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Evaluating Frontal Crash Test of Developed Vehicle Chassis Frame Structure to Identify Crashworthiness Through Scaled Model for Injury Reduction

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Abstract— Vehicle accidents can result in a wide range of injuries depending on the severity of the impact. The safety of passengers is the most important aspect in the vehicle industry. Collision-induced frame deformation could result in serious injuries. The majority of deaths in such cases are caused by excessive impact force and deceleration pulses on the human body. Accidents occur despite all human efforts to prevent them. It has been observed that many deaths and serious injuries occur in accidents that are tolerable. Unfortunately, capsulitis occurs because the vehicle's protective systems, such as seats, restraint systems, and cabin strength, were insufficient to protect the occupants in the event of an accident. Which could otherwise be harmless. To maximize survivability in a crash, the tolerance of humans to absorb sudden acceleration must be understood, and the vehicle must be designed to maintain cabin integrity up to the limits of human tolerance. This would be possible with the careful application of energy-absorbing techniques that reduce the accelerations experienced by the occupants. In this paper, an experimental crash test for full frontal impacts is performed on a developed prototype chassis frame to reduce the Cash Pulse during the accident.

Keywords— Vehicle, Chassis Frame, Crash, Impact Test

Introduction

Accidents cause injuries to the occupants of the vehicle, which may result in death. The purpose of this study is to figure out how to reduce injuries and fatalities in car accidents. Also discussed is how to improve the impact's longevity during high-speed collisions. The vehicle chassis is the most important component of the vehicle structure. The severity of the impact during the accident will be reduced if the vehicle chassis has an impact energy-absorbing system. It is possible to achieve this by modifying the vehicle structure to reduce the severity of the impact. The developed chassis frame model is subjected to impact testing. We performed crash tests on the developed chassis frame using a dynamic pendulum[1],[2],[3] with a mass of 21.6 kg. The chassis frame is made up of two parts: the base frame and the sliding frame. The pendulum is used to generate the impact force. The pendulum's impact speed ranges from 0.89 m/s to 5.13 m/s. The developed frame produced results for acceleration, impact force, and sliding frame displacement in the reverse direction. Vehicles deform significantly during frontal pendulum impacts. The pendulum crash test is useful for estimating vehicle behaviour during an accident. [4] The safety of occupants is based on deceleration pulses with respective time and strength of occupant compartment or how it deforms during the crash. Management of impacted energy over the vehicle structure so that maximum energy is absorbed will undoubtedly improve vehicle safety. The absorption of crash energy is primarily determined by the vehicle structure and mechanical properties of materials. [5]

A. Vehicle Crash Testing

A crash-test is a type of destructive test in which a vehicle is impacted over a rigid barrier or a heavy object is impacted over it while the vehicle remains stationary, and various dynamic parameters are assessed. such as impact velocity, acceleration, deacceleration and deformation, intrusion, crash pulse, and so on. Crash testing aids in the improvement of vehicle design standards for crashworthiness. Vehicle crash tests were conducted from various angles, sides, and with different objects to assess the vehicle's safety performance during accidents under various circumstances [6]. The following are some of the crash tests:

- Front impact test
- Front offset crash test
- Side impact test
- Roll over test

For this study, an experimental investigation of the frontal impact test over the developed chassis frame was conducted. and examined the chassis frame's energy balance graph and deceleration profile

This paper describes the new chassis frame for vehicles. Tests were carried out to determine how well it reduces the impact pulse and increases occupant safety. And how well it protects humans in the event of a head-on collision.

The goal of vehicle crash analysis is to design a vehicle that can absorb the maximum kinetic energy imparted on the vehicle structure during accidents, i.e. at sudden impact. And keep the deceleration pulse and intrusion at a controlled level so that they do not harm the occupants inside the vehicle [4] As the front portion of the vehicle structure is stiffened to absorb the impact (striking) energy generated during the collision. [7] To reduce the number of injuries sustained by accident occupants. If the kinetic energy of impact is to be absorbed evenly over a long period of time [8],At various impact forces, parameters such as acceleration pulse and energy dissipation curve are obtained in the current experimental work. One method for validating these experimental results is to compare them to numerical analysis [5] or analytical results.

