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AUTOMOBILE RESPONSE TO ROAD SAFETY BARRIERS UPON COLLISION

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Abstract. During a collision between an automobile and a road safety barrier, the vehicle will go through many behavior transition phases. This research will focus on determining the behavior of two car models including a sedan car and a pickup truck in collision with two safety road barriers using numerical simulation. This paper will also present images, total force graphs, and velocity graphs throughout the process to evaluate the vehicle's behavior at different impact speeds and angles. It is recognized that at similar impact speeds, collision angles, and barrier types, the pickup truck suffers more damage than the sedan. In addition, the pickup truck colliding with a concrete barrier exhibits the highest force, while the sedan colliding with a W-Beam barrier records the lowest force among the four collision types. Regarding the road safety barrier, the concrete barrier has a shorter force increase/decrease duration than the W-Beam barrier.

Keywords: crashworthiness, collision, automobile, road safety barriers, numerical simulation.

1. INTRODUCTION

For every new car model to be sold to customers, it has to undergo safety tests conducted by independent test centers such as: IIHS-HLDI [1], ANCAP [2], Euro NCAP [3] ... However, these tests only provide an overview of certain collision scenarios and cannot encompass all real accident cases due to various reasons. In this scientific report, multiple collision cases are simulated between cars and safety barriers with two car models: Chevrolet Silverado (2007) and Toyota Yaris, and two common types of barriers: concrete barriers and W-beam guardrails. These types of road safety barriers are widely used not only in Vietnam but also worldwide, making them ideal test subjects for collision in realistic conditions.

The scope of this study is to investigate the behavior of automobiles through collision simulations between two car models: Pickup truck - Chevrolet Silverado (2007), sedan car - Toyota Yaris (2010), and two types of barriers: W-beam guardrails and concrete barriers, at collision speeds of 40 km/h and 60 km/h, with collision angles ranging from 20 to 60 degrees, using numerical simulation. Three main goals aim to be achieved as follows:

- Automobile behavior at different collision speeds and angles through images and stress-strain map throughout the collision simulation process.

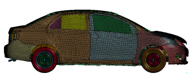
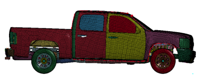
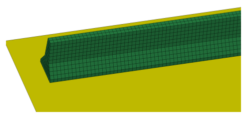
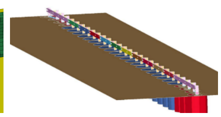
- Graphs of collision force and vehicle velocity throughout the collision process.

- Vehicle behavior during and after the collision process.

2. SAFETY BARRIERS AND AUTOMOBILE PARAMETERS

The parameters of two car models and two barrier types are presented in Table 1.

Table 1. Basic characteristics of cars and barrier models

	Toyota Yaris [4]	Chevrolet Silverado [5]	Concrete barrier [6]	W-Beam guardrail [7]
Images				
Weight	1064 ton	2377 ton	Not Available	Not Available
Car Type	Sedan	Pickup Truck	Not Available	Not Available
Engine	1.5L L4	4.8L V8	Not Available	Not Available
Material(s)	Varied	Varied	Concrete	Steel
Connection	Not Available	Not Available	Solid	Beams
Cross Section	Not Available	Not Available	New Jersey	W Shaped
No. of Elements	378376	251400	15237	124556
No. of Nodes	393165	262061	15240	126141
No. of Parts	919	603	2	217
Element Sizes	12–16 mm	15–25 mm	12–16 mm	12–16 mm
No. of Shell elements	Not Available	Not Available	2	95398
No. of Beam elements	Not Available	Not Available	0	58
No. of Solid elements	Not Available	Not Available	0	29026

3. SIMULATION PROCESS

3.1. Description of Collision Simulation Setup

In this scientific study, the simulations are conducted at two different impact speeds: 40 km/h and 60 km/h, at three different collision angles: 20 degrees, 40 degrees, and

60 degrees, resulting in a total of 24 scenarios for both vehicle models and road safety barriers. Fig. 1 illustrates the collision setup between the vehicle and the barrier.

