

Design and Analysis of Frontal Bumper and Crash Box Energy Absorption on Bishoftu Bus



By

Bulti Buzuneh Fufa

A Thesis Submitted to

The department of Mechanical Engineering

School of Mechanical, Chemical & Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in
Automotive Engineering

Office of Graduate studies

Adama Science and Technology University

Adama

November, 2022

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Advisor: Dr. Ramesh Babu Nallamothe



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DECLARATION

I hereby declare that this MSc thesis entitled “Design and Analysis of Frontal Bumper and Crash Box Energy Absorption on Bishoftu Bus” is my original work. That is, it has not been submitted for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name of student

Signature

Date

RECOMMENDATION

I, the major advisor of this thesis, hereby certify that I have closely advised/supervised the student while developing this research work and read the draft thesis work entitled “Design of Frontal Bumper and Crash Box Energy Absorption on Bishoftu Bus” prepared under my guidance by Bulti Buzuneh. Therefore, I recommend the submission of the final thesis work to the department for further review and evaluation.

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I/we hereby certify that the recommendation and suggestion given by the thesis work review committee are appropriately incorporated into the final thesis work entitled “Design and Analysis of Frontal Bumper and Crash Box Energy Absorption on Bishoftu Bus” by Bulti Buzuneh.

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We, the undersigned, members of the Board of Reviewers of the thesis work open defense by Bulti Buzuneh have read and evaluated the thesis work entitled “Design of Frontal Bumper and Crash Box Energy Absorption on Bishoftu Bus” and assessed the understanding of the candidate about the research. This is, therefore, to certify that the thesis work is accepted and we recommend the implementation of the thesis work.

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LIST OF ACRONYMS

BAI	Bishoftu Automotive Industry
EA	Energy Absorption
FEA	Finite Element Analysis
FEM	Finite Element Method
LS	Low Speed
MASH	Manual for Assessment Program
SEA	Specific Energy Absorption
SMC	Sheet Molding Compound
V&V	Verification and Validation

ABSTRACT

Bumper beams are shock-absorbing parts. They are attached to the front and rear ends of vehicles by means of brackets, which act as crash boxes by taking the loads mainly in the axial direction. Due to their heavy weight and speed in the city, accidents occurred on Bishoftu bus. Since no bumper and crash box on the bus it initiate to design energy absorber. The focus of this thesis work is to design frontal bumper beam and crash box for bishoftu bus for improving energy absorption during collision. In this work different models are analyzed and simulated to study the effect of impact load on bumper beam and crash box located on front face of bishoftu bus. SOLIDWORKS is used for modeling, ANSYS is used for analyses and simulation of the impact. Impact simulation is done a crash speed of 30 km/h, with mass of vehicle as 18000 kg. the material selected is PC/0.5 wt.% Nano Alumina (Nano composite foam) for the intersection of bumper and crash box. Reverse C Profile (RCP) is used for geometry. The bumper beam and crash box on frontal face of the bus were analyzed for energy absorption during impact and the obtained results were validated. In the frontal face of the bus without bumper and crash box, the maximum results of deformation, stress, and strain are $1.26\text{E-}03$ m, $1.78\text{E}+07$ Pa, and $7.31\text{E-}03$ J, respectively. Whereas, with bumper and crash box, the maximum results of deformation, stress, and strain are $2.89\text{E-}05$ m, $8.24\text{E}+05$ Pa, and $4.21\text{E-}03$ J, respectively. So , average percentile advantage of bumper beam and crash box for strain energy is 38.49%, total deformation is 2.52%, and alternative stress is 2.98%. The maximal percentile advantage of the bumper beam and crash box is, 57.56% for strain energy, 2.30% for total deformation, and 4.63% for von-mises stres. Therefore, it is recommended to take into account the bumper beam and crash box influence on maximum speed, average speed, and on both vehicle dynamic accidents in order to improve more energy absorption.

Keywords: Bishoftu bus, bumper, crash box, energy absorption, impact load

CHAPTER ONE

INTRODUCTION

Vehicle bumper beam is either a structural component placed behind plastic fascia in front or rear end of bumper system aimed to absorb kinetic energy during collision. In low speed collision bumper beam provide protection to occupant from severe injury. Previously bumper beam system consists of several parts that are made of conventional material such as steel or aluminum. The integrity between parts in bumper beam system played an important role in overall bumper beam performance. There are three factors to be considered in designing bumper beam; Manufacturability, assembly and cost. Recently a solitary bumper beam was introduced to reduce cost and to response towards current automotive trending and styling. There are two main components are molded in a solitary bumper beam system namely; horizontal beam and axial beam or crush box.

In mid-80's the application of polymer composite material has been introduced to replace conventional material such as plastic, aluminum and metal in bumper beam application. The advantages of this material because it can offer low weight, corrosion free, easier to produce complex shapes, high specific stiffness (stiffness/weight), high specific strength (strength/weight), and high impact energy absorption capacity over their metal counterparts. Furthermore, the use of polymeric based composite material for bumper beam was proposed for the quest of high fuel efficiency in automobiles, and having comparable properties to conventional fibers without sacrificing the safety of cars.

Crash Box - Frontal vehicle structure is of high importance through crash energy managements and crash boxes are the fundamental structural component for vehicle safety as well as after sales issues. This study will investigate the crash box with several square cross-section ratios about the ability to absorb impact energy. It is important to understand the natural frequencies and the mode shapes for vehicle structure such as crash box as it will be subjected to the dynamic loading in its real application. The purpose of the project is to develop a crash box that can be installed for diagnosis into the vehicle. Crash boxes (CBs) are widely used to absorb the energy of impact loads in collisions. Bumper and crash boxes are vehicle structural elements that convert the collision (kinetic) energy at the collision into deformation energy.

1.1 Background

Bishoftu Automotive Industry (BAI) was established in 1984 and placed under the management of the ministry of defense. It was incorporated into the metals and engineering corporation in 2010. This company located 45 km outside of Addis Ababa in the town of Bishoftu. Bishoftu Automotive industry at the project phase 40720 was equipped with appropriate technology, machinery and equipment that enable it to provide efficient services. One of the main activities under the company is assembly of city bus and cross country bus. City busses are specified for passengers in side city only and they carry people or passengers only across city from village to village. Their design and internal system is specified for short in side country travels. As a result, safety and the number of passengers is not restricted as they do not carry cargo and it needs safety part such as bumper beam and crash box to protect the damage due to collision.