B. Set Up for Impact Test

The current work employs an experimentally discovered energy balance graph and deceleration profile curve due to an impact load created by a pendulum. is assumed to be the actual behavior of a car that collided with a rigid wall. Many countries conduct frontal impact tests at 56 km/h, as specified by the Global New Car Assessment Program (GNCAP), with some using 64 km/h. According to the Bharat New Vehicle Safety Assessment Program (BNVSAP), a frontal offset crash test at a speed of 64km/h is proposed in India [9]. because the goal is to find a full Frontal Impact crash test at 64 km/h over a developed prototype model Conventionally, during a crash test, the vehicle is impacted against a rigid wall and the safety parameters are evaluated. In this experiment, instead of the vehicle being impacted over the wall, the chassis frame is kept stationary, and a pendulum is used to create an impact force that acts over the frontal side of the frame.[1],[2]. and then experimental safety parameters are analyzed.

This study looks at the energy balance graph, comparing the distribution of kinetic energy and increasing Potential energy, as well as studying Acceleration and Deacceleration during the impact. In the current work, two approaches were investigated: experimental solution and analytical solution [3], and experimental solution was later compared to numerical solution. The experimental pulse shapes were observed in this study. The comparison of analytical predictions is investigated. To study the vehicle collision response experimentally, impact analysis was performed on the same vehicle chassis frame at different collision test speeds. The analytical determination of dynamic crush and vehicle structure integrity is discussed. This study will demonstrate that the pulse shape of a developed vehicle chassis frame is highly controllable. [4]

Prototyping of a Scaled Model

In this work, a 1:5 scaled model of the chassis frame is created with length as the only consideration. For overall length, a Chevelle from 1968 to 1972 was used. [7] The prototype is tested experimentally and the results of the impact test are correlated. It should be noted that the scaling only applies to the body dimensions of the chassis frame (length and width), not the profile. The frame was modified and developed in such a novel way that it bears no resemblance to the original chassis frame. To facilitate experimental work in the laboratory, only the overall length and width are used to develop the porotype model. The cross-sections of the various members were chosen based on market availability. Based this consideration the scaling is not applied to the cross-section's members.

The developed chassis frames are made up of a base frame and a sliding frame. The sliding frame is attached to the base frame in such a way that it projects ahead of the base frame in the front direction. The vehicle's engine or power sources are mounted on the base frame, while the occupants' seats are mounted on the sliding frame. The sliding frame is attached to the base frame with an interlocking mechanism, giving it a single degree of freedom.

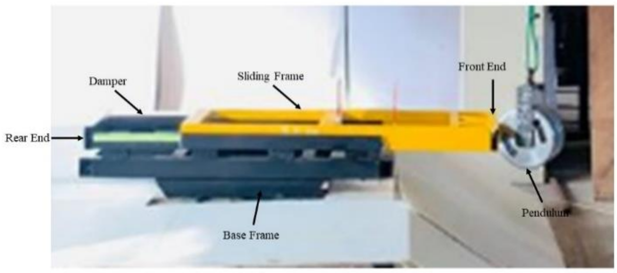


Figure 1Experimental Set up for Developed Chassis frame

It also provides rigid and strong support to the vehicle chassis frame in order to carry the load of all vehicle components. During an impact, the chassis frame's structure allows for sliding movement of the sliding frame. Without detaching the vehicle body from the chassis. In such cases, the risk of injury to the people (occupants) inside the vehicle is greatly reduced. To provide cushioning to the occupants, a shock absorber system consisting of a spring and a damper is mounted at the end of the sliding frame.

