Design and Analysis of Front-End Passive Safety System for Vehicle Collision

By

Kibru Aregahegn Gebretsadik

A Thesis Submitted to

Department of Mechanical Systems and Vehicle Engineering

School of Mechanical, Chemical and Materials Engineering

Presented in partial fulfillment for the requirement of the degree of Master's in Automotive Engineering

Office of Graduate studies

Adama Science and Technology University

Adama, Ethiopia

October 2021

Design and Analysis of Front-End Passive Safety System for Vehicle Collision

By

Kibru Aregahegn Gebretsadik

Advisor: Mr. Mekonnen Liben (assistant professor)

Co-advisor: Dr.Ramesh Babunallamothu

A Thesis Submitted to

Department of Mechanical Systems and Vehicle Engineering

School of Mechanical, Chemical, and Material Engineering

Office of Graduate studies

Adama Science and Technology University

Adama, Ethiopia

October 2021

DECLARATION

I hereby declare that this Master Thesis entitled "Design and Analysis of Front-End Passive Safety System for Vehicle Collision" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Kibru Aregahegn Gebretsadik	________________________	________________
Name of the Student	Signature	Date

RECOMMENDATION

We, the advisor(s) of this thesis, hereby certify that we have read the revised version of the thesis entitled "Design and Analysis of Front-End Passive Safety System for Vehicle Collision" prepared under my/our guidance by Kibru Aregahegn Gebretsadik submitted in partial fulfillment of the requirements for the degree of Master of Science in Automotive Engineering. Therefore, we recommend the submission of a revised version of the thesis to the department following the applicable procedures.

___________________________	________________________	________________
Advisor name	Signature	Date
___________________________	________________________	________________
Co-advisor name	Signature	Date

APPROVAL PAGE

I/we, the advisors of the thesis entitled "Design and Analysis of Front-End Passive Safety System for Vehicle Collision" and developed by Kibru Aregahegn hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Major Advisor	Signature	Date
Co-advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Kibru Aregahegn have read and evaluated the thesis entitled "Design and Analysis of Front-End Passive Safety System for Vehicle Collision" and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Automotive Engineering.

Chairperson	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
School Dean	Signature	Date
Office of Postgraduate Studies, Dean	Signature	Date

ACKNOWLEDGEMENT

Firstly, I Thank God that helps me to manage and complete the study after passing through many challenges. All praise and many thanks to GOD who gave the strength and confidence to me to complete the thesis entitled Design and analysis of front-end passive safety device for a vehicle collision.

I would like to express my genuine thanks to my advisor Assistant professor Mekonnen Liben for his valuable advice, constant motivation, and guidance during my study.

Also, my sincere thanks go to my co-advisor Dr.Ramesh Babunallamothu for his valuable advice, guidance, and supervision during my work.

Generally, I would like to extend my thanks to my families and to all the above people and those who are not mentioned here but contributed their part a lot towards the success of this thesis.

TABLE OF CONTENTS

CONTENTS **PAGE**

LIST OF TABLES

TABLES **PAGE**

LIST OF FIGURES

FIGURES **PAGE**

LIST OF ACRONYMS

RTA	Road Traffic Accident
SUV	Sport Utility Vehicles
ECM	Electronic Control Module
ICW	Intersection Collision Warning
WSN	Wireless Sensor Networks
TTC	Time To Collision
PID	Proportional Integral Derivative Controller
AEB-P	Autonomous Emergency Braking Pedestrian
C-NCAP	China-New Car Assessment Program
ICV	Intelligent Connected Vehicles
ADAS	The Advanced Driver Assistance System
ESC	Electronic Stability Control
AEBS	Advanced Emergency Brake System
ABS	Antilock Brake System
LED	Light-Emitting Diode
CWS	Collision Warning System
CAS	Collision Avoidance System
V2I	Vehicle-To-Infrastructure
CAR	Center For Automation And Robotics
R&D	Research and Development
DSS	Driver Support Systems
EBFD	Electronic Brake Force Distribution
ASR	Anti-Slip Regulation System

TCR	Traction Control System
ESP	Electronic Stability Program
ESC	Electronic Stability Control
BAS	Brake Assistant System
BLIS	Blind Spot Monitoring Or Blind Spot Detection
TPMS	Tire Pressure Monitoring System
SBR	Seat Belt Reminder
WRSB	Wire Rope Safety Barrier
CAD	Computer-Aided Drawings
FE	Finite Element
NCAC	National crash analysis center

ABSTRACT

Road crashes are hard-nosed affairs that can have a very negative influence on vehicles and vehicle occupants involved in them. Numerous efforts have been made to improve safety on our roads, including vehicle safety. But these systems are not effective in low-income countries because of that these systems require some advanced system and infrastructure in roads. In this work a new front-end, the passive safety system is designed, modeled using CATIA V5R20, and installed on a Geo-Metro sedan vehicle which is developed under NCAC, and by applying boundary conditions and testing the effectiveness and functionality of the system by using LS-DYNA. The designed passive safety device has one free rotation wheel installed horizontally at the vehicle lower front left and right corners, respectively. The wheels are the first contact of the vehicle in non-perpendicular forward collisions. The simulation of the vehicle indicates that the vehicle with a device at 45 degrees and 35km/h impact to the PCB-R diverts the harmful energy (about 69 KJ which is about 16.82 percent of total collision energy) into non-harmful energy and in addition, it increases the displacement of the vehicle about 447 mm into negative y-direction. In the same way, the vehicle tested to the pickup track at 20 degrees each other and with a pole, 90-degree offset indicates that the harmful energy is diverted to non-harmful energy and the vehicle displacement increased for the vehicle with a device. But at large collision angles the vehicle swing slide along the surface of the guardrail. When the vehicle is tested at a higher speed (120km/h) the mounting plate fails and no more protection for the occupant and the vehicle parts. For occupant response, the resultant rotational acceleration measured at the C.G accelerometer indicates for the vehicle equipped with a device was lower than the vehicle without a device. Generally, we can conclude that the vehicle with a device diverted to the safest place and the probability of occurrence of rear-end collision decreased, and the harm to the parts and occupant decreased.

Keywords: - Front-end passive safety system, vehicle collision, LS-DYNA, Geo-Metro, Non-perpendicular, Harmful/non-harmful Energy.

CHAPTER ONE
INTRODUCTION

1.1 Background

Traffic accidents expanded periodically at an alarming rate and it was a genuine issue all through the globe especially in developing countries like Ethiopia (Deme, 2019). Road traffic accident (RTA) is an occurrence, which happens or starts on a way or road open to public activity; coming about in one or more people being killed or injured, and at the slightest one moving vehicle is included. RTA incorporates collisions between vehicles, vehicles, and people on foot and vehicles and creatures or fixed obstacles (Woldu et al., 2020). Each year around the world the lives of approximately 1.35 million individuals are cut short as a result of a road traffic crash. Between 20 and 50 million more, individuals suffer non-fatal injuries, with many incurring a disability as a result of their damage. Road traffic wounds cause significant financial losses to people, their families, and countries as an entire. These misfortunes emerge from the cost of treatment as well as misplaced efficiency for those killed or disabled by their injuries, and for family individuals who need to take time off work or school to care for the harmed. Road traffic crashes cost most nations 3% of their net domestic item (Ivers et al., 2016). According to a World Health Organization report in 2015, Ethiopia is one of the 50 countries with the deadliest roads in the world (Tadege, 2020). Principally, injured people have occupied 30 to 70 percent of orthopedic beds in developing countries' hospitals (Deme, 2019). Road traffic accident-related causalities are extremely high in Ethiopia. Male young adults and vulnerable road users are at increased risk of RTAs. There is an urgent need for bringing road safety to the country's public health agenda. Pedestrian death in Ethiopia was common and high. Accordingly; about 74% of the fatal, serious, and slight injury accidents happened when pedestrians tried to cross streets (Abagaz & Gebremedhin, 2018).

Automobiles are much more dangerous to pedestrians than they are to drivers and passengers. Two-thirds of 1.3 million yearly auto-related deaths are pedestrians. Since at least the early 1970s, attention has also been given to vehicle design regarding the safety of pedestrians in car-pedestrian collisions (Waghe & S Y, 2014). With the increasing number of vehicles on the road, safety has become a focal point of consumers, governments, and society.

This special issue is focused on reviewing the history and background of automotive safety systems by presenting recent developments (Sabarinath, 2020). The normal approach of active and passive safety systems deliver their functionalities only at their phase specifically (Waghe & S Y, 2014). Active safety technology means the reasonable design of an automobile and scientific structure in the automotive research and development and production process, using the very advanced technology in the automobile industry, as far as possible to avoid or reduce the vehicle in normal driving sudden collision accidents, to improve the safety of their performance, to reduce the risk of a traffic accident then, to reduce the losses caused by the occupant (Wang et al., 2018). Passive Safety Systems play a role in limiting/containing the damage/injuries caused to the driver, passengers, and pedestrians in the event of a crash/accident. Airbags, Seatbelts, Impact Protection systems, etc. are common Passive Safety Systems deployed in vehicles these days (Sabarinath, 2020).

Finite element modeling plays important role in civil engineering and the automotive industry. Specifically, intensive work is being done towards the safety of passengers during collisions. Estimating the vehicle crashworthiness experimentally is expensive and time-consuming. For these reasons, different modeling approaches are utilized to predict vehicle behavior and reduce the need for full-scale crash testing. A crash simulation is a virtual recreation of a destructive crash test of a vehicle using a computer simulation to examine the level of safety of the vehicle and its occupants (Liu, 2013). Data obtained from a crash simulation indicate the capability of the vehicle body to protect the vehicle occupants during a collision against injury. This simulation technology has greatly increased the protection, dependability, and producing potency in today's vehicles. The advantage of the simulation is numerous and important (Kumar et al., 2019). Computer-aided parametric design software will be used for modeling of the problem to define all the coordinate values and geometrical details, then this CATIA data would be transferred to a FEM software for pre-processing, solution, and post-processing followed by generation and interpretation of results related to energies, acceleration, and displacements with different loads & boundary conditions possible in various accidental situations. The automotive industry has probably the widest application of crash simulation. Simulating the crashworthiness of the vehicle in terms of very simple models based on the spring-mass damper systems was the focus when the computers were very slow and the breakthrough occurred when LSTC was formed. Nowadays software such as LS-

DYNA and others have very wide practical aspects by incorporating special seat belt elements and passenger dummies for simulating precisely the occupant safety under various crash situations (Yadav & Pradhan, 2014).

The most collision happened when a vehicle turns and this results in the non-perpendicular collision into a harder surface. During a non-perpendicular collision, the first contact places of the vehicle are the two front corners of the vehicle. So the researcher tried to decrease the severity of the collision and to partially convert the collision harmful forces to non- harmful forces. To achieve these putting a front-end passive safety system, which has a wheel, a top-mounting plate, a top cap, and a bottom mounting plate, and a bottom cap is developed and tested for their effectiveness. Front end passive safety system is designed, and modeled using CATIA and analyzed for the functionality and effectiveness of the system by LS-DYNA. By using this software we tried to simulate and compare the results with a device and without a device. The front-end passive safety systems are assembled and installed at the two corners of the front chassis frame next to the bumper; normally, there are not many vehicle components in those areas, adding the front end passive safety system does not cause too much structural modification to the current vehicles, and the collision safer devices have good support from the frame during the angled collision and do not compromise the function of the crumpled structure.

1.2 Statement of the Problem

Vehicle collisions can happen at any place and anytime, any exterior portion of vehicles can be the primary collision point. In one sort of common collision, the vehicles move forward and collide into a hard surface non-perpendicularly, the primary collision contacts are the two front corners, which get all the collision drive. Putting a stronger material in those areas will not help, may make collision seriousness even worse. A passive approach which is to decrease the seriousness of the injuries when collisions truly happen, this approach incorporates occupant restraint systems (such as safety belts, child car seats), human body collision buffer (airbags), and controlled collision energy absorption structures (crumple zones). Safety belts and airbags are well known fundamental security items introduced on the vehicles to decrease the seriousness of damage of the individuals in the vehicles, however, the safety belts and airbags may not be sufficient to secure individuals, in some cases they fail to work, there were many factories reviews for safety belts and airbags within the past due to defects and people were slaughtered during the accidents. Individuals proceed to create a great effort to progress their effectiveness. Currently, the airbags are only introduced on little vehicles such as compact cars, pickups, sport utility vehicles (SUV) and Vans, not on the enormous buses and trucks, the occupants in such buses and trucks require more security during the collisions. For current vehicles on the markets and the streets, there's no viable component to diminish the initial harmful collision impact force when such collisions truly happen. In this paper, a new front-end passive safety device is designed and mounted to considerably diminish the collision force on individuals and vehicles and save lives.

1.3 Objectives

1.3.1 General objective

The general objective of this work is to design and analyze the front-end passive safety system for vehicle collisions.

1.3.2 Specific objectives

The specific objectives are to:

- ✓ Study the existing problems on a collision
- ✓ Selection of materials for the new design
- ✓ Design of the components
- ✓ Modeling of the designed parts using software, CATIA V5R20
- ✓ Simulation of the system using LS-DYNA
- ✓ Comparison of existing and new design

1.4 Significance

- ✓ The front-end passive safety system expected to decrease damage to the vehicle parts and harm to the passengers
- ✓ It may significantly expected to reduce the severity of the rear-end collision or even such rear-end collision can be avoided
- ✓ Adding the front-end passive safety system will not cause too much structural modification to the current vehicles.
- ✓ The system benefits automotive industries, passenger’s drivers, pedestrians and the country as a whole.

1.5 Scope

The study covers the design of new added parts which make up the front-end passive safety system, modeling of the designed system parts by using CATIA software, importing the vehicle and the modeled system into LS-DYNA, assembling of the modeled parts in LS-DYNA, applying simulation environment and running simulation for checking, experimental investigation of the vehicle collision for the validation of the result, comparing the result and draw a conclusion based on the result. But the researcher doesn't execute experimental investigation because of laboratory and other equipment investigation lack. So the researcher uses a comparison of the vehicles simulation result with and without the front-end passive safety system for the same simulation result and valid material specification. The effectiveness of the front-end passive safety system is checked for the selected Geo-Metro sedan reduced small vehicle and time restrict and the simulation and importing parameter is bulky and time-consuming, but the system works for other vehicles like buses, pickup track, etc.

1.6 Limitations of the Study

For the experimental investigation, it is better to get a laboratory that is designed for crash analysis to validate the result obtained from simulation in LS-DYNA. Even there is no lab set-up for the test of the model. The other shortcomings during this thesis work are due to the reason that simulation on LS-DYNA takes more time to run and complete the solution it is hard to check the device on real vehicles other than a Geo-Metro sedan vehicle for the effectiveness of the device. The design of the flywheel is also based on these Geo-Metro sedan device mass and energy. For another type of vehicle, the design may vary according to their specifications.

1.7 Organization of the Thesis

The thesis is organized into five chapters as described below.

Chapter One: Introduction:-This chapter introduces the current trend of vehicle accidents in Ethiopia, the current type of safety systems used for a vehicle on roads and tried to describe the most common methods used for the crash analysis LS-DYNA, and tried to introduce the new system.

Chapter Two: Literature- review: In this chapter, the related literature which is done in the past and used for reducing the vehicle collision after a collision happens and before the happening of impact is revised. In addition, the two types of safety systems widely used are briefly revised, and in road way driving the researcher tried to isolate the type of accidents that happened and what type of systems on road i.e. roadside safety barriers are used in the road is described. In this chapter, the collision behavior of a vehicle during a crash is described numerically and the rear-end collision is outlined. Energy conservation laws during a crash are also described. Based on this literature the researcher tried to identify some gaps and fill that gap.

Chapter Three: Materials and Methods:-It briefly describe the selection of material and the methods used for this thesis work. Under the method, the two types of data sources are described for the thesis work, and also the design of the flywheel and shaft is discussed. Modeling of the front-end passive system using CATIA, assembling of the parts, installing the designed system into a Geo-Metro sedan, pre-processing, running, and post-processing for LS-DYNA is briefly introduced.

Chapter Four: Result and Discussion: - Focuses on the result and discussion obtained from simulation result on a vehicle with and without a front-end passive safety system.

Chapter Five: Conclusion and Recommendations:-Deals with the conclusion drawn and recommendation depending on the result obtained.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The literature review has been referred to journals, reports, conferences, and books. Some research papers were also referred to have information on the previous art of research. Thus, this chapter tries to discover previous studies and expedite them for the current study in this thesis.

2.2 Categorization of Literature Review

The literature review in this study was divided into the following five main categories;

- ✓ Related literature reviews of this thesis work.
- ✓ Previous methods of collision mitigation systems used
- ✓ Vehicle safety system classification
- ✓ Types of the car accident
- ✓ Types of road safety barriers
- ✓ Energy curve definition during a vehicle collision

2.3 Previous Research Arts Review

Below are some of the reviewed literature that has been done by some researchers:

(Abagaz & Gebremedhin, 2018) evaluated the rates of injuries and fatalities linked with RTAs in Ethiopia. To achieve their study and evaluation they used a method of using secondary data from the 2016 Ethiopian Demographic and Health Survey that is involved in injuries. The survey polled 75,271 members of 16,650 households on injuries and accidents, including RTAs that occurred in the previous 12 months at that study time. Stratified cluster sampling was used to choose households from Ethiopia's nine regions and two municipal administrations. In the reference period, 123 of the 75,271 household members enumerated were involved in RTAs, with a rate of RTA-related injury of 163 (95 percent confidence interval (CI): 136–195) per 100,000 population. 28 of the 123 causalities were fatal, resulting in a fatality rate of 37 (95 percent confidence interval: 25–54) per 100,000 people. In Ethiopia, RTA-related deaths are highly common. The researchers generally concluded that RTAs are more likely to occur in male young adults and vulnerable road users. It is critical to prioritize road safety in the country's public health agenda.

(Khan et al., 2019) examined Crash avoidance technology and its advantages. The majority of light-duty vehicle crashes, according to the report, are caused by human error. So to avoid these vehicle crashes the vehicle manufacturer and users integrate Crash avoidance systems in their light-duty vehicles. But in this study, they use a method of studying net- societal and private benefits and costs associated with three crash avoidance technologies: blind-spot monitoring, lane departure warning, and forward-collision warning in the United States for all light-duty vehicles in 2019. These advancements can assist the driver in maintaining vehicle control when a potentially dangerous situation emerges by sending out alerts and, in some cases, responding to the situation itself. The result shows that three advances could help predict up to 1.6 million crashes per year, with 7,200 fatalities. The net-societal and net-private benefits of primary generation warning systems are both positive. Furthermore, the more recent generation of enhanced warning systems and dynamic brakes should increase net advantages.

(Dubey & Ansari, 2013) proposed Electromagnetic anti-collision device that measured the distance between two vehicles in extreme traffic conditions to avoid vehicular head-to-head/back collisions. The method was that they use a micro controller (ATMEGA 16) which receives echo signals from an ultrasonic range finding sensor. This information is used to excite solenoids to create an electromagnetic field. Ultrasonic sensors continuously read the distance between two vehicles and output is displaying on the dashboard of the vehicle. If the distance reduces to a certain level, the excitation circuit starts working to create an electromagnetic field. The result from their work shows that the framework works in two steps to avoid vehicle collisions/road accidents: - A range finder would continuously track the distance between two moving cars and send it to the ECM (electronic control module) using these inputs. If it detects one of the vehicles in the vicinity of the other, the sensor strip for Electromagnetic Induction will naturally trigger. The system is reliable, cost-effective, and fault-tolerant. In an adaptive control environment, these properties enable vehicle anti-collision.

(Basma & Refai, 2009) developed and tested an intersection collision warning (ICW) system based primarily on infrastructure communication. They used a method of using wireless sensor networks (WSN) to make the ICW recognize and communicate caution data to drivers and to avert accidents. Then they installed the system in intersecting roadways to help the real-time anticipation by monitoring oncoming activities and providing a warning system to vehicles when there is a high risk of collision. The first benefit of ICW is that it can predict rural intersection collisions. The framework was transferred into the highways surrounding the intersection and was purely based on framework communication. Generally, the ICW analyzes oncoming activity and alerting the driver if the likelihood of a collision is high, the technology offers genuine-time anticipation. To avert mishaps, ICW uses telematics and wireless sensor networks (WSN) to identify and exchange data. The system effectively alerts a driver by analyzing the probability of collision.

(Zhang et al., 2021) proposed a layered collision avoidance control approach based on warning value, standard collision time security show TTC(time to collision), and fuzzy PID (proportional integral derivative controller) to improve the security and real-time execution of vehicle longitudinal active collision avoidance (proportional integral derivative controller). The higher controller obtains the vehicle's braking deceleration by the relative speed and relative displacement of the object in front based on the collision time security show. The lower controller is based on fuzzy PID, and it agrees with the upper vehicle's brake deceleration speed. It achieves vehicle speed control by adjusting the weight of the vehicle's brake master cylinder. Finally, the collision avoidance effect of the controlled vehicle under various speeds was simulated and confirmed using the CarSim/Simulink co-simulation platform and the straight-line working condition as an example. The Simulation result shows the system controls the vehicle speed effectively. Generally using this proposed device may become effective in the future.

(Namazi et al., 2019) constructed AEB-P (Autonomous Emergency Braking Pedestrian) system meets the functional requirements of avoiding pedestrian collisions. After constructing the AEB-P the track safety level and work area of the AEB-P warning system were determined, by examining key theoretical systems such as TTC (time to collision) and brake safety distance. The genetic algorithm was also used to improve the fuzzy neural network model. The PID (proportional integral derivative controller) theory was used to develop the lower-layer controller of the AEB-P system, which converts the projected speed reduction to the pressure of a vehicle brake pipeline. The C-NCAP (China-new car assessment program) test requirements were used to create the applicable pedestrian test scenarios. The AEB-P system's Car-Sim and Simulink co-simulation model was created, and a multi-condition simulation study was performed. The findings demonstrated that the proposed control method was credible and trustworthy and that it could flexibly distribute early warning and brake time in response to changes in actual working conditions, reducing the number of pedestrian collision accidents.

(Sun et al., 2020) assessed collision evasion vehicle active safety control for intelligent connected vehicles (ICVs) in a real-world driving danger situation, using driving hazard recognition based on ICV innovation. Vehicle elements-based state-space equations conforming to model predictive controllers were built up in the research to essentially examine and recognize an active collision avoidance security space. Additionally, the model predictive controller was planned and calibrated, allowing the active collision avoidance strategy for cars based on the model predictive control approach to be implemented. Finally, the proposed dynamic collision avoidance control approach was put to the test in a planned complex activity environment. The research discoveries could successfully progress programmed driving, intelligent transportation productivity, and street activity security. Based on the assessment the directions of encircling vehicles were predicted and tracked in real-time.

(Mohamed et al., 2015) proposed a vehicle detection system. The system was based on two algorithms, a descriptor of the picture type haar-like, and a classifier type artificial neuron networks. In arrange to ensure rapidity within the calculation extracts features by the descriptor the concept of the integral image was utilized for the representation of the image. The learning of the framework is performed on a set of positive images (vehicles) and negative images (non-vehicle), and the test is done on another set of scenes (positive or negative). To address the execution of the proposed framework by varying one component among the determining parameters which is the number of neurons within the hidden layer; the results obtained have appeared that the proposed system may be a quick and robust vehicle detector. The proposed vehicle detection system has collected effective calculations in terms of image processing and terms of artificial intelligence. The combination of the descriptor haar-like classifier based on artificial neuron multilayer perceptron type networks gave satisfactory experimental results, which makes the proposed fast and strong framework for the location of vehicles in real-time. In any case, a few advancements can be made to this single object detection system to permit it multi-object detection (vehicle, pie tons. etc.) vigorous, quick and usable in real applications of road safety. These changes will be the objective of future works.

(Malhotra, 2019) studied and tested the working of a device for obstacle detection. The essential center was to create the vehicle securely and to guarantee the security of the driver. The presented paper deals with the development and working of a device for obstacle detection. Obstacle location may be a component used for the identification of any obstacle that will hinder the way of the vehicle the proposed system consequently turns left or right on detecting obstacles using ultrasonic sensors & an Arduino. An obstacle location security framework helps the driver to know the adjacent impediments and avoid them (for example Bicycle, guard rail, children, and walls). It is essential to moderate down the vehicle or switch when stopping. The front and rear bumpers are connected to ultrasonic sensors in this framework. These sensors calculate the distance between the driving vehicle and the obstacle around the front and rear bumpers, and when it beeps continuously, it means that the vehicle is about to collide with the obstacle. They use an ultrasonic sensor for obstacle detection, and then the sensor attracts the waves and bounces them back for detection, the system was used in alarms, pre-programmed door openers.

(Akhlaq et al., 2012) designed and modeled a camera-based advanced driver assistance system (ADAS). In any case, ADAS come only with advanced luxury cars because of their high cost and complexity due to several sensors employed. In this manner, camera-based ADAS are becoming an option due to their lower cost, higher accessibility, various applications, and capacity to combine with other systems. Targeting at designing a camera-based ADAS, they have conducted an ethnographic study of drivers to know what data around the driving environment would be valuable in avoiding accidents. It turned out that information on speed, distance, relative position, direction, and size, and sort of the adjacent objects would be useful and sufficient for implementing most of the ADAS capacities. A few camera-based techniques are accessible for capturing the required data. They proposed a novel plan of an integrated camera-based ADAS that puts technologies such as five ordinary CMOS picture sensors, an advanced image processor, and a thin display into a savvy framework to offer a dozen advanced driver assistance functions. A fundamental model was also actualized using MATLAB. Model testify that all the specified innovations are presently accessible for implementing a full-fledged camera-based ADAS.

(Markkula, 2015) studied generally about how to realistically model driver behavior in computer simulations of safety-critical traffic events, an increasingly important tool for evaluating automotive active safety systems. This approach permitted the conclusion that heavy truck ESC (Electronic Stability Control) provides a safety benefit in unexpected critical maneuvering, something which has not been previously demonstrated. Furthermore, ESC impact could be analyzed at the level of individual steering behaviors and scenarios, and this impact was found to range from negligible, when the simulated drivers managed well without the system, to large, when they did not. In severe skidding, ESC reduced maximum body slip in the simulations by 73 %, on average. Some specific ideas for improvements to the ESC system were identified as well. As a secondary applied example, an advanced emergency brake system (AEBS) is considered, and a partially novel approach is sketched for its evaluation in what-if re-simulation of actually recorded crashes. Several new insights and hypotheses regarding driver behavior in near-crash situations are presented: When stabilizing a skidding vehicle, drivers were found to employ a rather simple and seemingly suboptimal yaw rate nulling strategy. Collision avoidance steering was found to be best described as an open-loop steering pulse of constant duration, regardless of amplitude. Furthermore, by analysis of data from test tracks as well as real-life crashes and near-crashes, it was found that detection of a collision threat, and also the timing of driver braking or steering in response to it, may be affected by a combination of situation kinematics and processes of neural evidence accumulation. These ideas have been tied together into a modeling framework, describing driving control in general as constructed from intermittent, ballistic control adjustments. These, in turn, are based on overlearned sensorimotor heuristics, which allow near-optimal, vehicle-adapted performance in routine driving, but which may deteriorate into sub-optimality in rarely experienced situations such as near-crashes.

(Wambasi F.B, 2014) implemented an intelligent microcontroller-based Crash evasion system that will employ obstacle detection and distance measurement using ultrasonic sensors to detect obstacles and their distances. A warning signal is provided to the driver to alert them before the system takes automobile steering into control. Hazard lights are turned ON the moment a collision is detected and Brake lights are turned ON after activation of the brake assist system and the brakes which are preferably ABS (Antilock Brake System). Dashboard displays of LEDs (Light-Emitting Diodes) are incorporated to make the system more interactive. The system provides for manual control by the driver when they find the need to operate the automobile without it as in the case of parking and testing or driving in narrow confined paths. Once the obstacle has been detected and a safe separation distance is not provided, the automobile will perform safety braking and a further decrease in separation distance will cause the system to initiate steering control to reduce the severity of the collision.

(Milanés et al., 2012) presented an approach to the avoidance of rear-end collisions in congested traffic situations. They used a method of using two fuzzy controllers and developed a Collision Warning System (CWS) and a Collision Avoidance System (CAS). The former is in charge of alerting the driver in case of an impending rear-end collision to prevent or mitigate the crash. The latter is in charge of generating an output control signal for the steering wheel to avoid the collision. Both CWS and CAS have been tested with real cars using vehicle-to-infrastructure (V2I) communications to acquire data of vehicles. Generally, they conclude based on their study that the system installed in the infrastructure is capable of assessing road traffic conditions in real-time is responsible for transmitting the data of the vehicles in the surrounding area. The systems have been tested at the Center for Automation and Robotics (CAR)'s facilities with two mass-produced cars.

(Zhang et al., 2021) discussed and developed a measurement estimation algorithm of a target vehicle using a monocular camera. The method estimates two cases of vehicle widths for a target vehicle by using the detected lane information and a pin-hole camera model to improve the performance of the FCW/AEB system. After that, the position, velocity, acceleration, and TTC of a target vehicle are estimated by using a Kalman filter for each estimated vehicle width. To improve robustness, both estimation results using the detected lane information and the pinhole camera model are fused. The estimation algorithm was evaluated and compared with state-of-the-art technology. Generally from their study, the proposed measurement output estimation method can improve the performance of the FCW/AEB systems.

(Sabarinath, 2020) examined how to provide the safest ride for the people. The researcher tried his best to protect the precious life of the driver and the co-passengers during the accidents by increasing the distance between the impact zone and the passengers, peculiarly during the crash on the sides. To achieve this the researcher used the method of incorporating a pneumatic cylinder under the seats, which is then actuated by the solenoid valve triggered by the deformation caused by the crashing vehicle. The result of the work makes the seats tilted at the time of the accident away from the near side of the door, which saves the life. The high-pressure energy in the container gives ultimate kinetic energy using high velocity gives a sudden actuation of seats in a fraction of seconds clearly say 0.3 seconds. He also re-designed the structure and mechanism of car seats to make it possible to save precious lives. The design idea does not stop with a single possible way of saving a life, it extends to a lot of customization and adaptability based on the car structure and available space specific to various brands and models. From the total work the researcher generally concluded that the system greatly decreases the harm of accidents and passengers.

(Waghe & S Y, 2014) studied the two types of safety systems "Active" and "Passive”. These systems are simple but significant terms in the world of automotive safety. "Active safety" is used to refers to technology assisting in the prevention of a crash and "passive safety" to components of the vehicle (primarily airbags, seatbelts, and the physical structure of the vehicle) that help to protect occupants during a crash. They have focused on every aspect of a particular safety system. In this paper, they have discussed the working principle, sensors used in brief. A rearview mirror is an important safety device. Rearview mirrors on-road vehicles are primarily a protective safety device providing a clear view towards the rear of the vehicle. They have studied mirror impact testing of automotive rearview mirrors according to AIS: 001(Part 1) (Rev.1)2011 which is performed to simulate the crash of a human head hitting.

(Puthan et al., 2018) studied the limitations of existing safety systems on vehicles. Many active safety systems depend on infrastructure like proper lane marking, traffic signals, which are well developed in high-income countries. There is also a big difference in the share of road users when comparing developing countries to high-income countries. All these factors can have a substantial effect on the performance of active safety technology performance in real-life traffic. More studies on the effectiveness of safety technologies in low and middle-income countries are urgently needed. Effectiveness results from this study highlight the importance of introducing passive and active safety technologies together to maximize the reduction of road traffic fatalities. Advanced ADAS technology along with passive safety technologies has the potential to prevent about 20% of today’s fatalities. One should therefore not only consider passenger car safety technologies, but also other vehicle technologies. Another opportunity to reduce fatalities would be improving infrastructure and enforcing the traffic rules such as the usage of seatbelts and helmets. Generally based on their observation they concluded that all the active safety technologies are primarily developed and implemented in high-income countries. It is therefore a limitation to assume that all the active safety technologies have the same performance in developing countries as in high-income countries.

(Raja Raghavan & Bhuvaneswari, 2015) gave a summary of implementing safety and security services in conveyance systems of these days and future development. In the present developing world, innovations are blasting at each place to feed our humankind. There have been monumental advancements in automobile technologies over the past and still to come. But accidents still happening around us. Lack of traffic control facilities, violation of rules, and carelessness while driving has led to increased fatal rates. The paper aims at providing drive assist systems supported electronic sensor technologies and additionally it's involved with the implementation of the subsequent ideas in automobiles for safety and advanced security functions. The safety systems are Driver sleepiness Detection System, Alcohol Detector, and Pot Hole Detector. The ideas of Wireless protection and unlocking of vehicles, Advanced Key-less engine instigations are also mentioned. They finally concluded that by exploitation of these ideas, they hope that road accidents and vehicle thefts are going to be decreased. They also suggest that this can be one of the papers needed for current situations everywhere on the planet.