Vehicle bumper is a structural component, which contributes to vehicle crashworthiness or occupant protection during front or rear collisions. The bumper systems also protect the hood, trunk, fuel, exhaust and cooling system as well as safety related equipment. A bumper is a shield normally made of aluminum, steel rubber, composite or plastic that is mounted on the front and rear of a vehicle. When a low speed collision takes place, the bumper system absorbs the shock or energy to prevent or reduce damage to the vehicle. In some bumpers, energy absorbers or brackets are used and others are made with foam cushioning material.

Vehicle bumpers are not usually designed to be structural components that would significantly contribute to vehicle crashworthiness or occupant protection during front or rear collisions at high speed. The bumper should be designed as safety feature since it is intended to reduce the magnitude of deceleration during impact. The bumper systems are only designed to protect the hood, trunk, frame, fuel, exhaust and cooling system as well as safety related equipments, such as parking lights, headlamps and taillight at low speed collisions.

Bumper systems design has been changing drastically over the last 20 to 30 years. High demanding government safety regulations and different styling concepts have resulted in new designs. For example, reinforcing beams covered by plastic fascial were introduced in the early 1970's. Styling fashion has changed appearance values from almost 100% chrome-plated face bars to predominately fascia system that are color

coordinated with the body. The growths of light trucks, minivans and sport utility vehicles have created two classes of bumper systems in the eyes of the engineering world: one for passenger cars and another for the broad grouping of light trucks.

Energy absorption (EA) capability in the automobile sector is crucial for enhancing passenger protection due to the widespread use of cars. One of the key components of a bumper system that serves as a shock absorber is the bumper beam. They are fastened to the front and back of cars, which serve as crash boxes by absorbing most of the loads in the axial direction. For greater passenger and frontal compartment resistance during vehicle impact, existing bumper beams are typically box shaped. It's crucial to consider structural crashworthiness while designing automotive components. When a vehicle encounters an impact, it relates to how the vehicle reacts. Additionally, it performs well when the car and its occupants sustain less damage following a collision.

In order to determine the energy absorption, different studies have been conducted, particularly with thin-walled square tubes (Kohar *et al.*, 2015; Yousefsani *et al.*, 2013), circular tubes (Li *et al.*, 2015; Paz *et al.*, 2014), and sandwich plates (Bai *et al.*, 2015).

Previously, steel made up the majority of the bumper beam. However, the use of polymer composite material was introduced in the middle of the 1980s to replace traditional materials. Natural fiber polymer composite has been employed in automobile components in previous studies, but it is still about to be used in several investigations of bumper beam construction (Jeyanthi and Rani, 2014; Kim *et al.*, 2019).

One of the most significant industries, Bishoftu Automotive Industry (BAI) is responsible for the manufacture, designing, and assembly of the vehicle's body and some of its component elements. Since BAI hasn't done much in the way of detailed aerodynamic analysis yet, low speed impact considerations on the car and its occupants aren't taken into consideration. The primary vehicle assembled and produced at BAI is the Bishoftu Bus, which is used for passenger transportation.

In order to increase the safety of the bus chassis and its occupants, the goal of this thesis is to develop a composite bumper beam and crash box that can withstand impact loads and improve energy absorption for the frontal face of a Bishoftu bus. SOLIDWORK is used for the virtual modeling of the structural beam and crash box, while ANSYS software is used for the numerical analysis of the models.

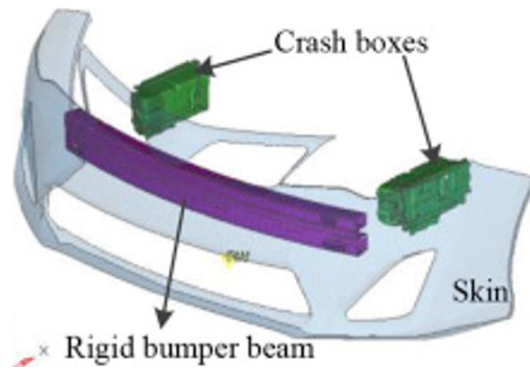


Figure 1. 1. Proposed rigid bumper and crash box system

1.2. Statement of the Problem

One of the main causes of increased passenger and driver injuries, increased fatalities, and damage to a country's economy is accidents, which is brought by car accidents. It is obvious that Bishoftu bus is one of the vehicles, which used to provide a people transportation services in Ethiopian cities. It is frequently seen that Bishoftu bus is overloaded with passengers because of lack of transportation, carrying more passengers than it is legally allowed to. As a result, if the bus crashes in a collision, a large number of passengers could suffer fatalities, significant injuries, or financial losses. Because of this, the issue becomes more noticeable and national attention. To address these challenges, numerous studies and research should be conducted in other vehicles. Therefore, initiated to design of the impact load energy absorber which is the bumper beam and crash box on the front of the Bishoftu bus and reduces the transmission of crash loads in collision.

1.3. Objectives

The following objectives are formulated for this master's degree level research work.

1.3.1. General objective

The general objective of this thesis is to design and analyze frontal bumper and crash box

1.3.2. Specific objectives

The specific objectives of this thesis are to:

- Develop the model of frontal bumper and crash box using SOLIDWORK.
- Determine composite material of frontal bumper and crash box
- Determine effects of geometry of frontal bumper and crash box.
- Analysis and simulation of the impact load effects
- Identify energy absorption on frontal bumper and crash box using ANSYS

1.4. Significance of study

The main significance of this study is that for improvement of the cost effective bumper and crash box development, which granted to reduce the accident in the collision. Due to this, injuries to passengers and bad economic effects will be reduced. The findings of this study will therefore be a substantial contribution to automakers' consideration of the best bumper and crash-box energy absorber combination.