Methodology

Crash pulse represents the behavior of vehicle motion during the crash impact, i.e., the vehicle's deceleration at that time. The shorter the time period of the deacceleration pulse, the more severe the crash pulse, and the longer the time period of the deacceleration pulse, the less severe the crash pulse. A crash pulse is a time-dependent curve of acceleration. During a crash test, these parameters were measured from the vehicle. The behavior of an occupant's injury can be predicted based on the shape of the crash pulse, time interval, and maximum acceleration of the crash pulse. We can also analyze the crashworthiness of a vehicle structure using crash pulse characteristics measured during crash tests. [5] The crash pulse allows you to understand the energy variations during the impact, which can be directly related to occupant injuries inside the vehicle

The vehicle crash pulse indicates a strong relationship between inside occupants' head and chest injuries. The occupant injury is directly related to the crash pulse. Lowering the severity of occupant injury by lowering the severe crash pulses. The current vehicle chassis frame design reduces the magnitude of the crash pulse to the point where the impact does not cause serious injury to the occupant. Important physical parameters were calculated while studying a crash pulse.

The following parameters were used to determine the activation of restraint systems..

Change in velocity (ΔV): The change in velocity is directly related to the severity of the crash and determines whether or not occupant restraint systems such as air bags are activated. For example, when a small change in velocity above 24 km/h, i.e. 6.6 m/s, is observed for the frontal impact, 90 percent of the driver side air bags are activated.

Displacement (x): Displacement provides an assessment of the overall structure's deformation during dynamic crush and rebound.

Jerk (J): Jerk is the rate of change of deceleration. or it is also known as an impulse The maximum value of jerk indicates the vehicle's sudden deceleration and acceleration due to inertia of motion..

Absorbed energy (E): The impact energy is absorbed due to the deformation of vehicle parts during the crash.

Experimentation

The prototype is tested experimentally, and the results of the impact test are correlated. To justify the experimental results obtained from the acquired crash-pulse data is validated by any two from the three methods Analytically vs experimentally, vs numerically. for this experimentation results were validated by comparing any of the above two methods. Crash Tests results and Analytical Solution and in some cases experimental results were compared with numerical solution are for the purpose of validation.

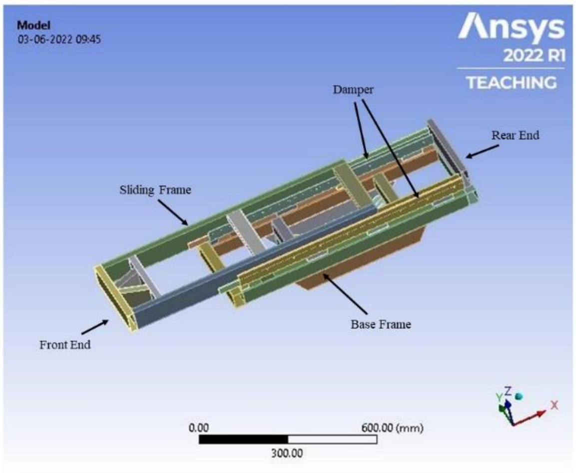


Figure 2 Developed Chassis Frame 3D model

Limitations

1. Experimenting with full-scale crash tests using modern sensors and equipment requires a large infrastructure and a well-established test facility.
2. This comes at a high cost in terms of money and man-hours.
3. To analyze crashworthiness of any vehicle structure crash test has been done over a prototype model
4. Dynamic Pendulum is used to create Impact force keeping Prototype Structure od chassis frame Stationary.
5. As the height of the pendulum is limited maximum speed achieved is 5.13 m/s ie 18.46 km/hrs Experimenting with full-scale crash tests using modern sensors and equipment requires a large infrastructure and a well-established test facility as a result, continuing in this manner is illogical. [8] As a result, experimentation is carried out on a chassis frame prototype model, and Impact Force is generated using a Pendulum.