(Ning li, 2014) investigated finite element modeling and simulation of occupant responses in highway crashes. In the study, the finite element model of a Hybrid III 50th percentile male dummy was developed for studying the driver's responses in vehicular crashes into highway barriers. After validation by standard crash tests, the dummy model was combined with the finite element model of a 2006 Ford F250 pickup truck and used in simulations of the vehicle impacting a concrete barrier and a W-beam guardrail under different impact speeds and angles. Finally, the dummy responses in these simulations were analyzed by correlating with existing human injury criteria to correlate impact severity to vehicular responses and ultimately to barrier performances. For vehicular crashes into the rigid concrete barrier, the simulation showed that some injury criteria based on vehicular responses correlate strongly with occupant injuries and could be reliably used to indicate the relative level of occupant injury, although a specific value would not give a clear indication of the actual injury level. For vehicular crashes into the semi-rigid W-beam guardrail, the correlation between vehicular responses and occupant injury was found not as strong as that observed in the case of the concrete barrier.

2.4 Vehicle Safety Systems

In vehicles´ development and design, it is given increasing emphasis to comply with the requirements of vehicle safety. These requirements are set by the applicable regulatory provisions and also by the requirements of the customers. Precisely because of the customer requirements, vehicle safety becomes one of the cornerstones of competitiveness in the contemporary market. Vehicle manufacturers dedicate to these issues more and more attention to the development of new vehicles and they are working also on the development of a variety of security features that could be installed in vehicles additionally (Garrett et al., 2000). The modern car is usually designed with a particular emphasis on ensuring a high level of safety of the crew and other road users (pedestrians, cyclists, other vehicles, etc.). To ensure the highest levels of safety the modern vehicles are equipped with systems for driver support that are in certain cases even capable replace the driver (e.g. automatic maneuvering system that moves a vehicle from a traffic lane into a parking spot, automatic car accident detection, and notification system that identifies the vehicle's position and calls for help, and so on) (Mikusova, 2017).

Safety systems in automobiles are divided into two categories based on whether they are used before or after a crash: Active Safety and Passive Safety. Active safety refers to the concept of assisting in the prevention of accidents, whereas passive safety refers to the concept of assisting in the protection of occupants in the event of a collision (Amit K. T.,2016-2017).

2.4.1 Active safety technology

Active safety technology refers to the rational design of automobiles and scientific structures in the automotive R&D and production process, using the most advanced technology available in the automobile industry, to avoid or reduce vehicle in normal driving sudden collision accidents, to improve the safety of their performance, and to reduce the risk of accidents. Active safety technology has become a major research focus of major car companies' R&D departments in recent years (Wang et al., 2018).

The active safety features, devices, and systems help maintain vehicles under control and prevent an accident occurrence. Active safety is a result of the harmonic structure of the vehicle chassis, which takes into account the wheel guidance, suspension, steering feedback, and stability of the brakes. It guarantees the optimum vehicle dynamic behavior also during the process of evading obstacles (Safety, 2018).As a part of the active safety we can recognize:

Autonomous active safety systems

- ✓ Permanently supporting driver,
- ✓ Actuating in a moment of expected impact;

Active safety systems cooperating

- ✓ With other vehicles,
- ✓ With infrastructure.

Autonomous active safety system:-Preventing traffic accidents is the most effective approach to lessen them. Active safety systems were created for this purpose. These systems can be divided into two categories based on their function throughout time: constantly functioning systems and systems that influence vehicle activity during a possibly dangerous situation (Anderson et al., 2016).

Autonomous active safety systems permanently supporting the driver: - Driver assistance systems, also known as Advanced Driver Assistance Systems (ADAS) and Driver Support Systems (DSS), are active safety systems that provide permanent support for the driver. Autonomous, always-on safety systems assist the driver in adapting to the current situation on the road, anticipating needs, and, if necessary, taking the initiative (Šucha et al., 2021).

The most known representatives of these systems are Power steering, Electronic Stability Program, Anti-lock Braking System, Electronic Brake-force distribution, Anti-slip Regulation, Electronic differential lock, Brake Assist System, Advanced Emergency Braking System, Multi-collision brake, Regulator of engine torque, Downhill Assist Control, Active Body Control, Speed Alert, Adaptive Cruise Control, Intelligent Speed Adaptation, Seat Belts Reminder, Signalization of an improperly closed doors, Lane Departure Warning System, Blind Spot Monitoring, City Safety, Collision Avoidance System, Pre-crash Sensing, Parking Assistance System, Driver Monitoring System, Lighting Xenon headlight, Adaptive Headlights, Vision Enhancement System, Alcohol

Interlocks, Route Guidance and Navigation Systems, Tire-pressure Monitoring Systems (Intelligent Tire System, Tire Pressure Monitoring System, Deflation Detection System), Run Flat tire, Heads-Up Display and Automatic Dimming Mirror (Jamroz et al., 2016).

A. Anti-lock braking system (ABS):- Anti-lock brakes keep the wheels from locking up when braking, allowing the driver to keep control of the car. Locked wheels are incapable of transmitting lateral guidance forces. Figure 2.1 below shows the effect of ABS on a vehicle when compared to without ABS. The control unit regulates the ABS wheel-speed sensors over several all-wheel-drive vehicle revolutions. If a single wheel becomes blocked, the solenoid valve will reduce the anti-skid control unit's brake pressure to that wheel until it no longer rotates freely. The pressure is then increased once more to prevent blocking**.** The intervention of the anti-lock system is felt by the driver as a mild pulse in the brake pedal. On dry surfaces, braking distances may be slightly longer. Its primary function is to allow the driver to brake and change the direction of the vehicle, especially on slippery road surfaces (Moravčík & Jaśkiewicz, 2016).

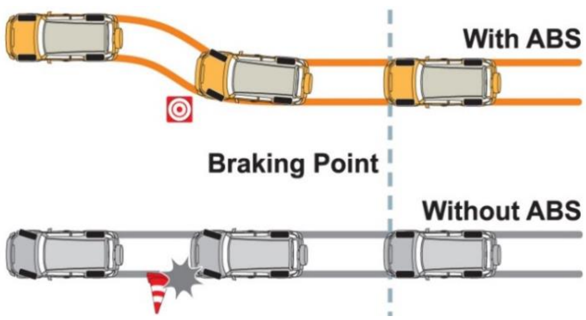


Figure 2. 1: Effect of Anti-lock braking system (ABS) (Sahil Jitesh, 2018)

B. Electronic Brake Force Distribution (EBFD):- Electronic brake force distribution (EBD or EBFD), sometimes known as Electronic brake force limitation (EBL), is a vehicle braking system that automatically adjusts the amount of force supplied to each brake based on road conditions, speed, load, and other factors. Figure 2.2 below shows the electronic brake force distribution and its components in detail. EBD can deliver more or less braking pressure to each tire to maximize stopping force when used in conjunction with anti-lock braking systems. Because the front end of the vehicle carries the most weight, EBD applies less braking pressure to the back brakes, preventing the rear brakes from locking up and causing a skid. The front and rear axle wheel speeds are compared. If the difference exceeds a certain threshold, the EBD system detects over braking on the rear axle and intervenes. The EBD system then closes the ABS inlet valves for the left and/or right rear wheels, preventing additional pressure build-up and maintaining wheel brake cylinder pressure. During initial brake application, EBD distributes more braking pressure to the rear brakes in some systems before the consequences of weight transfer become apparent. (Waghe & S Y, 2014).

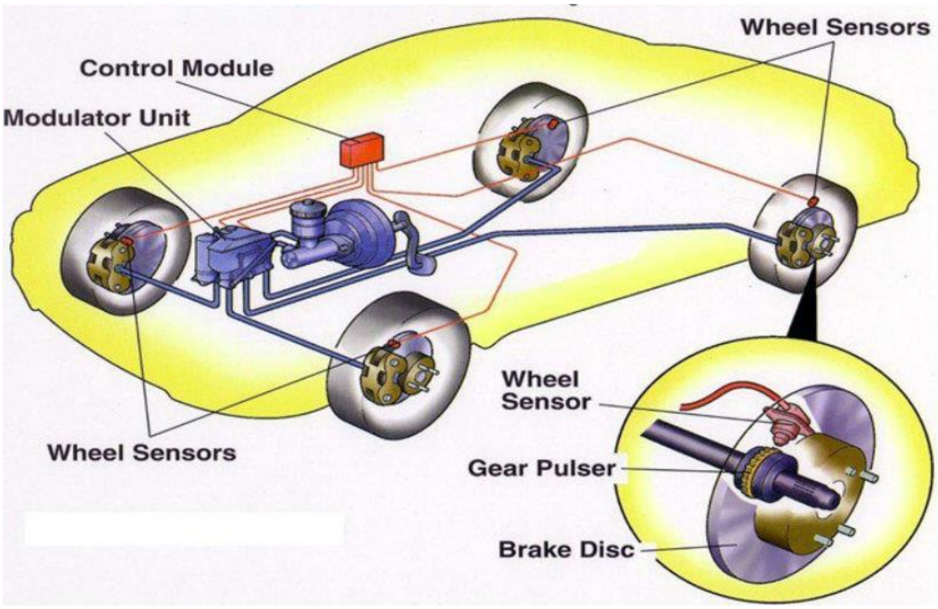


Figure 2. 2: Electronic Brake Force Distribution (EBFD) (Wu et al., 2018)

C. Anti-Slip Regulation system (ASR) or **Traction Control System (TCR):-** prevents wheel spinning on a slippery surface, changing direction on acceleration; smarter systems are capable on one axle torque split if one wheel is on a slippery surface and one on the hard disk (Moravčík & Jaśkiewicz, 2016). The following Figure 2.3 below shows the vehicle wheels are slipping on a slippery road. The vehicle which has ASR doesn't slip on slippery roads.

Figure 2. 3: Anti-Slip Regulation system (ASR) (Buznikov, 2018)

D. Electronic Stability Program (ESP) or Electronic Stability Control (ESC):- In all scenarios, it improves management control and automatically stabilizes the vehicle. The Electronic Stability Program detects crucial situations and prevents the vehicle from deviating from its intended path as shown in Figure 2.4 below with a vehicle in red color. It should actively prevent the car from skidding out of control and aid the driver in stabilizing the vehicle if it does skid. It works hand-in-hand with ABS and ASR. It compares the vehicle's behavior against calculated values. The desired direction of movement is determined by the steering angle, while the actual speed is determined by the wheel speed. Compares estimated values for lateral acceleration and vehicle rotation around the vertical axis. When cornering at excessive speeds, or when the road surface unexpectedly changes (water, ice, pollutants), or when doing an unexpected evasive maneuver, the vehicle may become unstable. Based on input from sensors, the regulating unit of the Electronic Stability Program recognizes the type of volatility and intervenes in engine management and brake control. When a vehicle understeers, it enters corners with its front wheels turning insufficiently. ESP applies brakes to the rear wheel on the inside of the bend and, if necessary, reduces engine power at the same time. If the driver applies the brakes on the outside of the bend, ESP engages and decreases the braking force (Electronic Stability Program (ESP), 2014).

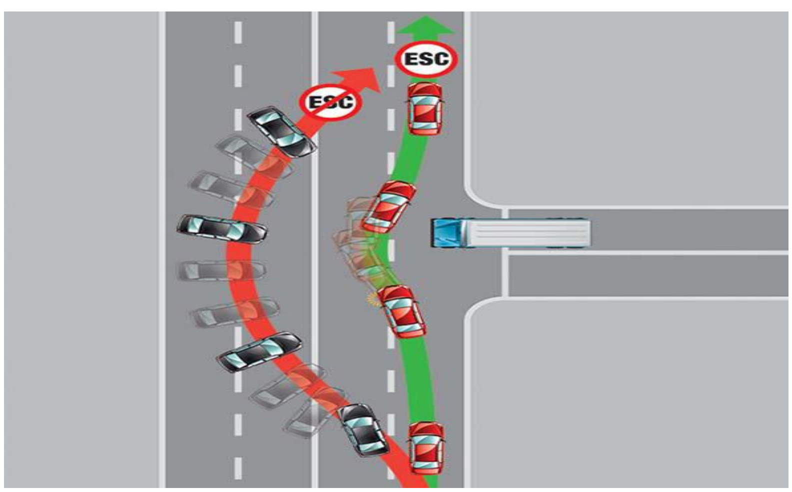


Figure 2. 4: Electronic Stability Program (ESP) or Electronic Stability Control (ESC) (Moravčík & Jaśkiewicz, 2016)

E. Brake Assistant System (BAS):- Assistance braking action; in emergencies and when ABS regulates brake pressure, the brake pedal may shake, prompting the driver to release the pedal to avoid the vibrations, reducing braking effectiveness. In the event of a crucial braking situation, Brake Assist is enabled. As shown in Figure 2.5 below, when a driver abruptly brakes, it will almost always cause significant delays. BAS evaluates the driver's rapid replies and automatically defines the braking system's will, increasing braking pressure in the system and shortening the braking distance by up to 2 meters. The pressure in the system is released again if the driver does not raise the pressure on the brake control system(Bali and Erzan Topçu 2018).

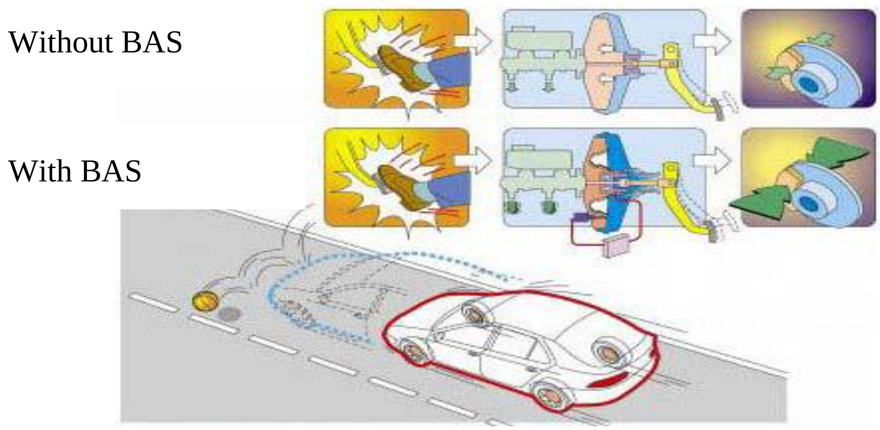


Figure 2. 5: Brake Assistant System (BAS) (Bali and Erzan Topçu, 2018)

F. Blind Spot Monitoring (BLIS) or **Blind Spot Detection:-**A blind spot is a zone around the car that the driver cannot see adequately because of an obstruction such as a headrest, passenger height, or a window pillar. The blind spot zone is shown in the following Figure 2.6 below. The vehicle is equipped with four sensors that monitor the vehicle's front, rear, and two sides. When an obstruction is identified in the blind spot area, the obstacle's distance is calculated and sent to the Arduino Mega for processing. The ultrasonic sensor HCSR04 has a measurement range of 2cm to 400cm and a ranging accuracy of 3mm. The Arduino microcontroller is at the heart of the system. Ultrasonic sensors, motor IC, and DC motor make up the system. When an obstacle is identified in the blind spot, data is collected using an ultrasonic sensor HC-SR04 with a specified range, and then supplied into the Arduino mega 2560's input. The ultrasonic sensor estimates the distance with time by measuring the time difference of the barrier in the area of the vehicle. The data is then modified to control the motors and reduce their speed by a predetermined amount (Ajay & Ezhil, 2016).

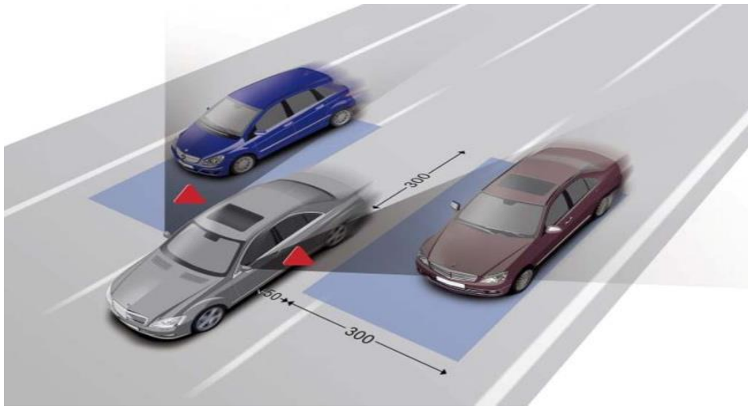


Figure 2. 6: Blind Spot Monitoring (Ajay & Ezhil, 2016)

G. Tire pressure monitoring: - The Tire Pressure Monitoring System (TPMS) is an in-vehicle sensor system that measures the inflation pressure in each of a vehicle's tires. TPMS has two main parts, the central control unit, and the TPMS module as shown in the following Figure 2.7 below. If a pressure loss occurs in any of the tires, the system can alert the driver via an in-car warning system. There are two types of TPMS frameworks: direct and indirect frameworks. Physical pressure sensors are not used in indirect TPMS. They are comparing tire rotation speeds. The technology can determine if a tire's diameter is changing by combining data from prior runs. Loss of pressure is seen as a reduction in diameter. Physical pressure sensors are used by direct TPMS within each tire. Each sensor measures the inflation pressure or the pressure fluctuation over time. Through a radio frequency transmitter, in-tire sensor modules broadcast their ID, as well as pressure, temperature, and other data, to a pressure control unit (Silalahi et al., 2019).

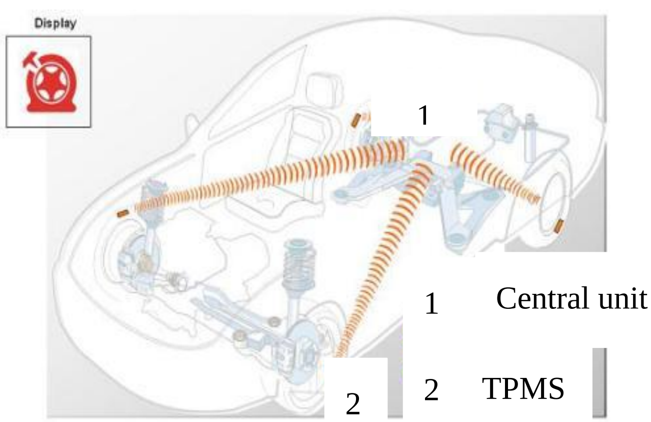


Figure 2. 7: Tire Pressure Monitoring System (TPMS) (Silalahi et al., 2019)

H. Seat Belt Reminder (SBR):-The following Figure 2.8 shows the SBR system to warn the driver and passengers that seatbelts are not being used.

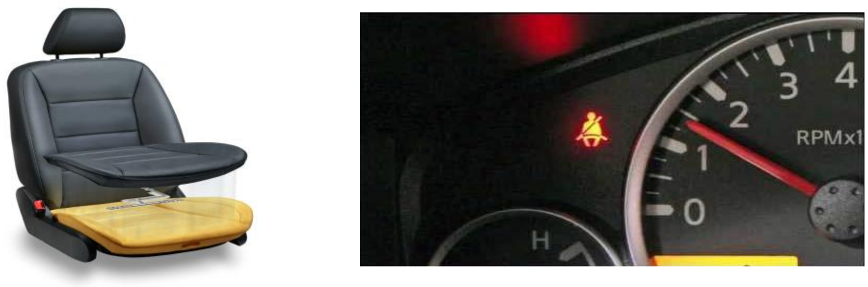


Figure 2. 8: Seat Belt Reminder (Ncap, 2007)

I. **Warning that the doors are not closed properly: -** The following Figure 2.9 shows a device to warn the driver when the doors are not closed properly.

Figure 2. 9: Door warning (Safety, 2018)

2.4.2 Passive safety technology

Passive vehicle safety innovation refers to the car's use of protective equipment after a collision to safeguard people inside and outside the vehicle as much as possible, minimizing harm. Most car-mounted occupant safety technologies nowadays include anti-collision bodies, pre-tensioning seat belts, and airbags, among other things (Wang et al., 2018).

A. Safety belt: - Seatbelts are outlined to hold individuals in their seats, and so avoid or decrease injuries suffered in a crash. They guarantee that as small contact is made between the occupant and vehicle interior as possible and significantly diminish the chance of being thrown from a vehicle. As shown in Figure 2.10 below Seatbelts are planned to work as the key portion of more extensive harm anticipation measures and security frameworks, such as airbags and head restraints, which cannot be as effective in decreasing the risk of damage if an occupant is not wearing a seat belt (The Royal Society for the Prevention of Accidents, 2018).

Figure 2. 10: Safety belt (The Royal Society for the Prevention of Accidents,2018)

B. Airbag: - In a front-end collision, airbags protect your head, neck, and chest from crashing into the dash, steering wheel, or windshield. They are not meant to explode in rear-end or rollover collisions, or the majority of side collisions. Airbags are designed to protect you in a crash that is similar to a car driving into a strong wall at 8 to 14 miles per hour. Figure 2.11 below shows the situation when a car collides with another vehicle or a solid object such as a tree, airbags are most likely to deploy. When a sensor detects a front-end collision, the airbags deploy. The sensor gives out a signal, which triggers a chemical reaction that fills the airbag with safe nitrogen gas (National High Way Safety Administration of US, 2020).

Figure 2. 11: Airbag (Wang et al., 2018)

2.5 Types of Car Accidents

Loss of control is most often the underlying cause for any driver involved in a traffic crash. What prompts this reaction to kick in depends on the type of car accident taking place. Each of the following types includes a brief description. (Raslavicius et al., 2017)

A. Head-On Collision: - You're driving north on the road and suddenly another vehicle traveling south jumps the median and heads right for you. They have lost control and realize their last swerve got brought them here and they are afraid to make another move. Figure 2.12 below shows a head-on collision situation between two vehicles on roads (Wali et al., 2018).

Figure 2. 12: Head-on collisions (Wali et al., 2018).

B. Vehicle Rollover: - When a car or truck (more frequently an SUV or van) flips onto its side, as shown in Figure 2.13, lands on the roof, or tumbles multiple times, it can cause occupants to be ejected. Unfortunately, there is no time to react, and the results of a vehicle rollover are serious injuries, at a minimum, with a high risk of fatality. When drivers and passengers have fastened their seatbelts, their survival rate is significantly increased (Yu et al., 2008)

Figure 2. 13: Vehicle rollover (https://www.shutterstock.com)

C. T-bone Car Accident: - One of the most dangerous collisions you can experience the T-Bone car accident happens when one vehicle crashes head-on into the side of another. Most frequently this "T" effect as shown in Figure 2.14 occurs on the driver's side of the impacted car which can cause broken bones, a brain concussion, and even fatality. Because these collisions are usually sudden and unavoidable, your best outcome is when your seatbelt has been locked in place (Side Collision - Wikipedia).

Figure 2. 14: T-Bone Car Accident (https://www.shutterstock.com)

D. Multiple Vehicle Collision: - Another highly vulnerable traffic accident is a multiple vehicle collision that involves three or more vehicles as shown in Figure 2.15 in a chain of events from a single event. These pileups can range from minimal to massive, resulting in a lot of confusion and multiple injuries, and fatalities. Whether you land in the mix may very well depend on your situational awareness and the distance you keep from others sharing the road (Prentkovskis et al., 2010)

Figure 2. 15: Multiple vehicle collision (Herman & Herman, P.L.L.C., 2016)

E. Sideswipe collision: - Whether you're on a country road or a freeway, driving right next to another vehicle is quite risky. Any distraction by the other driver may cause them to drift from their lane into yours resulting in anything from a minor bump to a disabling blow. Avoid these crashes by staying clear of blind spots (yours and the other drivers) and taking notice when others are driving too close to the lane divider.

F. Side impact collision: - When one vehicle is broadsided (hit in the side by another driver's front end) it is known as a side-impact collision. Most often, this type of car accident occurs at an intersection. Usually, there are witnesses and possibly there is a traffic camera atop the light, but it's not a guarantee. You have a chance to avoid these crashes by slowing down as you approach the junction whether or not you have the green light.

Figure 2. 16: Sideways collision

G. Single Car Accident: - A single-car accident as shown in Figure 2.17 inherently involves one vehicle but this doesn't mean its driver is always at fault. Generally caused when a single driver reacts by swerving to keep from hitting something maybe an animal or weaving driver and ends up colliding with a guardrail or tree, or an electrical pole. In these cases, the weather is often a factor that can present unavoidable hazards in your path. Your best bet is to slow down as you round a curve or draw near to a blind corner (allowing safer reactions).

Figure 2. 17: Single-car accident (https://image.shutterstock.com)

2.6 Types of Road Safety Barriers

Barriers are used to separate oncoming traffic, isolate objects on the roadside (trees, buildings, water reservoirs, and others) from possible interaction with the vehicle, and prevent animal access to the roadway. Based on their function, barriers are divided into two types – flexible and rigid systems. In some cases, the designation of semi-rigid systems is also found. As a result of vehicle collision, flexible barriers undergo permanent deformation. Collision energy is absorbed by both the barrier (barrier deformation) and the vehicle (vehicle deformation). Flexible barriers are usually made of steel or other deformable material (for example, aluminum and wood). Rigid barriers undergo insignificant deformation as a result of a vehicle collision. Collision energy is dissipated to vehicle deformation, movement of barrier elements, friction between the vehicle and the barrier, as well as lifting the vehicle onto the barrier (Butans et al., 2015).

2.6.1. Flexible safety barriers

In several nations throughout the world, flexible wire rope safety barrier (WRSB) systems are now commonly employed. These barriers are made up of a number (usually three or four) of wire ropes (cables) that are kept in place by steel posts spaced at 2.4m intervals. When a vehicle hits the ropes, they deflect, directing the car along the barrier while the posts gradually disintegrate. The following Figure 2.18 shows a flexible wire rope safety barrier system which is designed under the national crash analysis center.

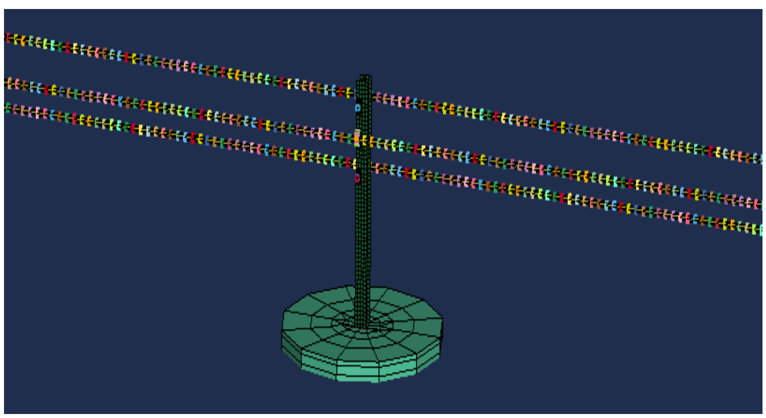


Figure 2. 18: Flexible crash barriers (NCAC, 2016)

The posts absorb the vehicle's kinetic energy, slowing it down. Wire rope safety barrier systems provide a far more forgiving roadside barrier than more rigid systems when appropriate deflection width is available (Jordan, 2010).

2.6.2 Rigid safety barriers

Rigid barriers include:

- ✓ Precast concrete barriers;

- ✓ Cast in situ reinforced concrete parapets;
- ✓ Extruded concrete barrier; and
- ✓ Combinations of the above.

Rigid barrier systems deflect extremely little, if at all when struck. They also enable the barrier system to be developed with more strength and rigidity to deflect high-mass vehicles. Rather than deflection of the system, energy is dissipated during collisions by raising and lowering the vehicle, as well as deformation of the vehicle body and mechanical components Rigid barriers are thus employed in situations where barrier deflection is limited, such as when the design vehicle exceeds the steel system's test level when the hazard is close to the running lane, or in narrow medians. The barrier must be able to resist the impact load through a combination of moment and shear loads to be effective (Butans et al., 2015). The following Figure 2.19 shows a rigid type of barrier developed under the national crash analysis center for crash analysis and crash worthiness test.

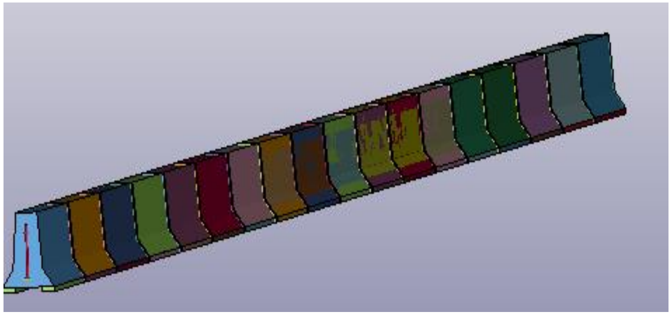


Figure 2. 19: Rigid barriers (NCAC,2016)

The other newly distributed type of roadside barrier is a roller-type roadside safety barrier. This barrier rotates and directs the vehicle to the lane and protects the vehicle not to be an exit into somewhere and absorbs the impact force during the collision. Figure 2.20 below is taken from the Ethiopian transport bureau annual report page in 2021.

Figure 2. 20: Roller type roadside-crash barrier (Ethiopian transport bureau report, 2021)

2.7 The First Contact Places of Vehicle Collisions

When a car collides, the first point of contact can be any part of the vehicle's exterior. When vehicles drive forward, for example, non-perpendicular collisions onto a hard surface occur; in these situations, the first colliding contact points are the two front corners illustrated in Figure 2.21 shaded by black (. These two front corners of the car are where we receive all of the collision force, thus if we try to improve these two front corners of the vehicle, we may be able to reduce collision harm and eliminate death. If we try to place tougher materials in these regions, it will not assist; in fact, it may make vehicle crash damage even worse.

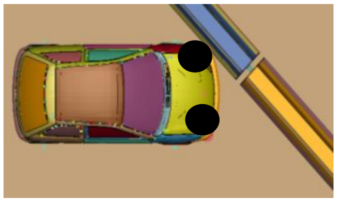


Figure 2. 21: First contact places during a non-perpendicular collision

2.8 Rear-End Collision

Rear-end crashes are regular incidents that occur during rush hour or on congested highways. Typically, numerous vehicles are involved and destroyed, and multiple persons are killed or injured. Rear-end crashes can be divided into two categories (Qingwan Xue et.al, 2018):

- ✓ The vehicle in front suddenly slows down quickly or stops in the driving lane, the vehicle behind follows too closely, does not have enough time to slow down, and collides into the vehicle in front;
- ✓ The vehicle in front has uncontrolled problems, drifts away from its normal driving lane, and collides into the roadside barrier (most likely with original speed), the vehicle behind follows too closely, does not have enough time to slow down, and collides into the vehicle in front.

2.8.1 Theoretical Analysis

Consider Figure 2.22, where a driver is driving his car at v mph and sees an object (bull A) in front of him. If the driver evaluates and considers whether or not the situation will result in a collision with the object, the time it takes the driver to evaluate the situation and try to stop the vehicle is the reaction time. The car continues to proceed at the same pace as before response time, so when the driver uses the brakes, the vehicle begins to slow down until it comes to a complete stop. The following equation calculates the total stopping distance D_{total} without collision.

$$D_{total} = D_{reaction} + D_{braking} = vt_{reaction} + \frac{v^2}{2\mu g} \qquad \text{(eq.1) (Wikipedia)}$$

Where

$D_{reaction}$ = Reaction distance traveled by the vehicle during the reaction time.

$D_{braking}$ = Braking distance from the time brake starts to its complete stop.

$t_{reaction}$ = Reaction time, 1.5s for humans in an un-alert situation.

μ = Friction constant of the rubber tire with the asphalt road surface (0.7) and

g = Gravity constant.

The equation (1) above is a relatively simplified theoretical model; in reality, many factors influence a vehicle's stopping distance. Road conditions, tire tread depth, and how alert you are as a driver will all have an impact, and these are all factors to consider when driving. However, for the sake of example, equation (1) should be enough. When the distance between the vehicle and the troublesome object (bull B) is less thanD_{total}, the vehicle will not be able to stop in time and will collide with it. According to the following equation, the collision energy decreases linearly with the collision distance:

$$E(d) = E_0\left(1 - \frac{d}{d_{braking}}\right) \qquad \text{(eq.2)}$$

Where d = Collision distance,

E_0 = Energy carried by the vehicle at the point that the braking starts.

