widely used in engineering and scientific areas due to its capacity to mathematically represent and numerically solve exceedingly detailed problems [8]. FEM studies are used to analyze and develop designs, while researchers in numerous scientific domains use this method to acquire insights into natural events and forecast their occurrence. The ability to predict design performance and anticipate natural phenomena is extremely valuable, allowing for increased safety and cost-effectiveness in design processes as well as the prevention of possible calamities.

## 1.2 Vehicle Crash Analysis

Crash tests are destructive tests used to ensure that different types of vehicles meet design standards for crashworthiness and crash compatibility. These tests evaluate the performance of vehicles, as well as their systems and components, under various accident conditions. Various types of crash tests include frontal impact tests, offset tests, side impact tests, and rollover tests, each focusing on a different component of a vehicle's safety performance. A vehicle 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 [9]. 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 [10].

## 1.3 Vehicle Impact Speed

The impact of speed on car accidents is a critical factor in determining the extent of injuries and fatalities. Several studies have investigated the relationship between impact velocity, impact speeds, and the probability of various injury outcomes in car accidents. For instance, Jurewicz et al. (2016) explored the relationship between impact velocity change, impact speeds, and the probability of different injury outcomes in car accidents, with implications for safer road design [11]. Additionally, studies by Torrão (2022) and Gunn (2022) have focused on the effects of speed on crash-related injuries and the severity of crash outcomes, emphasizing the importance of safe driving behaviors and proactive measures in road design to mitigate the impact of speed on car crashes [12][13]. Several investigations have utilized finite element analysis (FEA) to examine the collision and impact of light vehicles against traffic light poles at varying speeds. Study by Idrees et al. (2023) have employed FEA to assess the crashworthiness of vehicles, explore the impact analysis of car collisions on street poles, and evaluate the important aspects that can affect anticipated occupant safety levels [14]. These studies have provided valuable insights into the impact of speed on crash outcomes and the crashworthiness of vehicles using FEA.

## 2. Methodology

This chapter discusses the process of creating a research project using SolidWorks software to generate detailed geometric models of a structure and its components. The project's main objective is to analyse the impact of a vehicle colliding with a traffic light pole by simulating collision scenarios at speeds of 40 km/h and 80 km/h. The project aims to evaluate the dynamic response of the system and gather insights into the behaviour of the vehicle and the effects on the traffic light pole. The project also aims to investigate the impact forces and structural behaviour during realistic collision scenarios by simulating collision scenarios at speeds of 40 km/h and 80 km/h. These speeds were chosen because they represent low to moderate-speed impacts that are common in urban and suburban driving environments.

### 2.1 Material Selection

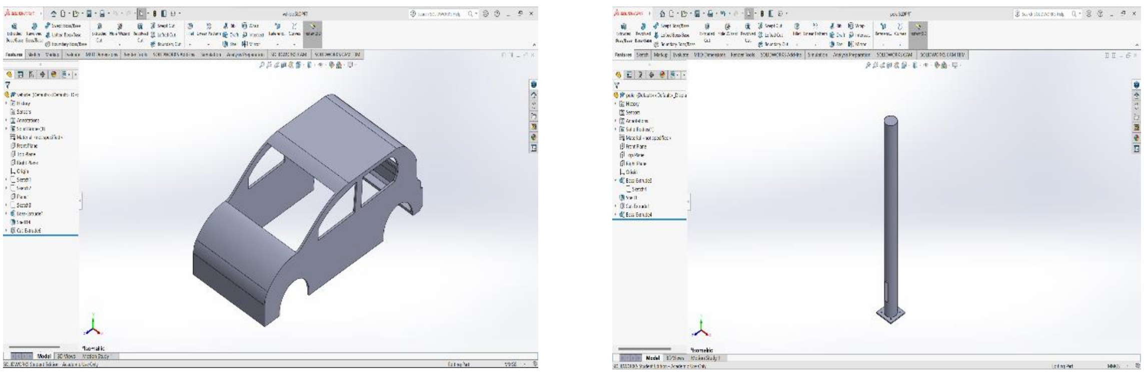
Material properties for geometry models are specified in ANSYS Workbench by determining the Engineering Data and selecting the suitable materials. Material selection is critical for accurately depicting the physical properties and behaviour of objects during simulation. The traffic light pole is built of structural steel, while the vehicle is made of aluminium alloy.

**Table 1** *Material Properties of Vehicle and Traffic Light Pole*

| Material | Density ($kg/m^3$) | Young Modulus (GPa) | Poisson's Ratio |
|---|---|---|---|
| Structural Steel | 7850 | 69 | 0.33 |
| Aluminium Alloy | 2770 | 200 | 0.30 |

### 2.2 Geometry Model

These dimensions are real-world measures that are obtained from company catalogues. In the case of the vehicle model, it concentrates solely on the automobile body structure. To ensure realism, the vehicle dimensions are based on actual automotive dimensions, such as the Perodua Myvi 2015 model, which measures 3695 x 1570 x 1665 mm. 4 m is a standard height for a pole in traffic light poles. The pole's dimensions are established by existing standards, with a diameter of 300 mm.