1.5. Scope and Limitation of the Study

This study's focus is on the geometry analysis and SOLIDWORK modeling of the front bumper and crash box. Additionally, it uses ANSYS for Bishoftu Bus for analysis in addition to simulation of the impact load effects and energy absorption on the front bumper and crash box. Since it is new design the validation of each variable are related with the results of software simulations. In addition, the sample selected for this study is specifically bishoftu bus bumper beam and crash box which used to protect the bus front straight collision danger. There is no focused beyond composite materials. Moreover, the design is limited to the low speed in the city transport.

1.7. Organization of the Thesis

There are five chapters in this study. The study's background, challenges, aims, relevance, scope, and organizational structure are all covered in the first chapter, which also serves as an introduction to the study. A variety of pertinent literature is covered in Chapter 2's second section, including information on investigations of bumper and crash-box energy absorption. Additionally, it includes the knowledge gaps that were used to develop the bumper and crash box for the Bishoftu bus. The resources and methodology used to accomplish the goal of this study are described in chapter three. In chapter four, the findings and related discussion are provided. This thesis's last chapter includes conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2. Introduction

In this portion, a part of the work that have been done before, focusing on impact load effects, as well as analysis and simulation of energy absorption for car bumper and crash box would be discussed. Different researchers conducted various analysis and followed different approaches to model impact load energy absorber on frontal parts of different model of vehicles. The most popular and closely related literatures are presented as follows.

2.1. Review of Related Literature

In the study of (Dagdeviren *et al.*, 2016), crashworthiness, and risk to others in crashes among two passenger vehicles were related for diverse types of vehicles. The results were exhibited that, the aspects such as crash harshness confounded the relationship between severe injury risk and vehicle body type. Whereas, in the chassis such as: the cross-sectional area geometry, reinforcements and thickness, the structural responses of a ladder frame pickup chassis during full frontal and pole side impacts were subjected to numerous adaptations, and specifically, an old model of Chevrolet pickup car was used. For investigation, and the result realized that the chassis had capable of absorbing around half percentage of the crash energy at different harshness. And, Kathiresan *et al.*, (2014) studied crashworthiness of glass fibre/epoxy laminated thin walled composite to predict energy absorption (EA) using ABAQUS software. So that the experimental results frequently matching with numerical analysis or finite element analysis.

According to the CMVDR 294, simulation was done effectively for frontal crash on a rigid wall of the car at about 48.3 km/hr using LS-DYNA. And the results containing the car's velocity, the transmitted interrelation of the energy, the acceleration time path, displacement, the dummy's injury value, achieve comprehensive and credible appraisalment with the frontal crash process and crash performance (Liu, 2013).

This study described mathematical modeling about a special purpose 2D vehicle model for time-efficient crash stage simulation. In addition, determine the equations that rule over the model first.

The Finite Element Method (FEM) was used to represent the basis for analytical formulation problems. But, the various vehicle areas' different stiffness involves its estimation using real vehicle-to-barrier crash tests. Based on the achieved stiffness value, achieved simulations prove the method applicability to the vehicle-to-vehicle impacts contained in databases like AREC, VERSUE, etc. (Vangi *et al.*, 2018).

The effects of crash factors in the dynamic response and analysis of crash simulation development done in automobile components and the related process parameters using finite element approach (Yadav and Pradhan 2014).

This study evaluated the use of deployable front- end airbags in terms of the potential effects on passenger vehicles when they are colliding on both ends with a heavy truck front face. A virtual testing methodology was done to evaluate various designs under impact conditions. The study reports on the potential effects of radar-activated, heavy-truck, front-end airbag systems on crash mitigation on both end impacts (Friedman *et al.*, 2017).

This research analyzed possible head injuries due to frontal collision and evaluated the safety of ITB's FSAE race car. Through developing a finite element model of the race car, a rigid wall, a dummy and a seatbelt, a renewal of frontal collision with an impact speed of 7 m/s to 15 m/s was made. For full-frontal barrier, test the rigid wall and race car were modeled, without incorporating the dummy inside the car. The deceleration effect of impact load was analyzed (Mihradi *et al.*, 2017).

The geometrical optimization was done of bumper beam profile made of pultruded composite by numerical simulation (ABAQUS software). In order to optimize beam curvature and section profile of crashworthiness, low velocity impact finite element simulations were performed. And the result shown that pultruded bumper beam has equivalent energy absorption ability with respect to the steel normal production solution (Belingardi *et al.*, 2013).

The new bumper beam for passenger car was developed. Shape/ cross section factors that affecting energy absorptions were considered. Consequently, Cross-section has significant effects on the energy-damping rate and bending resistance which is magnifies its strength (Davoodi *et al.*, 2011)

Various automotive parts can be manufactured by the roll forming process using a conventional mild steel as well as an advanced high strength steel (AHSS). Also, automotive

structural parts, such as a bumper beam, a side sill, were being manufactured by the roll forming process using AHSS. Although the roll forming process is one of useful forming technologies especially for AHSS, it can only make the part having a uniform cross-sectional profile. In order to overcome this limitation, POSCO multi-directional Roll Forming (PosRollForm) technology was suggested. In this work, PosRollForm process was applied to the bus frame part having a variable cross-section along the longitudinal direction with SPFH540 in length of 7m and in thickness of 4.5mm. Forming rolls with the flower pattern and process parameters were optimized for the PosRollForm process by numerical analysis (Kim *et al.*, 2017)

Investigation was done on the correlations between the LGFRP and strain rate, which was applied to crash-worthiness and energy absorbing property analysis of a bumper beam under the longitudinal impact. Firstly, strain rate dependent material properties were determined, for which the experimental procedure was explained in detail on the tensile specimens of long glass fiber and polypropylene matrix based composite configurations. The gained experimental results provided the input parameters for a numerical analysis of specimens. The numerical results of properties were compared with those from tests. The constitutive model that fits for LGFRP was employed to crash-worthiness and energy absorbing property analysis of a bumper beam under the longitudinal impact (Duan *et al.*, 2017)

In this project the selection of the most suitable material for an automotive bumper beam was done. The selection method was based on the material selection requirements such as mechanical properties, physical properties and economic value. The constraint values were documented in the product design specification (PDS) derived from experimental work and design calculation. The KBS would be ranked the materials in the form of a hierarchical graph for the best five of the most suitable materials. The top ranking materials had the closest specification values to the user's defined value (Sudin *et al.*, 2007)