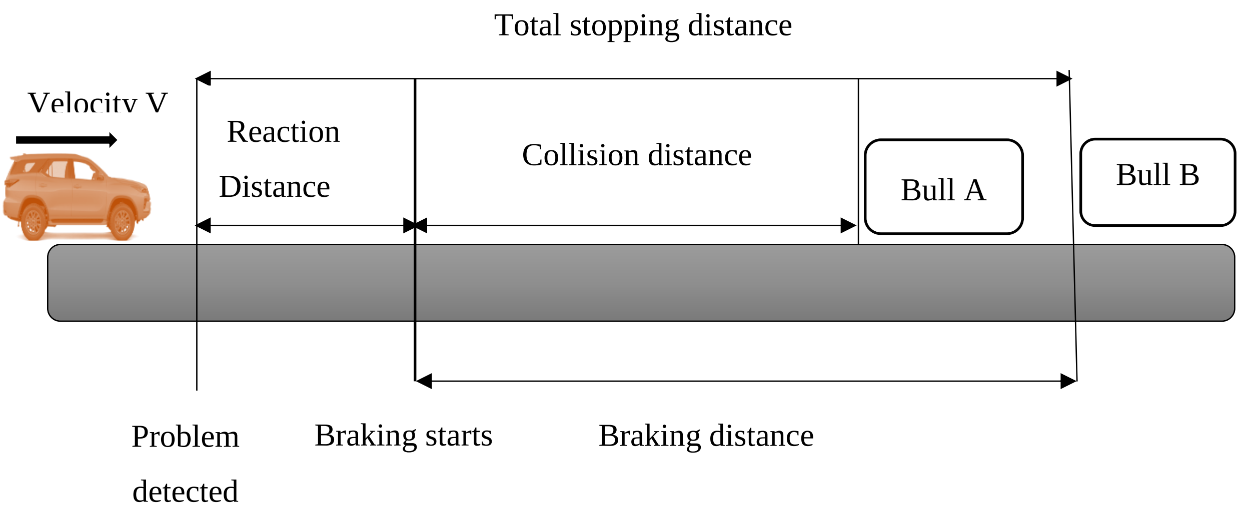


Figure 2. 22 Stopping and collision distance

Figure 2.23 depicts the situation of a rear-end collision. When two vehicles separated by a separation distance of ds travel in the same direction, consider that if vehicle A in front encounters a problem and collides into a roadside crash barrier, this collision of vehicle A with a roadside crash barrier is referred to as the first collision of vehicle A, and the vehicle continues to move forward with remaining energy until it may collide with another vehicle. If the initial separation distance between vehicles A and B is too short, vehicle A's traveling speed and distance are determined by its original speed and the severity of the damage sustained in the first accident. When the driver of vehicle B notices vehicle A slamming into a roadside crash barrier, he uses all of his braking force to try to stop vehicle B from colliding with vehicle A. However, if the separation distance ds is too short, vehicle B will crash with vehicle A (second collision), which is frequently referred to as a rear-end collision. However, the term "rear-end collision" is inaccurate because the collision is a front-end collision for vehicle B (Hasan et al., 2015).

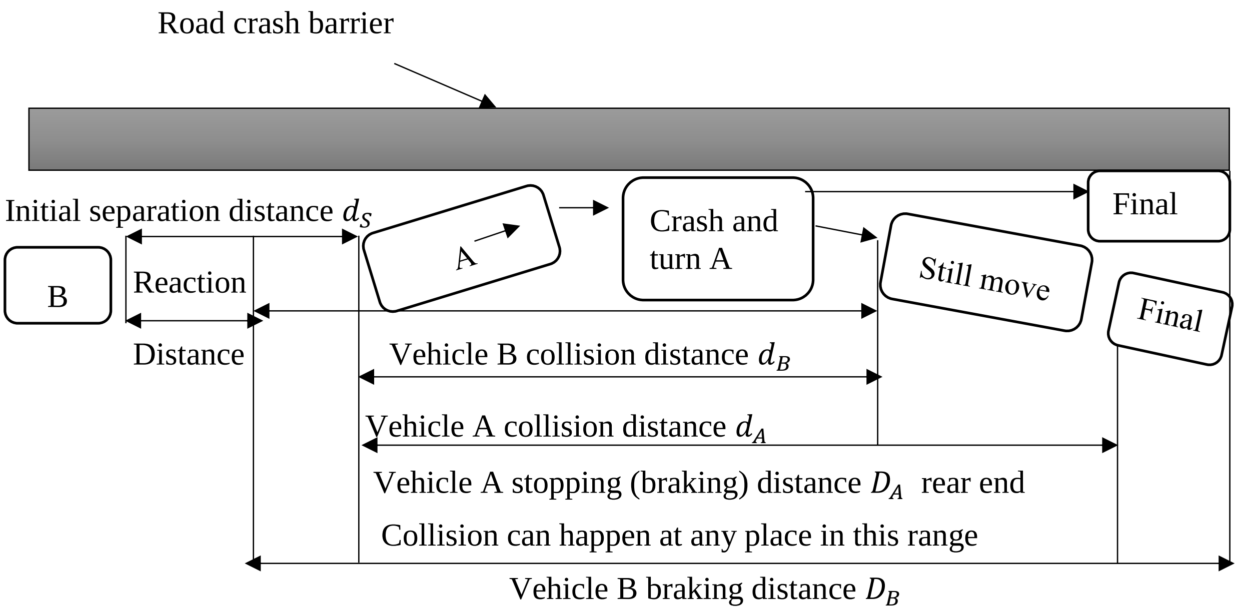


Figure 2. 23 Descriptions of rear-end collision

$$E_0 = \frac{1}{2} MV^2 \quad \text{(eq.3)}$$

Where M=Mass of vehicle

V= Speed of the vehicle

The relationship between rear-end collision energy and collision distance (from the initial point of vehicle B to the location of the second collision) is shown in Figure 2.25. The following parameters were used to generate this graph:

- ✓ The initial separation distance is 30 m
- ✓ The initial velocity of vehicle B is 100 km/hour or 27.77 m/s
- ✓ The initial velocity of vehicle A after the first collision is 20 m/s
- ✓ The tire/road friction coefficient is 0.7
- ✓ The reaction time is 1.5 s
- ✓ The gravity is 9.8 m/s^2

When two cars are traveling at the same speed, a collision happens only when the following vehicle's speed exceeds the preceding vehicle's speed. Figure 2.24 illustrates the positional relationship.

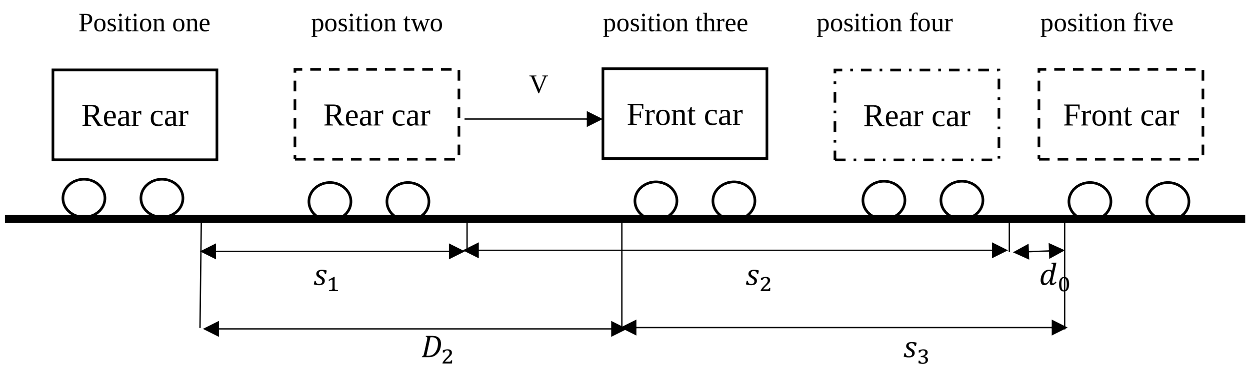


Figure 2. 24 Positional relations when the following vehicle's speed exceeds the preceding vehicle's speed

Assume that the rear car is in position 1 and the front car is in position 3, the rear car will reach position 2 after reaction time *t*, and then it starts to brake. During the reaction time, the rear car maintains a constant speed, and the distance traveled is.

$$s_1 = v_B t = 41.6m$$

Where s_1 =Distance traveled during reaction time

v_B =Speed of the rear car

t=Reaction time which depends on many factors as described in the following Table.

Many factors are affecting the driver's driving behavior, and the impact of these factors can be measured by the reaction time of drivers. The reaction time of various types of drivers is different when they face the same situation, so the required safety distance is also different as listed in Table 2.1 below (Luo et al., 2020).

Table 2. 1: Reaction time of different types of drivers (Luo et al., 2020).

Driver types	Conservative C=0.1	Cautions C=0.3	Conventional C=0.5	Radical C=0.7	Adventitious C=0.9
Hydraulic brake/Q=0.15	1.91	1.74	1.55	1.36	1.44
Barometric brake/Q=0.4	1.94	1.81	1.66	1.49	1.25

At position 2, assume that the rear car begins to decelerate until its speed is the same as the front car; meanwhile, the front car arrives at position 5 and the rear car arrives at position 4. In this process, the distance traveled by the rear car and the front car is, respectively,

$$s_3 = v_2\, t_2 \qquad \text{(eq.4)}$$

$$s_3 = \frac{v_A(\, v_B - v_A)}{a_1}$$

But $a_1 = \text{Road coefficient} \times \text{gravity} = 0.7 \times 9.81 = 6.867\ \frac{m}{s^2}$

$$s_3 = \frac{20(27.77\text{-}20)}{6.867} = 22.63\text{m}$$

Where v_2 = Speed of the front car

a_1=Deceleration of the rear car Until its speed is equal with the front car

The distance in which the speed of the two-vehicle becomes equal is

$$D = s_1 + s_2 + s_3 \qquad \text{(eq.5)}$$

$$D = 41.66 + 22.63 + 27.02 = 91.4\text{m}$$

The minimum safety distance d_0 required to avoid collision of two cars is

$$d_0 = \text{Total stopping distance - D} \qquad \text{(eq.6)}$$

$$d_0 = 97.8\text{m} - 91.4\text{m} = 6.4\text{m}$$

To avoid collisions of two cars, the minimum safety distance needed to maintain is

$$D_2 = s_1 + s_2 - s_3 + d_0 \qquad \text{(eq.7)}$$

$$v_1 t + \frac{(v_B{}^2 - v_A{}^2)}{2\, a_1}$$

$$D_2 = 41.6 + 22.63 - 27.02 + 6.4 = 46.95\text{m}$$

Where a_1 = Maximum braking deceleration of the rear car and

d_0 = Minimum safety distance required for the two cars.

Based on these values given above if we calculate rear-end impact energy and generate a graph for arbitrary point for rear-end collision distance of vehicle B from its original position. First, we have to calculate E_0, the energy carried by the vehicle at the point that the braking starts.

$$E_0 = \frac{1}{2} MV^2$$

When driver B sees that vehicle A in front of him is in trouble he decided to react to his vehicle, the reaction distance $D_{reaction}$ becomes

$$D_{reaction} = V_B t_{reaction} \quad \text{(eq.8)}$$

$$D_{reaction} = 41.66\text{m}$$

But if from the initial separation distance of 30 to the distance of 41.66 is the distance in which the second collision happens, the speed remains the same in this interval and the velocity becomes V_B which is 100 km/h or 27.77 m/s, and if we assume the mass of the vehicle is 1400kg

$$E_0 = 539.821\text{KJ}$$

From the above formula the total distance or $D_{total} = vt_{reaction} + \frac{v^2}{2\mu g}$ in these cases, we consider the speed of the vehicle as v= V_B=27.77 m/s

$$D_{total} = 97.8\text{m}$$

The total stopping distance of vehicle B is 97.8m

And the total distance is the total sum of mainly the braking distance $D_{braking}$ and the reaction distance $D_{reaction}$. i.e. $D_{total} = D_{braking} + D_{reaction}$.From this equation, we can calculate the braking distance of vehicle B i.e. $D_{braking} = D_{total} - D_{reaction}$

$$D_{braking}\text{=97.8m-41.655m=56.15m}$$

Based on these calculated values if we calculate the rear-end collision energy by considering arbitrary collision distance it becomes constant, because of that the velocity of the vehicle is the same.

$$E(d) = E_0 = 539.821\text{KJ}$$

If we consider the distance from 41.66 to the distance of 46.95, above the distance 46.95, the rear end collision energy of vehicle B follows the equation

$$E(d) = E_0(1 - \frac{d}{d_{braking}})$$

$$\frac{1}{2}M(v_B - v_A)^2 = 34300\text{J}$$

By considering different collision distances above 46.95 we have to see the values of rear-end collision energy, we get the values in Table 2.2.

Table 2. 2: Rear-end collision energy and collision distance of vehicle B

Rear-end collision distance of vehicle B (m)	Rear-end collision impact energy (KJ)
30	539.82
41.66	539.82
46.95	280.7
50	263.84
55	236.24
60	208.642
65	181.04
70	153.45
75	125.85
80	98.25
85	70.65
90	43
95	15.45
97.8	0

The distance at which the second collision may occur depends on the speed and the deceleration rate of the vehicle. Mathematically it is defined as $s=\frac{v^2}{2a}$, so if we take different values for deceleration of vehicle we have some values of stopping distance of vehicle A as shown in the following Table 2.3 below by considering the initial separation distance is 30m.

Table 2. 3: Deceleration and the distance at which the second collision happens

Deceleration ($\frac{m}{s^2}$)	Velocity (m/s)	The distance in which the second collision occurs (m)
-20	20	40
-10	20	50
-6	20	63.33
-3	20	66.66
-2	20	100

The acceleration of vehicle A may be the only variable to consider in the computation after vehicle A's initial impact on road crash barriers. Figure 2.25 shows four alternative sections of the graph that can be examined for the second collision curve.

- ✓ If the second collision occurs between 30 and 41.6 meters, i.e. between the initial separation distance of the two vehicles and the reaction distance of vehicle B, the speed of vehicle B (following vehicle) does not change in this section, and the vehicle B crashes into vehicle A with its initial energy (539.82 KJ), vehicle A sustains severe damage and stops immediately after the first collision.
- ✓ Beginning at a collision distance of 41.6 meters, the driver of vehicle B applies the brakes and the vehicle slows down, reducing the energy carried by vehicle B.
- ✓ If the second collision occurs between 41.6m and 46.95m, vehicle A will have already stopped before the second collision occurs. In this situation, the collision energy in the second collision will follow the equation $E(d) = E_0(1-\frac{d}{d_{braking}})$, and it will decrease as the collision distance increases. Because Vehicle A has already stopped before the second collision, the second collision energy is only proportional to $v_B{}^2$ from 30m to 46.95.
- ✓ After 46.95 m, when the second collision happens the vehicle A is still in motion, the second collision energy is relative to the square of speed contrast (VB-VA) of vehicle B and vehicle A. One can see that the second collision (rear-end collision) energy drops strongly with collision distance, this result is exceptionally vital which tells us that a few meter collision separate increment will essentially diminish the rear-end collision energy, may alter the fate of the involved occupants, so we ought to make each exertion to decrease the seriousness of the primary collision of vehicle A and amplify its moving distance as long as possible

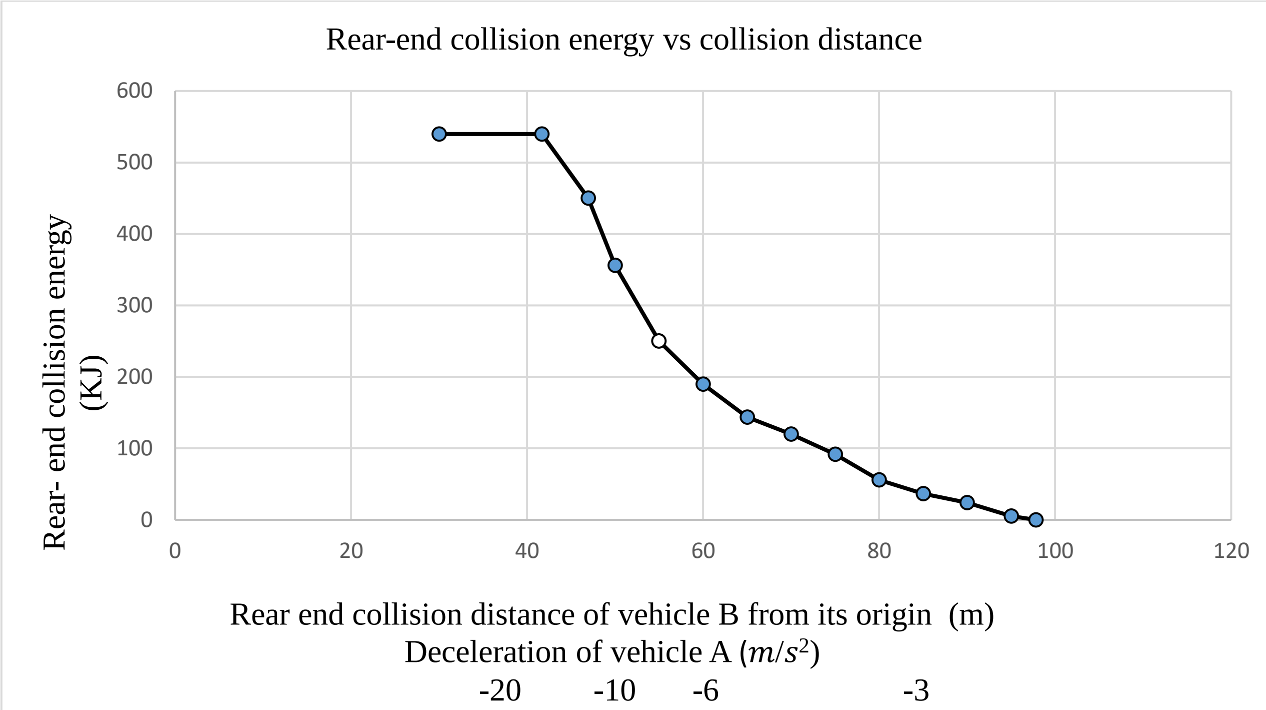


Figure 2. 25: Rear-end collision energy and collision distance of vehicle B relationship.

The accelerations of vehicle A are recorded at the bottom of Figure 2.25 above and compared to the distance of the second collision; for example, if the acceleration of vehicle A is -20 m/s2, the second collision will occur 40 m from the initial point of the vehicle B; if the acceleration of vehicle A is -5.88 m/s2, the second collision will occur 60 m from the initial point of vehicle B. Vehicle B's speed is equal to that of vehicle A at 91.42 meters, thus there is no collision; beyond 91.42 meters, vehicle B's speed is less than that of vehicle A, so there will be no collision.

2.9 Energy Conversion Law in Vehicle Collision

Collision refers to the process in which two vehicles or vehicles are in violent contact with obstacles, exchanging momentum, deforming (mainly plastic deformation), and consuming the kinetic energy of the vehicle. Usually, the process of automobile collision involves displacement, rotation, deformation of automobile shell structure; plastic flow and hardening of materials; contact friction of boundary (Chi & Gong, 2020). The collision time is very short, it carries a lot of information about the collider. Strictly speaking, car crashes have the following characteristics:

- ✓ The phenomenon of exchanging moving energy between vehicles;

- ✓ Mutual extrusion, through the body damage and fixture damage, consume part of the movement energy;
- ✓ It is a phenomenon that some parts are mutually damaged while others are mutually exclusive.
- ✓ There is not only the exchange of motion energy but also the phenomenon of converting part of motion energy into angular motion.
- ✓ There is intense relative movement between vehicles and passengers and cargo.
- ✓ Collision usually takes place in 0.1-0.2 seconds.
- ✓ Most of the kinetic energy in the collision process is converted into the internal energy of the car because the metal plastic deformation after the collision increases the internal energy a lot Other kinetic energy is converted into heat energy, sound energy, etc. (Compared with the increase of internal energy, it can be neglected in engineering) (Rebelo, 2016). Figure 2.26 shows the energy change curve of vehicle frontal impact. For vehicle collision stopping distance is an important factor. The shorter the stopping distance and the quicker the rate of the stop, the more energy transferred to the occupant, and the more damage or injury will occur.

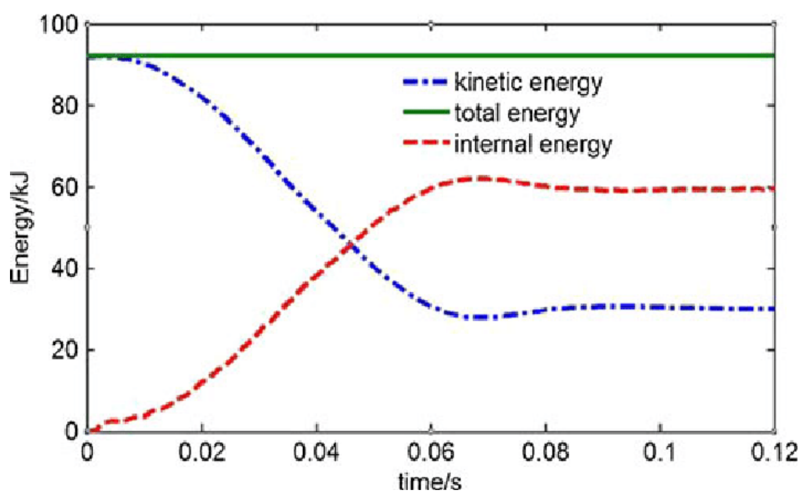


Figure 2. 26: Energy balance for vehicle crash (Hou et al., 2014)

If it hits a wall (or something else) and the wall is not broken, then kinetic energy is converted into internal energy. If you hit something else, such as another car, and the other car is hit, then part of the kinetic energy is converted into internal energy. The above condition is that the car collides on a horizontal road. If a collision occurs on a slope, the energy conversion part also includes potential energy. There must be energy loss in the collision of macroscopic objects (mechanical energy loss, which is kinetic energy loss when potential energy is not involved) because the objects are heated when colliding, which conforms to the conservation of energy (Asplundh & Steckmest, 2014). Under ideal conditions, the mechanical energy of the system is conserved. Ideal conditions do not exist. All actual collisions are incomplete elastic collisions. During the collision, inelastic deformation will be caused, and some mechanical energy will be transformed into internal energy. To stop the car, all this energy must be converted into other forms. If the brakes stop, they dissipate energy by generating heat through friction. In the case of a crash, energy dissipation is achieved by bending and extrusion of the metal outside the car (Satinder Singh & Beant Singh, 2014).

2.10 Research Gap

In general, from those reviews of the literatures some gaps was observed and tried to avoid them, i.e. latest researchers are only concerned with active systems which reduce the possibility of harm before the collision happens and passive systems that are highly concerned with airbags crumple zones and seat belts mostly. These passive systems are mostly used in small cars and even if they fail to work there are no other passive safety systems to tackle these problems. All the active safety technologies are primarily developed and implemented in developed countries. Many active safety systems depend on infrastructure like proper lane marking, traffic signals, which are well developed in high-income countries. There is also a big difference in the share of road users when comparing developing countries to high-income countries (Puthan, Thalya, and Lubbe 2018). All these factors can have a substantial effect on the performance of active safety technology performance in real-life traffic. It is therefore a limitation to assume that all the active safety technologies have the same performance in developing countries as in high-income countries. Our country Ethiopia is a low-income country and there is a strong concern to decrease the fate of roadside collisions. The most common type of collision occurs when the road vehicle turns left in front of the other vehicle. The result is an oblique collision with the right front corner of the other vehicle (Opala, 2015). From the above list of the type of car accidents, we can generally conclude that Most of the collisions are non-perpendicular. For vehicle Collison in one sort of non-perpendicular collision, the first contact places are the two front corners of the vehicle which receives all collision energy during a collision. To fill this gap the researcher tried to design and analyze a front-end passive safety system for these non-perpendicular collisions. This newly designed device can be installed easily without any modification and these are used in heavy vehicles such as buses, compact cars, pickup trucks, and small vehicles.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

In this chapter, we will select the material for the assignation of the material properties in LS-DYNA, design and assembly of the main parts of the front-end passive safety system using CATIA, selecting vehicles and guard rail models from the NCAC, import and assemble the vehicle and the system in LS-DYNA, apply boundary conditions for the vehicle simulation test and configure and simulate the vehicle.

3.2 Materials

The front-end passive safety system to be designed contains a wheel, a top-mounting plate, a top cap, and a bottom mounting plate, and a bottom cap. The wheel encompasses a rim-type structure to diminish the weight and material used, the caps seal the rim-type wheel to avoid dust entering the interior of the wheel, and the mounting plates are utilized to mount the wheel on the body frame of the vehicle. The materials are simply selected for the material and thickness assignation of the parts in LS-DYNA as shown in Table 3.1.

Table 3. 1: Material used for the production of vehicle safer devices

S.No.	Items	Material
1	Wheel	ASTM steel
2	Top and Bottom Mounting Plate	Carbon steel
3	Top and Bottom Cap	Steel
4	Gap Seals	Plastic Material

3.1.1 Stainless Steel Sheet metal

The materials used in this thesis must be corrosion resistant and easily machine able etc. So the material that has those properties is stainless steel. Thus the same is applied in this thesis and should pass through various manufacturing processes such as drilling, grinding, and welding. Thus, the material is selected by considering the following aspects like corrosion resistance, electrical and thermal conductivity, reflectivity, ductility, odorless, recyclability, weld ability (Dr.P.K.Sharma et al, 2017). Steel is the most historical popular choice, and due to its high Young’s modulus and scope for very high yield strengths. Due to its stiffness and high yield, steel is most applicable for high energy applications, such as front crash structures, designed for higher velocity impacts. The high strength and stiffness of steel also makes it useful as a material for components that can be used to ensure more effective stress distribution over a whole system, for instance as a bumper.

3.2 Methods

For the victory of the study using data is an exceptionally vital strategy. Data is a set of values of qualitative or quantitative variables (Wikipedia, 2016). Data is facts or figures from which conclusions can be drawn. Sometimes recently one can show and interpret information, there needs to be a handle of gathering and sorting data. Fair as trees are the crude fabric from which paper is created, so as well, can data be seen as the crude fabric from which information is gotten. Data as a common concept refers to the truth that a few existing information or knowledge is spoken to or coded in a few frames reasonable for way better utilization or preparation. Data is collected and analyzed; data as it were gets to be information appropriate for choosing a few designs (Ajayi, 2017). The data/source I took may be both essential and auxiliary sources. For the study purpose, both primary and secondary data are used. To attain the objectives we utilized both primary and secondary sources. The primary and secondary data have been collected to cover every aspect of the study.

3.2.1 The Primary Survey

Primary resources are original and relevant to the topics of the research study so the degree of accuracy is very high. In this work, the researcher tried to survey different primary information's in different areas in which serious injuries and crashes occurred. Most of the accidents occur from the front side part of the vehicle in which the driver tried to turn the vehicle and when the driver is at the intersection offset collision crashes mostly occurred as the researcher recognized and observed. Based on this observation the researcher plays his role to design the front-end passive safety system which deals with collision mitigation using the software. Additionally, on these primary sources, the researcher uses some software to model and analyze based on the desired part. Based on visual observations, the researcher has decided to devise a means of collision mitigation systems that reduces the seriousness of crash which is passive and which benefits when a collision happens.

3.2.2 The Secondary Survey

Among the secondary sources the researcher in this thesis used; referring books, different automobile and collision mitigation-related books. By referring that researcher jotted output from the study. Discussion with an advisor, like reference books in the study if some problems happened or the way the researcher handling is correct or incorrect advisor is my best guidance as a secondary survey. Referring to different internet links**,** in addition to reference books and advisor support using different links for searching collision-related journals, publications, joining with a different website using scholars for my targets. From different websites and published journals the researcher has got the different passive and active safety systems to mitigate and decrease or prevent collision-related harms. Different systems are made to happen to prevent the harm of collision of the vehicle during an accident.

3.3 Flow Chart of the Thesis Work

The overall flow of the research work, in general, is described in the following flowchart 3.1.

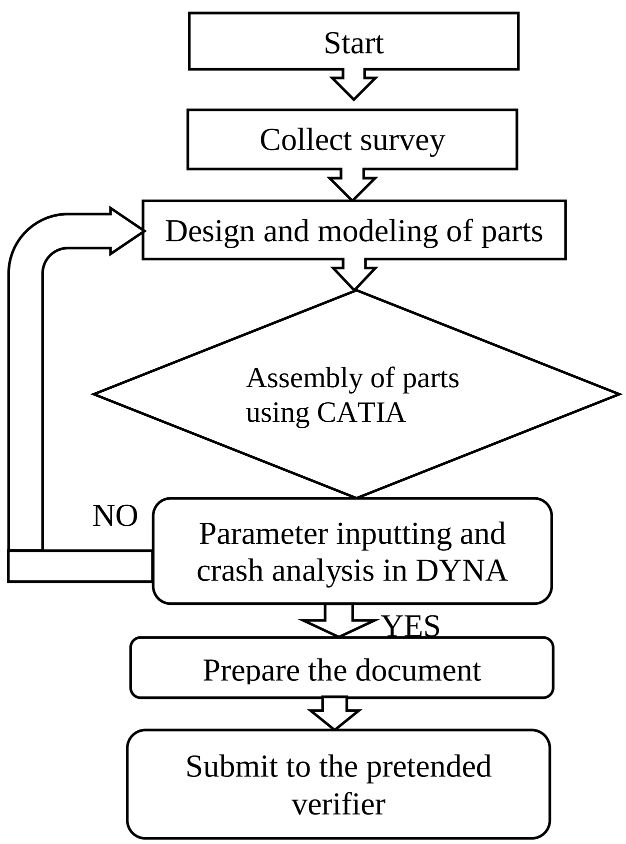


Figure 3.1: Flow charts of the thesis procedures

3.4 Design of the Components

First, the researcher tried to design numerically the main parts of the front-end passive safety systems as shown below. To design the main parts of the system first a Geo-Metro small vehicle which is a reduced model is tested in LS-DYNA at a speed of 98.6 km/h and 80 degrees offset from the guardrail. The specification of the vehicle is as shown in Appendix A. Since the model is reduced and some parts are removed to take advantage of simulation time, the vehicle mass becomes 632.8 kg.

3.4.1 Rim type flywheel and shaft

A flywheel used in machines serves as a reservoir that stores energy during the period when the supply of energy is more than the requirement and releases it during the period when the requirement of energy is more than supply. In machines where the operation is intermittent like punching machines, shearing machines, riveting machines, crushers, etc., the flywheel stores energy from the power source during the greater portion of the operating cycle and gives it up during a small period of the cycle. Thus the energy from the power source to the machines is supplied practically at a constant rate throughout the operation. For designing a front-end passive safety system assume that

- ✓ The density of steel is 7890 MPa
- ✓ The vehicle is assumed to run at 96.8 km/h
- ✓ The collision angle is assumed at an 80 degree
- ✓ The vehicle selected for the design is a Geo-Metro vehicle with a total mass of 632.8 kg

For designing the system first we have to consider at which collision angle the harmful force is maximum. The vehicle is on its way to collide with an object, in this case, a roadside crash barrier, another object, or another vehicle, as shown in Figure 3.2. From Figure when a vehicle collides with the collision surface at point A, the perpendicular force component F_{A1} maybe a destructive force, causing damage and harm. The response force from the roadside crash barrier will immediately act on the vehicle and its occupants, causing death and injury to the occupants as well as damage to the vehicle. The dashed line with the arrow direction indicates the vehicle's forward movement with an angle relative to the object's collision surfaces and collides at point A.

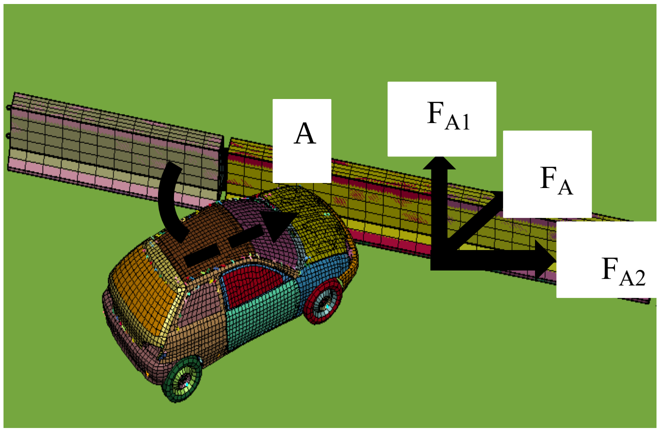


Figure 3. 2: Vehicle collision to a barrier at an angle (LS-DYNA designed)

F_A Becomes the total collision force absorbed by the vehicle, and it can be divided into two components: F_{A1} (opposite the collision surface) and F_{A2} (perpendicular to the collision surface). If a vehicle collides with a roadside crash barrier at an angle, as shown in Figure 3.2 for illustration, the initial harmful impact force F_{A1} is a function of the collision angle α as the following equation:

$$F_{A1}=F_A \times \sin(\alpha) \quad \text{(eq.1) (Hongjun.p., 2019)}$$

Where F_{A1} =Collision force opposite to collision surface

F_A = Total collision force absorbed by the vehicle.