(a) (b)

**Fig. 1** *Geometry model of (a) Vehicle; (b) Traffic Light Pole*

## 2.3 Assembling Geometry Models

In the GEOMETRY section, access SpaceClaim by right-clicking and selecting the option to EDIT GEOMETRY IN SPACECLAIM. Once SpaceClaim is launched, proceed by clicking on ASSEMBLY. From the FILE menu, choose the respective geometry files in the desired format. Adjust the position of the geometries within the SpaceClaim environment until the desired arrangement is achieved.

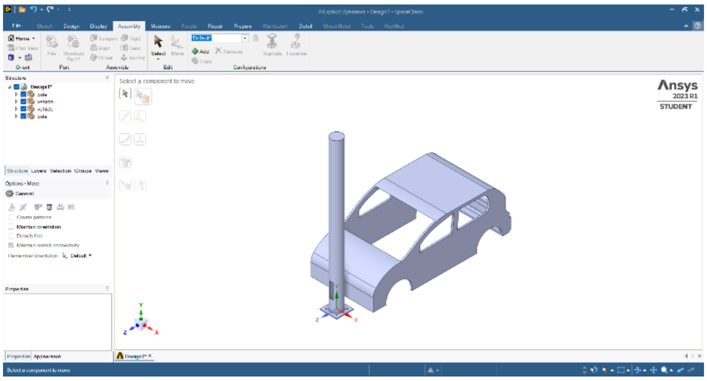


**Fig. 2** *Assembled Geometry Models*

## 2.4 Mesh

Meshing aids in problem solving by dividing the domain into multiple parts, each of which represents an element. The meshing is more defined in the front of the vehicle to get an accurate result because the front deformation must be observed. The mesh statistics reveal that the model comprises 4,929 elements and 2,205 nodes, well within the constraints of the ANSYS student version, which allows a maximum of 32,000 elements or nodes. To enhance efficiency and accuracy, face sizing is applied, reducing element size on non-frontal faces while fine-tuning element sizing on the critical frontal area, including the bumper and contact region. The volume of the vehicle model and traffic light pole is specified as 0.4667 $m^3$ and 0.2827 $m^3$, respectively. While refining frontal elements is crucial for a comprehensive analysis of post-collision deformation, the trade-off involves an impact on solution time. A solution with a time step of 0.0327 s takes approximately 15 minutes to complete, acknowledging the influence of the machine's capabilities on solution time. Striking a balance between mesh refinement for accuracy and computational efficiency becomes imperative, considering the impact on both result precision and the time required for the analysis within the constraints of the ANSYS student version.

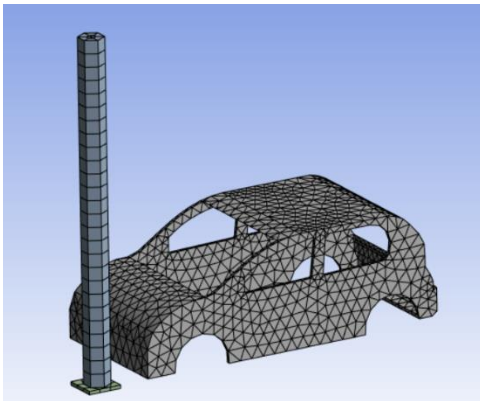


**Fig. 3** *Final Mesh*

## 2.5 Simulation

Simulation, particularly in the context of finite element analysis (FEA) and ANSYS Workbench, involves creating vehicle and traffic light pole models and using computational techniques to predict the behaviour of real-world systems under various conditions. To initiate the process, launch the ANSYS Workbench software. Then, locate and select the appropriate analysis system module from the toolbox. Access the material parameters and choose the materials for both geometries. To set up a mesh connection in ANSYS mechanical, the user needs to navigate to the connections section and verify that the desired connection type is selected, add a manual contact region, generate the mesh for the geometry model, and confirm the presence of a green "arrow" sign next to the connections, indicating successful setup. additionally, the user can adjust the sizing of the geometry using the sizing feature by clicking on insert and selecting sizing, allowing for modifications to the body or face of the geometry. To set up initial conditions and apply velocities to the vehicle and traffic light pole models in ANSYS, the user should access the initial condition section, insert a new velocity, select the vehicle model using the body command, and apply the desired velocity and direction using the components option. additionally, to fix the support and restrict the vertical movement of the vehicle model, a fixed support should be inserted, and a displacement should be applied to the appropriate face. similarly, to assign velocity to the car model, the explicit dynamics section should be used, and the desired velocity and direction should be applied to the car model. To solve the analysis in ANSYS, the user should input the desired end time based on the required displacement, set the number of points under output control to 100, initiate the pre-processing phase by clicking solve, insert the deformation feature, insert the total deformation, and select the equivalent von mises option by right-clicking on stress, and then right-click on the solution tab and select evaluate all results to obtain a comprehensive assessment of the obtained results.