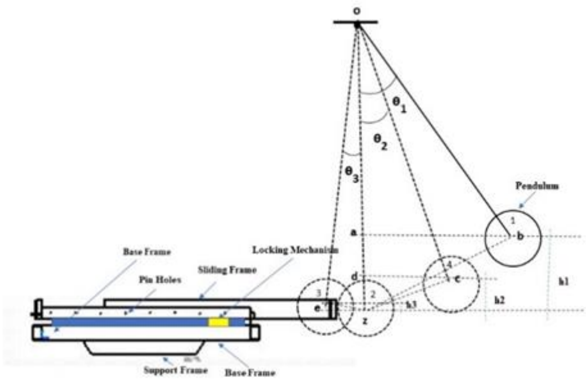


Figure 3 free body diagram of chassis frame under impact loading

The thickness of the extruded rectangular hollow sections used in the scaled model ranges from 1.6 mm to 2.0 mm depending on the section. which is determined by market availability The prototype of the scaled model is created using arc welding. IS 4923:1997 hot formed structural steel rectangular pipes are used [9][10]. To increase trust in the simulation procedures for frontal impact assessment. Pendulum, a scaled prototype of the basic chassis frame developed and tested for full frontal impact, is used to generate impact force. In some publications, an Impact Testing Machine (ITM) is used to generate impact force for crash tests. [11]

In the majority of countries For full frontal NCAP simulations, the vehicle is impacted at 56 kph (35 mph) versus a rigid wall, and the deceleration pulse is measured [12]. In our case, we are creating a range of impact forces with a pendulum. by releasing the pendulum from various inclinations, changing velocity and impact force simultaneously The inclination range for this experiment is 10^0 to 60^0. The pendulum's striking velocity is calculated analytically and experimentally. Displacement and acceleration are also compared analytically and experimentally.

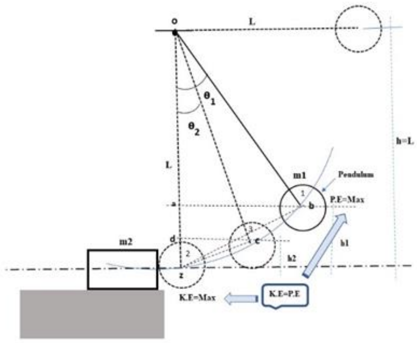


Figure 4.Creating Impact force using Pendulum

Number of assumptions are considered during the impact .

- First forces due to air drag are assumed to be zero during the impact, because of that momentum is preserved.
- Second, the vehicle masses and moments of inertia are kept maintained during the course of collision. and then impulse is modelled by impact force.

From the definition of change in velocity we can get [13] momentum and through the principal of conservation of momentum

$$m1u1 + m2u2 = m1v1 + m2v2 \ldots\ldots\ldots\ldots, (1)$$

$$\Delta v = v - u \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots,(2)$$

Equating equations (1) and (2)

$$\Delta v1 = \Delta v2(\frac{m2}{m1})$$

Impulse is the change in momentum

Impulse=Ft (N.s)

High Impulse means High magnitude of Impact Force for a very short time span whereas low Impulse means Low magnitude of Impact Force for more time span.

Ft=mv-mu

Ft=m (v-u)

$$F = m\left(\frac{v-u}{t}\right)$$

F=ma

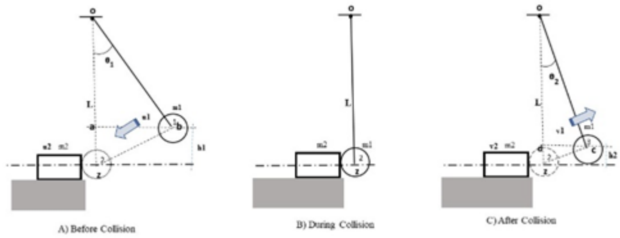
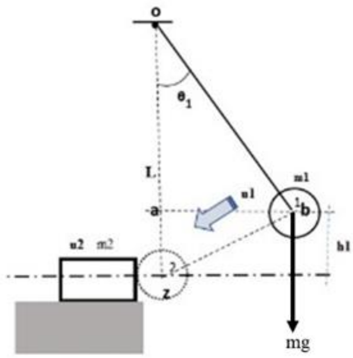


Figure 5 Schematic representation of transfer of momentum

Figure 5 is schematic diagram of transfer of momentum form pendulum to the mass "m_2" (object representing chassis frame)