α = Collision angle

Based on this equation above if we calculate for some selected collision angle we can finalize our ideas. By considering that the collision force F_A is constant and this force is 10 KN (this force is arbitrarily taken to demonstrate at which angle harmful collision force is maximum for further study). By assuming the initial collision impact force is 10.

At an angle of 10-degree collision, $F_{A1}=10\times\sin(10)=1.7$ KN, in the same process we can calculate for different angles. The following Table 3.2 shows the calculated above value in tabulated form.

Table 3. 2: The relationship between harmful collision force and collision angle

S.No.	Initial collision force F_A (KN)	Collision angle (α)	Harmful collision force F_{A1} (KN)
1	10	0	0
2		10	1.7
3		20	3.42
4		30	5
5		40	6.428
6		50	7.66
7		60	8.66
8		70	9.39
9		80	9.85
10		90	10
11		100	9.85

By using Table value 3.2 Figure 3.3 is drawn which shows the effect of change in collision angle on harmful collision force. The harmful collision force at point A F_{A1} is maximum when collision surface and colliding vehicles are perpendiculars (where α is 90 degrees) at the time of the collision. Theoretically,

- ✓ At 45- degrees, the harmful collision force F_{A1} is about 30% less than the total collision force of a vehicleF_A.
- ✓ The harmful collision force is only 1/3 of the original force when the collision angle is 20 degrees, this indicates that the severity of the collision will be dramatically reduced when the collision angle decreases.
- ✓ Most collision angles are in the range of 10 to 45 degrees, so the front-end passive safety system will provide additional protection to the people and reduce the property damages in those collisions.

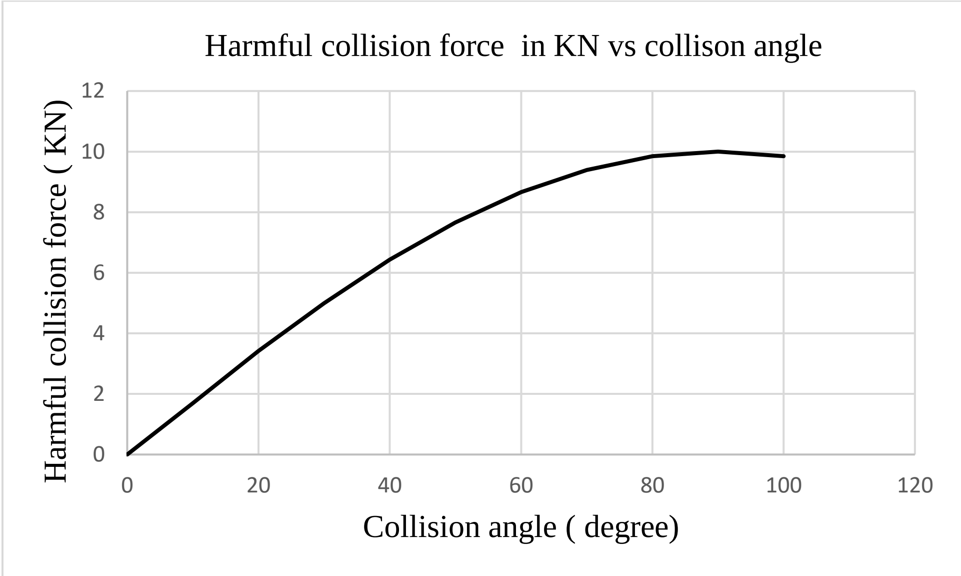


Figure 3. 3: Harmful collision force and collision energy

For the design of the front end passive safety system, based on the above calculations for the relation of collision force and collision angle, when the vehicle and colliding material, for this case roadside guardrail the maximum harmful force is induced at 90 degrees. But it has no benefit in a 90-degree position so we consider the design close to 90 degrees. For considering different parameters for the design of the flywheel the vehicle collides into a guard rail at 80 degrees which is close to 90 degrees. We use the vehicle with a mass of 632.8 kg which runs at a speed of 26.82 m/sec as shown in Figure 3.4 below.

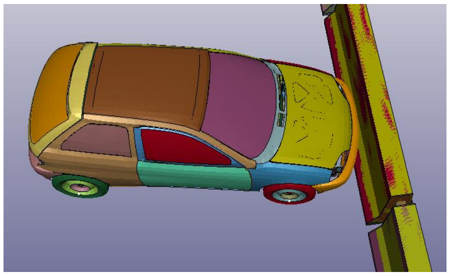


Figure 3. 4: Collision set-up at 80 degree

From the simulation result plotting impact force vs. time, we get the impact force of the vehicle from the guard rail becomes 74.5 KN as the following Figure 3.5 below.

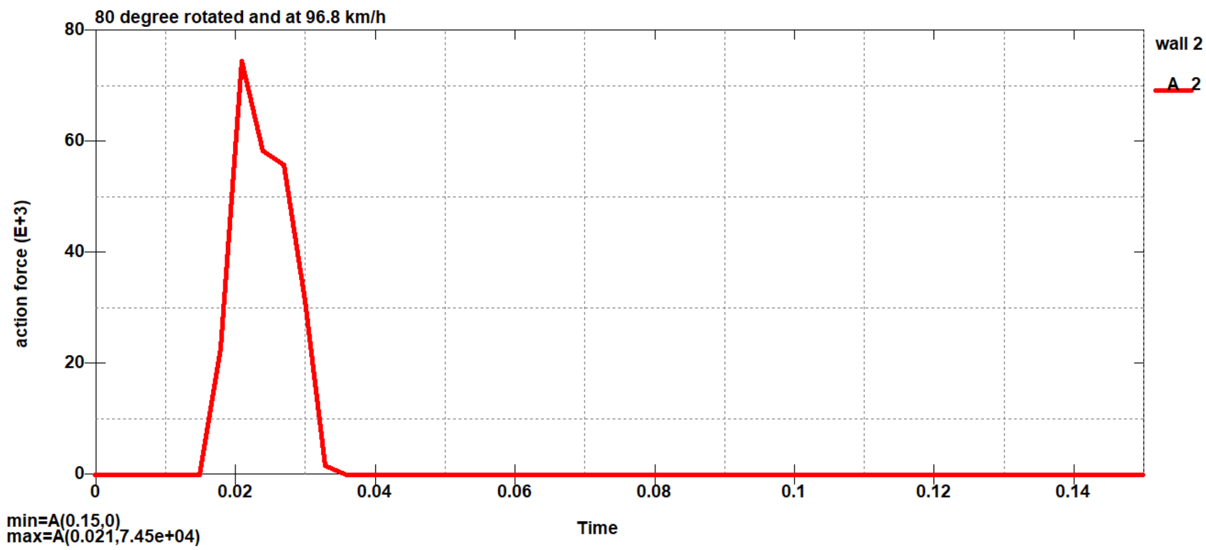


Figure 3. 5: Impact force vs time graph

The following Figure 3.6 below shows the vehicle configuration layout and the force component during a vehicle collision. But the force required to rotate the flywheel is F_{A2}. So we use this horizontal component of force to design the flywheel. F_{A2} Becomes maximum when the collision angle α is 0^0. But $\alpha=0^0$ means the vehicle and a roadside crash barrier is parallel so we have to consider the collision angle which is close to 90^0 for an effective design according to the above calculation. Let us consider the collision angle of 80^0 F_{A2} becomes

$$F_{A2} = F_A \times \cos\alpha$$

$$F_{A2} = 12.93 \text{ KN}$$

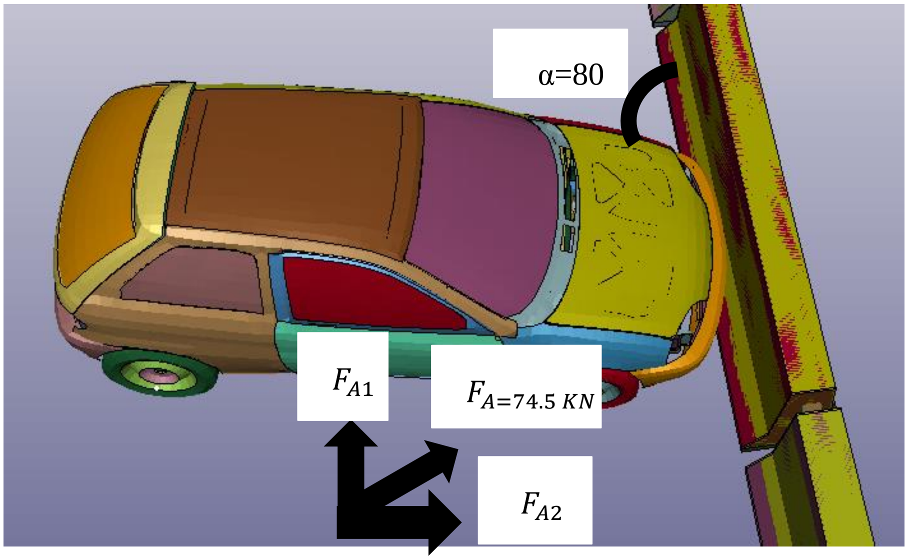


Figure 3. 6: The layout of vehicle collision

So we can calculate the power from this force for the flywheel

$$p = \frac{w}{t} \quad \text{(eq.2)}$$

Where p = Power,

W = Work,

t = Time of impact

However

$$w = F_{A2} \times d$$

$$W = 1.3 \text{ KJ}$$

(By considering that the vehicle move 0.1 m after impact) and from the relation that

$$F_{A2} = \frac{w \times v}{t} \quad \text{(eq.3)}$$

$$v = 4.48 \text{ m/s}$$

The linear speed of the flywheel becomes 4.48 m/s.

The impact time is assumed short and if we take 0.45 sec

$$p = \frac{w}{t}$$

$$p = \frac{1.3 \text{ KJ}}{0.45 \text{ sec}} = 2.88 \text{ KW}$$

The rotational speed of the flywheel is directly related to the linear speed because we design a flywheel at maximum rotational speed, this maximum speed of the flywheel occurs when F_{A2} is maximum because the flywheel is made to rotate by this force.

To convert the linear speed of the vehicle into rotational speed we follow the following step. By assuming that the flywheel radius is not greater than 50 mm for space requirements of the Geo-Metro vehicle

First convert m/sec into rad/sec, so $\frac{4.48\ \text{m/sec}}{0.05\text{m}}$=89.6 rad/sec

To convert rad/sec into rev/min we have: 9.5493×89.6 rad/sec= 855.6 RPM

So the mean torque becomes,

$$T_{mean} = \frac{p \times 60}{2\pi N} \qquad \text{(eq.4)}$$

$$T_{mean} = \frac{2.88 \times 10^3 \times 60}{2\pi \times 855.6} = 32.15\ \text{Nm}$$

If we assume that the maximum torque (T_{max}) is $1.5T_{mean}$=1.5×32.15 Nm=48.4 Nm

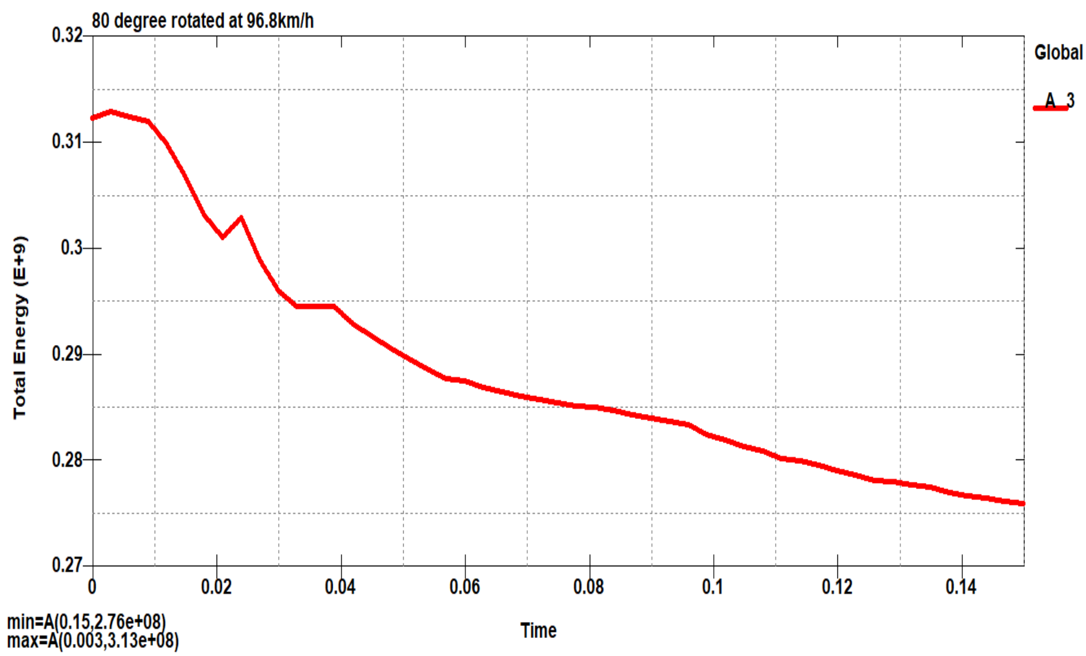


Figure 3. 7: Total energy vs time

From the above Figure 3.7, the total energy from the simulation on the vehicle is 313 KJ. According to some literature, most about 50% of the energy of the impact is absorbed by front structures. Let the flywheel is designed to furnish this 10% of 156.5 KJ by assuming that 10 % of the total energy of the frontal structure is applied on the flywheel and from the figure above from simulation. But the total energy is lost by a factor of loss for the flywheel. By considering the factor for loss of 0.075 for the total energy for the flywheel becomes 1.17 KJ

The maximum fluctuation of energy,

$$\Delta E = 2 \times E \times Cs$$ (eq.5) (Bansal R.K, 2009)

Where E = Energy furnished by flywheel and Cs is the coefficient of fluctuation of energy

$$\Delta E = 0.093 \text{ KN-m}$$

We can simply select the Cs=0.03 values from the following Table 3.3 for machine tools.

We know that the hoop stress (σ_t) is

$$\sigma_t = \rho v^2 \qquad \text{(eq.6)}$$

$$\sigma_t = 2 \text{ MPa}$$

Where ρ is the density of the material which is 7980? $\frac{kg}{mm^3}$

We can calculate the outer diameter of the flywheel by using the relationship that the peripheral velocity;

$$v = \frac{\pi D N}{60} \qquad \text{(eq.7)}$$

$$D = \frac{1.49 \times 60}{\pi N} = \frac{4.48 \times 60}{\pi \times 855.6} = 0.1 \text{ m} = 100 \text{ mm}$$

So the maximum size of the flywheel must be 100 mm.

The mass of the front end passive safety system flywheel rim (m) can be calculated as

$$\Delta E = m\omega^2 R^2 Cs$$ (eq.8) (Rathod Balasaheb S, 2014)

$$m = \frac{\Delta E}{\omega^2 R^2 Cs} = 10.4 \text{kg}$$

Table 3. 3: Coefficient of fluctuation of speed ($\boldsymbol{C_S}$) (Rathod Balasaheb S, 2014)

S.No.	Type of machine or class of service	Coefficient of fluctuation of speed (Cs)
1	Crushing machines	0.2
2	Electrical machines	0.003
3	Engine with belt transmission	0.03
4	Hammering machine	0.2
5	Machine tools	0.03
6	Punching, shearing and power presses	0.1 to 0.15
7	Spinning machinery	0.1 to 0.02
8	Rolling mills and mining machines	0.025

The mass of the front-end passive safety system rim is about 10.4 kg. Most of the mass of the flywheel is accompanied by the rim and if we assume that the rim mass is 90 percent of the total flywheel mass (Rathod Balasaheb S, 2014), so the total flywheel mass becomes 11.4 kg.

The cross-sectional dimension of the rim as shown in Figure 3.8 becomes as the following. Let t be the depth or thickness of the rim in meters and b is the width of the rim in meters which is equal to 2t so the cross-sectional area of the rim becomes

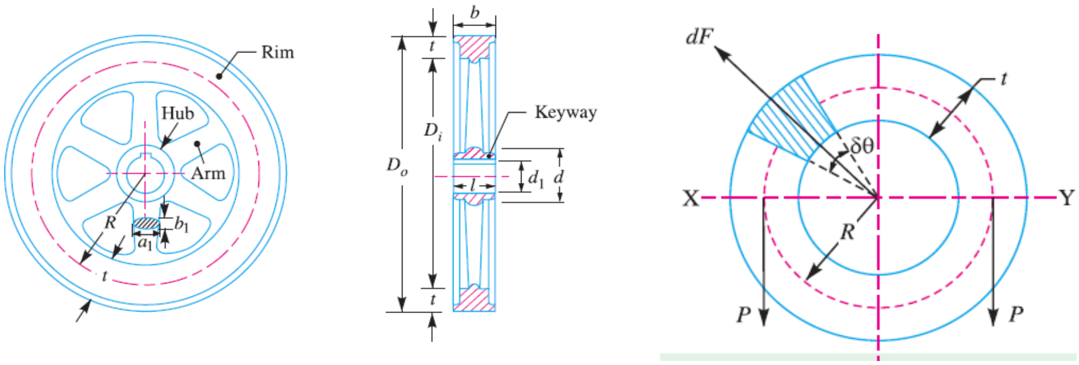


Figure 3. 8: Cross-sectional views of the flywheel (Keval .C, 2015)

$$A = bt = 2t \times t = 2t^2 \quad \text{(eq.9)}$$

But we know that the mass of the flywheel rim (m) is

$$m = A\pi D\rho \quad \text{(eq.10)}$$

Assume ρ = 7980 kg/m^3

$$11.4\ \text{kg} = 2t^2 \times 3.14 \times 0.1 \times 7980$$

From this

$$t = 0.0476\ \text{m} = 47.6\ \text{mm}$$

The thickness of the rim of the flywheel is 47.6 mm, so the width of the rim becomes

$$b = 2t = 95.4\ \text{mm}$$

The diameter and length of the hub can be calculated as follows

Let d= diameter of hub, d1 = diameter of the shaft, and l = length of the hub

We know that the maximum torque (Tmax) acting on the shaft so

$$T_{max} = \frac{\pi}{16}\ \tau \times d_1^3$$

(Assume $\tau = 65\text{N/mm}^2$ (eq.11)

$$48.4\ \text{Nm} = \frac{\pi}{16} \times 65 \times d_1^3$$

$$d_1 = 15.59\ \text{mm}$$

The diameter of the shaft becomes 15.6 mm for the flywheel

The diameter of the hub is made equal to twice the diameter of the shaft and the length of the hub is equal to the width of the rim $d=2d_1$=31.2mm. The cross-sectional dimension of the elliptical arms became the following.

let

a = major axis and c = minor axis and assume c = 0.5a N = number of arms, in this case, N = 6 and σ_b=bending stress for the material and assume $\sigma_b = 20$MPa, We also know that the maximum bending moment in the arm at the hub end, which is assumed as a cantilever is given by

$$M=\frac{T_{max}}{D\times N}(D-d) \quad \text{(eq.12)}$$

$$M = 875\text{Nm}$$

And section modulus of the cross-section of the arm

$$z = \frac{\pi}{32}\times c\times a^2 \quad \text{(eq.13)}$$

$$z = \frac{\pi}{32}\times 0.5a\times a^2 = 0.05a^3$$

We know that bending stress

$$\sigma_b = \frac{M}{Z} \quad \text{(eq.14)}$$

$$20\text{MPa} = \frac{875}{0.05a^3}$$

$$a = 1.05 \text{ mm}$$

The cross-sectional dimension of the major axis is 1.05 mm.

3.4.2 Design of mounting plate

Since the diameter of the shaft is 34.94 mm, so we can select the base of the plate as 60 mm, and the height is assumed as “t” mm. The mounting plate is assumed as a rectangular with base “b” and height or thickness “t” and length “l” in which the compressive load (p) is applied on the mounting plate by considering the mounting plate as a column. The cross-section is described in Figure 3.9. For compressive loads C and I sections are used for maximum strength, but for this system the mounting plate is assumed collapsible to prevent penetration into another vehicle parts and it is preferable to hold the wheel to the frame of vehicle, so the rectangular cross section is selected.

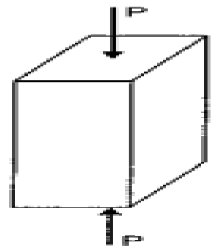


Figure 3. 9: Column under compressive load

Since the mounting plate fixed from one end to the rail of the vehicle and the end that the shaft and flywheel are to be installed is considered as a free end, the moment of inertia becomes the following.

$$I_{XX} = \frac{bt^3}{12} \quad \text{(eq.15)}$$

And

$$I_{yy} = \frac{tb^3}{12} \quad \text{(eq.16)}$$

But for space requirements, the thickness is assumed less than the base of the mounting plate. the mounting plate will bend first in the direction of the least moment of inertia direction. So the least moment of inertia happens in the x-direction, so we use I_{XX} for the design of the mounting plate.

The load at which the mounting plate buckle or bends is called crippling load. The length of the mounting plate is taken for space fitting to mount at the right place and dimension for a Geo-metro sedan vehicle. So the length is taken which is equal to the length of the distance from the rail end to the side corner of the vehicle, and it is taken as 278 mm. The length from the rail to the system mounting plate outer end is designed to fit the length. The following Figure 3.10 shows the separation distance between the bumper and rail at a degree for a Geo-Metro small vehicle measured measured by using node to node (N2N) distance measurement method in LS-DYNA..

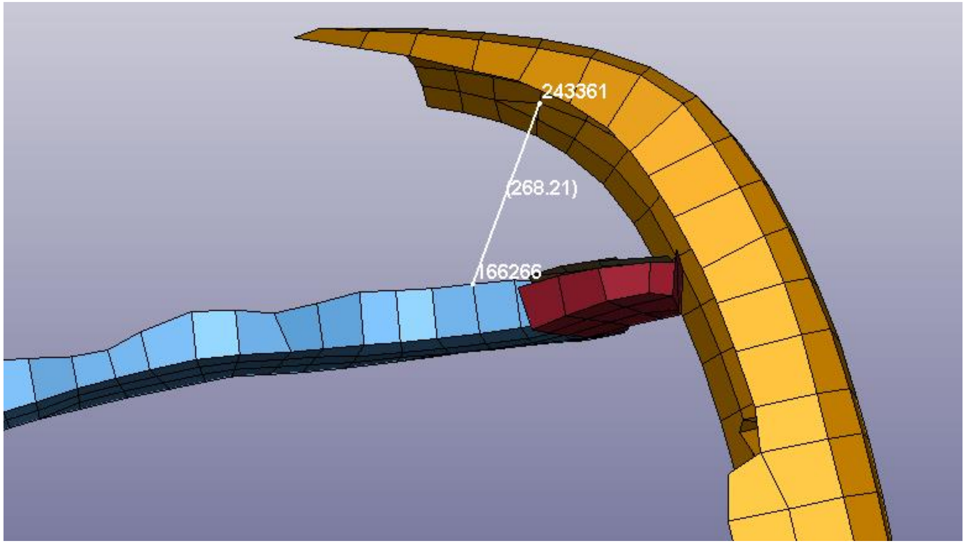


Figure 3. 10: Length from the rail to the bumper for Geo-Metro

The crippling load is defined mathematically as,

$$p = \frac{\pi^2 EI}{L^2} \qquad \text{(eq.17)}$$

Where L = Length of a mounting plate,

E = Youngs modulus of the material ($2\times10^5 N/mm^2$) for material carbon steel

I = Moment of inertia of the mounting plate

3.4.3 Software used

A. CATIA V5R20: For the modeling and assembling of the parts the researcher use CATIA V5 R20 and the final work is saved as product CATIA V5 R20 file and IGES format for the use of the second software LS DYNA for analysis of collision behavior of the modeled vehicle.

B.LS DYNA: The researcher used this software for the generation of mesh, for imputing variables, and analyzing collision behavior of the designed system, so that to compare the vehicle with the designed system and without the designed system.

3.5 Modeling and Assembling of the Components

The wheel encompasses a rim-type structure to decrease the weight and material used without compromising its performance as shown in Figure 3.11. The mounting plates are used to install the wheel on the body frame of the vehicle. The caps seal the rim-type wheel to prevent dust from entering the interior of the wheel. All components of the passive safety system are included in assembly order as shown below: a wheel, a top-mounting plate, a top cap, and a bottom-mounting plate, and a bottom cap.

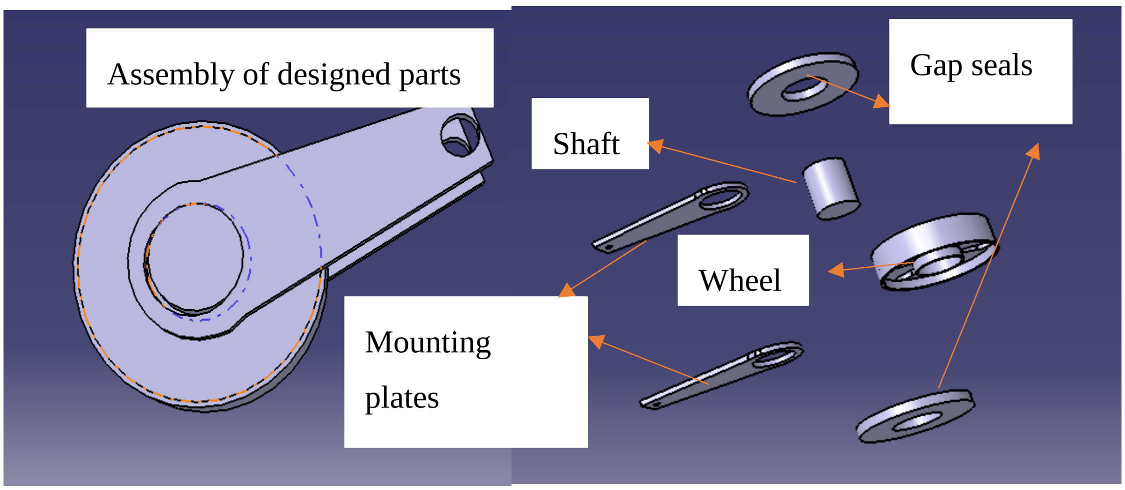


Figure 3. 11:Front-end passive collision safer systems in assembly order

3.6 Installation of Front-End Passive Safety System

Figure 3.12 demonstrates the configuration and assembly of front end passive safety systems at the two front sides of the front end chassis outline next to the bumper, there aren't any numerous vehicle parts in those areas, including the front end passive safety system will not lead as well many modifications to the current vehicles, and the front end passive safety system; regularly, have good support from the outline during the angled collision and does not compromise work of the crumpled structure. The mounting plate is connected to the frame of the vehicle with bolts. When the vehicle collided with another object the wheel starts to rotate if the wheel is the contact surface of the vehicle. Between the shafts and the wheel, we can use bearings and allow the wheel to freely rotate with a small impact force.

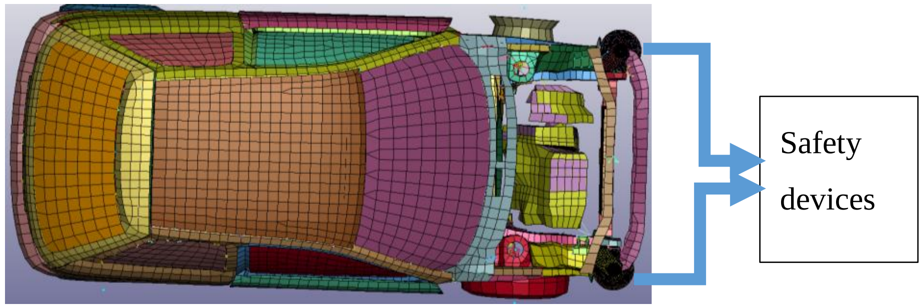


Figure 3. 12: Front-end passive collision safety system installed on bumper location

3.7 Distance of the System from the Ground to the Height of the Crash Barrier

Because the height of the common roadside crash barrier (or guardrail) is standard across the country, and people will be protected by the front end passive safety system no matter where they are, the spacing between the front end passive safety system of all vehicles from the ground should match the height of the common roadside crash barrier (or guardrail), as shown in Figure 3.13

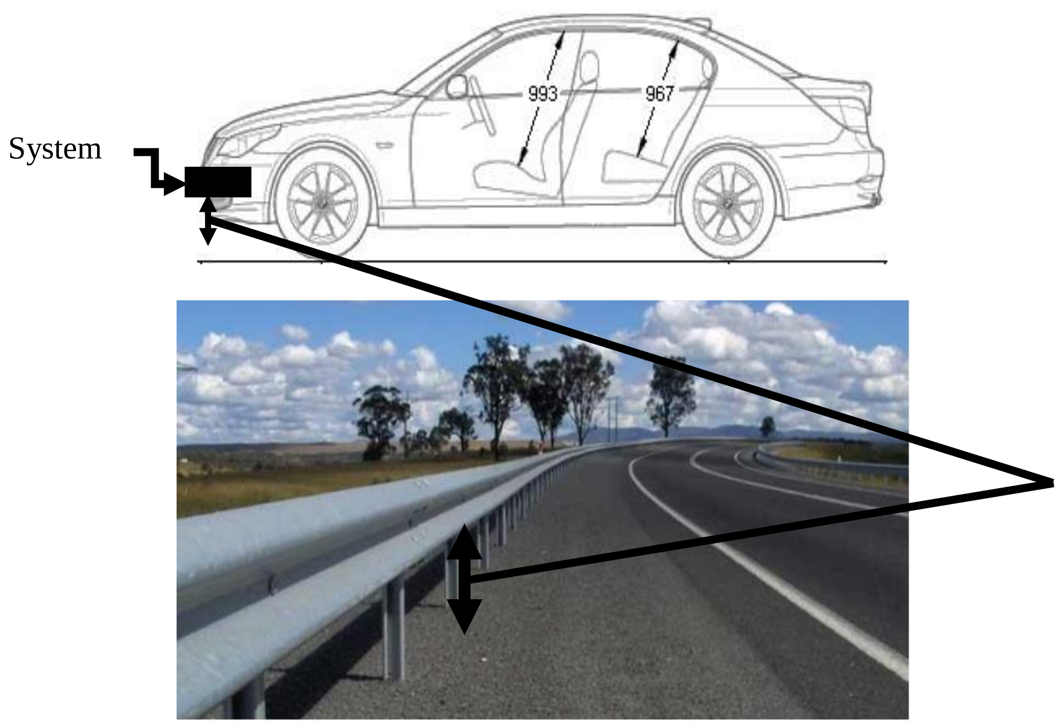


Figure 3. 13: Height of the passive system and height of the roadside guard rail

3.8 Simulation of the Designed System Using LS-DYNA

The procedure for explicit dynamic analysis consists of three main steps:

- ✓ Build the model
- ✓ Apply loads and obtain the solution
- ✓ Review the results

BOM= BILL OF MATERIAL

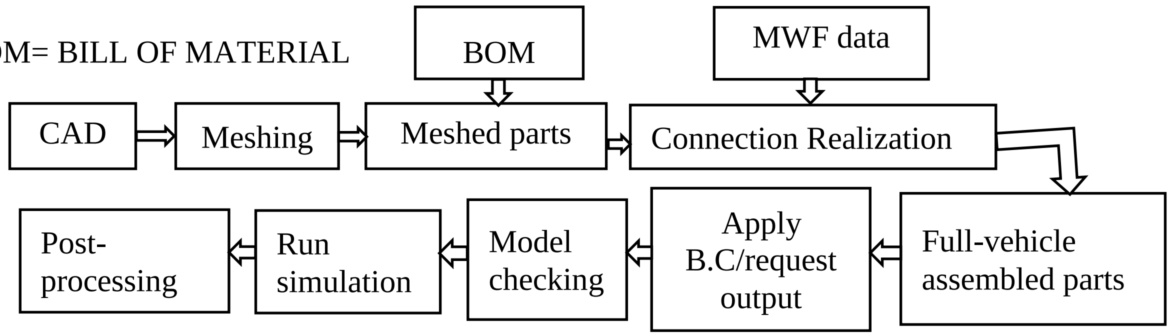


Figure 3. 14 Simulation process overview

For the analysis of the modeled and assembled parts of the front-end passive safety systems, first, we have to save them in IGES format in CATIA so that our systems will become readable in LS DYNA for further analysis. The front-end passive safety system for Geo metro (reduced model) is designed by using CATIA V5R20 software as per the dimensions. Over the past two decades, the National Crash Analysis Center (NCAC) has developed several vehicle models that could be used in studies of vehicular crashworthiness and roadside barrier crashes. These vehicles vary from small passenger cars to pickup trucks and are available in the public domain (URL10). In constructing these FE models, a reverse engineering technique was used (and the majority of the models were partially or fully validated using experimental data of full-frontal impacts). For simulations involving the impact of a sedan, passenger car, a 632.8 kg small car model known as Geo Metro developed and validated by NCAC (National Crash Analysis Center) was utilized. Figure 3.15 shows the FE model of this vehicle which includes 16260 elements and 19216 nodes before installing the device(left) and approximately 24,000 elements and 25800 nodes with a device (right). Due to its low weight and small dimensions, its passengers are exposed to relatively high injury risk, caused by large accelerations that occur during the collision. The crucial parameter ASI is calculated from accelerations at the basis of the car's center of weight.