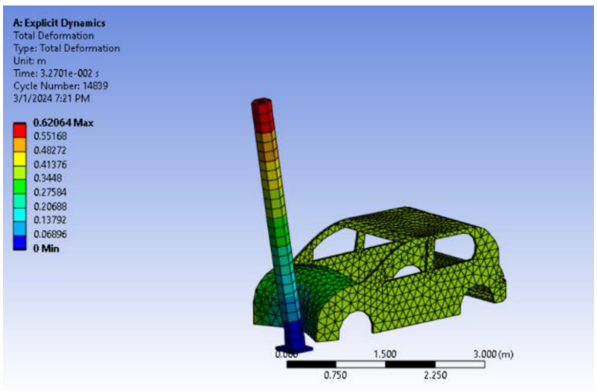
## 2.6 Solution

In this analysis, the vehicle, composed of aluminum alloy, collides with a traffic light pole made of structural steel, and their material properties. Simulations are conducted at velocities of 40 km/h and 80 km/h, with the traffic light pole's bottom base fixed as a support, and the top free to move. The focus is on determining the total deformation at the frontal area of the vehicle, including the bumper and contact region, post-collision. The analysis emphasizes directional deformation along the x-axis to understand how the vehicle moves and deforms during and after the collision. Additionally, the equivalent (von Mises) stress is considered to assess whether the materials are likely to yield or fracture under specific loads, providing insights into the point of yielding and potential structural deformations during the impact with the traffic light pole.

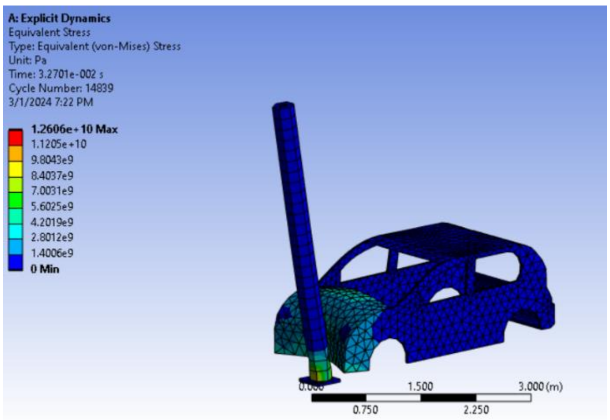
# 3. Results and Discussion

## 3.1 Simulation Result at 40 km/h

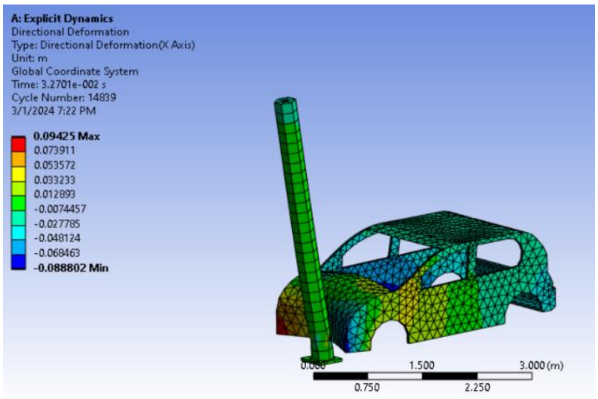
The visualization illustrates the comprehensive deformation of the car following a collision with a traffic light pole at a speed of 40 km/h, serving as the initial condition for the entire vehicle body throughout the simulation. The total deformation map provides a detailed representation of how the vehicle structure deforms and distorts due to the interaction with the traffic light pole.




(a)

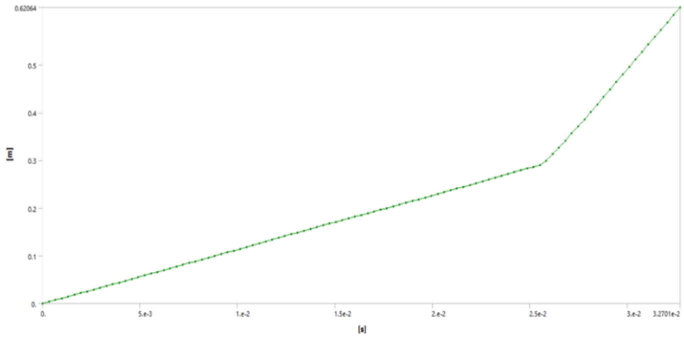



(b)