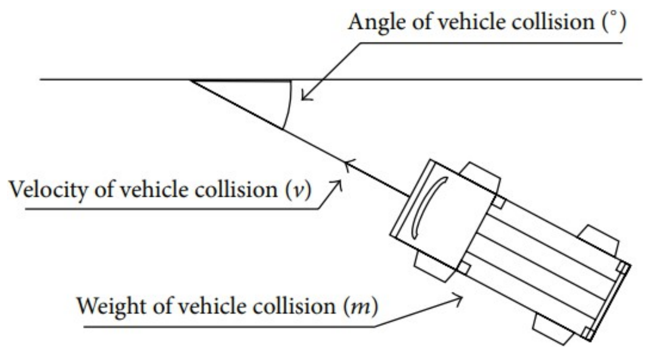


Fig. 1. Illustration of Collision Model Setup

The simulation setup process is carried out according to the following flowchart in Fig. 2.

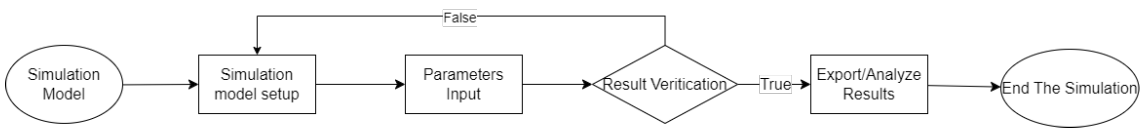


Fig. 2. Flowchart of the Collision Simulation Setup between Vehicle and Safety Barrier

3.2. Parameters Setup

For crash analysis, values for static (μ_s)/dynamic friction coefficient (μ_d) for each pair of materials are required, in this analysis, there are 3 pairs, namely:

Steel-Steel: $\mu_s = 0.7$, $\mu_d = 0.6$ [8].

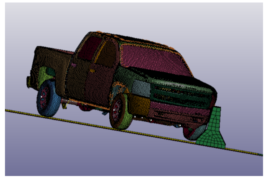
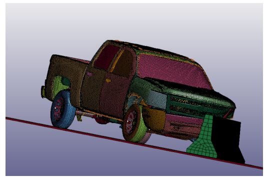
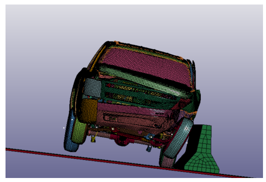
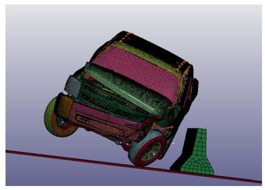
Steel-Concrete: $\mu_s = 0.281$, $\mu_d = 0.261$ [9].

Tires and road surface (dry, asphalt road): $\mu_s = 0.9$ [10].

4. VERIFICATION

The collision models developed by NTHSA and CCSA are validated for accuracy through comparison with real-world experiments. Verification is conducted using the study by Dhafer et al. [11], comparing with the Chevrolet Silverado model under similar conditions. Therefore, it is convinced that models and simulation setup are applicable for further study.

Table 2. Simulation setup proof

Real Test	Marzougui et al.	Simulation Result
		
		
		
		

Another approach to check the validity of the model is presented in Dhafer et al. [11] as follows: "The validity of the model can also be assessed by analyzing the distribution of energy associated with the crash event. The laws of physics dictate that total energy is balanced", "there are no unusual characterizations in the structure of the model that would be an unrealistic sink (point of dissipation) of the energy. The kinetic energy associated with the motion of the vehicle dropped off as the velocity decreased during the crash. Further, there was an increase in internal energy as components of the vehicle absorbed energy through deformation. Sliding energy, which is associated with the friction between the vehicle and the barrier, also increased during the simulations. The sum of the increase in internal and sliding energy was equal to the reduction in kinetic energy, as would be expected".

As for the energies being checked on the simulation, it is as follows:

- Kinetic Energy;

- Internal Energy;

- Total Energy;

- Hourglass Energy;

- Sliding Energy.

Both the result of Dhafer et al. [11] simulation and my simulation result on energy distribution are presented in Fig 3 and Fig. 4, which show high similarities on every type of energies.