The Geo-Metro (also known as Suzuki Swift) car meets all normative requirements and can be used in certifying processes for road barriers based on numerical simulations. Because of the above reason and the Geo-metro vehicle has small number of parts and so the elements and nodes are less for selecting from NCAC, so it is simple and timely economical to run simulation so the geo-metro is selected.

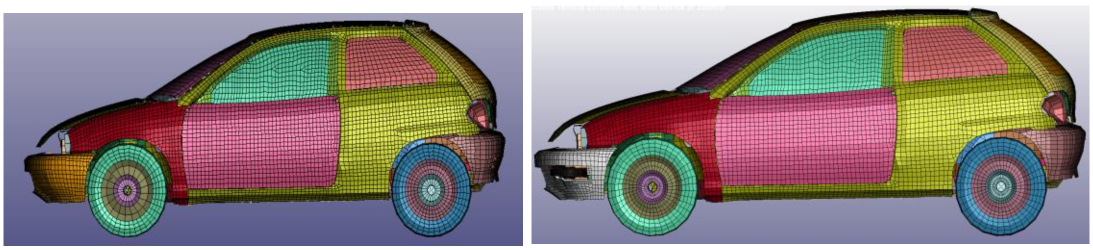


Figure 3. 15: Imported model into LS-DYNA

3.8.1 Guardrail Model

Portable concrete barriers (PCBs) that are modeled under the National Crash Analysis Center (NCAC) are used as colliding material. Typically, the PCBs are attached end-to-end by a load-bearing connection. The finite element model of the PCB system consisted of ten 6.1-m long, PCB Segments comprising the total system length of 61 m. Each barrier segment had a height of 813 mm and was attached with a vertical I-beam connection pin to adjacent PCBs. To represent the real behavior of a dynamic impact on a concrete barrier, the PCB segment had three primary components: concrete, steel reinforcement, and end connection hardware. The PCB is selected because that the other type of barriers and guard rails are more deformable than a PCB. So it is advantageous to use harder material for checking the exit angle after the collision (it is better to study the vehicular response after impact). Figure 3.16 below shows the PCB-R type guard rail.

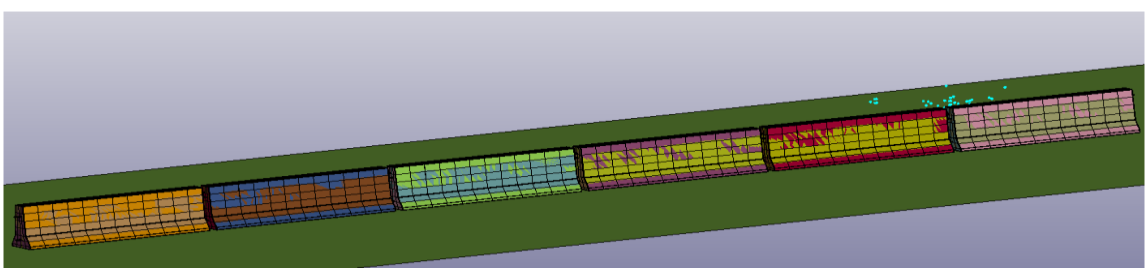


Figure 3. 16: PCB-R type guard rail

3.8.2 Systems of consistent units

The finite element code will accept any units that are input without error checking. Thus, if engineering units are input using an inconsistent system of units, or a left-handed coordinate system is used, the results will be flawed. The modeler should be careful with units of force, mass, and density. All parameters in this work are in the following units.

General units

- ✓ length [mm]
- ✓ mass [kg]
- ✓ time [sec]

Mechanical units

- ✓ density [kg/mm^3]
- ✓ Modulus of elasticity [kg/mm/sec^2]
- ✓ yield stress [kg/mm/sec^2]

3.8.3 Mesh quality

Mesh quality is "The characteristics of a mesh that permit a particular numerical partial differential equation simulation to be efficiently performed with fidelity to the underlying physics and with the accuracy required for the problem. Therefore, mesh quality is very important and plays a crucial role in the numerical calculation accuracy and stability; mesh quality control was the first step before the mesh generation process. The overall system mesh quality was controlled in the modeling process, shown in Table 3.4.

In general, mesh quality and element selection of a vehicle model, along with numbers of nodes and elements (large numbers implying more structural details yet high computational cost), are of major concern concerning the reliability of crash simulation results. All vehicle models under NCAC are fully or partially validated models and the Geo-Metro model was previously used for different analyses by different authors, so we have to use these. But for the designed front-end passive safety system, because that the system is not validated yet, we have to use finer meshes for an accurate result.

Table 3. 4: Quality parameters and their allowable minimum and maximum value

Quality parameters	Allowable min/max
Aspect ratio	10
Warpage	15
Jacobian	0.6
Minimum side length	5
Maximum side length	12
Minimum quadrilateral internal angle	45
Maximum quadrilateral internal angle	145
Minimum triangular internal angle	15
Maximum triangular internal angle	120
triangles	5

3.8.4 Mesh generation

For the generation of the mesh after importing our IGES file we can use Auto Meshes. The purpose of the Auto Meshes software is to generate a Lagrangian Finite Element (FE) mesh from 3D Computer Aided Drawings (CAD). The Auto Meshes opens a batch of STEP files in LS-PrePost (LSPP) and executes shape-specific algorithms on each CAD file to modify the geometry and prepare it for meshing operations. The generated mesh of each part is then included in a master input file that groups all parts into one LS-DYNA formatted input deck. For the time mixed elements of linear quadrilateral and triangular elements were used, with an average element size for the whole model with an element size of 3 for the front-end passive safety system. The overall mesh of the vehicle with a system is illustrated in Figure 3.17 below.

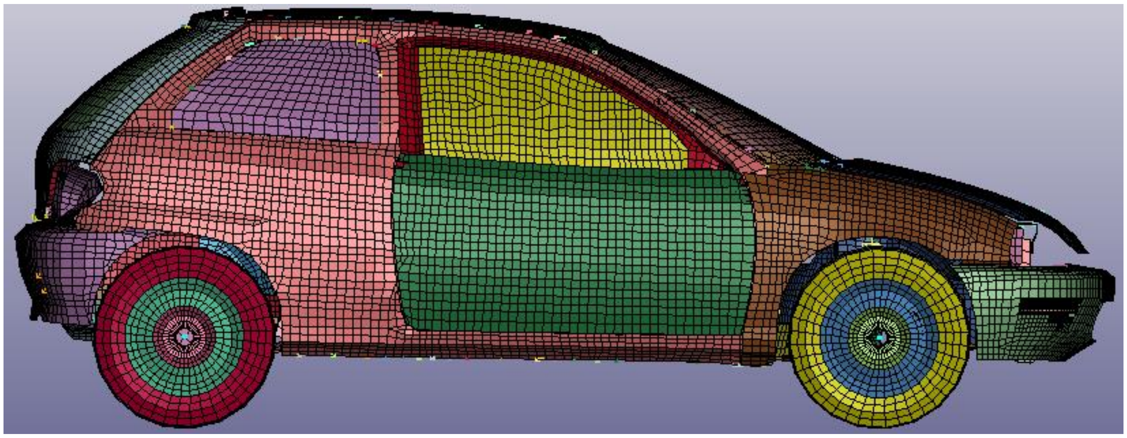


Figure 3. 17: Mesh generation for the whole vehicle

3.8.5 Element formulation

The completed model contains approximately 205 parts, 205 materials, and 16260 elements and 19216 nodes for normal vehicle test and 512 parts, 510 materials and 24,000 elements, and 25,800 nodes for a vehicle with device test. Structural components and specific element types used in the model include

- ✓ Solid elements
- ✓ shell elements

3.8.6 Material properties and thickness of the vehicle components

Vehicle material types and properties are the most important factors, which affect significantly the accuracy of the impact simulation. Moreover, material types and properties should fulfill the automotive criteria, such as safety, environment, lightweight, fuel consumption, cost, and design. Mostly, the vehicle model consists of shells, which need to identify thicknesses for every single shell besides mechanical material properties. However, it has 9 solid parts, so it was only a requirement that the material properties of structures such as suspensions, cushions, engine, fuel tank, battery, knuckle, and rims be assigned. The vehicle components materials were selected by the LS-DYNA material library. The material for the flywheel and the shaft is selected for the maximum stiffness to deformation and the material for the mounting plate is selected by considering the chassis rail maximum deformation effect results from these mounting plate force transmits to it and by considering that the mounting plate is higher stiffer than the front bumper structure because of that the bumper starts to deform and absorb energy even if the collision force is at low speed.

But for the vehicle with a device, it is assumed that some of the harmful force is converted to non-harmful force, so it is advisable to use higher stiffness material, but by considering that if the mounting plate is not collapsible at higher speed and higher impact force it may cause intrusion to other vehicle parts, the material which is collapsible at higher impact force is selected. For LS-DYNA material assignation of the parts the wheel and the shaft is assigned MAT-RIGID, which is also useful for creating REVOLUTE JOINT between the flywheel and the shaft and for mounting plate MAT-PIECEWISE LINEAR-PLASTICITY and their general mechanical and general units as below table 3.4. The thickness of the material also affects the deformation strength of the parts. So the section of the parts is also defined as below Table 3.5.

The tire was modeled by MAT_ELASTIC. While the windscreen and vehicle structures were modeled by MAT_PIECEWISE_LINEAR_PLASTICITY. Cushions were modeled by MAT_FOAM_LOW_DENSITY. There are three beams, eight discrete, 185 shells, and nine solid sections. There are enormous parts and material assignation, generally, for the normal test, there are overall 205 materials, from which the majority of the material is piecewise linear plasticity (156), damper viscous (20), honeycomb (1), spring elastic (4), elastic (6), RIGID (34). Table 3.5 and 3.6 below shows the material and section definition for the front-end passive safety system parts respectively.

Table 3. 5: Material and section definition of the designed system

Vehicle item	Mass density(kg/ mm^3)	Young's modulus (GPA)	Poisons ratio	Yield stress (GPA)
Flywheel	7.890e-09	2.000e+05	0.3	300
Mounting plate	6.8e-9	1.89e+5	0.28	200
Shaft	7.890e-09	2.000e+05	0.3	300

Table 3. 6 : Section definition of the designed system

Vehicle components	Thickness (mm)
flywheel	47.6 mm (from design result)
Mounting plate	0.46 mm (from design result)
shaft	15.6 mm (from design result)

3.8.7 Vehicle components constrain

The designed front-end passive safety system is jointed into the vehicle front-end frame at the bumper location by a CONSTRAINED NODAL-RIGID BODY. The designed system mounting plate and shaft are joined by constrained EXTRA-NODE-SET. But between the shaft and the rotating wheel which is allowed to rotate freely on the shaft upon impact, constrained JOINT-REVOLUTE is created as the following Figure 3.18. All of the vehicle components of the simplified model were jointed together by using different constraint types within the FE software, LS-DYNA (LS-Pre-Post), to decrease the motion space.

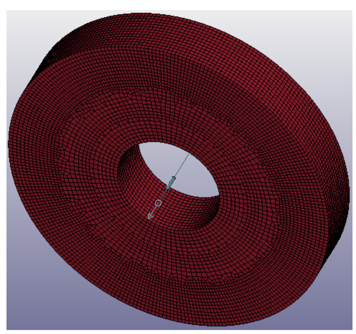


Figure 3. 18: JOINT-REVOLUTE between a shaft and rotating fly-wheel

Constrained Nodal Rigid Body (CNRB) (385) was the main constraint type used to connect the vehicle components and sixteen JOINT_REVOLUTE were used. There is also 787 SPOT-WELD for the joining of the surface and main parts of the vehicle. In these models, there are also JOINT CYLINDRICAL (4), JOINT SPHERICAL (2), and, EXTRA NODE SET (26), and RIGID BODIES (10) type of constraints used.

3.9 Collision Simulation Environment

The simulation setup includes the final impact conditions in the LS-DYNA environment.

The following parameters identify the impact simulations:-

- ✓ Vehicle collision positions (at different angles of vehicle contact).
- ✓ Contact types and friction coefficients.
- ✓ Ground types.
- ✓ Gravity and vehicle impact velocities.
- ✓ Solution control.
- ✓ Database definition for results collection.
- ✓ Results filter and frequency.

3.9.1 Vehicle contact angles position and vehicle contact regions

Different vehicle contact angles and impact positions could provide varied data of post kinematic response, injury metrics, and injury risk. However, collision angle and collision velocity variations could cover a greater range of vehicle collision accident data. Therefore, at this time the vehicle with the device and without the device is given different initial speeds and the angle of contact is varied and tested for advancement and improvement. The test vehicles were positioned at different degrees to the collision hard surface (in this case a PCB-R roadside barrier and a pickup truck) in contact with the roadside crash barrier. The vehicles were given a different velocity.

3.9.2 Contact types and friction coefficients

Accurate modeling of contact interfaces between bodies is critical for predictive finite element simulations. In this research, different contacts were used, nodes to a surface (6), is a contact interface, which uses either a kinematic or penalty type constraint method to tie offset slave nodes to the master segment and it was the first contact type used to define the contact between the vehicle windscreen and the adhesive solid part. AUTOMATIC_SURFACE_TO_SURFACE is simple, fast, and robust, and widely used, therefore, it was used to define the contact between the vehicle tire and the ground along the moving path with a friction coefficient of 0.9. To simulate the test vehicle collision with a roadside rigid guard rail at different degrees of collision with a logical post kinematic response of the crash and to avoid penetration issues, which could cause numerical instability, selecting a robust and efficient contact method to define the interaction between the rigid wall and the test vehicle components was of great importance. Consequently, AUTOMATIC_SURFACE_TO_SURFACE with a friction coefficient of 0.18 was used for contact between the vehicle surface and the guardrail, and a coefficient of 0.9 was used for contact between the vehicle surface and the guardrail.

3.9.3 Ground type

A planar ground was used for the primary impacts (roadside crash barrier -vehicle-contact). While, the road surface, was modeled as concrete for the secondary impacts which is rigid ground.

3.9.4 Impact velocity and gravity

INITIAL_VELOCITY was used to define varied vehicle impact velocity as described in the vehicle configuration part below. The front and rear wheels of the vehicle are given a translational velocity and their corresponding rotational velocity by creating a SET-PART entity for the vehicle part and the wheel. In addition, LOAD_BODY_Z was used to define the gravity of 9.806e-003 $\mathrm{m/s^2}$.

3.9.5 Solution control

Solution control has a significant influence on simulation stability and accuracy. Control contact was used (Rigid wall penalty scale factor for contact with deformable parts during implicit calculations which is equal to one).CPU, ENERGY (to command the calculation to include hourglass energy), OUTPUT, PARALLEL, AND SHELL are controlled for better time and solution results. CONTROL_TERMINATION was used to define the simulation termination time. For this simulation time is assigned as 0.15 and 0.5 sec. Furthermore, although increasing the simulation time of an impact scenario could be considered computationally expensive. As recommended by the LS-DYNA manual, using MAT_PIECESWISE_LINEAR_PLASTICTY, the shell element minimum time step assignment (TSLIMT) was applied as zero, and time step size for mass scaled solution (DT2MS) is defined as -1.700e-06.

3.9.6 Database definition for results collection

It was essential to define all the output results, which needed to be calculated and collected before running all the roadside crash barrier-vehicle impact simulations. Therefore, DATABASE was used to define the expected results using D3LPOT.In this simulation other than D3LPOT, in ASCII options, airbag statistics(ABSTAT), discrete element force(DEFORC), global statistics(GLSTAT), joint forces (JNTFORC), material energies (MATSUM) for calculating kinetic hourglass sliding internal and total energy of each part, for nodal displacement velocity and acceleration output(NOD OUT) is defined.

3.9.7 Verification of the results

For verification of the result obtained, we use the comparison of the results with and without the system for the same parameter and boundary condition and compared with each other.

3.9.8 Impact Configurations

For testing the Geo metro reduced model with and without a device the FE model of the vehicle and the barrier or vehicle to vehicle collision evaluation and simulation, the researcher considers three scenarios i.e. at a normal speed of the vehicle, at a higher impact force of a vehicle and higher angle of impact.

For the first scenario i.e. at a normal speed of the vehicle the following configuration is set up.

A. At an angle of impact of 45 degrees and low speed (35km/h):-Under Motor Vehicle Safety Regulations, a low speed of the vehicle is in the range of below 35 km/h (20 mph) on a paved level surface (Feng et al., 2020). For testing the designed system validity for low speeds, Geo-Metro vehicle with and without the designed system is positioned 45 degrees rotated and collides with a PCB-R barrier at an initial velocity of 35 km/h. The configuration of the vehicle and the barrier is shown in Figure 3.19 below viewed from the top.

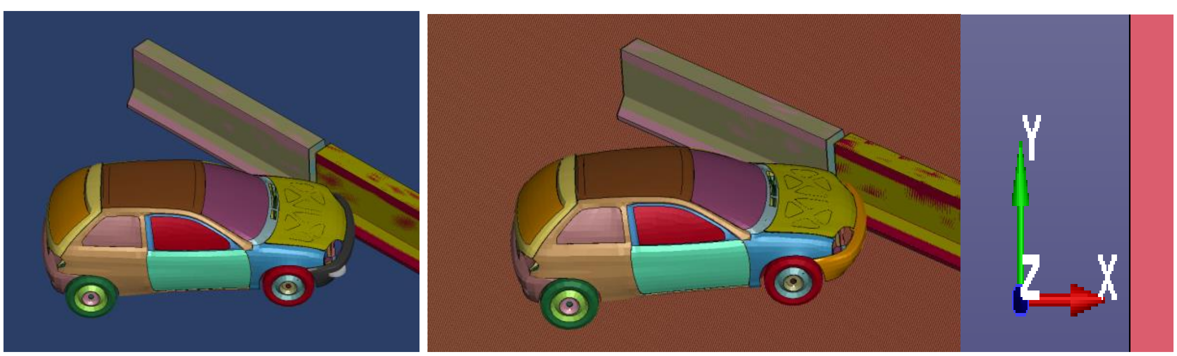


Figure 3. 19: Simulation configuration of a vehicle with a barrier.

B. Geo-Metro small vehicle with and without a system collide with a pickup truck at 35km/h at an angle of 45:-The Geo-Metro small vehicle with and without a designed and modeled system is positioned and made to run at an offset angle of 45 degrees from a pickup truck at an initial velocity of 35km/h for testing the functionality of the device. The following Figure 3.20 below shows the configuration of the vehicles for testing in LS-DYNA software.

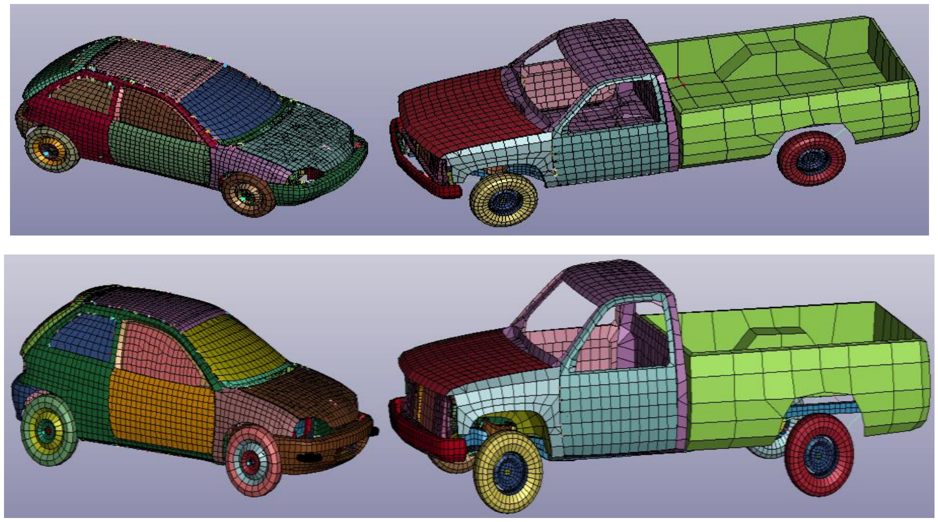


Figure 3. 20: Head-on angled crash simulation configuration

C. Side collision between Geo-metro and pickup with and without a system at 20 degrees each other and 35km/h:- Figure 3.21 below shows the configuration of a Geo-Metro small vehicle with and without a front-end passive safety system which is to make a side collision at 20 degrees into a pickup truck at a speed of 35km/h.

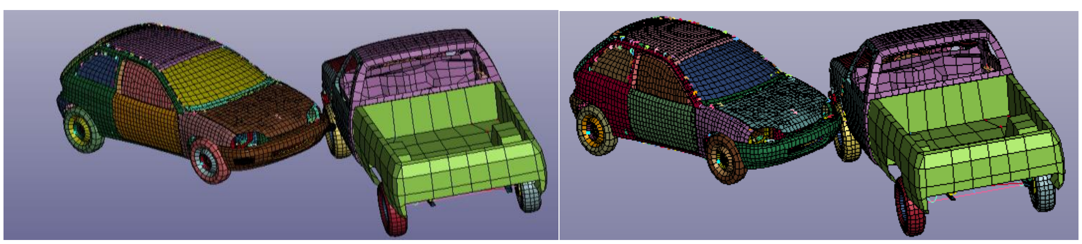


Figure 3. 21: Side crash simulation configuration

D. Geo-Metro with and without a system collides with a rigid pole head-on offset:- For the test of the device with a rigid round pole, a Geo-Metro small vehicle with and without a front-end passive safety system is positioned 90 percent offset into one corner of the test vehicle (the first contact place of a vehicle is the front-side corner of the vehicle), from the rigid round pole, with an initial velocity of the test vehicle at 35 km/h. The following Figure 3.22 shows the configuration of the vehicle with and without a designed and installed safety system that collided into a rigid round pole at an initial velocity of 35km/h during an offset head-on collision.

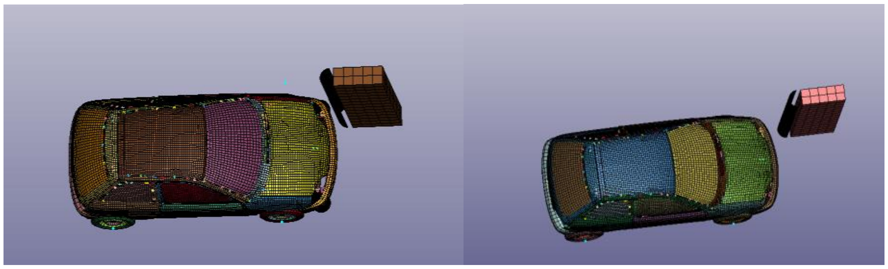


Figure 3. 22: 90 Percent offset crash configuration to a round-pole

The second scenario is when the vehicle makes a collision with a rigid body (PCB-R barrier) at the non-perpendicular position at a large collision angle. So to see the result of these the vehicle is tested as the following.

E. Vehicle test at large collision angle 70 degrees: - For testing a collision of a Geo- Metro vehicle with a designed front-end passive safety system with a PCR-B barrier at a large angle and to see the behaviour of the vehicle response the vehicle is positioned at 70 degrees from the barrier and the vehicle is given 70km/h initial velocity. Figure 3.23 shows the setup of a vehicle and PCR-B barrier for the test.

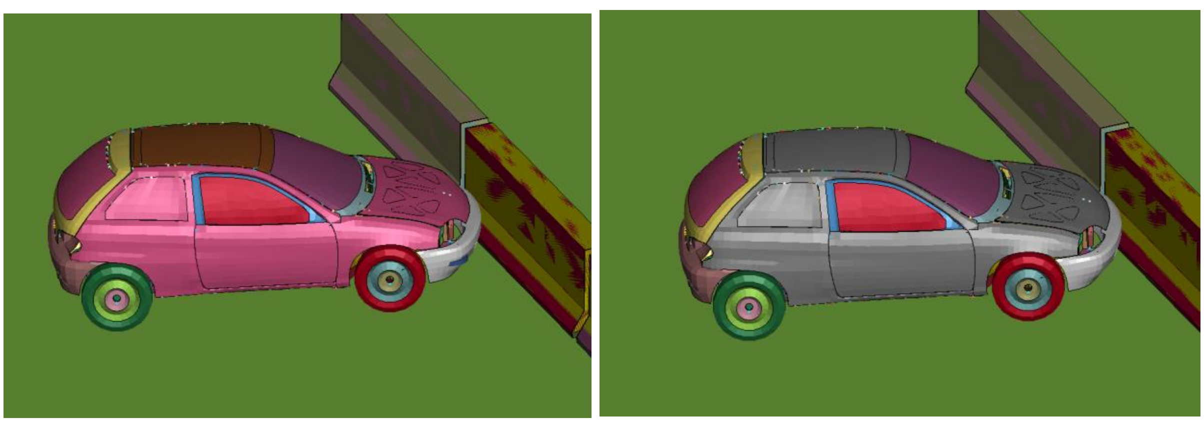


Figure 3. 23: Vehicle crash configuration at large collision angle

The third scenario is when a vehicle makes a collision with a rigid body (PCB-B barrier) at high impact force i.e. the initial vehicle velocity is too high. The following configuration is to test the vehicle at high speed.

F. At an impact angle of 45 degrees and High-speed (120 km/hr.):- In contrast, high-speed collisions occur when a vehicle travels more than 30 miles per hour (48km/h). For this simulation result, the Geo-Metro small vehicle with a designed front-end passive safety system and without a safety system is positioned 45 degrees from the PCB-R barrier and at a speed of 120 km/h. The initial configuration of the setup is shown in below Figure 3.24.

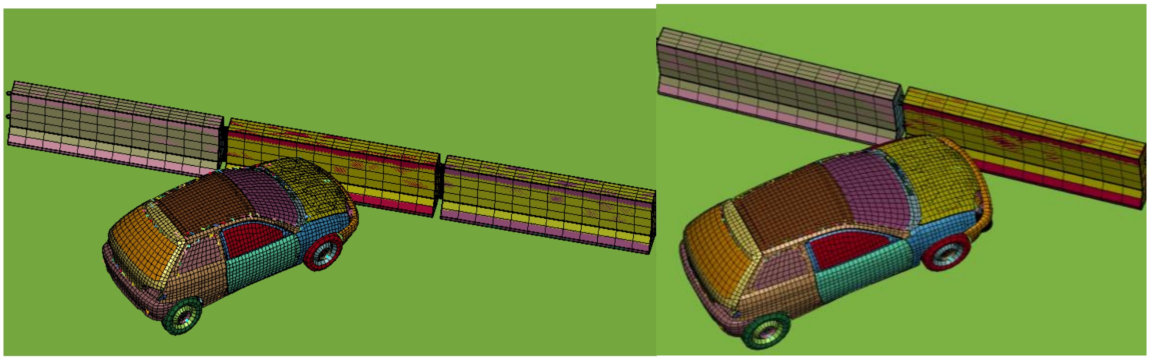


Figure 3. 24: Vehicle crash configuration at a high vehicle speed

3.10 Vehicular response

Vehicular responses are the most concerning parameters in evaluating safety performances of the barrier systems in state-of-the-art practices and researches. Crash testing agencies need to follow the specified procedures defined in the manual for assessing safety hardware (MASH). Similar procedures were used here in crash test simulations. The yaw angle indicated how much the vehicle was redirected into another adjacent lane during the crash. The vehicle's post-impact responses are also important: it is preferred that the vehicle does not intrude into adjacent traffic lanes after being redirected by the barrier. One measure of the vehicle's post-impact response is the exit angle, which is defined as the angle between the barrier's longitudinal direction and the vehicle's travel direction at the time when the vehicle loses contact with the barrier. The preferred exit angle should be less than 60% of the initial impact angle as specified by MASH. The following Table 3.6 lists the preferred exit angles specified by MASH.

Table 3. 7: Preferred maximum exit angles specified by MASH

Impact-angle	20	30	40	50	60	70	80	90	100
Preferred maximum exit angle	12	18	24	30	36	42	40	54	60

The vehicle exit angles are measured in LS- DYNA for different speed and impact angles between the Geo-Metro small vehicle with a front-end passive safety system and the PCR-B barrier collision.

The yaw, pitch, and roll of the vehicle, as defined in Figure 3.25 below, were used to examine the vehicle's orientation and stability during an impact. The yaw angle indicated how much the vehicle was redirected, and the pitch and roll angle could be used to assess the stability of the vehicle during the crash. A large pitch or roll angle implied unstable vehicle behavior and as required by MASH the pitch and roll angles should not exceed 75°.

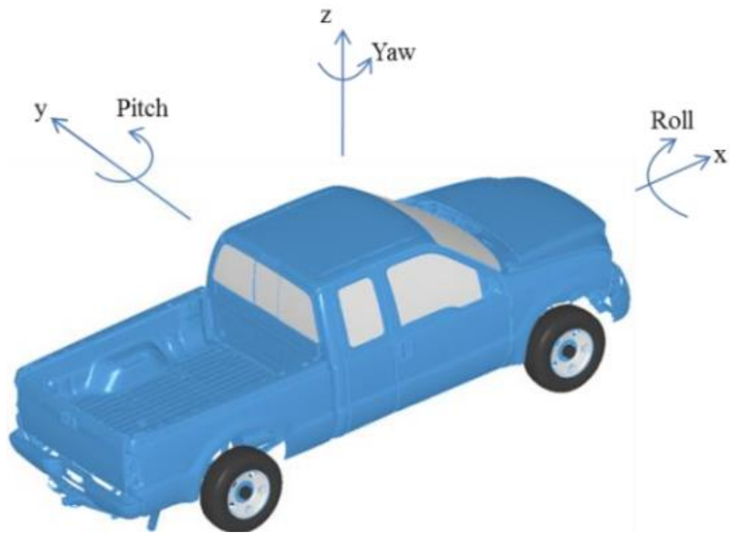


Figure 3. 25 Definition of yaw, pitch, and roll

3.11 Chapter summary

Under the chapter the materials was selected for assigning the material properties for the parts of the front-end passive safety system in LS-DYNA, designing the thickness and section of the main parts, modeling using CATIA ,selection of the model of vehicle and guard rail, Appling boundary conditions and configuring simulation environment was done. At last the vehicular response measurement and identification is introduced.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

Under this chapter, all the initial conditions and simulation environment are constant when the researcher tried to validate the result of collision by comparing the simulation result of Geo-Metro small vehicle with and without the front-end passive safety system. A Geo-Metro small vehicle with and without a system which is under impact at a different speed and angle to the PCB-R barrier, a rigid pole, and a pickup track simulation results i.e. energy balance curve, displacement-time graph, vehicular response (pitch, roll, and yaw angles), rotational acceleration, and energy ratio is compared to see the benefit of the installed device over the vehicle without a system.

4.2 Impact at an Angle of 45 Degrees and 35 km/h

The Geo Metro car is considered for analyzing the energy changes experienced with and without a system that makes a collision to a roadside crash barrier at an angle of 45 degrees. A velocity of 35 km/h is assigned and a run time of 0.15 S is given and the results are interpreted as follows from Figure 4.1 below. The tabulated data is listed on the appendix portion for this portion only because that the data is very large and tedious to extract from the LS-DYNA plot window and tabulate in excel.

Figure 4.1 shows the energy curves of a Geo- metro small vehicle with and without a front-end passive safety system that is in collision with a PCB-R crash barrier at an angle of 45 degrees and an impact speed of 35km/h. The Figure shows that for a vehicle without a system, the kinetic energy is decreased from 409 kJ to 160 kJ and the internal energy of the vehicle increases from 0 kJ to approximately 219 kJ. But for a Geo-Metro vehicle test with a system, the energy curve indicates that the kinetic energy decreases from 410 kJ to approximately 225 kJ and the internal energy is increased from 0 kJ to 150 kJ.