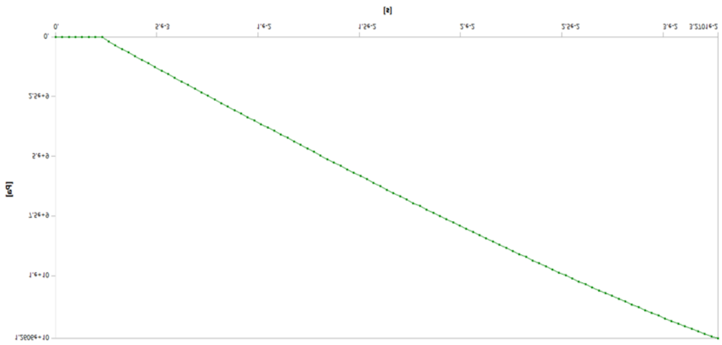



**(c)**

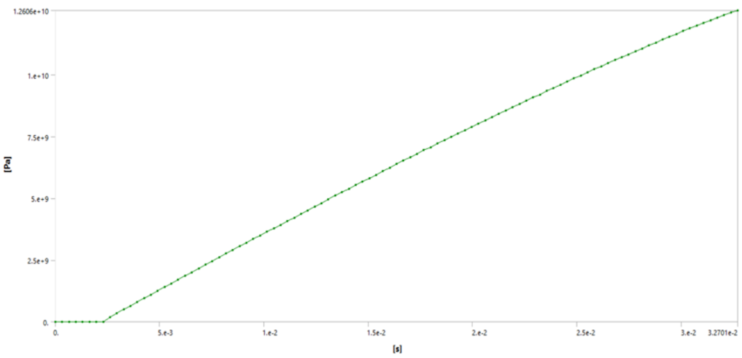
**Fig. 4** *40 km/h of (a) Total Deformation; (b) Equivalent Von-mises Stress; (c) Directional Deformation*




**(a)**



**(b)**




**(c)**

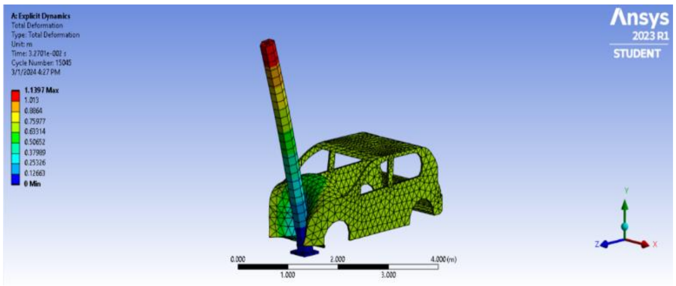
**Fig. 5** *40 km/h of (a) Total deformation vs time graph; (b) Von- mises stress vs time graph; (c) Directional deformation vs time graph*

**Table 2** *Result Solution at 40 km/h*

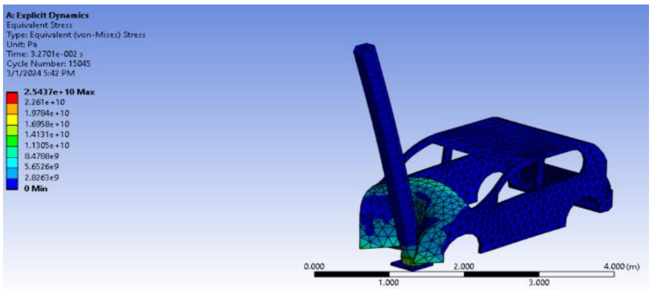
| Analysis Type | Max Value Over Time | Min Value Over Time |
|---|---|---|
| Total Deformation | 0.62064 m | 0 m |
| Equivalent Von- mises | 1.2606e+10 Pa | 0 Pa |
| Directional Deformation | 0.09425 m | -0.088802 m |

## 3.2 Simulation Result at 80 km/h

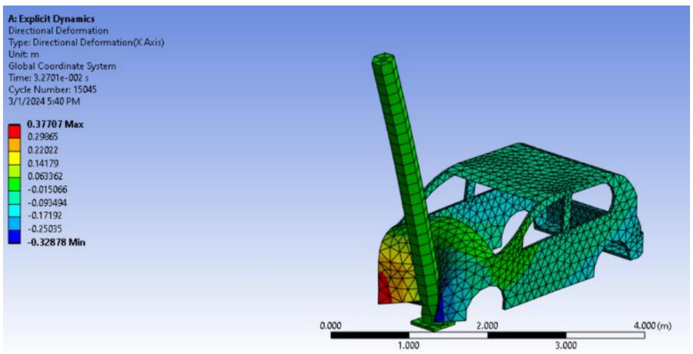
The presented figure illustrates the overall deformation resulting from the collision between the vehicle's frontal region and a traffic light pole. The simulation initiates with an initial condition applying a velocity of 80 km/h to the entire vehicle body. This visual depiction of total deformation, equivalent stress, and directional deformation provides crucial insights into the structural response of the vehicle during the specified collision scenario. The chosen velocity of 80 km/h significantly influences both the magnitude and distribution of deformation across the vehicle. Analyzing these deformation patterns offers valuable information for assessing the severity of impact and identifying potential structural vulnerabilities in the frontal area of the vehicle following the collision with the traffic light pole.