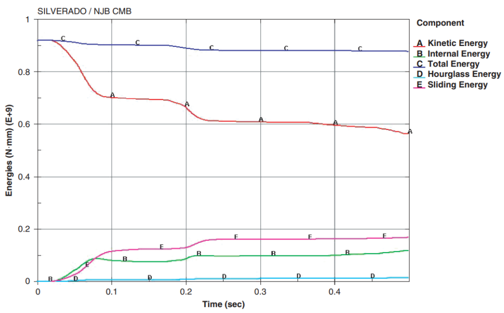


Fig. 3. Dhafer et al. [11] Energy Balance simulation result

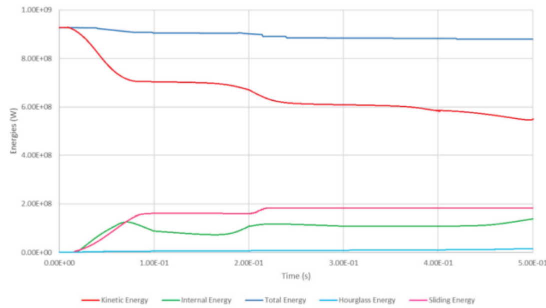


Fig. 4. My Energy Balance simulation result

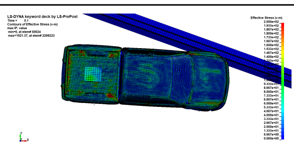
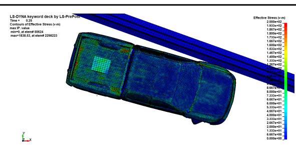
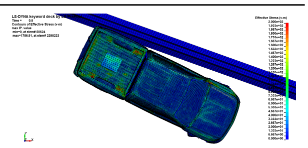
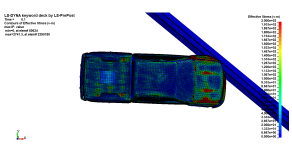
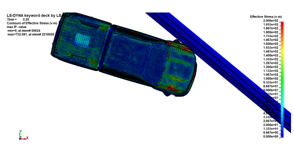
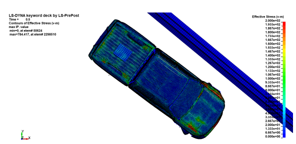
5. SIMULATION RESULT

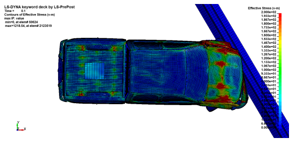
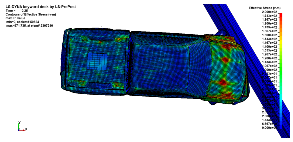
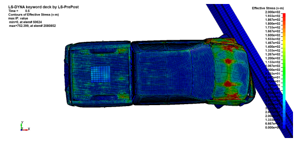
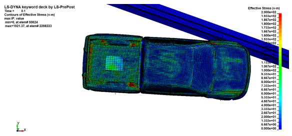
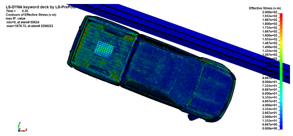
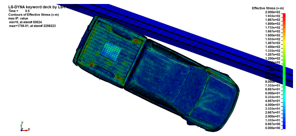
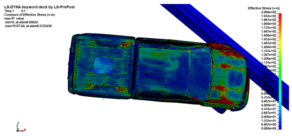
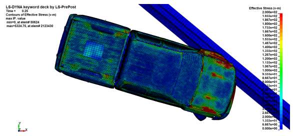
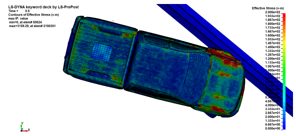
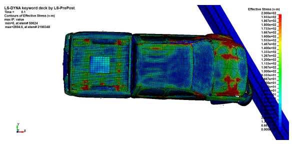
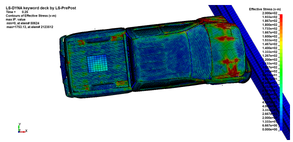
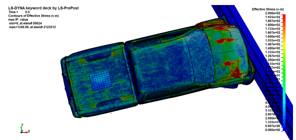
5.1. Collision simulation results

5.1.1. *Collision Case between the pickup truck model and Concrete barrier*

The simulated collision images and stress diagrams at different velocity and angle values are presented in Table 3.