The collisions of vehicles and it cause damage to both vehicle and passengers. Bumper was one of the key factor which helps in avoiding damage to vehicle and passengers present inside the vehicle. The production of bumper in composite material results in increased safety during collision and it was cheaper and reduces the weight of vehicle. The cross-section of beam, energy absorber and its materials was designed and analyzed, with referring to the result safe and strong bumper system was discussed. When compared to current bumper, the composite bumper with energy absorber results in greater shock absorption and

increased strength which increase the overall effectiveness of the bumper and its function(Chinnasamy and Periasamy 2021)

The objective of this research was to increase the strength of bumper by using composite material carbon fibre 395. Carbon fiber 395 has low price and excellent strength. The 3D model of bumper is done on Catia V5 software and Explicit Dynamics was done on Ansys 19.2 Software to find out the deformation, Stress and Strain. The main problem of bumper during collision was the wear and tear of bumper at high speed so to increase in the strength and reduce the wear and tear of the 3 bumper for that the new bumper with proper new material was manufactured(Journal n.d.)

This research was focused on a hybrid of kenaf/glass fiber to enhance the desired mechanical properties for car bumper beams as automotive structural components with modified sheet molding compound (SMC). A specimen without any modifier was tested and compared with a typical bumper beam material called glass mat thermoplastic (GMT). The results indicated that some mechanical properties such as tensile strength, Young's modulus, flexural strength and flexural modulus were similar to GMT, but impact strength was still low, and shows the potential for utilization of hybrid natural fiber in some car structural components such as bumper beams(Davoodi *et al.*, 2020)

In this research, a front bumper beam made of three materials: aluminum, glass mat thermoplastic (GMT) and high-strength sheet molding compound (SMC) was studied by impact modelling to determine the deflection, impact force, stress distribution and energy-absorption behavior. The mentioned characteristics are compared to each other to find best choice of material, shape and thickness. The results show that a modified SMC bumper beam can minimize the bumper beam deflection, impact force and stress distribution and also maximize the elastic strain energy. In addition easy manufacturing due to simple shape without-ribs, economical aspects by utilizing low-cost composite material and reducing weight with respect to others can be achieved by SMC material(Marzbanrad *et al.*, 2009)

This paper expressed the use of natural fibres and its hybrid as reinforcement in a synthetic polymer matrix for automotive polymer bumper beam material. Possible modifications employed to improve the relevance of natural fibre for this application over synthetic fibre were also considered. Lower impact properties were deduced from the mechanical evaluation of the various researches using hybrid natural fibre as a major limitation when compared with the conventional glass mat thermoplastics and the long fibre-reinforced

thermoplastics used as typical bumper beam material. The use of various modifiers as toughness has not been able to achieve comparable strength with GMT and LFRT. However, the need for nano bio composite should be explored for possible improvement on the impact properties in this area of application(Adesina 2019).

The most appropriate one for suitability of use in manufacturing automotive bumper beam was determined by considering eight main selection factors and 12 sub-factors. The AHP analysis reveals that the glass fibre epoxy was the most appropriate material because it has the highest value (25.7%, mass fraction) compared with other materials. The final material was obtained by performing six different scenarios of the sensitivity analysis. It was proved that glass fibre epoxy was the most optimum decision(Hambali *et al.*, 2010)

Crashworthiness of a bus bumper system with a special honeycomb beam was optimized under impact loading using a multi-fidelity optimization approach. The crash performance of the bumper system was evaluated using two metrics: crush force efficiency (CFE) and specific energy absorption (SEA). Commercial finite element software LS-DYNA was used to compute CFE and SEA values. Multi-fidelity modeling was used to combine data of low-fidelity model at all training points with high-fidelity data at some randomly selected training points to obtain accurate response predictions in less computational time. It was found that multi-fidelity optimization can reduce the computational cost by 33% with only 2% smaller composite objective function value compared to the high-fidelity optimization alternative(Acar *et al.*, 2020).

2.2. Summary of Literature Review and Research Gap

The studies of crashworthiness on various types of vehicles were explored utilizing a variety of methodologies, including the finite element approach, analytical analysis, and experimental analysis, as can be seen from the aforementioned literature reviews. In order to increase the safety of vehicles and passengers during transportation, it is required to take into consideration vehicle accident protecting mechanisms, as evidenced by the agreement between the studied regions and their limitations (gap). The evidence was clear when the researchers concentrated on the design and analysis of bumpers for various automobiles to increase passenger and vehicle safety. Although the researchers concentrated on the design and study of bumpers for different vehicles, they neglected to create a bumper and crash box for the Bishoftu bus in order to increase its capacity to absorb energy brought on by impact loads on its front face during collisions.

The inference prompts the design of the Bishoftu bus's bumper and crash box to absorb energy. The goal of this research work is to use composite materials to improve the energy absorbing capacity of the front face of the Bishoftu bus while reducing weight and distortion. In the event of a frontal collision accident, the energy-absorbing front structure of the bus is modified and examined in order to protect the passengers from harm and the bus from damage.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3. Introduction

To attain the objective formulated for this work, the required materials are listed below, and the methodology depicted in the step chart diagram is implemented in systematic and structured ways.

3.1. The Following Softwares are Used in this Work

SOLIDWORKS: Helps to construct the model of Bishoftu Bus Bumper and Crash Box.

ANSYS Fluent: It is used to simulate the effect of impact load on front Bumper and Crash box of Bishoftu Bus due to collision, and calculate the absorbed energy.

3.2. Method

In this work the methodology followed are expressed as following.

Review different related published papers and other information sources about frontal bumper and crash-box energy absorber. Secondly, modeling the parts and assembling them using SOLIDWORKS version 18 software. The third work is identification of properties of material such as tensile strength, impact strength, manufacturing properties and cost of the material to select the final material which used for ANSYS analysis. Finally, the Simulation and Analysis by ANSYS is done in the following steps. Import 3D model into ANSYS 22 software, apply the material properties and the external loads then run the simulation.