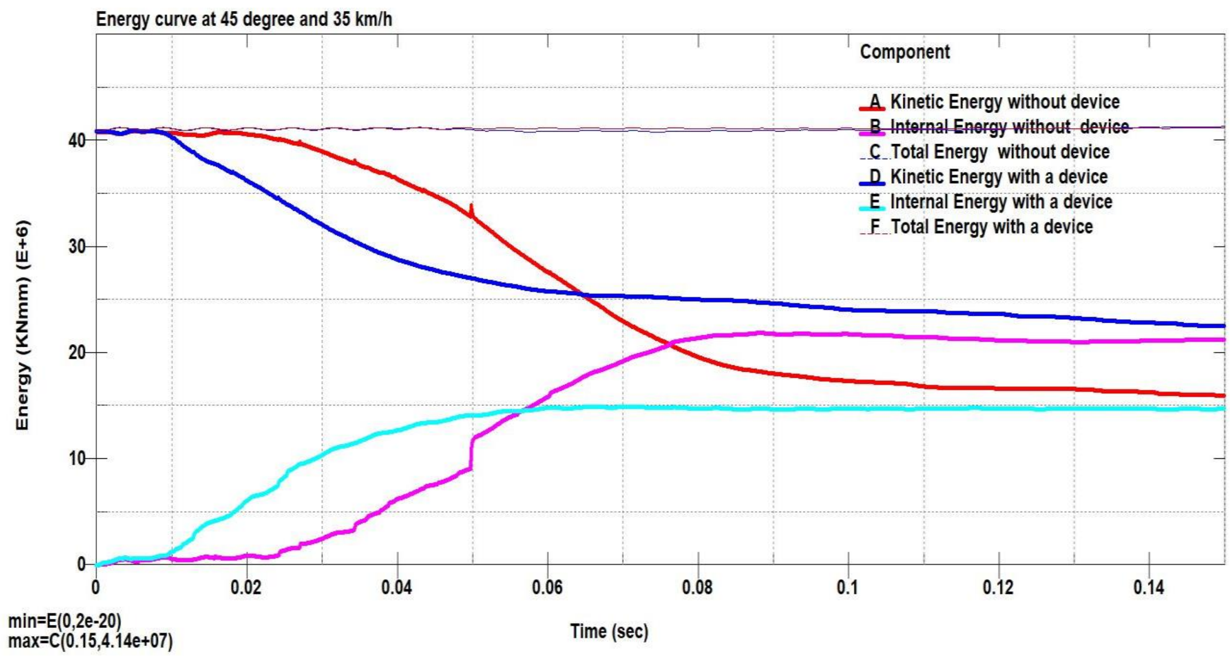


Figure 4. 1: Energy curves of a vehicle collision at an angle of 45 degrees and 35km/h

When we compare the increase in internal energy of the vehicle with and without a system, there are approximately (219 kJ-150 kJ) equal to 69 kJ of internal energy increase for a vehicle without a system, and this means that for a vehicle with a device 69 kJ of harmful force is diverted to the safest place by the rotation of wheels during the collision, and rear-end vehicle collision which may occur as a result of the vehicle, travels close behind the first collided vehicle have avoided because of that the driver of the front vehicle gain some time and distance to apply brake by assuming that the driver does not give additional driving force. Since the total energy for the crash simulation is constant there is little or no more total energy loss as the total energy for the two simulation results is constant.

To check whether the energy is conserved or not we have to see the energy ratio of the crash analysis of the vehicle with and without a system at crash analysis. Energy ratio above 0.7% means the simulation result total energy is not conserved and there is more total energy loss and gain, this violates the conservation of energy. Figure 4.2 depicts the energy ratio of the vehicle simulation at 35 km/h and 45 degrees under impact to a PCB barrier. The energy ratio curve is below 0.7% for the vehicle with and without a system simulation result. So there is no more total energy gain or loss under the simulation process and the theorem of energy conservation is met under this.

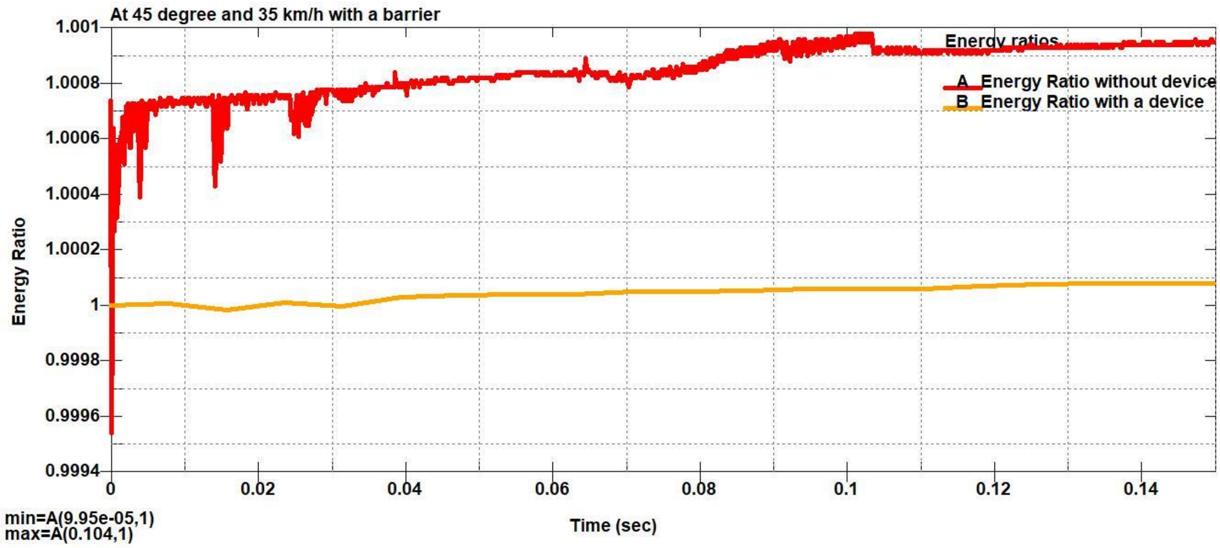


Figure 4. 2: Energy ratio vs time

It is also important to analyze the vehicle simulation result based on the distance traveled after impact to the barrier to indicate the possibility of rear-end collision happening. Generally, Figure 4.3 depicts the y-displacements of the vehicle which is equipped with and without a system that is simulated at 45 degrees from the barrier and an initial speed of 35km/h. The vehicle was initially positioned in the x-direction, rotated 45 degrees from the barrier, and accelerated at an initial speed of 35km/h. Vehicle simulation without a system moves 222 mm in the negative y-direction, 5260 mm in the positive x-direction (APPENDIX A), and 333 mm in the positive z-direction (APPENDIX A). But when we see a displacement-time graph of the vehicle simulated with a system, it moves 669 mm in the negative y-direction, 5200 mm in the positive x-direction (APPENDIX A), and 31.8 mm in the positive z-direction (APPENDIX A). The vehicle with a system moves 446 mm more distance in the y-direction when compared to the vehicle without a system. But the vehicle without a system moves 60 mm more distance in the positive x-direction and 301.2 mm in the positive z-direction when compared to the vehicle with a system.

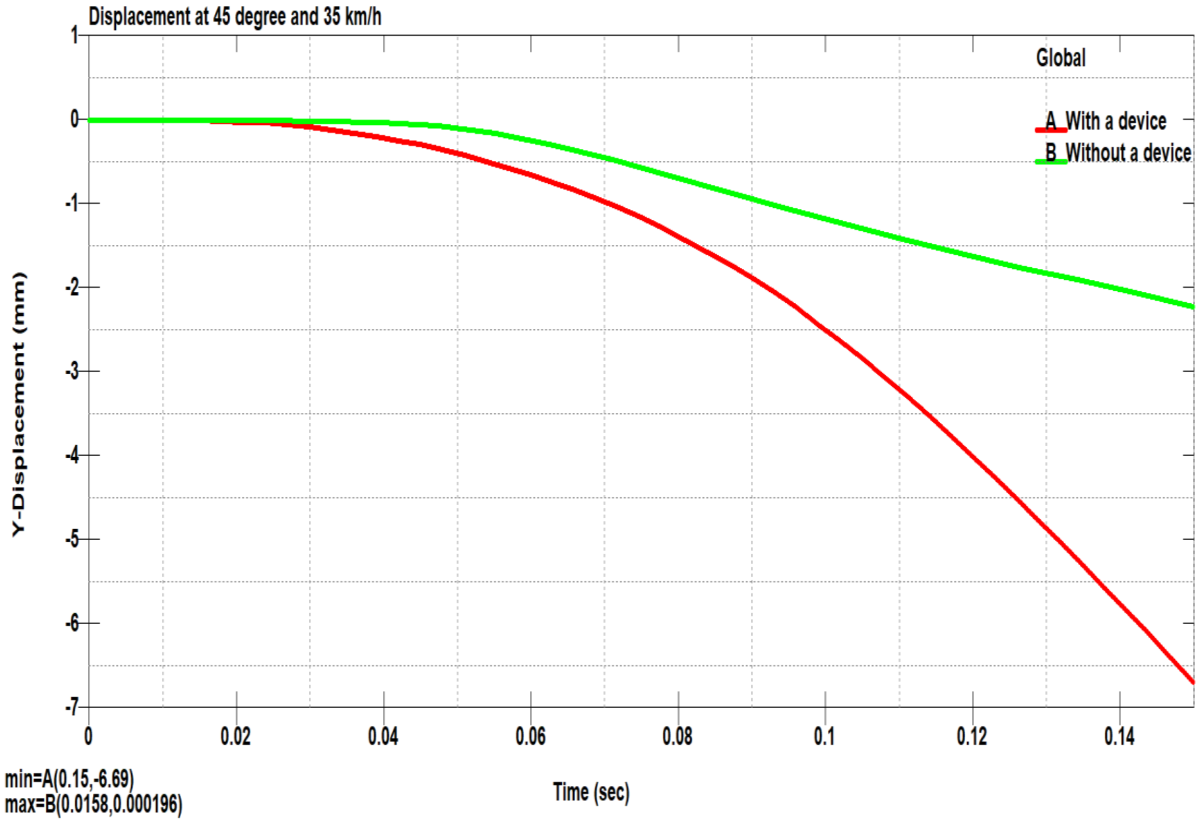


Figure 4. 3: Y- displacement-time graph of vehicle collision to a barrier

This more distance movement of vehicle with a system in the negative y-direction indicates that at the time of impact, the wheel is rotated by the non-perpendicular force and the rotation of the flywheel directs the vehicle to the negative y-direction and gives the driver more time to react to the brake and it gives the possibility to avoid the rear-end collision. The vehicle without a system moves more distance to the positive z-direction, which may indicate that the vehicle leaves the ground and became uncontrollable and the increase in instability may increase than the vehicle with a device. There is also a slight increase of distance moved in the positive x-direction for the vehicle without a system which may also indicate that the interaction between the vehicle and the barrier is greater and the guard rail deformed more.

For vehicular and passenger response and impact severity, we can use the lateral, longitudinal, and vertical rotational acceleration time histories. But at the time we have to compare the rotational acceleration for the same vehicle with and without a system simulation results.

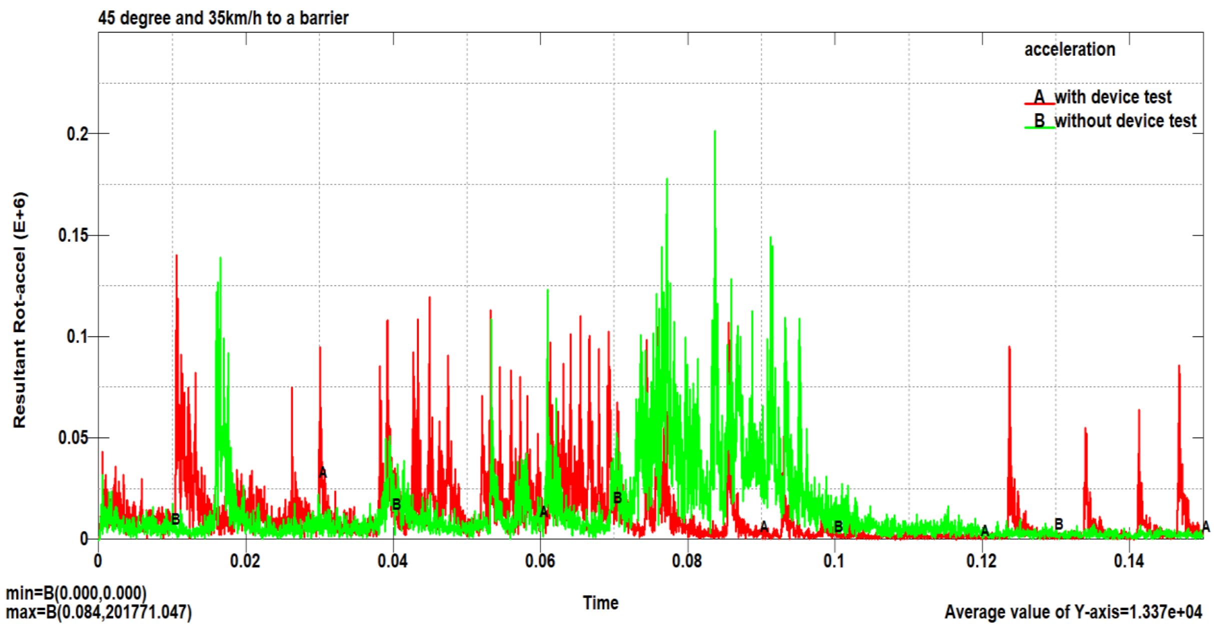
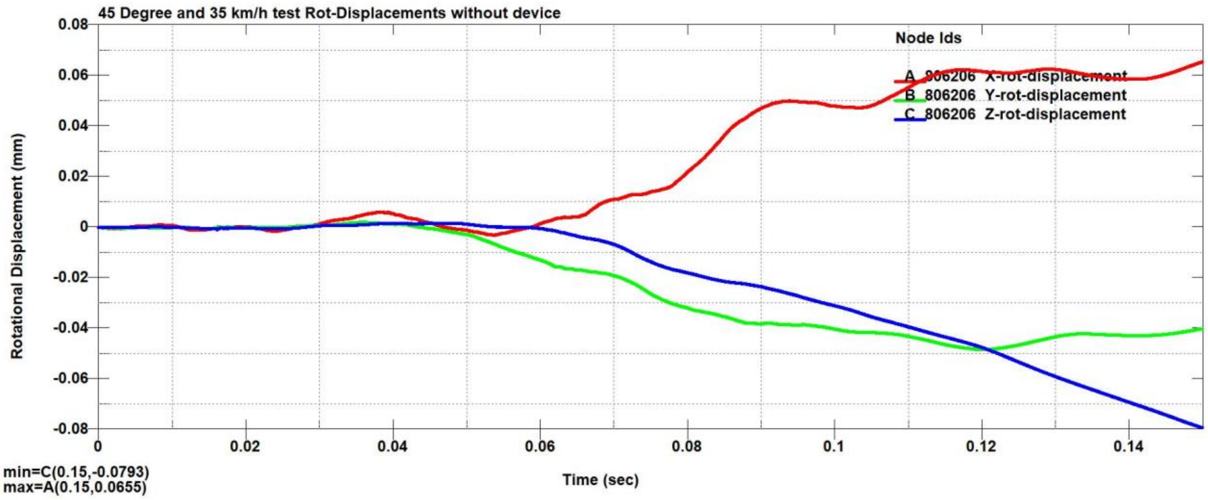
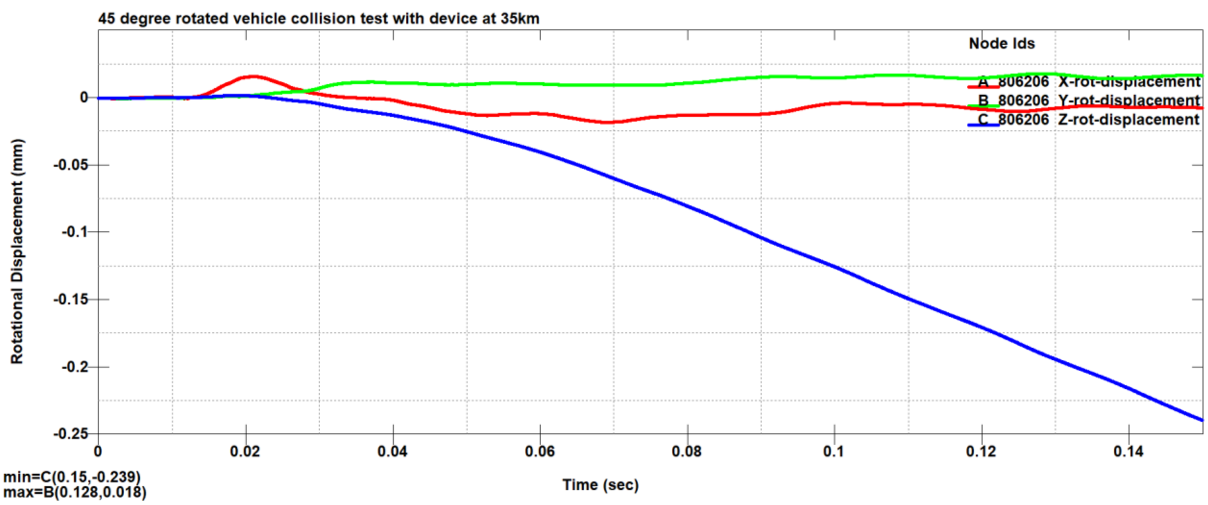


Figure 4. 4: Resultant rotational acceleration time histories

From Figure 4.4 we see that the peak rotational acceleration for the simulation without a system test is higher than the peak rotational acceleration for the simulation with a system. The acceleration time histories which is recorded at the C.G accelerometer indicate the severity level of the impact on the passengers and vehicle parts. There are x, y, and z- rotational time histories, but for the time we take the resultant one to illustrate whether the system effectively diverts the harmful force into the safest place or not. From Figure 4.4 above, we can see that the peak acceleration for the vehicle without a system is much higher than the vehicle without a system. So the impact force on the passenger's decreased when a vehicle is equipped with a system.



(a)



(b)

Figure 4. 5: Yaw, pitch, and roll displacement of the vehicle

The vehicle's post-impact responses are also important: it is preferred that the vehicle does not intrude into adjacent traffic lanes after being redirected by the barrier. One measure of the vehicle's post-impact response is the exit angle, which is defined as the angle between the barrier's longitudinal direction and the vehicle's travel direction at the time when the vehicle loses contact with the barrier. The preferred exit angle should be less than 60% of the initial impact angle as specified by MASH. The yaw, pitch, and roll of the vehicle, as defined in Figure 4.5, were used to examine the vehicle's orientation and stability during an impact. The yaw angle indicated how much the vehicle was redirected, and the pitch and roll angle could be used to assess the stability of the vehicle during the crash.

A large pitch or roll angle implied unstable vehicle behavior and as required by MASH the pitch and roll angles should not exceed 75°. Figure 4.5 shows the vehicle's response to the impact force during a crash into a PCB-R barrier at a speed of 35km/h and 45 degrees with a system (a) and without a system (b). X and Y-rotational displacement of a vehicle without a system are more when compared to the vehicle with a system simulation result. This pitch and roll of the vehicle indicate the vehicle without a system is unstable than the vehicle with a system. But when we see z-rotational displacement the vehicle with a system rotates more along the z-axis than the vehicle without a system. This rotation of the vehicle along the z-axis indicates the rotation of the flywheel directs the vehicle away from the surface of the barrier. But this yaw motion must be within a specified limit, if the vehicle intrudes into another vehicle lane there may be an occurrence of dangerous collision with another vehicle. So as specified by MASH the vehicle's exit angle must be lower than 60% of its entering angle. So the yaw angle is measured by the 3 node angle measurement method and we get an exit angle of 12.44 degrees which is below 27 degrees, so the exit angle is within the specified limit.

4.3 Head-On Collision at an Angle of 45 degrees and 35km/h

The following Figure 4.6 below shows the simulation results of Geo-Metro small vehicle with and without a front end passive safety system impact to a pick-up truck head-on at an offset angle of 45 degrees and an initial velocity of 35km/h. The energy curve for the Geo-Metro with a system shows that the kinetic energy drops from 411 kJ to approximately 310 kJ and the internal energy increases from 0 kJ to 104 kJ. But the energy balance curve for the Geo-Metro without a system shows that the kinetic energy drops from 410 kJ to approximately 205 kJ and the internal energy increases from 0 kJ to 195 kJ. From these energy balance curves, we see that more energy is absorbed for the Geo-Metro small vehicle without a system installed, so the internal energy which is responsible for vehicle crashes and injury of occupants increases, because that the kinetic energy lost is transformed into internal energy according to the conservation of energy theorem’. The total energy for the two cases is constant and this indicates that there is no more total energy loss and the crash analysis simulation fulfills the conservation of energy theorem.

But for the Geo-Metro vehicle with a system, the vehicle with more energy is rotated into a safe place by the rotation of the fly-wheel, so the internal energy which is absorbed by the vehicle body and the passengers decreases when compared to without a system collision, and the vehicle with a system have enough kinetic energy to go more distance and this gives the driver more time to act to the brake

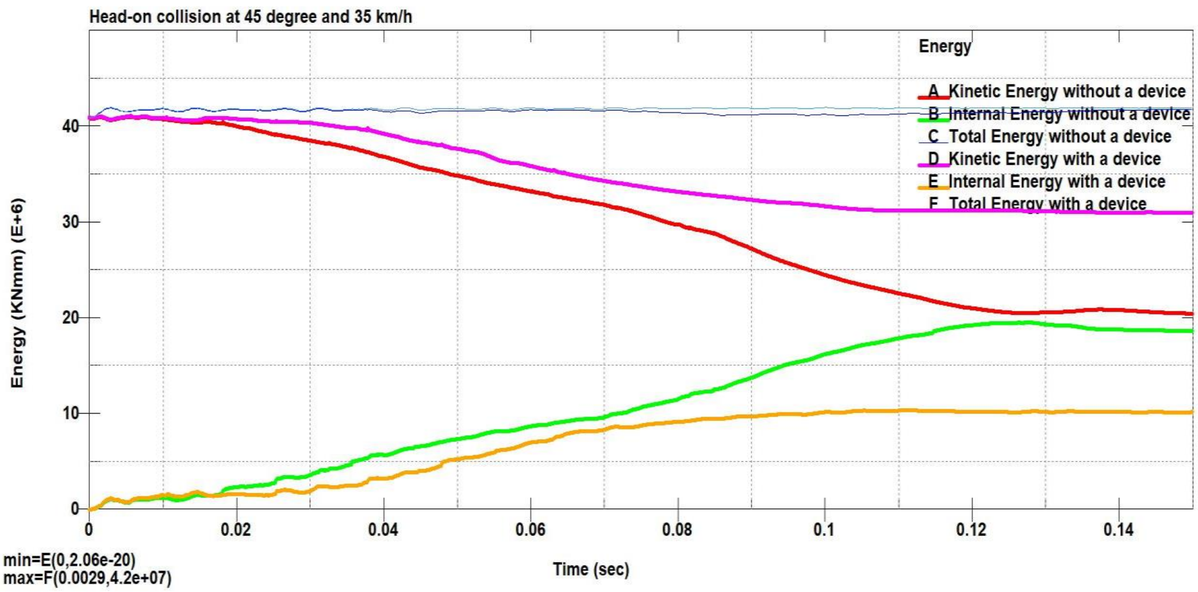


Figure 4. 6: Energy balance curve at 45 degrees and 35km/h.

According to the conservation of energy principle energy is neither created nor destroyed, but transformed from one form of energy to another form. So during the collision, the total energy must be nearly constant and no more total energy loss occurs. The energy needed to be conserved throughout the simulations. No significant energy loss or gain should be observed in numerical simulations. In LS-DYNA the energy conservation is measured by a so-called energy ratio defined as

$$\Omega(\mathrm{t}) = \frac{w(t)}{w(0) + w^0(t)}$$

Where $w(t)$the total energy at any time t, $w(0)$is the total energy at time 0 and $w^0(t)$ is the work done by external forces. If the energy is well conserved, the energy ratio will be ideally 1.0 at every time instant. But it is also acceptable that the energy ratio is close to one up to 0.7 % unit variation above and below one (Ning Li,2014).

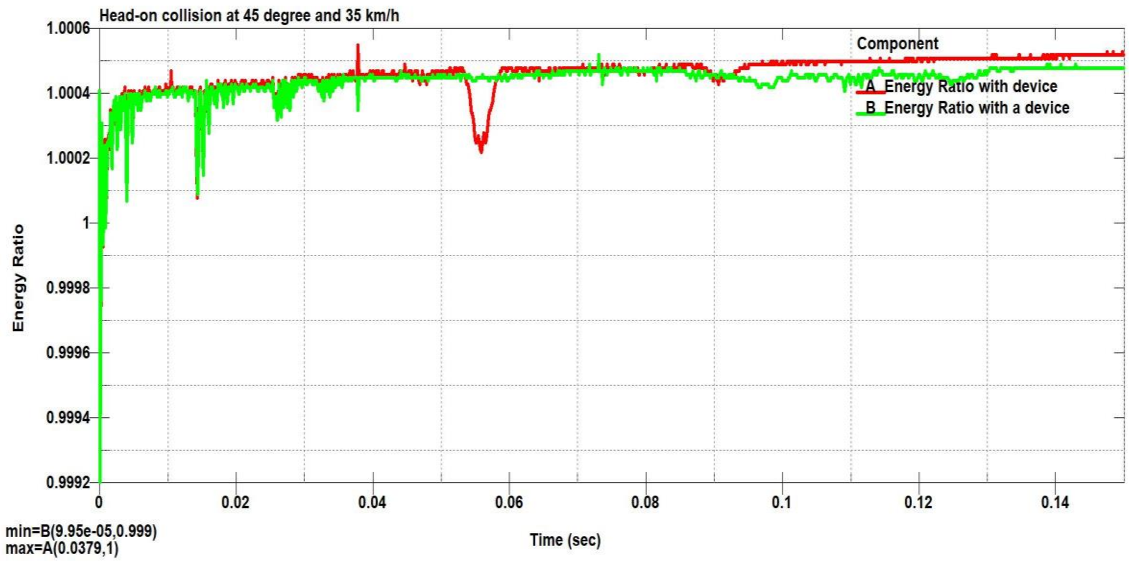


Figure 4. 7: Energy-ratio vs time

Figure 4.7 depicts the energy ratio of the vehicle simulation with and without a system. The energy ratio for the two simulation results is in the range of 0.999 to 1. So the energy ratio is within an acceptable variation, i.e. the variation is less than 0.007 increase. So the energy is well conserved, and no more energy gain or loss is observed in the simulation. Generally, the simulation process is acceptable.

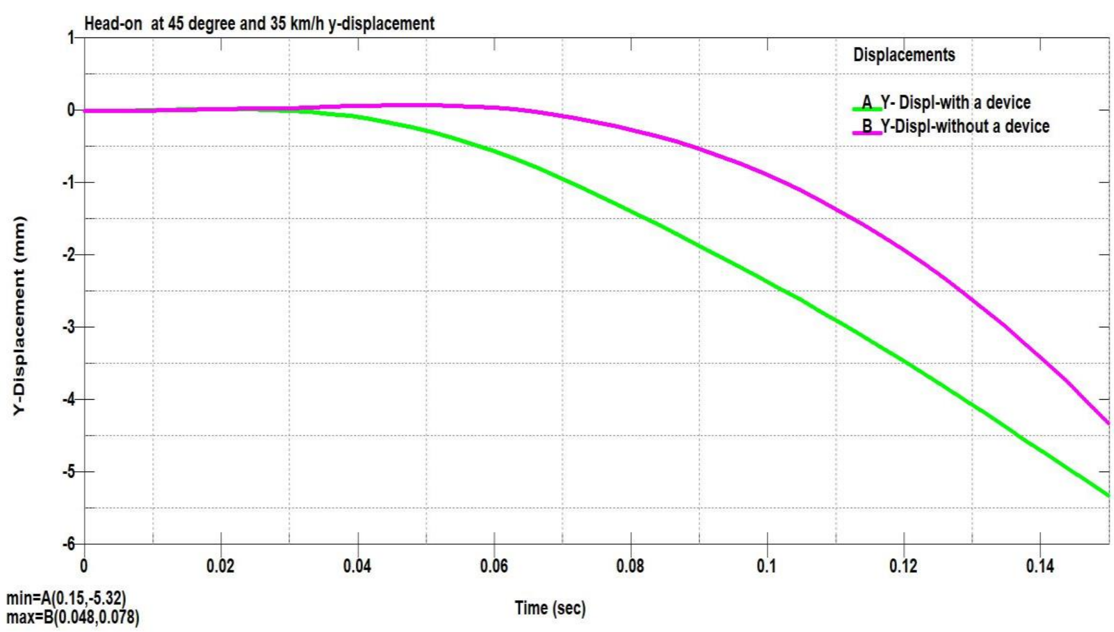
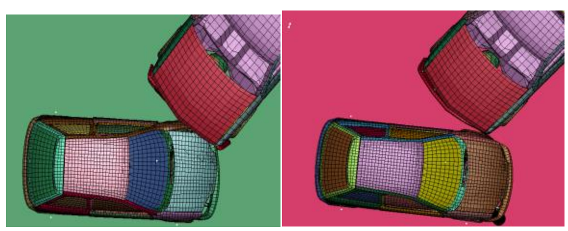


Figure 4. 8: Y-rigid body displacement vs time at an angle of 45 degrees and 35km/h

The above Figure 4.8 shows the Y-rigid body displacement vs time graph for a vehicle with and without a system collision with a pickup truck head-on at an angle of 45 degrees and 35km/h. The vehicle with a system moves 5.32 mm in the negative y-direction. But a vehicle without a system moves 4.31 mm in the negative y-direction. A vehicle equipped with a front-end passive safety system moves more distance when compared to the vehicle collision without a system. So the probability of the occurrence of rear-end collision is decreased when a vehicle is equipped with a system if another vehicle is moving closer to the rear of the disturbed vehicle. The vehicle with and without a system originally before impact moves in the positive x-direction, but after impact, it is directed to the negative y-direction by the reaction force of the pickup truck and flywheel rotation. But when we compare the final position. A vehicle without a system moves less distance than the vehicle with a system, and it indicates that the vehicle closer behind has a high probability of rear-end collision happening with an altered vehicle.



(A) (B)

Figure 4. 9: The final position of the vehicle at 15 ms

A Geo-Metro small vehicle with a system impact to a pickup track intrudes into the surface of the pickup truck and doesn't leave the surface of the pickup truck (Figure 4.9 A). But for a vehicle with a system, it slides over the front bumper of the pickup truck and leaves the surface of the vehicle more when compared to the test without a system as shown in Figure 4.9 B. Generally for an angled head-on collision of a vehicle it is observed from simulation result that some of the harmful forces are converted to non-harmful force by rotation of the wheel which is installed at the front corner of the vehicles. But if the vehicle lacks this system as shown in Figure 4.9 A above the harmful impact force is absorbed by the vehicle parts and the vehicle moves a shorter distance and stops because of that the kinetic energy is converted fastly to the internal energy. So the driver does not have enough time to react to the brake and, if there is a vehicle that moves very closer to the disturbing vehicle, there may be a probability of rear-end collision happening. So rear-end collision is mitigated and decreased by using this front-end passive safety system for a vehicle collision.

The severity of the accident on the passengers is determined from the acceleration time histories, which are measured at accelerometers. The following Figure 4.10 shows the resultant rotational acceleration time histories of a Geo-Metro small vehicle measured at a center of gravity accelerometer. The peak acceleration measured at the center of gravity accelerometer for the vehicle with a system is very much less than the peak acceleration for the vehicle without a system.