Table 3. Overview of the collision process between the pickup truck model and Concrete barrier at different time intervals

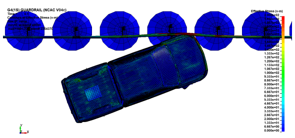
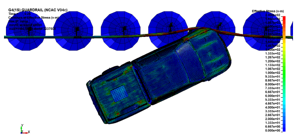
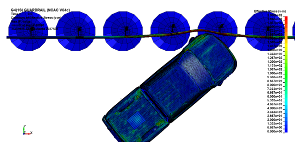
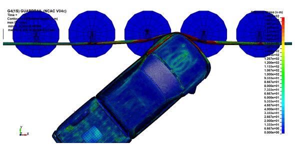
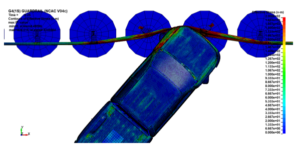
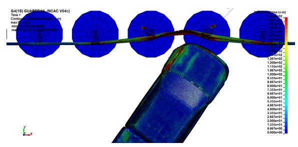
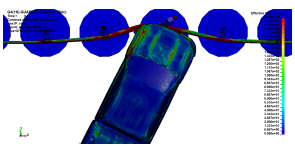
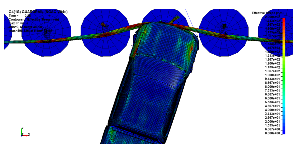
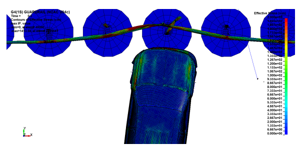
Cases	T = 0.1 s	T= 0.25 s	T = 0.5 s
V = 40 km/h, 20°			
V= 40 km/h, 40°			

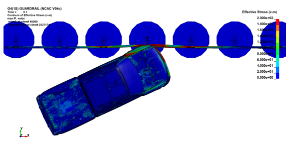
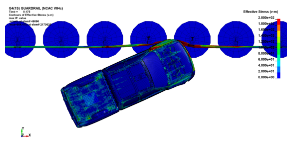
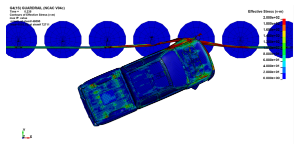
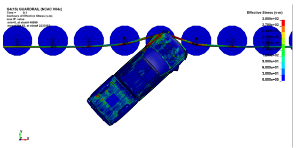
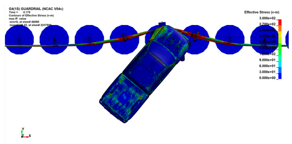
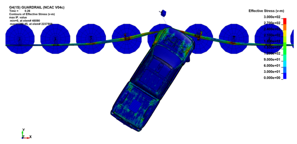
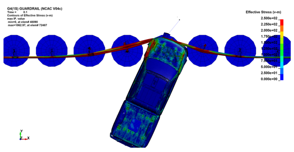
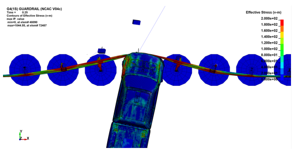
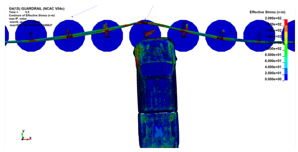
Cases	T = 0.1 s	T= 0.25 s	T = 0.5 s
V = 40 km/h, 60°			
V = 60 km/h, 20°			
V = 60 km/h, 40°			
V = 60 km/h, 60°			

5.1.2. *Collision case between the pickup truck and W-Beam guardrail*

The simulated collision images and stress diagrams at different velocity and angle values are presented in Table 4.

Table 4. Overview of the collision process between the pickup truck model and W-Beam guardrail at different time intervals

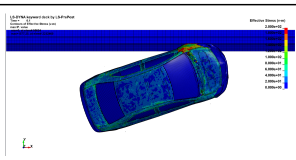
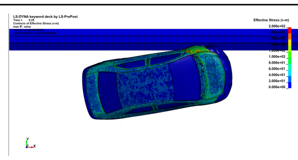
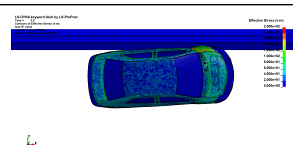
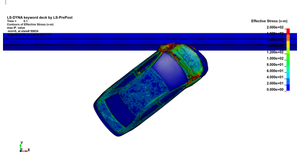
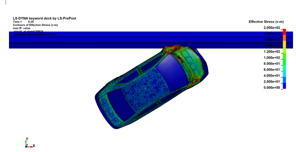
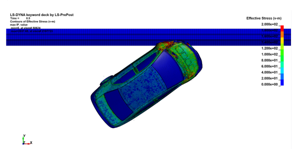
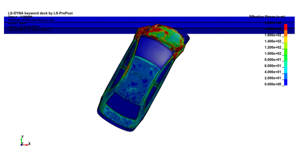
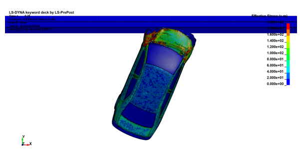
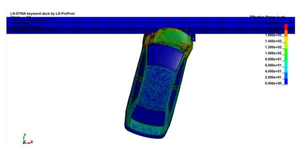
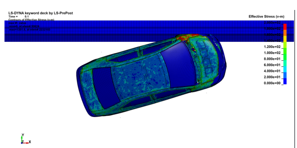
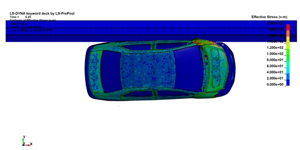
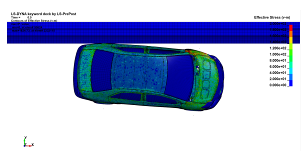
Cases	T = 0.1 s	T= 0.25 s	T = 0.5 s
V = 40 km/h, 20°			
V= 40 km/h, 40°			
V = 40 km/h, 60°			