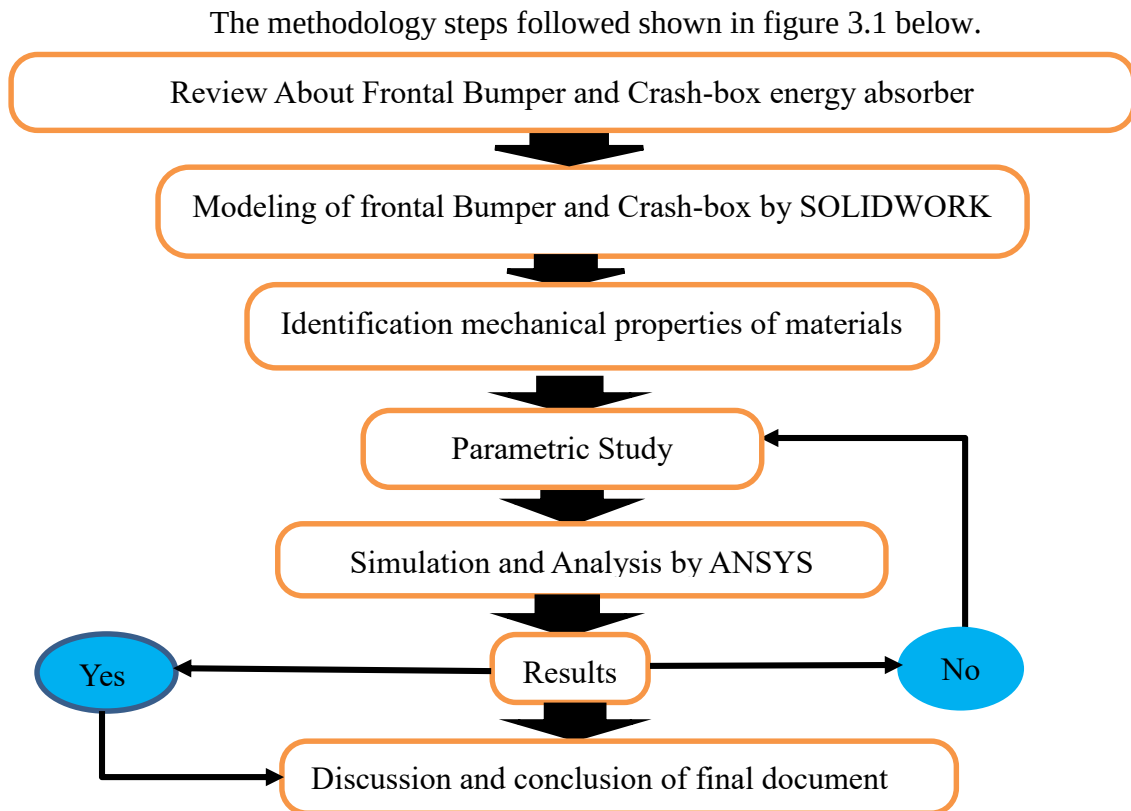


Figure 3. 1. Step chart for the work

3.3. The Required Materials for the study

The bumper is one of the key structural part, which plays an important role in the frontal crash area of a vehicle. The most important parameters of a vehicle's front bumper such as material, shape, and impact condition should be studied to improve the bumper and crash box (Hasanzadeh *et al.*, 2017).

Material selection is a major thing in the design process, and desired performance of the products for all of the engineering applications. A bumper beam is one of the most important vehicle structures that is used to protect from the impact load or bulk of energy in collision by absorbing energy. Therefore, selecting the best bumper beam and crash box material that has the highest satisfaction is necessary (Hasanzadeh *et al.*, 2017). The selection of the best material for vehicle bumper beam and crash box depends on many criteria such as the following:

a) Tensile Strength (TS)

Tensile strength is the ultimate tensile stress that a material can tolerate before it undergoes cracking, fracture, or plastic deformation.

b) Impact Strength (IS)

Impact strength is one of the most important criteria in selecting the appropriate material for the bumper beam. The impact strength is the absorbed impact energy by the cross-section area of the material.

c) Cost (C)

It is clear that the cost plays a very significant role in determining the most appropriate material for the bumper beam. In this research, the cost is defined as the cost of the raw materials.

d) The Manufacturing Process (MP)

Another important parameter is the difficulty of the manufacturing process of material for selecting the proper material for the bumper beam. This criterion is according to the author's experience during production.

Results of ranking alternative materials indicate its height impact and tensile strengths on top of its low cost of raw material. In addition, the sensitivity analysis was performed to verify the selection criteria and results as well. The alternative materials are given in Table 3.1.

Table 3. 1. The alternative materials considered (Hasanzadeh *et al.*, 2017)

Material number	Materials
M-1	PA6/0.5 wt.% MWCNT (Nano composite foam)
M-2	PA6/1 wt.% MWCNT (Nano composite foam)
M-3	PA6/1.5 wt.% MWCNT (Nano composite foam)
M-4	PC/0.5 wt.% Nano Alumina (Nano composite foam)
M-5	PA6/1 wt.% Nano Alumina (Nano composite foam)
M-6	PA6/1.5 wt.% Nano Alumina (Nano composite foam)

The above table 3.1 material values range is between the highest cost (i.e. 6) and lowest cost (i.e. 1). And also, the manufacturing process is ranged between most difficult (i.e. 6) and the easiest (i.e. 1).

According to criteria weighting, the results shown that the impact and tensile strengths are the most important criteria for material selection. The criteria of material properties decision are given in Table 3.2.

Table 3. 2. The criteria of material properties decision (Hasanzadeh *et al.*, 2017).

Alternative	Criteria			
	Tensile strength (TS) MPa	Impact strength (IS) j/m ²	Cost	Manufacturing process (MP)
M-1	25.00	113.07	4	1
M-2	37.55	103.54	5	2
M-3	34.79	96.51	6	3
M-4	450	224.58	1	4
M-5	141.71	154.06	2	5
M-6	141.92	133.53	3	6

Table 3. 3. The ranking of alternative materials (Hasanzadeh *et al.*, 2017)

Alternative	M-1	M-2	M-3	M-4	M-5	M-6
Values	4	5	6	1	2	3

Therefore, graphical representation of material effectiveness is determined as following graph in figure 3.2.