**(a)**

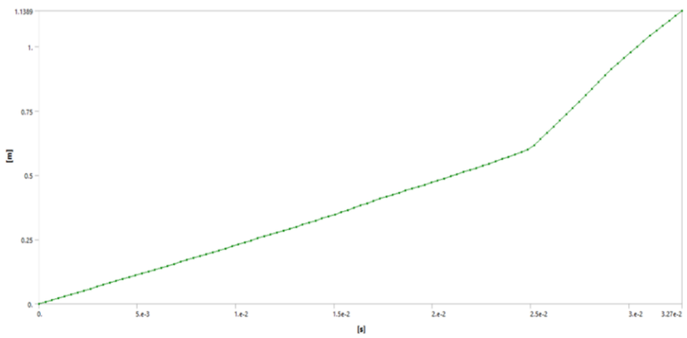



**(b)**

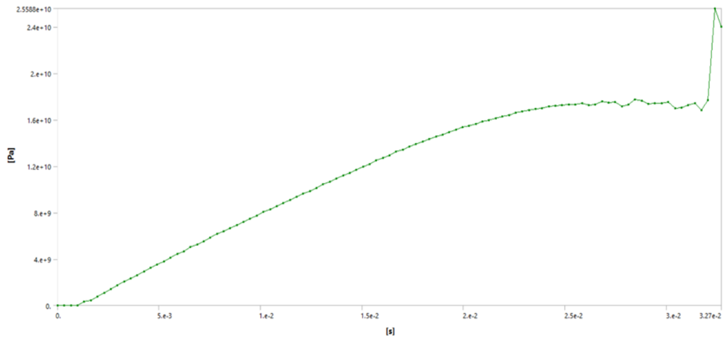



**(c)**

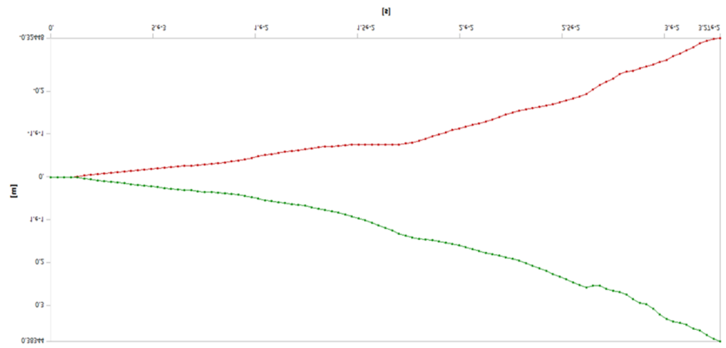
**Fig. 6** *80 km/h of (a) Total Deformation; (b) Equivalent Von-mises Stress; (c) Directional Deformation*



**(a)**



**(b)**



**(c)**

**Fig. 7** *80 km/h of (a) Total deformation vs time graph; (b) Von- mises stress vs time graph; (c) Directional deformation vs time graph*

**Table 3** *Result Solution at 80 km/h*

| Analysis Type | Max Value Over Time | Min Value Over Time |
|---|---|---|
| Total Deformation | 1.1397 m | 0 m |
| Equivalent Von- mises | 2.5437 e+10 Pa | 0 Pa |
| Directional Deformation | 0.37707 m | -0.32878 m |

## 3.3 Analysis on Total Deformation

The analysis of results highlights a consistent pattern in the relationship between deformation, internal energy, and kinetic energy throughout and after the interaction between the vehicle and the traffic light pole. Notably, a clear correlation emerges as deformation increases with rising internal energy, signifying energy transfer during the collision. The highest deformation occurs concomitantly with peak internal energy, emphasizing that the collision induces maximal deformation. Examining various velocities, the greatest deformation at 40 km/h registers at 0.62064 m, reaching its highest point during the impact. With an increase in velocity to 80 km/h, the maximum deformation escalates to 1.1397 m, reflecting heightened impact energy. Plots consistently depict that higher vehicle velocities correlate with increased maximum deformation over time, indicative of more severe frontal deformation during crashes. The association between elevated velocities and higher internal energy underscores potential risks to occupants in collisions with rigid objects. Notably, the aluminum alloy's ability to compress more than structural steel allows for substantial absorption and release of internal energy, contributing to the vehicle's safety by mitigating deformation and, consequently, minimizing risks to occupants during collisions with rigid objects.