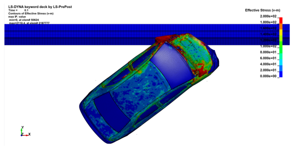
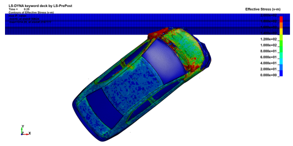
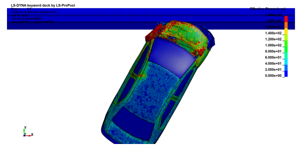
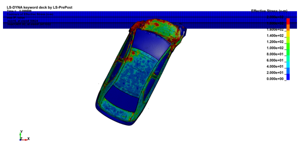
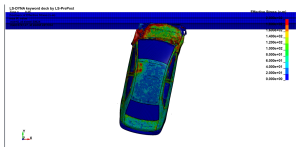
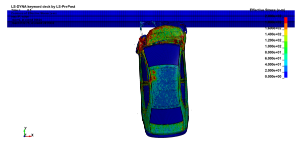
Cases	T = 0.1 s	T= 0.25 s	T = 0.5 s
V = 60 km/h, 20°			
V = 60 km/h, 40°			
V = 60 km/h, 60°			

5.1.3. *Collision case between the sedan car and Concrete barrier*

The simulated collision images and stress diagrams at different velocity and angle values are presented in Table 5.

Table 5. Overview of the collision process between the sedan car model and Concrete barrier at different time intervals

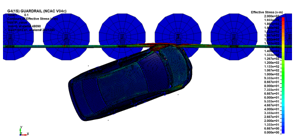
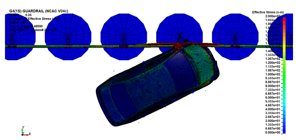
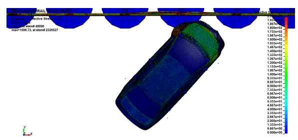
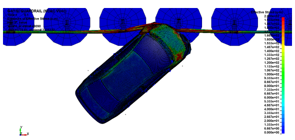
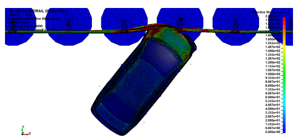
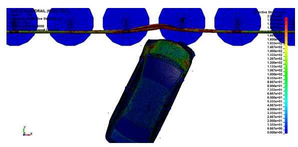
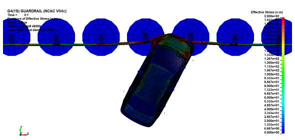
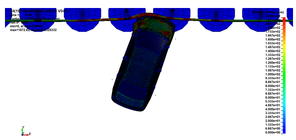
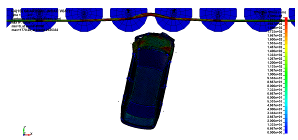
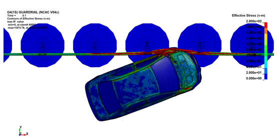
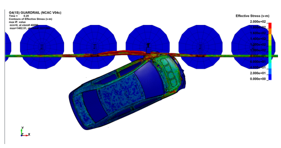
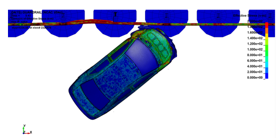
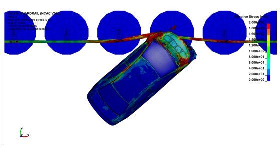
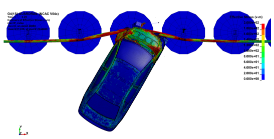
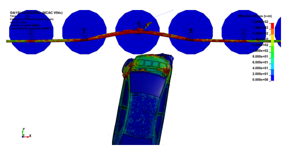
Cases	T = 0.1 s	T= 0.25 s	T = 0.5 s
V = 40 km/h, 20°			
V= 40 km/h, 40°			
V = 40 km/h, 60°			
V = 60 km/h, 20°			