Force by Pendulum



A) Before Collision

Applied force by Pendulum (Fp)
Fp= $\sin^{\theta}$.mg
Frictional Force (Fr)= Dynamic Coeff. x Normal Force
Net Force (Fnet)= Fp -Frictional Force Fr

Table 1Momentum Parameters for Pendulum

SN	θ_1	u_1	v_1	u_2	v_2
1	10	0.89	0.18	0	1.72
2	15	1.34	0.19	0	2.76
3	20	1.78	0.22	0	3.74
4	25	2.22	0.36	0	4.47
5	30	2.65	0.45	0	5.30
6	35	3.08	0.47	0	6.28
7	40	3.51	0.54	0	7.13
8	45	3.92	0.63	0	7.92
9	50	4.33	0.72	0	8.68
10	55	4.74	0.80	0	9.43

11	60	5.13	0.88	0	10.20

Crumple zones were provided in the front of the vehicle to reduce the Impulse. The crumple zone lengthens the time it takes for the vehicle to come to a complete stop. This reduces the average force required to provide the vehicle with the necessary impulse to reduce momentum to zero in the crash.

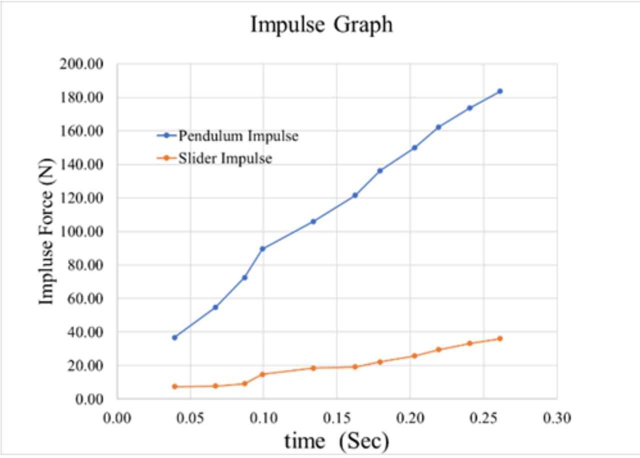


Figure 6Impulse Graph of Pendulum and Slider Frame

Figure 6 depicts a graph of force and time. The impulse of a pendulum impact at maximum speed is more than 7500 N, whereas the impulse of a sliding frame is relatively low, close to 300 N.

Occupant safety in vehicular crashes

There are two generalized methods for evaluating the safety of occupants: direct method and indirect method. The direct method entails calculating the Acceleration Severity Index experimentally using a dummy. The indirect method is concerned with the dynamic response of the vehicle during an accident. Data is collected from a number of accident situations and classified as A, B, or C. Level A indicates that the occupant is safer than level B, and level B is safer than level C.

The acceleration severity index (ASI) is a function of Acceleration with respective time, computed as follow

$$\mathrm{ASI}(t) = \left[\left(\frac{\bar{a}_x}{\hat{a}_x}\right)^2 + \left(\frac{\bar{a}_y}{\hat{a}_y}\right)^2 + \left(\frac{\bar{a}_z}{\hat{a}_z}\right)^2\right]^{0.5},$$

where , ãx, ãy, and ãz represents the values of acceleration of vehicle's at its center of gravity .Values in denominator ie ãx, ãy, ãz, are the limit values of components which are equal to 12g, 9g and 10g (g denotes freefall acceleration).[14]

Table 2. Impact Severity level

Impact Severity Level	Index Value	
A	ASI≤1.0	THIV≤33km/h
B	ASI≤1.4	
C	ASI≤1.9	

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Only acceleration along the x axis is addressed in this experiment.