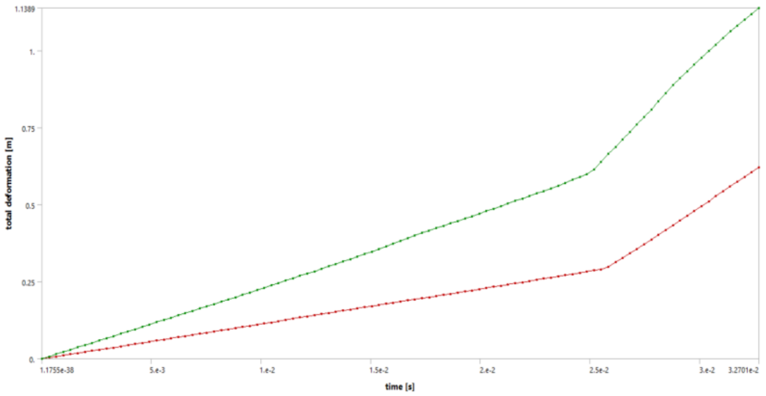
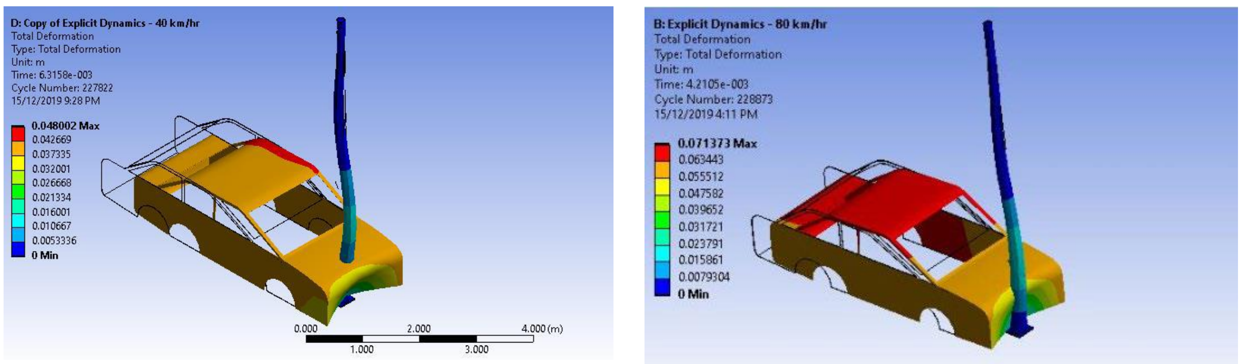



**Fig. 8** *Total deformation vs time graph for 40 km/h and 80 km/h*

The total deformation analysis conducted at 40 km/h and 80 km/h serves as a stage for the initial validation of this paper in comparison to other literature sources. This choice is informed by the fact that, at higher speeds, the kinetic energy is directly proportional to the square of the velocity, potentially leading to significant differences that could introduce uncertainties in the validation process. To establish validation, the absorbed energy obtained from collision analyses on steel street poles by Hayati Ismail et al., 2021 is compared with the results presented in this paper [15]. The deformation pattern in this study is notably more pronounced when compared to the study with similar total deformation patterns at both velocities. The total deformation value in the previous study for 40 km/h (0.048 m) and 80 km/h (0.071 m) is significantly less than in this study. The enhanced clarity and distinctiveness of the observed deformation in the current findings underscore the significance of the run time being the same at different velocities, allowing for a more detailed analysis of the impact dynamics at play. This provided specific points for velocities and the geometry of both models, offering a more comprehensive understanding of the deformation patterns. The boundary conditions applied to the models in the current study might have been different from those in the previous study, leading to different deformation patterns. Moreover, boundary conditions can significantly influence the behavior of a material under deformation, defining specific points for velocities and the geometry of both models, providing a more detailed insight into the impact dynamics at play.




**(a)** **(b)**

**Fig. 9** *Total deformation pattern at (a) 40 km/h; (b) 80 km/h (Hayati Ismail et al., 2021)*

## 3.4 Analysis on Equivalent Von- Mises Stress

The Equivalent Von-Mises stress during the impact is illustrated in the figures, providing insights into how materials respond to energy or force and indicating potential yielding. Material properties play a critical role in understanding how structural steel and aluminum alloy react to impact forces, with notable distinctions given structural steel's approximately four times greater strength and density compared to aluminum alloy. Evaluating

Equivalent Von-Mises stress allows for an assessment of the materials' structural integrity under specific impact conditions. Graph analysis reveals that maximum stress occurs during the impact at the highest internal energy, reaching 1.2606 e+10 Pa at 40 km/h and increasing to 2.5437 e+10 Pa at 80 km/h. The continuous rise in stress with increasing velocity indicates a proportional increase in equivalent stress on the material. Notably, the stress values surpass the yield strength of aluminum alloy, leading to yielding during the collision. This observation underscores the material's deformation behavior under the applied forces during the impact, highlighting the importance of considering material properties for design considerations and safety assessments in collision scenarios.