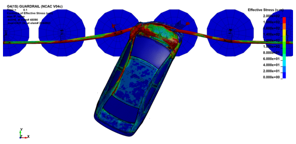
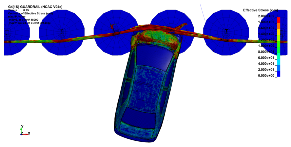
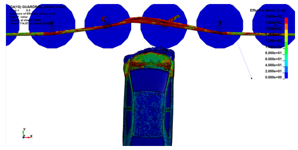
Cases	T = 0.1 s	T= 0.25 s	T = 0.5 s
V = 60 km/h, 40°			
V = 60 km/h, 60°			

5.1.4. *Collision case between the sedan car and W-Beam Guardrail*

The simulated collision images and stress diagrams at different velocity and angle values are presented in Table 6.

Table 6. Overview of the collision process between the sedan car model and W-Beam guardrail at different time intervals

Cases	V_{total}	V_x	V_y
V = 40 km/h, 20°			
V= 40 km/h, 40°			
V = 40 km/h, 60°			
V = 60 km/h, 20°			
V = 60 km/h, 40°			

Cases	V_{total}	V_x	V_y
V = 60 km/h, 60°			

5.2. Velocity - Resultant force graphs

5.2.1. *Pickup truck and Concrete barrier*

In the velocity graph (Fig. 5), the case of collision angle at 60 degrees at both velocities: 40 km/h and 60 km/h have the fastest velocity reduction rate. Conversely, at collision angle of 20 degrees, have the slowest velocity reduction rate. Velocity tends to decrease sharply from 0 s to 0.1 s, then stabilizes till the end of the simulation. Corresponding to this time interval, the peak force generated is highest in the case of 60 km/h, collision angle of 60 degrees, measuring 807810 N, while the lowest peak force is in the case of 40 km/h, collision angle of 20 degrees, measuring 192770 N (Fig. 6).

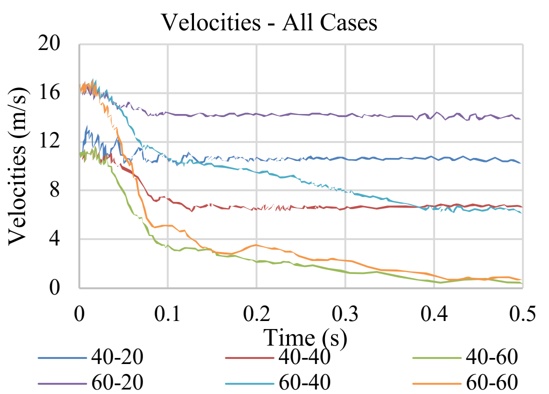


Fig. 5. Velocity-time of the pickup truck colliding with the Concrete barrier at different collision angles

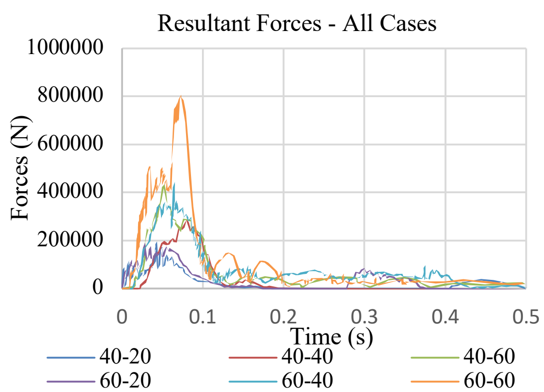


Fig. 6. Resultant Force-time of the pickup truck colliding with the Concrete barrier at different collision angles

5.2.2. *Pickup truck and W-Beam guardrail*

In the velocity graph (Fig. 7), the case of collision angle: 40 degrees at 60 km/h and 40 km/h, have the fastest velocity reduction rate. Conversely, at collision angle of 20 degrees, have the slowest velocity reduction rate for both velocity values. Velocity tends to decrease sharply from 0 s to 0.2 s, then stabilizes till the end of the simulation. Corresponding to this time interval, the peak force generated is highest in the case of

60 km/h, collision angle of 60 degrees, measuring 311560 N, while the lowest peak force is in the case of 40 km/h, collision angle of 20 degrees, measuring 151740 N (Fig. 8).