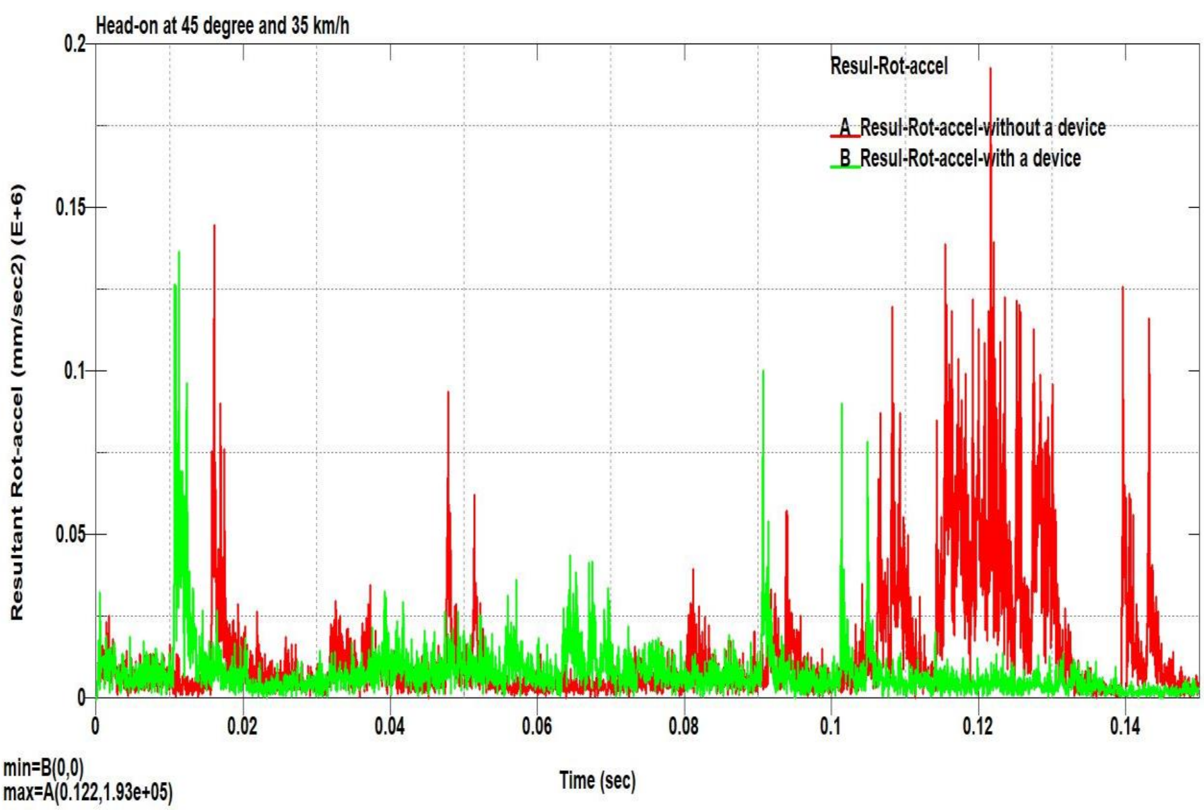
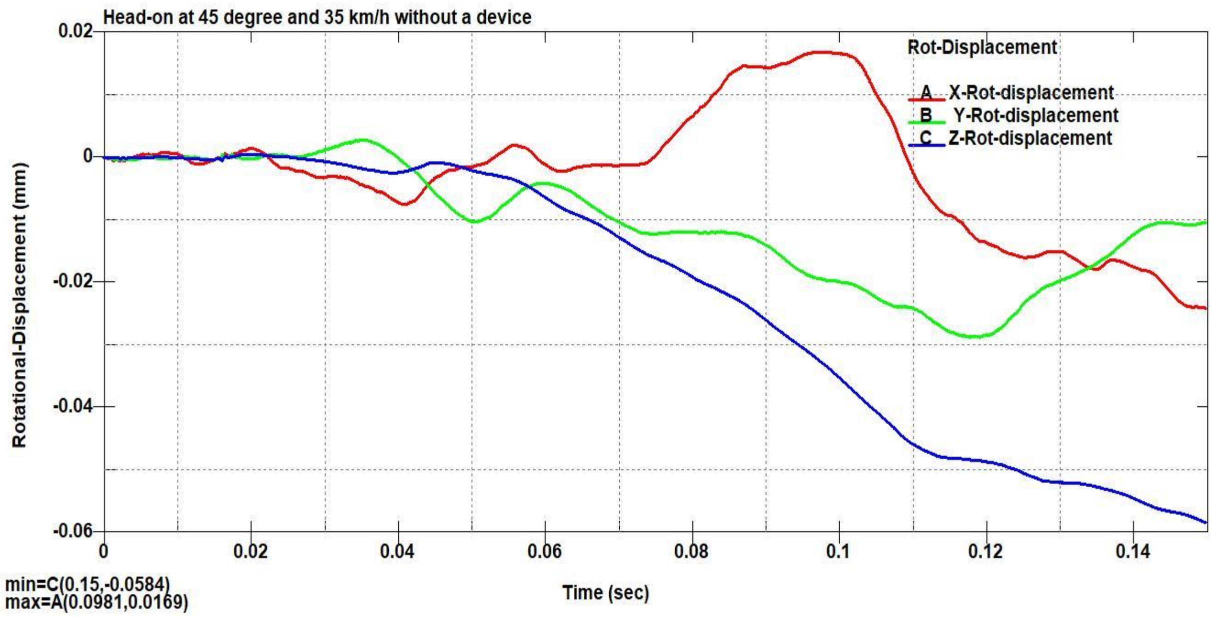
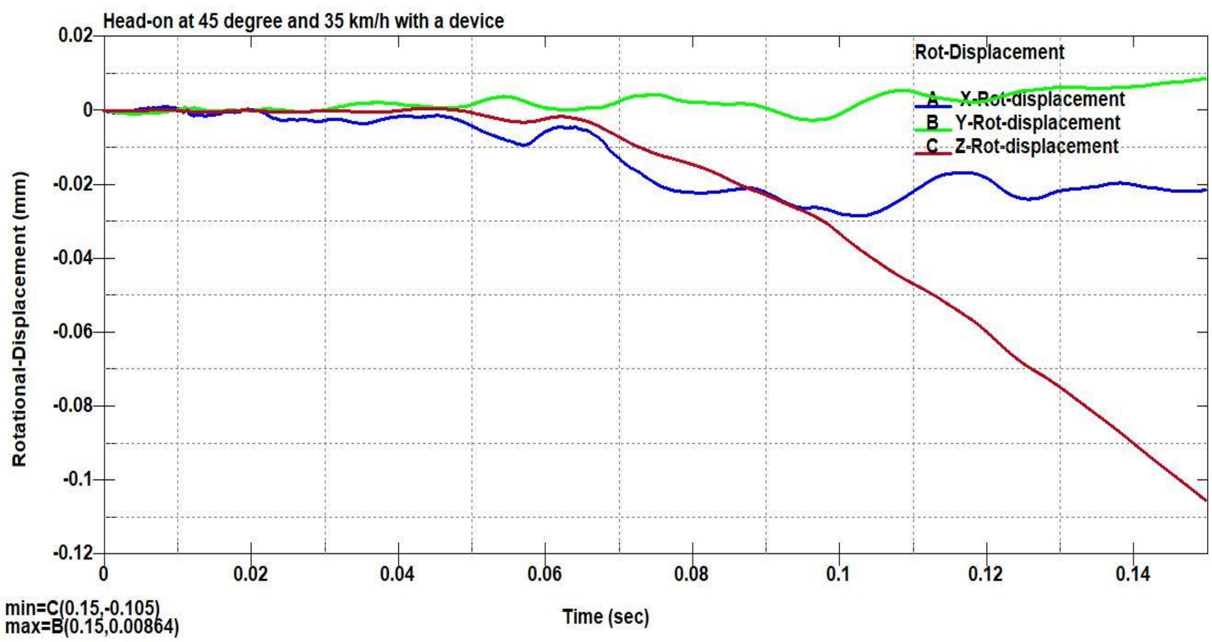


Figure 4. 10: Acceleration-time history

But if we consider the rotational displacement of a Geo-Metro small vehicle for measuring and indicating the vehicle's stability and restitution angle from the following Figure 4.11, the yaw motion of the vehicle with a system shows a slight increase when we compare to the yaw motion of the vehicle without a system.



(a)



(b)

Figure 4. 11: Rotational displacements of the vehicles without (a) and with (b) a system

This yaw motion along the z-axis of the vehicle indicates the vehicle is directed to the safest place by the rotation of the installed flywheel. But the x-and y-rotational displacement for the vehicle without a system is higher (Figure 4.11 (a) than the vehicle with a system , x and y rotational displacements as shown in Figure 4.11 (b). These high x and y rotational displacement indicates that the vehicle without a system is unstable than the vehicle with a system.

Generally from the above graph, the vehicle with a system is stable, and the equipment is safe at this speed and the contact of the vehicle with a device to the barrier is smooth and acceptable.

4.4 Side Collision at 20 Degrees and 35 Km/h

The result of the simulation of a side collision between a Geo-Metro small vehicle and pickup track with and without a system is shown in Figure 4.12. For a vehicle without a system more kinetic energy is converted to internal energy within a short period, and for the overall simulation result, more kinetic energy is converted to internal energy. The conversion of the kinetic energy with a short period means there is no smooth contact between the two bodies. So increasing the collision time decreases the impact force on the occupant. The overall internal energy for the two-vehicle test finally converges in the same manner but to see the advantage of the front-end passive safety system we can see the time rate in which the internal energy is increasing. The internal energy is increasing with a short period for a vehicle without a system, and the time rate is more for the vehicle with a system. The total energy for the two simulation results is constant, there is no more energy loss or gain during the simulation and the energy is well conserved during simulation.

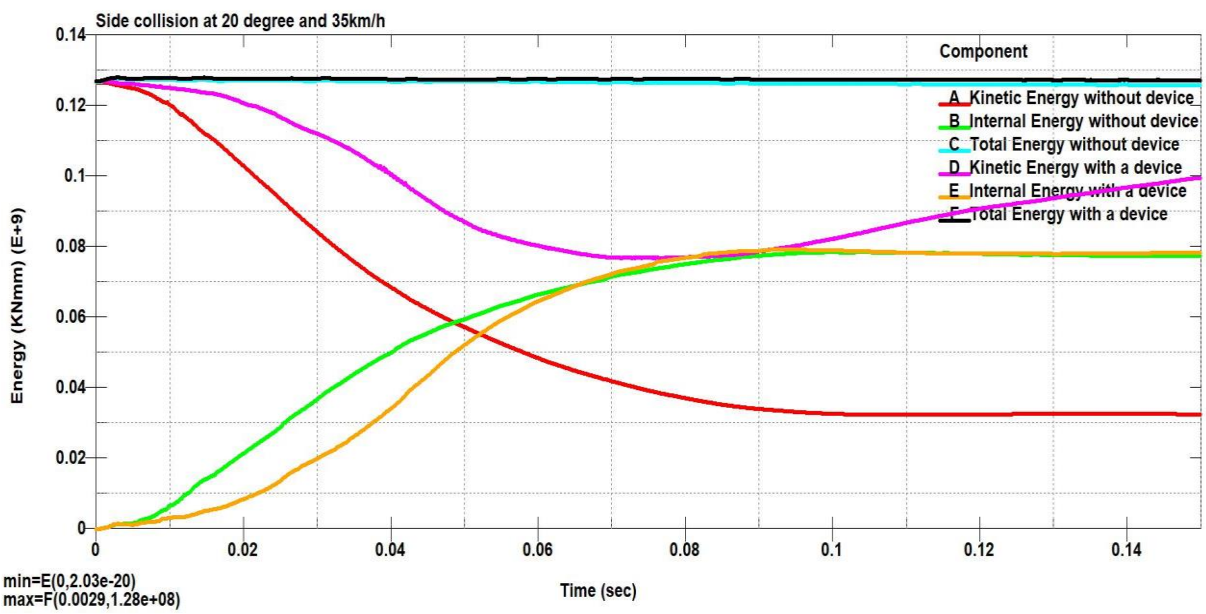


Figure 4. 12: Energy balance curves for side impact

From Figure 4.12 we can see that the internal energy becomes constant finally at a simulation time of approximately 0.08 sec. To further check whether these absorbed energies are transferred to the passengers and parts of the vehicle more, we have to see the resultant rotational acceleration.

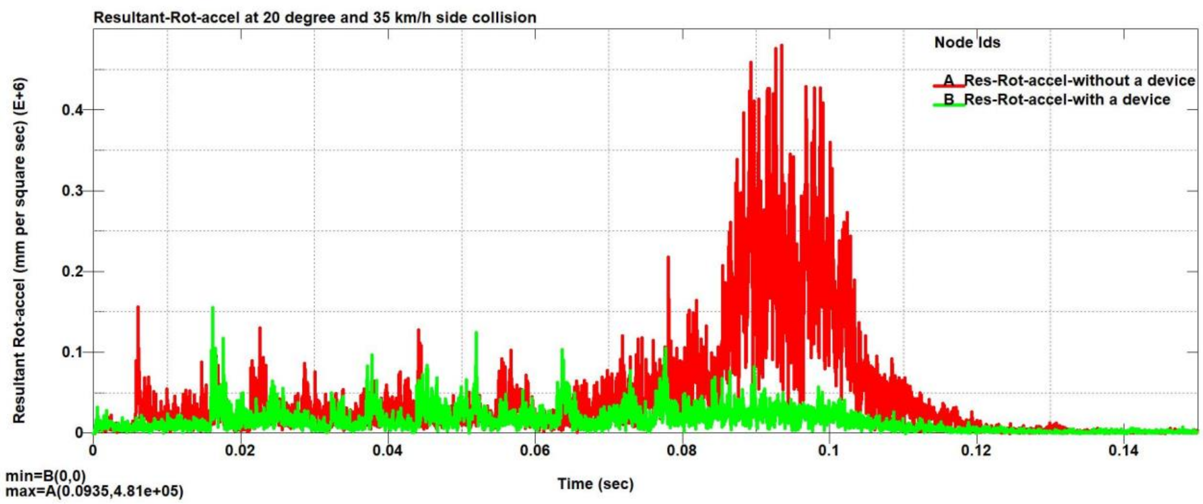


Figure 4. 13: Resultant rotational acceleration for side collision.

The resultant rotational acceleration time histories were measured by an accelerometer installed at the C.G of the vehicle as shown in Figure 4.13 above. Peak rotational acceleration is higher for the test without a system, but it is very less for the test with a front-end passive safety system. It indicates that the injury of the occupant increases for the impact without a system.

To see that the total energy loss or gain is within the specified limit and, there is no more energy gain or loss in the crash analysis, we have to check the energy ratio is within the 0.7% limit.

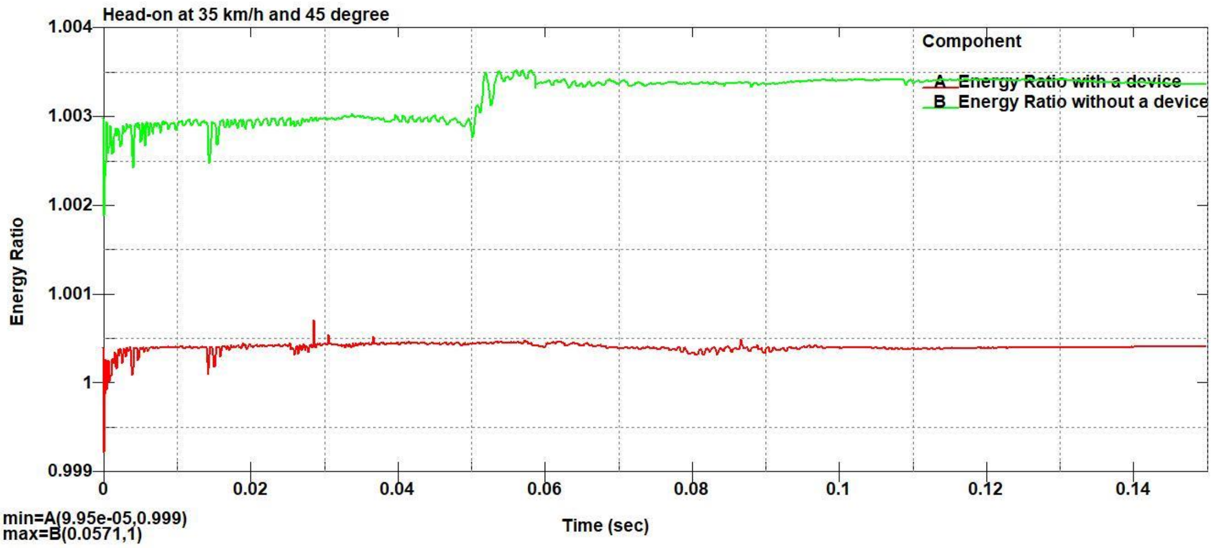


Figure 4. 14: Energy ratio vs time for a head-on collision

Figure 4.14 shows the energy ratio curve of a vehicle with and without a system angled head-on collision at 45 degrees and 35km/h. The energy ratio varies from 0.999 to 1 and, the energy ratio is within the specified limit. So during the crash simulation, there is no more energy loss or gain and the energy is well conserved.

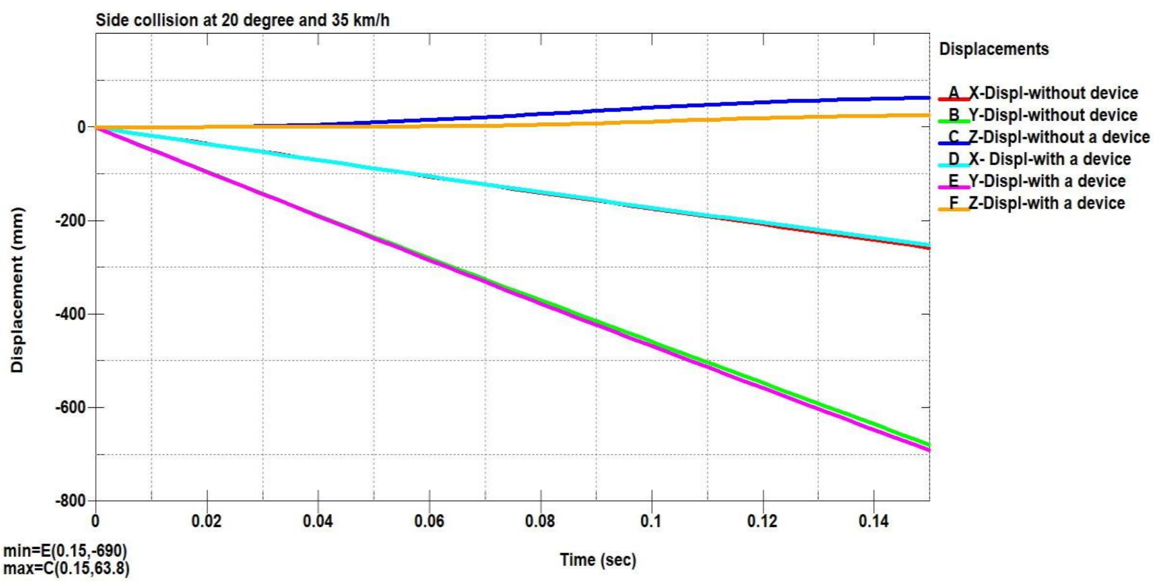


Figure 4. 15: Displacement- time graph for side impact

From the displacement-time Figure, 4.15 above the x-displacement with a system becomes 257 mm and without a system, it becomes 252 mm in the positive direction, it is almost the same. But the vehicle with a system moves 690 mm in the negative y-direction, and for the vehicle without a system, the vehicle moves 678 mm in the negative y-direction. Generally, the vehicle with a system moves more distance in the negative y-direction. This more distance indicates the vehicle is directed towards the safest place by the rotation of the flywheel. By considering z-direction displacement, we see that the vehicle without a system moves more distance into positive z-direction when compared to the vehicle with a system. This high z- displacement indicates the vehicle stability altered more for the vehicle without a system and it leaves the ground more, so it is hard to apply the brake.

Vehicle stability is also the main concern when we simulate vehicle collision in LS-DYNA. The vehicle with large x-and y- rotational displacement indicates the vehicle is unstable, and the vehicle with large z-rotational displacement indicates the vehicle yaw motion along the z-axis.

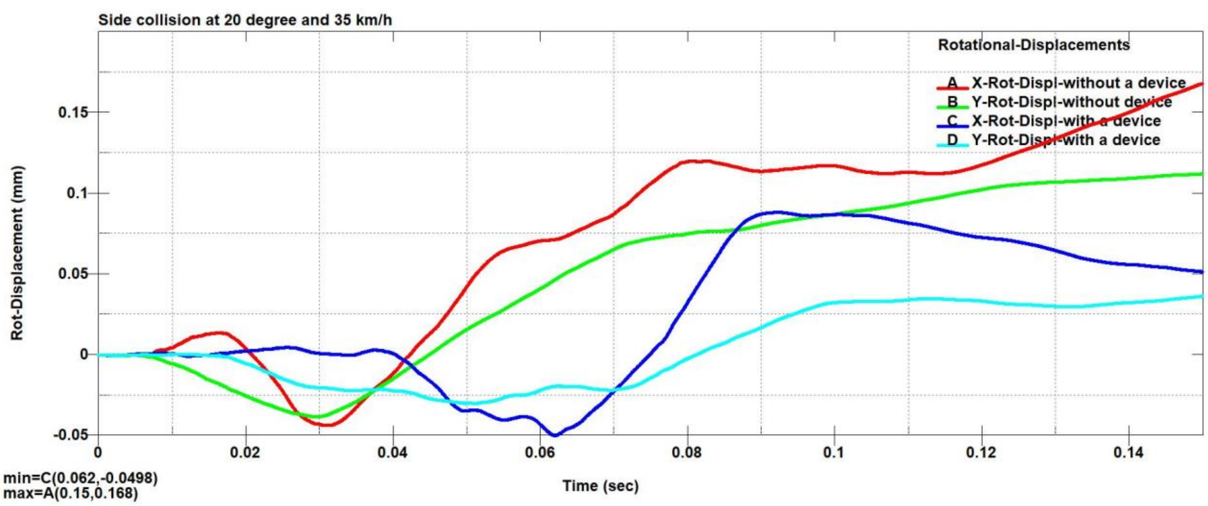
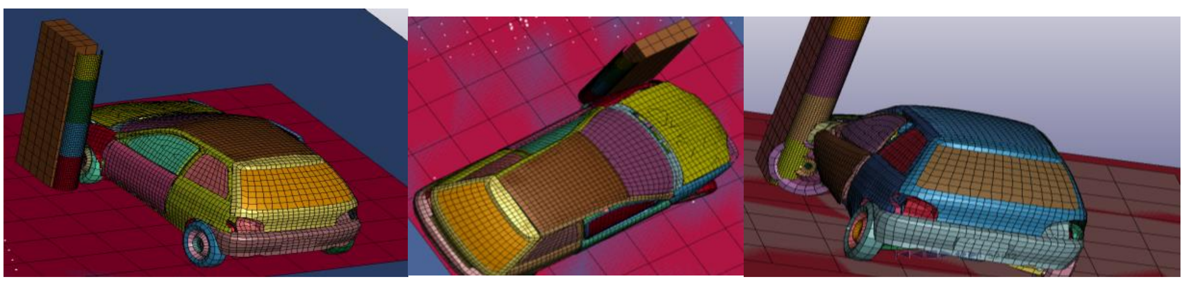


Figure 4. 16: Rotational displacements vs time for side collision

Figure 4.16 shows the rotational displacement time graph of vehicle side collision at 45 degrees and 35 km/h. The vehicle's x-and y-rotational displacement without a system is higher, and for the vehicle with a system, the x-and y-rotational displacement is lower when compared with each other. So based on Figure 4.16 we can conclude that the stability of the vehicle is more under impact when equipped with a front-end passive safety system.

4.5 Offset Impact on the Round Rigid Pole

Figure 4.16 depicts the final position of the vehicle with and without a system when impact with a round circular post at a speed of 35km/h and 90 percent offset from the round post to indicate the maximum benefit of a system. Figure 4.17 (a) and (b) shows the screenshot of the final position of the result of the vehicle impact simulation with a system at the side and top view. It generally shows that the rotating flywheel rotate-slide along the round post surface and directs the vehicle in the direction away from the pole with no harm of parts. But for a vehicle without a system, the vehicle parts interact with a round pole without sliding along the round post surface, and the tire of the vehicle entangled into a pole as shown in Figure 4.17 (c) below, the vehicle wheel is not directed to the safest place and the parts of a vehicle damaged hardly when compared to a vehicle with a system.

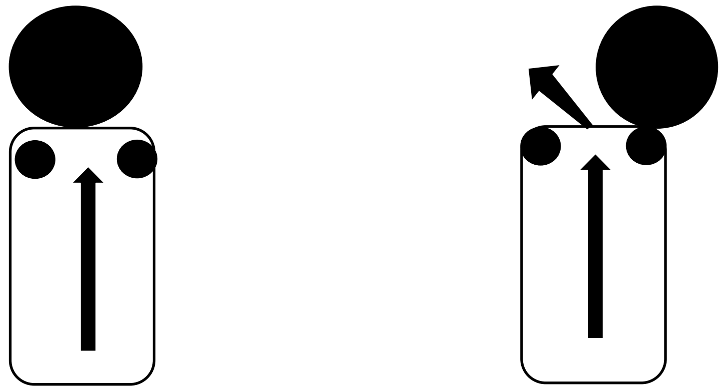


(a) (b) (©)

Figure 4. 17: Final position of the vehicle after impact offset to the round post.

In a head-on collision of the vehicle, for the system to effectively divert the vehicle into the safest place, the wheel must contact the colliding surface during impact.

Figure 4.18 depicts the benefit of a front-end passive safety system in a collision with a large circular (bridge) post. It will have little effect in in-line head-on crashes because of that the wheel may not be in contact with the circular round pole, but it will have a significant benefit in an offset collision that occurs at a fair speed.



Inline: Head-on collision: No benefit

Offset collision: the severity should be significantly reduced, much high chance to survive.

Figure 4. 18: Vehicle with a device in collision with a large circular (bridge) post.

4.6 Rear-End Collision for the Vehicle with and Without a System.

Let's consider Figure 4.2 above which shows a y-rigid body displacement vs time for a Geo-Metro vehicle that collides with a PCB-R barrier at a speed of 35 km/h and 45 degrees each other. A Geo-Metro without a system moves a distance of 3.5 mm at a negative y-direction. But with a system, it moves a distance of 6.689mm at a negative y-direction. Generally from the simulation, we can conclude that the car equipped with a system goes a greater distance (6.689mm). As a result, the driver has plenty of time to react to the brakes and bring the vehicle to a complete stop, and the second rear-end accident may be ignored. However, if a vehicle lacks this system, the distance the vehicle moves is short (3.5mm), and the risk of a rear-end collision is greatly increased. It is hard to screenshot the initial and final position of the vehicle at the same time at the simulation window but for illustration, we can use the graph data and illustrate the stopping distance of the vehicle by drawing for illustration as shown in Figure 4.19 below. When we compare the distance traveled for a vehicle with and without a system, the y-direction body displacement is increased for the vehicle with a system. So by this premises, the following conceptual drawing shows the difference.

Generally rear-end collision distance becomes short when a vehicle is equipped without a front-end passive safety system and if a vehicle is equipped with a front-end passive safety system the rear-end collision distance significantly increases. Generally, Collision distance increases when a vehicle is equipped with a front-end passive safety system.

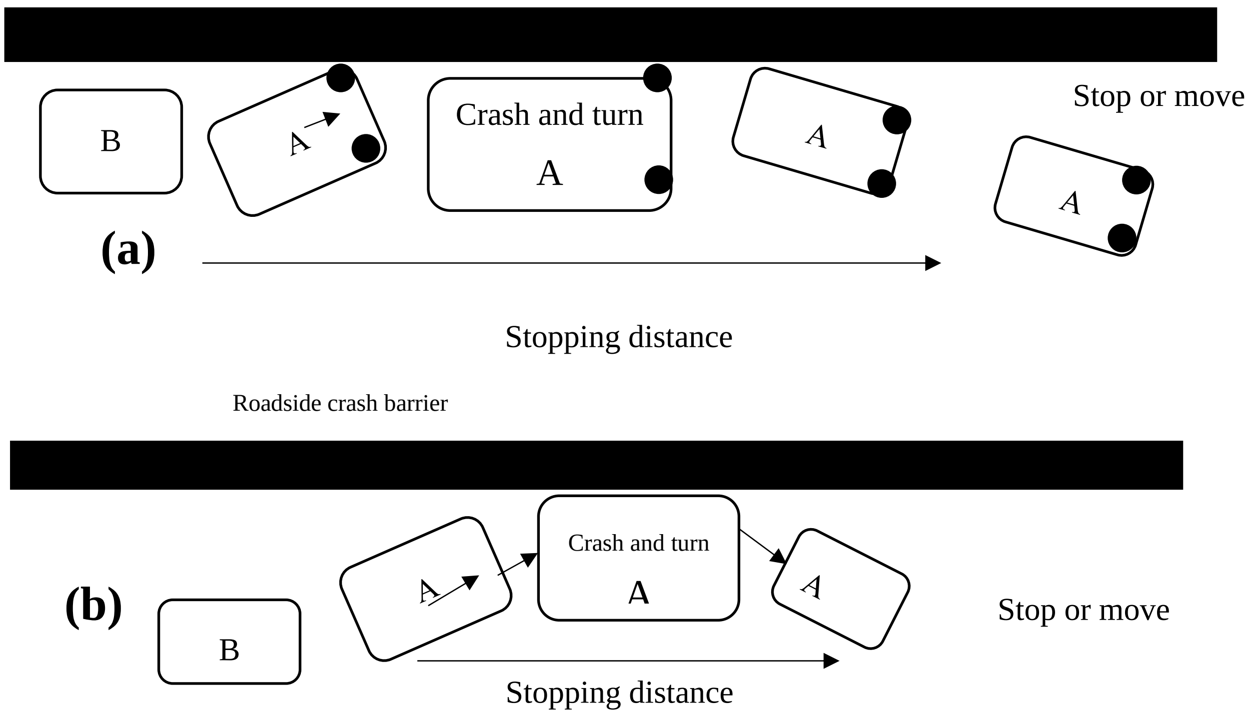


Figure 4. 19: Collision distance of a vehicle with (a) and without (b) a system

4.7 Damage to Other Vehicle Parts during Collision

From the simulation test result, the parts are more damaged for the vehicle that doesn't have a front-end passive safety system when compared to the vehicle with a system. The following Figure 4.20 shows the damage to the bumper of the pickup truck which collides with a Geo-Metro vehicle at an angled head-on position at an angle of 45 degrees with each other and a speed of 35 km/h. The damage to the pickup truck bumper which makes a collision with a Geo-Metro small vehicle with a system (Figure 4.20 a) is less severe when compared to the collision without a system (Figure 4.20 b).

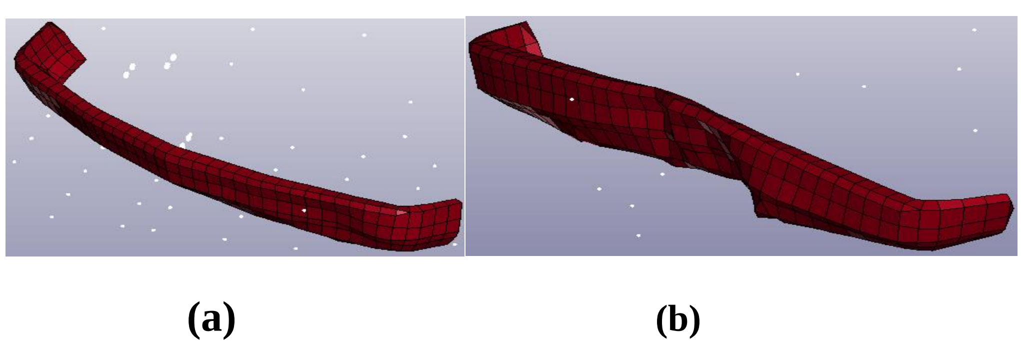


Figure 4. 20: Damage to the pickup truck bumper with (a) and without (b) a system

If a vehicle rolls-slides over the contact surface, the colliding vehicle has speed and energy, and the full body of the vehicle rotates towards a smaller angle. The process resembles an airplane touch-down landing, with no more injury occurring. Figure 4.21 shows the wheel roll-slide along the surface of the barrier during the vehicle collision.