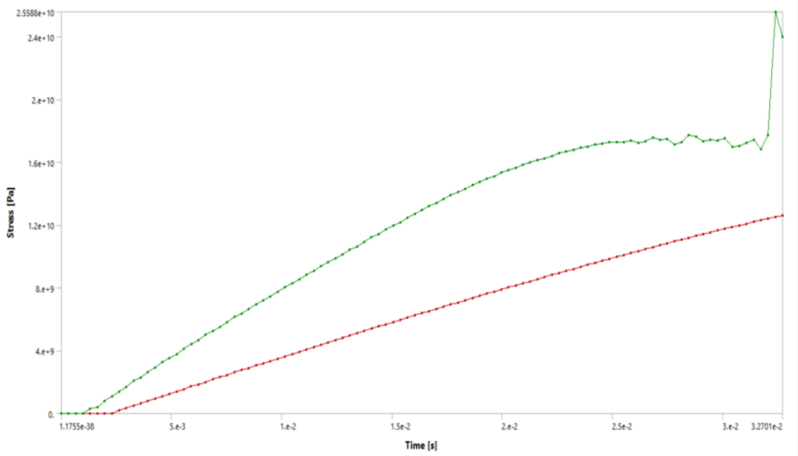
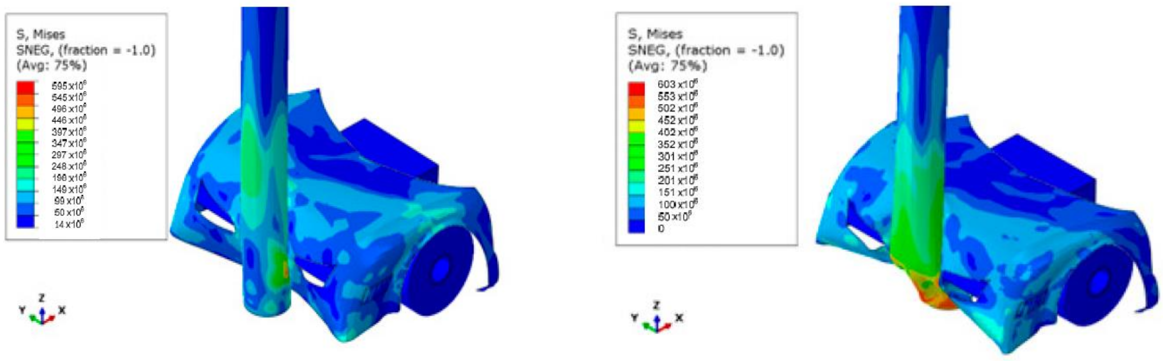



**Fig. 10** *Von- mises stress vs time graph for 40 km/h and 80 km/h*

Validation involved comparing findings with Alardhi et al., 2022, showing similar impact force and deformation patterns at 43 km/h and 80 km/h collisions [16]. Maximum Von-Mises stress was 595×10⁶ Pa at 43 km/h and 603×10⁶ Pa at 80 km/h. Differences in diameters, time, and a slight velocity variance (40 km/h to 43 km/h) exist. This study employs a larger dimension (approximately 250 mm), contributing to increased impact forces. Geometric variations may introduce computational differences. Unlike Alardhi et al., which analysed aluminium and steel, our focus is on a steel pole (300 mm diameter). This comparison is specific to structural steel street poles.




**(a)** **(b)**

**Fig. 11** *Von- misses stress distribution of central impact on steel street pole at (a) 40 km/h; (b) 80 km/h (Alardhi et al., 2022)*

## 3.5 Analysis on Directional Deformation

The results of directional deformation have rarely been published. Due to the absence of validation sources, this section focuses on presenting novel results. The aim is to enhance the understanding of directional deformation at different velocities. The analysis of deformation data reveals a consistent alignment between maximum deformation in the x-axis direction and the point of maximum internal energy. This correspondence echoes the overall trend observed in total deformation results, consistently showing that deformation peaks when internal energy reaches its maximum. This connection underscores the pivotal role of impact energy in causing material deformation during the collision between the vehicle and the traffic light pole. The conclusions drawn from maximum deformation values over time indicate a pattern where the highest deformation at 40 km/h reaches

0.09425 m, increasing to 0.37707 m at 80 km/h. This consistent pattern emphasizes the proportional relationship between impact velocity and resultant deformation, highlighting that higher velocities lead to larger deformations over the duration of the collision. The observed alignment between the greatest deformation values and the overall trend in total deformation underscores the impact of internal energy on deformation. The crucial observation is that, as internal energy increases, maximal deformation values also rise, emphasizing the significance of internal energy in regulating deformation levels during the collision. This interconnected relationship stresses the importance of internal energy awareness and management in predicting and mitigating the impact of crashes on the structural integrity of the vehicle.