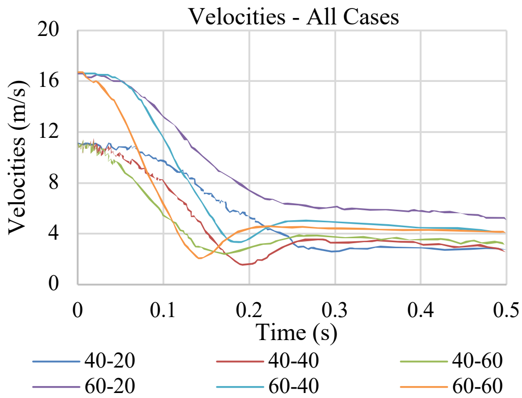


Fig. 7. Velocity-time of the pickup truck colliding with the W-Beam Guardrail at different collision angles

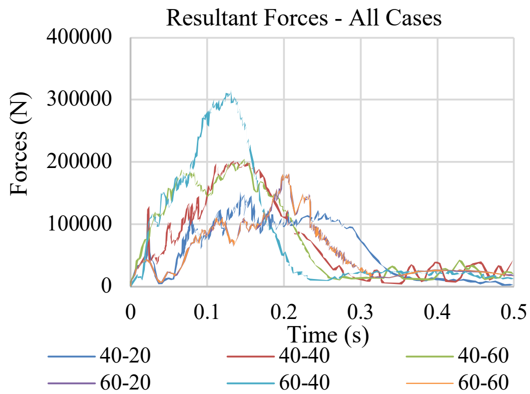


Fig. 8. Resultant Force-time of the pickup truck colliding with the W-Beam Guardrail at different collision angles

5.2.3. *Sedan car and Concrete barrier*

In the velocity graph (Fig. 9), the case of collision angle: 60 degrees at 60 km/h and 40 km/h, have the fastest velocity reduction rate. Conversely, at collision angle of 20 degrees, have the slowest velocity reduction rate for both velocity values. Velocity tends to decrease sharply from 0 s to 0.1 s, then stabilizes till the end of the simulation. Corresponding to this time interval, the peak force generated is highest in the case of

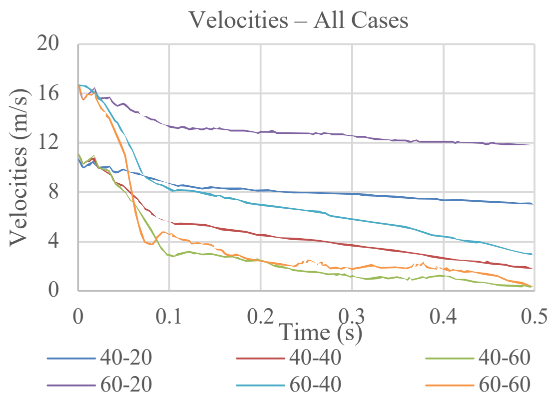


Fig. 9. Velocity-time of the sedan car colliding with the Concrete barrier at different collision angles

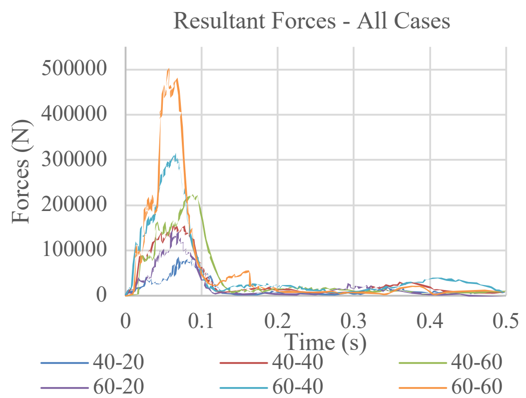


Fig. 10. Resultant Force-time of the sedan car colliding with the Concrete barrier at different collision angles

60 km/h, collision angle of 60 degrees, measuring 504610 N, while the lowest peak force is in the case of 40 km/h, collision angle of 20 degrees, measuring 86813 N (Fig. 10).