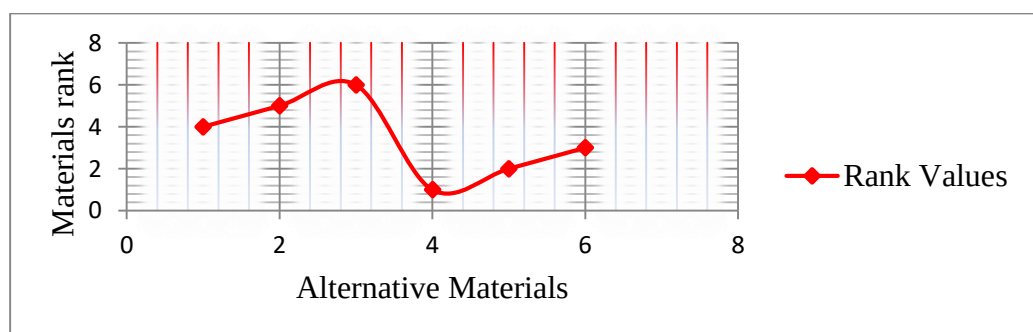


Figure 3. 2. The ranking of materials

Generally, due to best energy absorbing properties, foam materials are selected from Hasanzadeh detail study. Therefore, based on the analysis and the graphical results, the selected material is material 4 which has tensile strength (TS) 450 Mpa . The martial rank indicates sequence of materials advantage to design bumper beam and crash box.

3.4. Geometry of Bumper Beam

Geometric optimizations have a significant role in structural strength improvement. This study focused on selecting the best geometrical bumper beam concept to fulfill the safety parameters of the defined product design specification (PDS). Eight bumper beam concepts with the same material model under low impact test standard conditions are simulated. It is concluded that proper concept selection has an important role in structural strength, while material is considered as a constant factor. The idea of the geometrical 3D model came up with benchmarking different brand of passenger's car, patents, and industrial design practice and car manufacturer products. Completely 3D concepts were designed in SOLIDWORK software symmetrically as similar as the real bumper beam with the same overall dimensions, i.e. height, breadth, thickness, radius and material model (Davoodi *et al.*, 2011). The Finite element preliminary output data are given in Table 3.4.

Table 3. 4. Finite element preliminary output data (Davoodi *et al.*, 2011)

No.	Properties	Weight	Reverse C Profile (RCP)	Closed Oblique Profile (COP)	Curved C Profile (CCP)	Double Hat Profile (DHP)	Double C Closed (DCC)	Double C Profile (DCP)	Simple Hat Profile (SHP)	Simple C Profile (SCP)
										
1	Material cost	0.15	24.40	29.00	18.60	25.5	29.40	25.60	21.90	22.50
2	Easy to manufacturing	0.1	2	1	4	3	2	4	3	5
3	Product weight	0.2	2.44	29	1.86	2.55	2.94	2.56	2.19	2.25
4	Strain Energy	0.3	2482.82	43419.92	38825.14	76106.53	63671.64	44910.27	47231.52	2137.62
5	Add Rib Possibility	0.1	2	1	5	5	4	5	4	5
6	Min Deflection	0.15	16.92	29.86	21.34	18.34	25.72	21.15	22.92	16.73

The relative closeness to the ideal solution are given in Table 3.5.

Table 3. 5. The relative closeness to the ideal solution(Davoodi *et al.*, 2011)

RCP	COP	CCP	DHP	DCC	DCP	SHP	SCP
-----	-----	-----	-----	-----	-----	-----	-----

Therefore, in order to design exact and good energy absorber bumper beam for Bishoftu Bus measured or actual dimension values are used and by comparing precision with the published values. The published values are less since there are assembling or manufacturing accuracy as well as publisher data measuring effects.

3.5. Modeling of frontal Bumper and Crash-box

The 3D model of Bishoftu Bus bumper beam and crash box which used to absorb slow speed impact load to protect the vehicle and the passengers from damage is drawn using SOLID works 2018 SP5.0 as following figure 3.4 and 3.5:

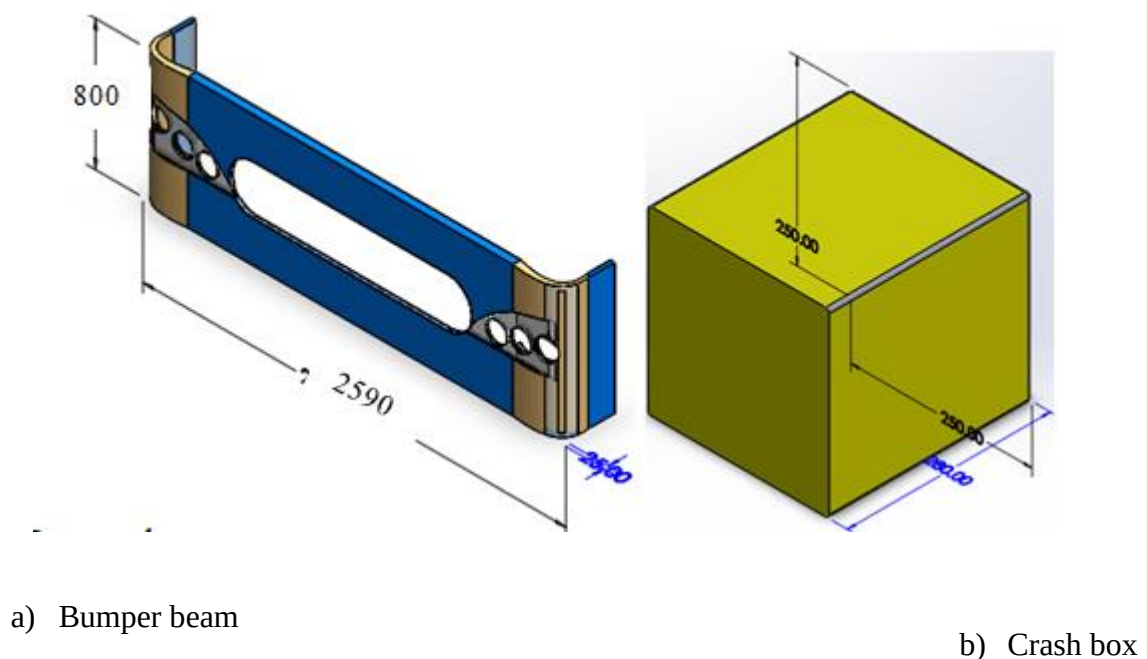


Figure 3. 4. 3D part modeling of Bishoftu Bus bumper and crash box

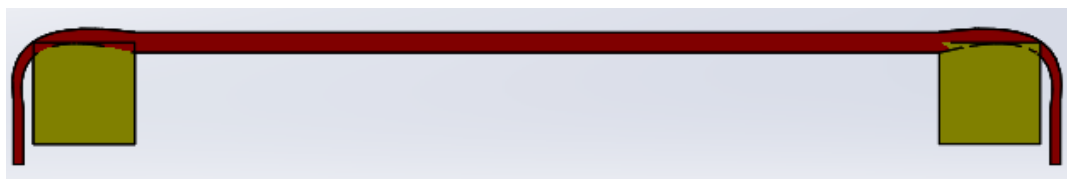


Figure 3. 5. Bottom View 3D modeling of Bishoftu Bus Bumper and crash box

3.6. Theoretical and Analytical Analysis.

The theoretical and analytical analysis focus on the evaluation of the Bumper Beam and Crash Box energy absorption values using the theoretical rule and mathematical formula. In this portion by the loads on the bumper beam, the various results related to the energy

absorption such as deflection of bumper and crash box can be understood. In order to easily calculate, bumper is considered as beam and crash box is considered as supporter.

3.6.1. Forces Acting on a Bumper Beam and Crash Box

Driving force mainly depends on the power of the driving mechanism and this power depends on speed of the vehicle. Analysis of the bumper and crash box absorption is considered for the low speed forces which is generated during the horizontal motion of the Bishoftu bus. The minimum speed is selected since the bus gives service in the city at minimum speed.

In this analysis the bus is considered as its collision is with the parked bus. The conditions considered in the collision of the Bishoftu bus are given in Table 3.7.

Table 3. 7. Considered conditions of Busses on collision

No.	Conditions	Bus under study	Bus on opposite side
1	Face of Bus	Front	Front
2	Type of applied load	UDL and point load	UDL and Point load
3	Driving Speed	Minimum speed	At rest or fixed at a place
4	Point of collision	At center, through all length	At center, through all length
5	Crash box and bumper beam tips	Bounded on bus	----
6	Bumper beam	Bounded on Crash box	----
7	Direction of force	Horizontal	Horizontal
8	Total applied load	Static friction force /Reaction of applied force – kinetic friction force	Action of applied force – kinetic friction force

Table 3. 8. Considered parametric specification for ZK6118HGA Model Bishoftu bus

No.	Parameter	Specification of Studied Bus	Specification of Opposite Bus
1	Min. Driving Speed	30 km/hr	0 km/hr
2	Max. Driving Speed	100 km/hr	0 km/hr
3	Weight of bus	12,750 kg	12,750 kg
4	Gross vehicle weight	18000 kg	18000 kg

The study is considered as the Bishoftu bus is collision with the same stationary bus, so putting the specification of opposite bus is necessary to analysis the energy lost and required energy absorption.

3.6.2. Crash Theory

In this research, the collision between the two crash buses are perfectly inelastic that expose the front part of the bus to impact. Therefore, the total initial kinetic energy (E_k) can be determined. The mass and speed of the vehicle 1 and 2 are m_1 , V_1 and m_2 , V_2 respectively. Then the energy lost is given from the conservation of momentum principle and assuming that after crashing the two vehicles are moving together with the same residual speed V_f (Tanlak *et al.*, 2015; Kumar *et al.*, 2017).

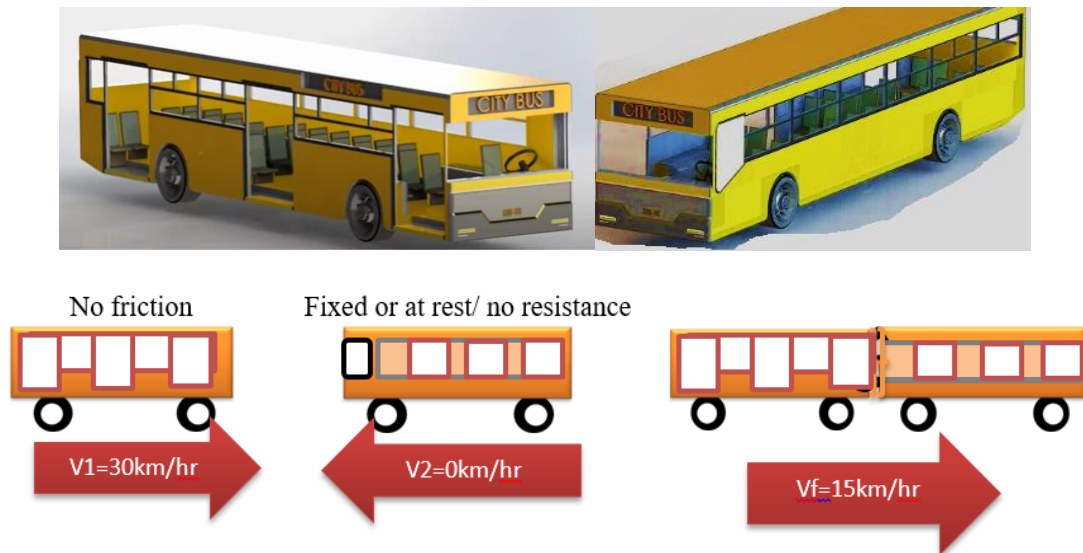


Figure 3. 6. Drawn 3D and 2D modeling of Bishoftu Bus for further explanation

Therefore, on the above figure 3.6, the following effects are observed which effects are: isolated system collision, energy lost, heat created, conservation of momentum, stick together after collision, same final velocity and one direction collision.