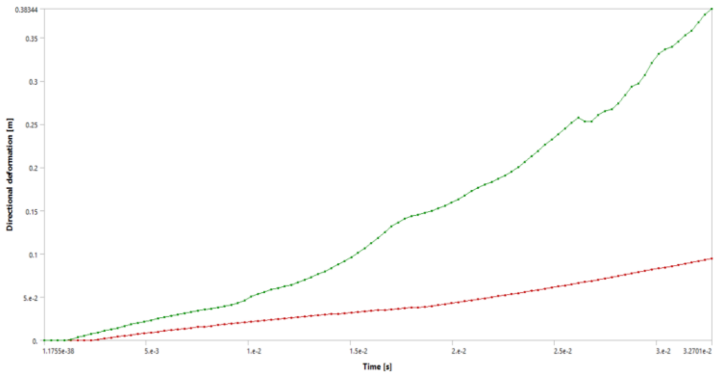



**Fig. 12** *Directional deformation vs time graph for 40 km/h and 80 km/h*

## 4. Conclusion

The study successfully achieved its objectives by utilizing SolidWorks for geometry creation and ANSYS Space Claim for assembly file construction, ensuring a comprehensive representation of the vehicle and traffic light pole. The model employed aluminium alloy for the vehicle and structural steel for the traffic light pole, with a meticulously optimized meshing method within the ANSYS student edition limits. Face scaling algorithms enhanced mesh efficiency, particularly in the frontal area, crucial for deformation studies. The analyses of total deformation, equivalent Von-Mises stress, and directional deformation provided detailed insights into the dynamic response of the collision, revealing consistent patterns in the relationship between deformation, internal energy, and kinetic energy. The interplay between impact conditions, material qualities, and subsequent deformation, as indicated by the findings, offers valuable information for design considerations and safety assessments in collision scenarios. The data underscores the importance of impact energy in inducing material deformation, with implications for the risk to occupants in high-velocity crashes. The study concludes that safety measures, including softer bumpers, play a crucial role in absorbing impact energy and mitigating severe deformation in collisions with hard or static objects.

## Acknowledgement

The author wish to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia that has supported on the accomplishment of research activity.

## References

[1] The Lancet Global Health. (2019). Speaking up for global road safety. The Lancet Global Health, 7(6), e681. https://doi.org/10.1016/S2214-109X(19)30192-5
[2] Ameratunga, S., Hijar, M., & Norton, R. (2004). *Road-traffi c injuries : confronting disparities to address a global-health problem*.
[3] Abdel-Nasser, Y. A. (2013). Frontal crash simulation of vehicles against lighting columns using FEM. *Alexandria Engineering Journal*, *52*(3), 295–299.
[4] Ispas, N., & Nastasoiu, M. (2017). Analysis of car's frontal collision against pole. *IOP Conference Series: Materials Science and Engineering*, *252*(1). https://doi.org/10.1088/1757-899X/252/1/012012
[5] Pawlus, W., Nielsen, J. E., Karimi, H. R., & Robbersmyr, K. G. (2010). Mathematical modeling and analysis of a vehicle crash. *Proceedings of the 4th European Computing Conference, ECC '10*, *May*, 194–199.
[6] Venkatesh, C., Suresh, G., Reddy, J. L., Yadav, G. N., Kumar, S. S., & Raza, M. (2022). Design and Modelling of Frontal Crash Analysis of Car. 07, 2688–2695.
[7] Yamaguchi, E. (2014). Finite element method. Bridge Engineering Handbook: Fundamentals, Second Edition, 225–251. https://doi.org/10.1201/b15616
[8] Chandrupatla, T. R., & Belegundu, A. D. (n.d.). Co· Rom

[9] Yadav, S., & Pradhan, S. K. (2014). Investigations into dynamic response of automobile components during crash simulation. Procedia Engineering, 97, 1254–1264. https://doi.org/10.1016/j.proeng.2014.12.404
[10] Patil, M. P. S. S. P. A. V. (2021). "Analysis Of Frontal Impact On A Car After Crash Using FEA." 7(3), 2021. www.ijariie.com
[11] Jurewicz, C., Sobhani, A., Woolley, J., Dutschke, J., & Corben, B. (2016). Exploration of Vehicle Impact Speed - Injury Severity Relationships for Application in Safer Road Design. Transportation Research Procedia, 14, 4247–4256. https://doi.org/10.1016/j.trpro.2016.05.396.
[12] Torrão, G. (2022). Speed related variables for crash injury risk analysis: what has been used? International Journal of Crashworthiness, 27(5), 1560–1567. https://doi.org/10.1080/13588265.2021.1959152
[13] Gunn, C. (2022). How Does Speed Affect the Impact of a Car Crash? https://www.corbangunn.com/how-does-speed-affect-the-impact-of-a-car-crash/
[14] Idrees, U., Ahmad, S., Shah, I. A., Talha, M., Shehzad, R., Amjad, M., & Rahiamin Koloor, S. S. (2023). Finite element analysis of car frame frontal crash using lightweight materials. Journal of Engineering Research, 11(1), 100007. https://doi.org/10.1016/j.jer.2023.100007
[15] Alardhi, M., Sequeira, R., Fahed, M., Alrajhi, J., & Alkhulaifi, K. (2022). Assessing the Crashworthiness Analysis on Frontal and Corner Impacts of Vehicle on Street Poles Using FEA. *Applied Sciences (Switzerland)*, *12*(23). https://doi.org/10.3390/app122312287
[16] Hayati Ismail, N., Norihan Ibrahim, M., & Emran Ismail, A. (2021). Dynamic Response Analysis of Frontal Crash on Vehicle Against Lighting Column Using FEM. *Journal of Advanced Mechanical Engineering Applications*, *2*(2), 74–81. http://penerbit.uthm.edu.my/ojs/index.php/jamea