5.2.4. *Sedan car and W-Beam guardrail*

In the velocity graph (Fig. 11), the case of collision angle: 60 degrees at 60 km/h and 40 km/h, have the fastest velocity reduction rate. Conversely, at collision angle of 20 degrees, have the slowest velocity reduction rate for both velocity values. Velocity tends to decrease sharply from 0 s to 0.2 s, then stabilizes till the end of the simulation. Corresponding to this time interval, the peak force generated is highest in the case of 60 km/h, collision angle of 60 degrees, measuring 241790 N, while the lowest peak force is in the case of 40 km/h, collision angle of 20 degrees, measuring 112660 N (Fig. 12).

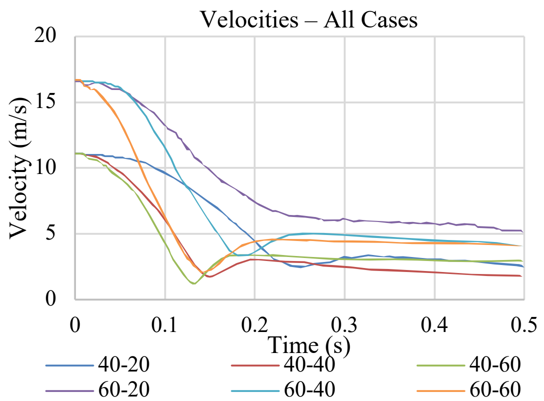


Fig. 11. Velocity-time of the sedan car colliding with the W-Beam guardrail at different collision angles

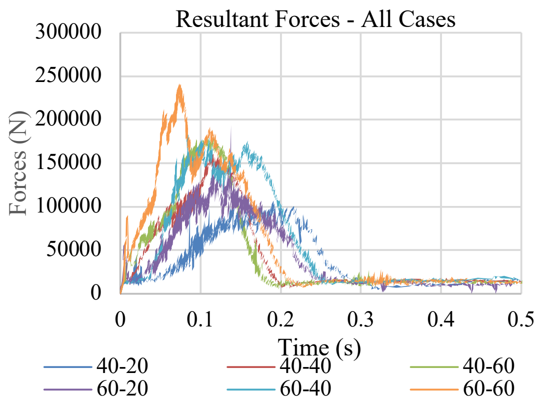


Fig. 12. Resultant Force-time of the sedan car colliding with the W-Beam guardrail at different collision angles

6. DISCUSSION - CONCLUSION

This study used Toyota Yaris (2010) as a sedan, Chevrolet Silverado (2007) as a pickup truck and Concrete barrier, W-Beam guardrail to study the behavior of automobiles through collision with road safety barriers. Several conclusions are drawn as follows:

- The collision force graph typically shows a rapid increase followed by a decrease to zero after impact. The pickup truck colliding with a concrete barrier exhibits the highest force, while the sedan colliding with a W-Beam barrier records the lowest force among four collision types;

- The collision force graph shows that the concrete barrier has a shorter duration of force increase/decrease compared to the W-Beam barrier. This is due to the W-Beam guardrail's deformable structure, which deforms in impact, allows for better force absorption than the inherently rigid structure of Concrete barrier;

- Concerning the collision velocity of the vehicle, all cases share the common feature of reaching a maximum value equal to the initially set value and then decreasing rapidly, with this velocity value being maintained when the collision process ends;

- Car velocity's fluctuation rate depends on the initial velocity, collision angle and the rigidity of the barrier itself. In the cases of 40 km/h – 20 degrees, 60 km/h – 20 degrees, on both car model and barrier, the velocity of two car model reduces slower than other velocity and collision angle cases, because at those angles and velocities, the deformation caused by the car to barrier is slight which the car can be slowed down only by friction between the car and barrier. Other velocity and collision angle caused more deformation to the barrier itself which helps reduce the velocity faster, the velocity will raise a bit after causing deformation to the barrier because of rebound;

- For the case of 40 km/h – 40 degrees, the Concrete Barrier does not deform much, which causes the car to run along the barrier itself and the velocity graph dips down much slower than the W-Beam Guardrail, which deforms more in this case;

- At the same velocity value, collision angle, barrier type, the pickup truck suffers more damage than the sedan. This can be explained by the softer front design of the sedan, allowing for more deformation and better absorption of collision forces compared to the rigid front design of the pickup truck.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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