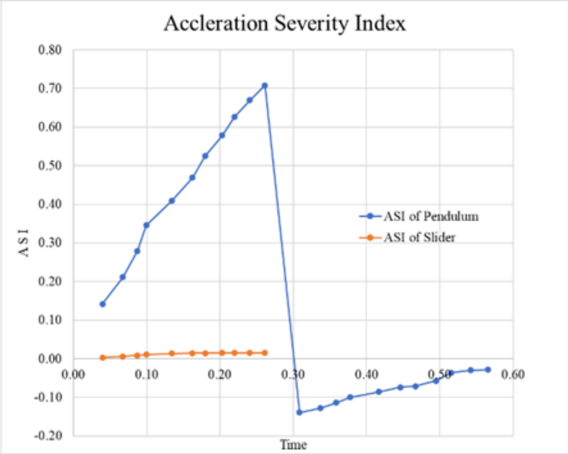

Figure 7 Acceleration Severity Graph

Figure 7 depicts the graph of ASI vs. Time in the accident situation. Analyses of the graph suggest that the ASI for pendulum impact is close to 3. That means it is higher than category "C," indicating a severe scenario. ASI for sliding chassis frame is significantly safer because it is less than 1 level "A." This indicates that it is extremely safe.

Table 3 Acceleration and Deacceleration of Pendulum and Frame

Time (t)	Acceleration of Pendulum	Acceleration of Slider
0.04	1.70	0.04
0.07	2.54	0.08
0.09	3.36	0.11
0.10	4.15	0.13
0.13	4.91	0.17
0.16	5.63	0.18
0.18	6.31	0.18
0.20	6.94	0.18
0.22	7.51	0.18
0.24	8.04	0.18
0.26	8.50	0.19
0.31	-1.67	0
0.34	-1.53	0
0.36	-1.37	0
0.38	-1.20	0
0.42	-1.03	0
0.45	-0.89	0
0.47	-0.85	0
0.49	-0.68	0
0.52	-0.43	0
0.54	-0.36	0

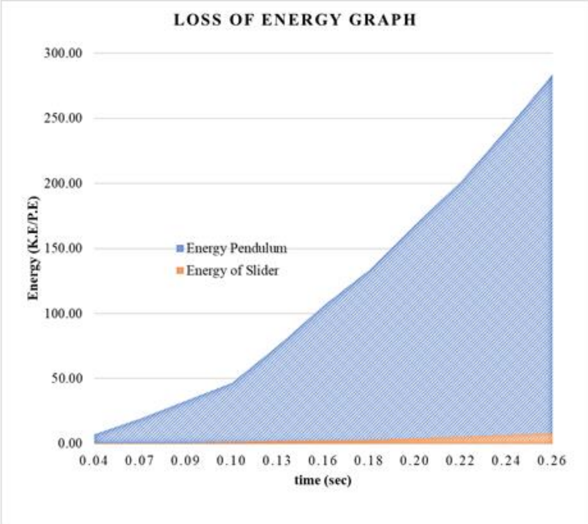

Figure 8 Loss of Energy Graph

Figure 8 depicts an energy vs. time graph. This graph is also known as an energy balance graph. This graph clearly shows that whatever potential energy exists at each point for the pendulum is turned into the same amount of kinetic energy.

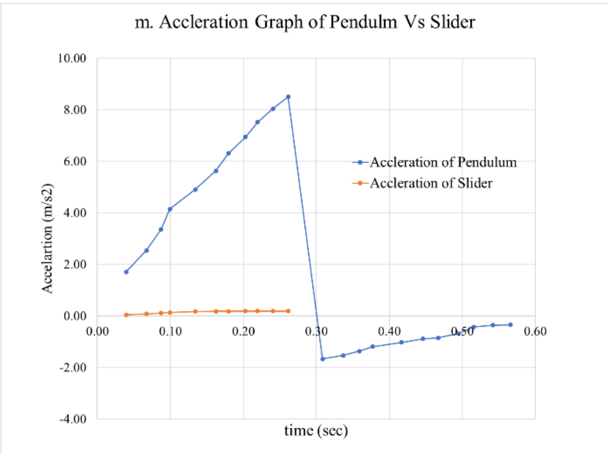

Figure 9 Acceleration Vs Time graph of Test Mode

Figure 9 depicts a graph of acceleration vs time. And it is obvious from the graph that the acceleration of the pendulum is greater than 35 m/s2 at the highest value of pendulum inclination. However, the acceleration value for the sliding frame is close to 4.82 m/s2, which is relatively low. That means the impact felt by the occupant is not severe and will not result in major injuries.