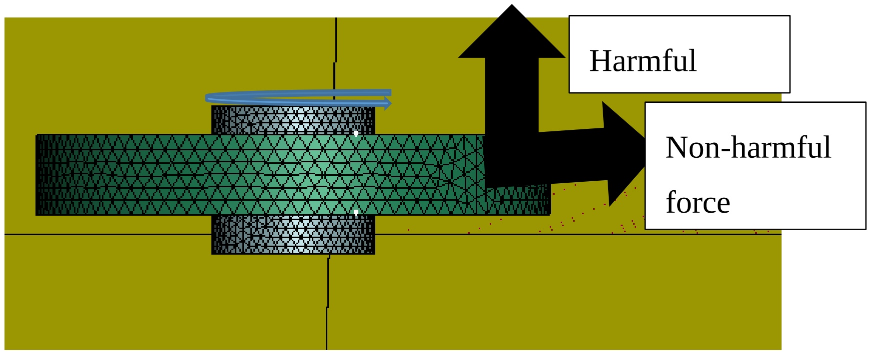
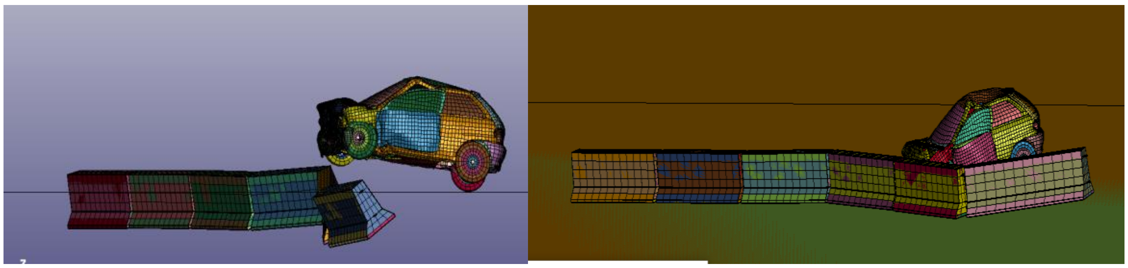


Figure 4. 21: Close looks of flywheel roll-slide on barrier surface

With the premise that the driver gives no additional driving energy to the colliding vehicle until all of the vehicle's energy is released, the car continues rolling-sliding, resulting in a much "smoother" or "softer" crash. In such a case, the driver may restore control of the vehicle, preventing the disaster.

4.8 Vehicle Test at Large Collision Angle (70 Degree)

The vehicle simulated without a system at a large collision angle interacts into a guard rail and jumps to the air and leaves the ground, and experiences more damage and stops. At large angles i.e. at 70 degrees the Geo-Metro small vehicle with a system collision with a PCR-B barrier makes a swing slide motion along the collision surface. The vehicle collision angle is 70 degrees but the vehicle stop angle is 74 degrees, which indicates that the vehicle swing slides along a collision surface. But a vehicle with a system is stable and doesn’t leave the ground and there is minimum damage to the barrier and the vehicle parts as shown in Figure 4.22 (b). But for the vehicle without a system, the vehicle leaves the ground and the guard rail is deflected more when compared to a vehicle with a system test as shown in the following Figure 4.22 (a). In the final position from the simulation result as shown below in Figure 4.22, the vehicle without a system experiences more damage which is under impact at an angle of 70 degrees, and the vehicle stability is affected more. But for the vehicle with a system, a vehicle swing-slides at the barrier surface but is still stable and doesn't leave the ground and the barrier doesn't experience more damage when compared to a vehicle without a system. The final position of the vehicle impact simulation with and without a system installed is shown in Figure 4.22 below.



(a) **(b)**

Figure 4. 22: Vehicle swing slide at large collision angle

4.9 At an Impact Angle of 45 Degrees and High-Impact Force (120 Km/h.)

Geo-Metro small vehicle with and without a system simulation at high impact force experiences the same damage, because of that for a vehicle with a system the structure mounting plate fails at the start of collision. The crash impact force is too great, the structure can't handle it and is damaged, and the severity of the accident on the people can be mitigated by controlled crumpled structure deformation, safety belts, and airbags (if available).

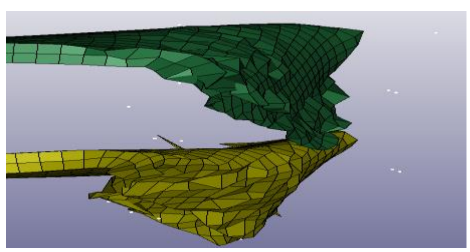


Figure 4. 23: Mounting plate fails at high impact force

The failing of the mounting plate as shown in Figure 4.23 is happened from the side of the rail, because of that from the rail end the mounting plate is hollow and the strength is less from this end of the parts.

4.10 Vehicular Responses

The following table is a list of the value of some of the yaw angle done to check at different speed and impact angle to see that whether the vehicle under impact with a device intrude into another adjacent lane or not.

Table 4. 1: Impact speed, impact angle, and their yaw angle

Impact angle	Impact speed km/h		
	35	50	70
30	14.46	9.14	11.79
50	14.2417	12.79	
70	Swing-slide (81.12)	Swing slide (79.2)	Swing slide(76.9) and the mounting plate starts to fail

From the Table value, we can generally conclude that the vehicle under normal speed with a system does not intrude into an adjacent lane and the contact to the barrier is smooth and redirection of the vehicle is also smooth like a plane landing on the ground.

4.11 The Hourglass Energy in Crash Simulation

In the process of modeling, the hourglass energy may be very unstable when parameters change the mesh size, element formulation, and type of integration method have a significant effect on hourglass energy values (LS-DYNA manual, 1998-2018). Based on these the hourglass value is assumed to become in low percent. The hourglass energy must be controlled low to the total energy of the vehicle (Tang et al., 2016).

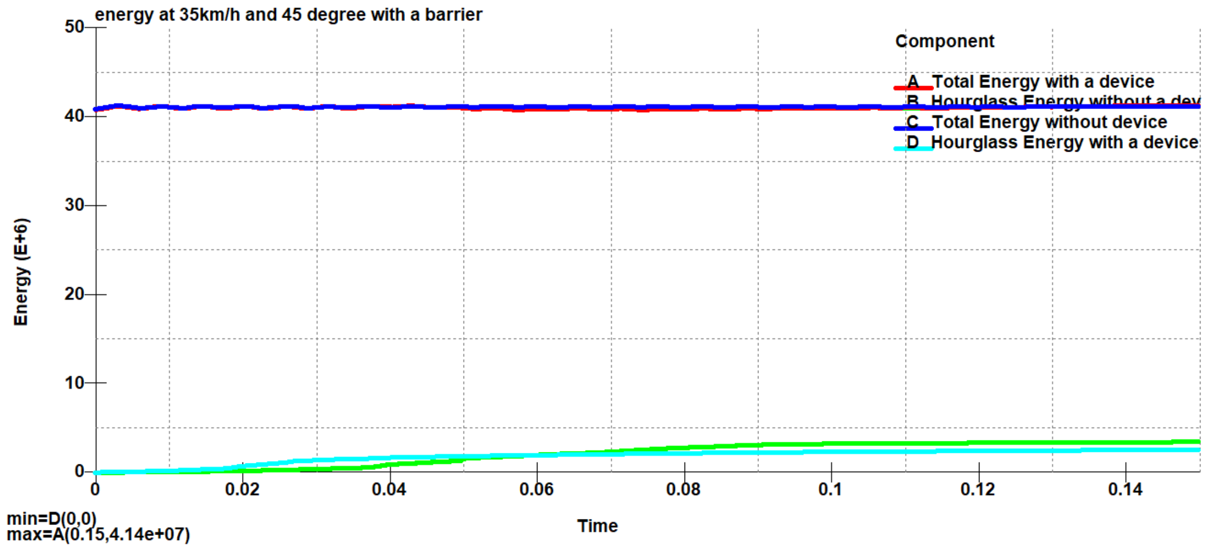


Figure 4. 24: Hourglass energy vs time when compared to total energy

Figure 4.24 depicts the hourglass energy vs time curve when compared to the total energy of the vehicle in a collision to a barrier at 35 km/h and 45 degrees. For the test with and without a system, the hourglass energy is low. We can generally conclude that the hourglass energy is low for all simulation, because of that the hourglass energy is unstable when mesh size, element formulation, and type of integration method is varied. But all the above parameters are kept constant for all simulations, and the only varied input parameters are the vehicle speed and the angle of contact which are not connected to hourglass energy variation.

4.12 Summary

Under the chapter the simulation results was interpreted for checking the advantage of the front-end passive safety system. The energy curves, displacement-time curves, the yaw pitch and roll motion of the vehicle, energy ratio, and vehicular responses are studied and analyzed for different boundary condition of simulation for a Geo-Metro small vehicle with and without a system which simulated under impact with a PCB-R barrier, a pickup track, and a pole.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

- ✓ It should be understood that the aim of the designed and modeled front-end passive safety system is to reduce the collision impact force on occupants and save lives, does not intend to build a strong structure against the collision, instead, it only intends to divert the collision force under current main frame structure of vehicles based the old philosophy "use softness to overcome hardness", more precisely, to partially convert the harmful collision force into non-harmful force at the very beginning of the non-perpendicular collisions.

5.2 Conclusions

From the simulation result of the collision simulation of a Geo-Metro small vehicle test with a PCR-B barrier a round rigid pole and a pickup track at different test criteria, we can generally conclude that

- ✓ The kinetic energy for a vehicle with a system does not decrease more and the internal energy does not increase more when we compared to the simulation result without a system and the vehicle moves more distance after impact when it is simulated with the front-end passive safety system. This more distance after collision gives the driver more time and distance to apply the brake.
- ✓ The designed and modeled front-end passive safety system for automobiles can efficiently divert the collision force and partially convert the harmful force into non-harmful force, the severity of the collision significantly reduced, saving lives and repair costs. It significantly extends the moving distance after its first collision with roadside barriers and a pickup truck and gives the vehicles followed behind much more time and distance to brake and slow down the vehicles, so the severity of rear-end crashes is dramatically reduced and lives will be saved, even the rear-end collision can be avoided. It is simple, low cost, and easy included into current vehicle designs without compromising the function of crumple zone structure; instead, it works perfectly with crumple zone structure as excellent partners and provides additional protection.

- ✓ The simulation result of a Geo-Metro small vehicle test with a PCB-R barrier and a pick-up truck indicates that the vehicle with a front-end passive safety system has a significantly longer moving distance than a vehicle without a system. The vehicle with a system significantly increases the moving distance after its first collision and gives more time and distance to the vehicles behind to react, brake, or even manipulate the vehicle to avoid the rear-end (second) collision.
- ✓ The vehicle with a system under impact at higher angles swing slides along the collision surface
- ✓ If the vehicle is high impact force (high speed) the mounting plate fails, and the occupants are protected by other systems like air-bag, seat-belt, and crumple structures if available.
- ✓ In the world, most collisions occur at the non-perpendicular position, so it is reasonable to highly conclude from the simulation result that during the accident and collision millions of lives will be saved, damage to the vehicle parts and injury to the passengers will strongly be reduced, when the front-end passive safety system is installed in all common vehicles around the world in the future.
- ✓ Generally, the front-end passive safety system will benefit all road drivers and vehicle occupants in the world if all common vehicles are installed with such systems in the future, this will reduce the severity of rear-end collisions, save lives and reduce vehicle and property damage.

5.3 Recommendations

- ✓ I would like to suggest the future researchers should hold to do on this area and try to reduce the harm of vehicle collisions in Ethiopia. Proper right here the thesis is finished for a Geo-Metro small vehicle with a reduced mass and element.
- ✓ I would like also to recommend automotive industries and auto users to install and use this front-end passive safety system for their safety in the future.

5.4 Future Work

The research may be extended in the destiny in the following area

- ✓ This work is the simplest attempt for starting, so it will be better if it will be done for other types of vehicles.

- ✓ The researcher who will try to improve the design should concern the serviceability of the components as much as easy for a user during changing parts of it and also will try to improve to compensate the energy absorbing performance and rotation of the flywheel.
- ✓ If the researcher will work on this area, it is better to consider the aesthetics of the vehicle when incorporating the device with modification.
- ✓ However, each vehicle maker may have its only criteria if it decides to add this concept to its future vehicles. The headwind may cause the rotating flywheel of the front-end passive safety system to rotate when driving at high speed, so a lock mechanism can be set in which the wheel can rotate only when the rotating force is strong enough, say, collision at the speed of 10 miles/h because the collision force at this speed should be much stronger than the headwind force with high vehicle speed.

Special Acknowledgement

This research project is funded by Adama Science and Technology University under the grant number ASTU/SM-R/321/2, Adama, Ethiopia.

REFERENCES

Abagaz, T., & Gebremedhin, S. (2018). The magnitude of road traffic accident-related injuries and fatalities in Ethiopia. BioRxiv, 1–10. https://doi.org/10.1101/382333

Ajay, T. S., & Ezhil, R. (2016). Detecting Blind Spot By Using Ultrasonic Sensor. 5(05), 195–196.

Akhlaq, M., Sheltami, T. R., Helgeson, B., & Shakshuki, E. M. (2012). Designing an integrated driver assistance system using image sensors. Journal of Intelligent Manufacturing, 23(6), 2109–2132. https://doi.org/10.1007/s10845-011-0618-1

Al-Graitti, A. J., Khalid, G. A., Berthelson, P., Mason-Jones, A., Prabhu, R., & Jones, M. D. (2017). Auto Rickshaw Impacts with Pedestrians: A Computational Analysis of Post-Collision Kinematics and Injury Mechanics. International Journal of Biomedical and Biological Engineering, 11(11), 568–587.

Anderson, J., Kalra, N., Stanley, K., Sorensen, P., Samaras, C., & Oluwatola, O. (2016). Autonomous Vehicle Technology: A Guide for Policymakers. In Autonomous Vehicle Technology: A Guide for Policymakers.

Asplund, E., & Steckmest, D. (2014). Design with Regard to Collision Impact Comparison of Response between a Simplified 2DOF system. 227.

Wambasi (2014) .Auto Crash Automobile Evasion System.

Bali, E., & Erzan Topçu, E. (2018). Design of on-Off Type Solenoid Valve for Electropneumatic Brake Systems and Investigation of Its Static Characteristics. International Journal of advances on Automotive and Technology, 2(3), 175–184.

Basma, F., & Refai, H. H. (2009). Collision Avoidance System at Intersections Final Report - FHWA-OK-09-06. System, 2216.

Butans, Gross, K. A., Gridnevs, A., & Karzubova, E. (2015). Road safety barriers, the need and influence on road traffic accidents. IOP Conference Series: Materials Science and Engineering, 96(1). https://doi.org/10.1088/1757-899X/96/1/012063

Buznikov, S. E. (2018). System analysis of vehicle active safety problem. IOP Conference Series: Materials Science and Engineering, 315(1). https://doi.org/10.1088/1757-899X/315/1/012005

Chi, H., & Gong, B. (2020). Analysis of energy conversion law in vehicle collision accident. Journal of Physics: Conference Series, 1486(7).

Deme, D. (2019). Road Traffic Accident in Ethiopia from 2007/08-2017/18. American International Journal of Sciences and Engineering Research, 2(2), 49–59.

Department of Main Roads Road Planning and Design Manual Chapter 8 Safety Barriers and Roadside Furniture. (2005). Design, June, 117–181.

Dubey, S., & Ansari, A. W. (2013). Design and Development of Vehicle anti-collision System using Electromagnet and Ultrasonic Sensors. 1, 80–83.

Electronic stability program (ESP). (2014). 102–123. https://doi.org/10.1007/978-3-658-03978-3

Feng, H., Shi, W., Chen, F., Byon, Y. J., Heng, W., & Pan, S. (2020). A Calculation Method for Vehicle Movement Reconstruction from Videos. Journal of Advanced Transportation, 2020. https://doi.org/10.1155/2020/8896826

Garrett, T. K., Newton, K., & Steeds, W. (2000). Vehicle safety. Motor Vehicle, 924–955. https://doi.org/10.1016/b978-075064449-5/50037-7

Hasan, J., Khan, M. M. A., Saha, S., & Nahar, S. (2015). Rear End Collision: Status, Drivers' Perception and Impact of Rear Light Configurations on Driver Reaction Time. International Journal of Engineering Sciences & Research Technology, 4(11), 215–219.

Hou, S., Liu, T., Dong, D., & Han, X. (2014). Factor screening and multivariable crashworthiness optimization for vehicle side impact by factorial design. Structural and Multidisciplinary Optimization, 49(1), 147–167. https://doi.org/10.1007/s00158-013-0957-y

Road Safety Factsheet Seatbelts (2018).: Advice and Information.

Ivers, R., Brown, K., Norton, R., & Stevenson, M. (2016). Road Traffic Injuries. In International Encyclopedia of Public Health (pp. 393–400). https://doi.org/10.1016/B978-0-12-803678-5.00391-X

Jamroz, K., Kustra, W., Budzynski, M., & Zukowska, J. (2016). Pedestrian Protection, Speed Enforcement and Road Network Structure the key Action for Implementing Poland's Vision Zero. Transportation Research Procedia, 14, 3905–3914.

Deme. D. (2019). Road Traffic Accident in Ethiopia from 2007/08-2017/18 (Since Ethiopia Millennium). 18(January). https://doi.org/10.1313/aijser.v2i2.90

Jordan, P. (2010). A Brief Introduction to Safety Barriers.

Khan, A., Harper, C. D., Hendrickson, C. T., & Samaras, C. (2019). Net-societal and net-private benefits of some existing vehicle crash avoidance technologies. Accident Analysis and Prevention, 125, 207–216. https://doi.org/10.1016/j.aap.2019.02.003

Kumar, K. N. K., Raja, A., Chander, P. R., Reddy, Y. M. M., & Vivekananda, K. (2019). Design Evaluation & Improvement Analysis of Vehicle Structural Crashworthiness using CAE in IIHS Frontal Crash Test. International Journal of Engineering and Advanced Technology, 9(1), 1575–1582. https://doi.org/10.35940/ijeat.f8597.109119

Liu, Y. P. (2013). Simulation of vehicle's frontal crash with a dummy inside. Advanced Materials Research, 760–762(Iccsee), 1244–1249. https://doi.org/10.4028.

Luo, Q., Chen, X., Yuan, J., Zang, X., Yang, J., & Chen, J. (2020). Study and Simulation Analysis of Vehicle Rear-End Collision Model considering Driver Types. Journal of Advanced Transportation, 2020. https://doi.org/10.1155/2020/7878656

Malhotra, R. (2019). Construction of a Device for Obstacle Detection. International Journal of Recent Technology and Engineering, 8(4), 2312–2315.

Markkula, G. (2015). Driver behavior models for evaluating automotive active safety. From neural dynamics to vehicle dynamics. In Mobility and Transport (Vol. 39, Issue 5). http://ec.europa.eu/roadsafety

Mikusova, M. (2017). Crash avoidance systems and collision safety devices for vehicle occupants. MATEC Web of Conferences, 107. https://doi.org/10.1051/matecconf/201710700024

Milanés, V., Pérez, J., Godoy, J., & Onieva, E. (2012). A fuzzy aid rear-end collision warning/avoidance system. Expert Systems with Applications, 39(10), 9097–9107.

Mohamed, A., Issam, A., Mohamed, B., & Abdellatif, B. (2015). Real-time Detection of Vehicles Using the Haar-like Features and Artificial Neuron Networks. Procedia Computer Science, 73(Awict), 24–31. https://doi.org/10.1016/j.procs.2015.12.044

Moravčík, L., & Jaśkiewicz, M. (2016). Intelligent Safety Vehicle Systems. Autobusy: Technika, Eksploatacja, Systemy Transportowe, 17(11), 106–115.

Namazi, E., Li, J., & Lu, C. (2019). Intelligent Intersection Management Systems Considering Autonomous Vehicles: A Systematic Literature Review. IEEE Access, 7, 91946–91965. https://doi.org/10.1109/Access.2019.2927412

Ncap, E. (2007). Seat Belt Reminder - SBR.

Opala, M. (2015). Passive safety in design process of tram front.

Prentkovskis, O., Sokolovskij, E., & Bartulis, V. (2010). Investigating traffic accidents: A Collision of two motor vehicles. Transport, 25(2). https://doi.org/10.3846/transport.2010.14

Puthan, P., Thalya, P., & Lubbe, N. (2018). Active and passive safety passenger car technologies: Potentials to save lives in India. Conference Proceedings International Research Council on the Biomechanics of Injury, IRCOBI, 2018-April(April), 11–16.

Raja Raghavan, M., & Bhuvaneswari, N. S. (2015). Intelligent safety and security systems in automobiles. Proceedings - 2015 IEEE International Conference on Technological Innovations in ICT for Agriculture and Rural Development, TIAR 2015, September, 188–192. https://doi.org/10.1109/TIAR.2015.7358555

Raslavicius, L., Bazaras, L., Keršys, A., Lukoševicius, V., Makaras, R., & Eidukynas, V. (2017). Assessment of bicycle-car accidents under four different types of collision. Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, 231(3), 222–234. https://doi.org/10.1177/0954411917690417

Rathod Balasaheb S, S. M. R. (2014). A Case Study on Design of a Flywheel for Punching Press Operation. International Journal of Engineering and Advanced Technology (IJEAT), 3(4), 32–35. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.673.3325&rep=rep1&type=pdf

Rebelo, P. M. (2016). Design Study of a Side Intrusion Beam for Automotive Safety. Instituto Superior T´ecnico, Lisboa, Portugal.

Sabarinath, P. (2020). Passive Safety System for Side Impact in Cars. Shanlax International Journal of Arts, Science, and Humanities, 7(4), 115–120. https://doi.org/10.34293/sijash.v7i4.1623

Safety, V. (2018). Vehicle Safety 2018.

Satinder Singh & Beant Singh. (2014). Design Optimization and Statistical Crash Analysis of Chassis Frame for Off-Road Vehicle. International Journal of Automobile Engineering Research and Development (IJAuERD), 4(6), 9–14. http://www.tjprc.org/view-archives.php?year=2014_48_2&id=1&jtype=2&page=2

Anti-Lock Braking System (2018).

Side collision - Wikipedia. (n.d.).

Silalahi, L. M., Alaydrus, M., Rochendi, A. D., & Muhtar, M. (2019). Design Of Tire Pressure Monitoring System. 23(1), 70–78.

Šucha, M., Risser, R., & Honzíčková, K. (2021). Advanced driver assistant systems focused on pedestrians' safety: A user experience approach. Sustainability (Switzerland), 13(8). https://doi.org/10.3390/su13084264

Sun, C., Zheng, S., Ma, Y., Chu, D., Yang, J., Zhou, Y., Li, Y., & Xu, T. (2020). An active safety control method of collision avoidance for intelligent connected vehicles based on driving risk perception. Journal of Intelligent Manufacturing. https://doi.org/10.1007/s10845-020-01605-x

Tadege, M. (2020). Determinants of fatal car accident risk in Finote Selam town, Northwest Ethiopia. BMC Public Health, 20(1), 1–8. https://doi.org/10.1186/s12889-020-08760-z

Tang, Z., Liu, F. J., Guo, S. H., Chang, J., & Zhang, J. J. (2016). Evaluation of coupled finite element/meshfree method for a robust full-scale crashworthiness simulation of railway vehicles. Advances in Mechanical Engineering, 8(4), 1–13.

Waghe, R., & S Y, G. (2014). Study of Active and Passive Safety Systems and Rearview Mirror Impact Test. International Journal of Mechanical Engineering, 1(3), 5–10. https://doi.org/10.14445/23488360/ijme-v1i3p103

Wali, B., Khattak, A. J., & Xu, J. (2018). Contributory fault and level of personal injury to drivers involved in head-on collisions: Application of copula-based bivariate ordinal models.

Accident Analysis and Prevention, 110(November 2017), 101–114.

Wang, X. Y., Jiang, Y. H., Li, R. B., & Chen, M. Z. (2018). Automobile safety technology and its improvement. MATEC Web of Conferences, 160, 1–6.

Woldu, A. B., Desta, A. A., & Woldearegay, T. W. (2020). Magnitude and determinants of road traffic accidents in Northern Ethiopia: A cross-sectional study. BMJ Open, 10(2), 1–9. https://doi.org/10.1136/bmjopen-2019-034133

Wu, Y., Shu, M., & Ge, H. (2018). Research on Brake Force Distribution Control Strategy of Electric Vehicle Subtitle as needed. IOP Conference Series: Materials Science and Engineering, 452(3), 0–9. https://doi.org/10.1088/1757-899X/452/3/032054

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

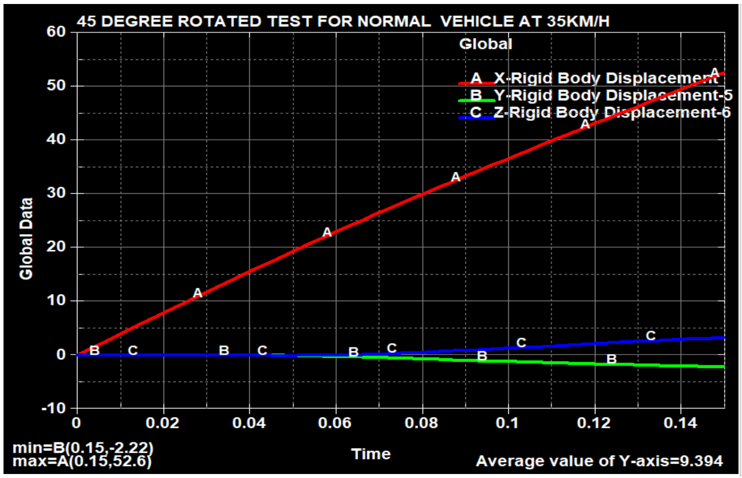
Yu, H., Technologies, H., Guvenc, L., & Ozguner, U. (2008). Heavy duty vehicle rollover detection and active roll control. February 2015. https://doi.org/10.1080/00423110701477529

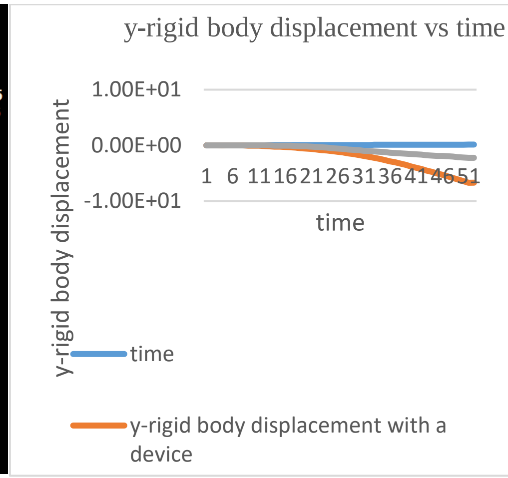
Zhang, K., Liu, W., Li, J., & Zhang, L. (2021). Stratified Control Strategy of Vehicle Longitudinal Active Collision Avoidance. Journal of Physics: Conference Series, 1735, 012003. https://doi.org/10.1088/1742-6596/1735/1/012003

APPENDICES

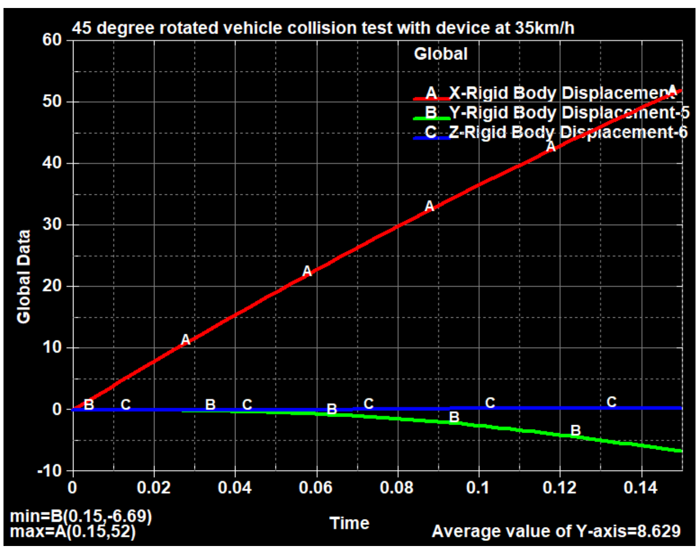
APPENDIX-A

Figure: displacement-time graph of vehicle collision to the barrier (a) without the device and (b) with a device at 45 degrees and 35km/h.





(A) (C)



(B)

APPENDIX-B

Table: Tabulated data for a vehicle with a guard rail at 35km/h and 45 degree

Time	kinetic energy without device	kinetic energy with a device	internal energy with a device	internal energy without device
0.00E+00	4.09E+07	4.09E+07	2.00E-20	2.00E-20
7.89E-03	4.09E+07	4.08E+07	8.05E+05	6.09E+05
1.58E-02	4.08E+07	3.78E+07	4.22E+06	7.74E+05
2.37E-02	4.02E+07	3.47E+07	7.30E+06	8.44E+05
3.16E-02	3.86E+07	3.15E+07	1.08E+07	2.97E+06
3.95E-02	3.66E+07	2.90E+07	1.26E+07	5.97E+06
4.74E-02	3.40E+07	2.74E+07	1.39E+07	8.26E+06
5.53E-02	2.99E+07	2.63E+07	1.45E+07	1.40E+07
6.32E-02	2.62E+07	2.57E+07	1.48E+07	1.71E+07
7.11E-02	2.26E+07	2.53E+07	1.49E+07	1.95E+07
7.89E-02	2.00E+07	2.51E+07	1.48E+07	2.13E+07
8.68E-02	1.84E+07	2.49E+07	1.47E+07	2.18E+07
9.47E-02	1.77E+07	2.44E+07	1.47E+07	2.18E+07
1.03E-01	1.73E+07	2.40E+07	1.48E+07	2.17E+07
1.11E-01	1.68E+07	2.39E+07	1.48E+07	2.15E+07
1.18E-01	1.67E+07	2.37E+07	1.48E+07	2.13E+07
1.26E-01	1.67E+07	2.34E+07	1.47E+07	2.11E+07
1.34E-01	1.64E+07	2.31E+07	1.48E+07	2.11E+07
1.42E-01	1.61E+07	2.28E+07	1.47E+07	2.12E+07
1.50E-01	1.60E+07	2.25E+07	1.47E+07	2.13E+07

y- displacement with a device	y-displacement without device	resultant acceleration with a device	resultant acceleration without a device
0.00E+00	0.00E+00	4.11E+02	2.50E+02
9.47E-05	-1.74E-04	5.56E+02	4.08E+02
-7.22E-03	1.96E-04	7.58E+02	2.90E+02
-3.09E-02	1.82E-04	1.01E+03	5.70E+02
-9.46E-02	-8.99E-03	1.05E+03	7.42E+02
-2.02E-01	-2.56E-02	5.53E+02	8.46E+02
-3.36E-01	-6.15E-02	1.63E+03	1.86E+03
-5.21E-01	-1.55E-01	8.06E+02	1.48E+03
-7.40E-01	-2.93E-01	1.72E+03	2.79E+03
-1.00E+00	-4.70E-01	1.10E+03	8.70E+02
-1.33E+00	-6.64E-01	2.24E+03	2.03E+03
-1.71E+00	-8.63E-01	1.22E+03	7.45E+02
-2.14E+00	-1.06E+00	2.26E+03	3.96E+02
-2.67E+00	-1.24E+00	1.38E+03	1.07E+03
-3.24E+00	-1.41E+00	1.93E+03	3.71E+03
-3.87E+00	-1.58E+00	2.38E+03	5.79E+02
-4.53E+00	-1.75E+00	1.07E+03	1.98E+03

APPENDIX-C

Geo-metro vehicle specification

Dimensions

Length	3745 mm, 147.44 in.
Width	1575 mm, 62.01 in.
Height	1330 mm, 52.36 in.
Front track	1365 mm, 53.74 in.
Rear (Back) track	1340 mm,52.76 in
Wheelbase	2265 mm, 89.17 in.

General information

Brand	Geo
Model	Metro
Generation	Metro
Modification (Engine)	1.0 (55Hp)
Start of production	1989 year
Powertrain Architecture	Internal Combustion engine
Body type	Hatchback
Seats	4
Doors	2

Performance specifications

Fuel consumption (economy) - combined	4.9 l/100 km 48 US mpg 57.65 UK mpg 20.41 km/l

Fuel type	Petrol (Gasoline)
Acceleration 0 - 100 km/h	20 sec
Acceleration 0 - 62 mph	20 sec
Acceleration 0 - 60 mph (Calculated by Auto-Data.net)	19 sec
Maximum speed	140 km/h
Weight-to-power ratio	13.6 kg/Hp, 73.3 Hp/tonne
Weight-to-torque ratio	9.5 kg/Nm, 105.3 Nm/tonne

Engine specification

Power	55 Hp @ 5700 rpm.
Power per liter	55.4 Hp/l
Torque	79 Nm @ 3300 rpm. 58.27 lb.-ft. @ 3300 rpm.
engine displacement	993 cm^3 60.6 cu. in.
Number of cylinders	3
Position of cylinders	Inline
Cylinder Bore	74 mm 2.91 in.
Engine location	Front, Transverse

Space, Volume and weights

Kerb Weight	750 kg, 1653.47 lbs.
Trunk (boot) space - maximum	159 l, 5.62 cu. ft.
Fuel tank capacity	40 l ,10.57 US gal | 8.8 UK gal