Table 4 Displacement of Slider Frame against degree inclination of pendulum

SN	Inclination of Pendulum (in Degree)	Displacement of Slider in (mm)
1	10	21
2	15	38
3	20	55
4	25	64
5	30	84
6	35	88
7	40	89
8	45	91
9	50	92
10	55	92
11	60	92.5

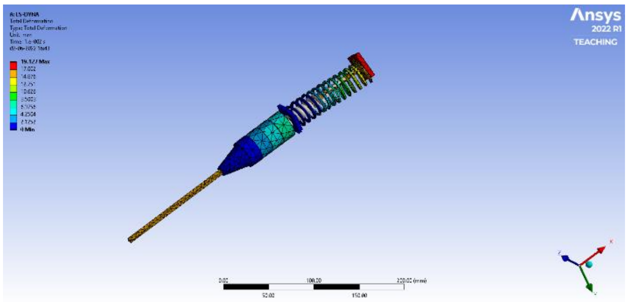

Figure 10 Displacement Profile of Damper Assembly under compression

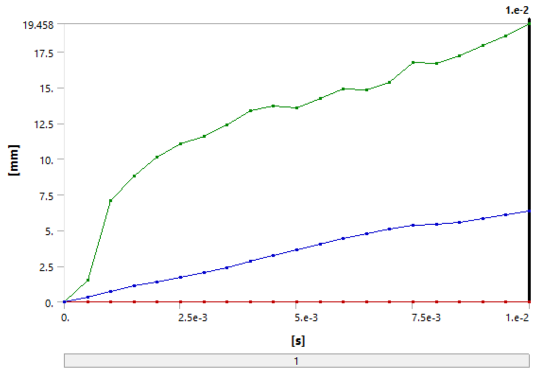

Figure 11 Displacement graph of Damper Assembly

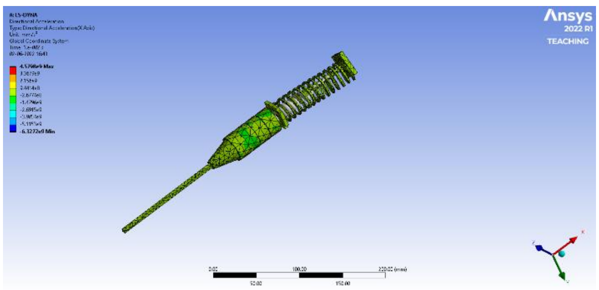

Figure 12Acceleration profile of Damper Assembly

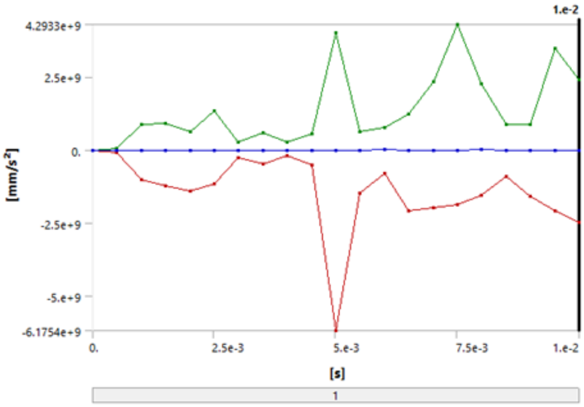

Figure 13 Acceleration graph of Damper Assembly

CONCLUSIONS

This paper presents a novel structure for a vehicle chassis frame for crash worthiness, which will aid in reducing the acceleration over the occupants and vehicle structure during an accident. With increased time, the developed model shows a significant reduction in crash pulse. This will help to reduce the severity of injury in the event of an accident. For this experiment, an impact force is generated by striking the Pendulum over a wide range of degrees of inclination in order to predict the behavior of the structure. Using pendulum impact over the frame structure and the result at each inclination of the pendulum shows the response of the frame correspond to acceleration. When compared to pendulum results, the magnitude of the acceleration pulse obtained for the sliding frame is very small. Ultimately it will help to reduce crash pulse during the crash.

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