General equation

Conservation of momentum equation

$$(net\ mv)_{befor} = (net\ mv)_{after} \quad (\text{Eqn. 3.1})$$

$$V_{i1}m_1 + V_{i2}m_2 = v_{f1}m_1 + v_{f2}m_2$$

Since the two cars have the same final velocity after collision and the second car is at rest or zero velocity

$$V_{i1}m_1 + 0 = (m_1 + m_2) v_f$$

$$v_f = \frac{V_{i1}m_1}{(m_1+m_2)} = \frac{\frac{30km}{hr} \times 18000kg}{(18000kg+18000kg)} = 15 \text{ km/hr}$$

Kinetic Energy Loss

The kinetic energy before colliding is equal to the kinetic energy after colliding plus the energy lost in the collision (Tanlak et al., 2015; Kumar et al., 2017).

$$K_{Ei} = \frac{1}{2}(m_1v_{i1}^2 + m_2v_{i2}^2) = \frac{1}{2}(m_1v_{f1}^2 + m_2v_{f2}^2) + \text{loss} \quad (\text{Eqn. 3.2})$$

From these four equations, the dissipated energy used to deform both vehicles can be calculated. It is equal to the difference between the initial and residual energy.

$$\begin{aligned} E_d &= K_{Ei} - K_{Er} = \frac{1}{2}(m_1v_{i1}^2 + 0) - \frac{1}{2}(m_1 + m_2)v_f^2 \quad (\text{Eqn. 3.3}) \\ &= \frac{1}{2} \left(18000kg \times \left(\frac{30km}{hr} \right)^2 + 0 \right) - \frac{1}{2} (18000kg + 18000kg) \left(\frac{15km}{hr} \right)^2 \\ &= 312,500J \quad \text{or} \quad = 75,000N \end{aligned}$$

i) Deflection Analysis

If bumper beam and crash boxes are subjected to uniformly distributed loads or point loads, they deflect from their original position. The quantity by which a bumper beam and crash box are deflected from their position are calculated. The investigation focuses on the static bumper beam and crash box deflection. Finally, the energy absorption of bumper beam and crash box is compared with the deflection results and decided the absorption capacity of bumper beam and crash box in the condition of bus collision at minimum speed. The total deflections and slopes at points of interest are obtained from the plots, and combined with orthogonal vector addition, that is:

$$\delta_T = \sqrt{\delta_Y^2 + \delta_Z^2}, \quad \theta_T = \sqrt{\theta_Y^2 + \theta_Z^2} \quad (\text{Eqn. 3.4})$$

Where, δ_T is total deflection, θ_T is total slope Y indicate y direction, Z indicate z direction.

This approximate formula is used to identify the shaft Bumper beam and Crash box deflection

Then use

$$\sum \delta_z = 0 \text{ And } \sum \delta_y = 0 \text{ are safe} \quad (\text{Eqn. 3.5})$$

To find the reaction forces on tips of bumper beam and crash box of all analysis, the rule of equilibrium equating of forces and moments on bumper beam used.

ii) Lateral Rigidity (Deflection) of Bumper Beam and Crash Box

In this research the bumper beam and crash box have uniform cross-section or thickness, so the lateral deflection of a bumper beam and crash box are obtained by using the deflection formulae as in strength of materials. In this investigation, the bumper beam is considered as beam that is Macaulay's method is used in finding slopes and deflections at any point of bumper beam. Therefore, all of the bumper beam and crash box lateral deflections are analyzed using the following main governing equations relation.

$$\text{Bending moment: } M = EI \frac{d^2n}{dx^2} \quad (\text{Eqn. 3.6})$$

$$\text{Slope: } \theta = EI \frac{dn}{dx} \quad (\text{Eqn. 3.7})$$

$$\text{Deflection: } \delta = EIn \quad (\text{Eqn. 3.8})$$

iii) Free Body Diagram of Bumper Beam and Crash Box.

Case 1. Bumper beam is subjected to UDL

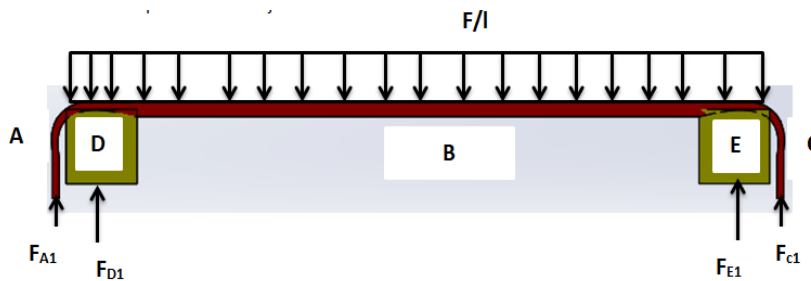


Figure 3. 7. Bumper beam under UDL

To find support reactions, UDL is converted in to point load as following:

$F = \text{UDL} * L$ and located at a center of the beam

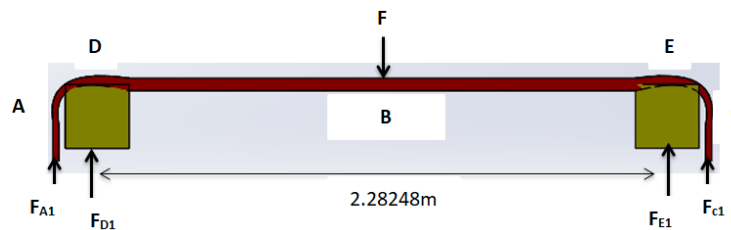


Figure 3. 8. Bumper beam under concentrated point load

To find deflection, consider the section X in the second part of the bumper beam (i.e., in length BD) at a distance x from the right load C.

Vertical Plane (y –axis) deflection: The summation of horizontal forces is: -

$$\sum F_V = -F_B + F_{A1} + F_{D1} + F_{E1} + F_{C1} = 0 \quad (\text{Eqn. 3.9})$$

The summation of moments at D is: -

$$\sum M_{(D)} = F_{C1}x_{L_{DC}} + F_{E1}x_{L_{DE}} + F_{Bx}L_{DB} - F_{A1}x_{L_{DA}} = 0 \quad (\text{Eqn. 3.10})$$

Bending moment, slope and deflection:

$$EI \times B.M. = EI \frac{d^2y}{dx^2} = F_{C1}xx : + F_{E1}x(x - L_{CE}) : - F_Bx(x - L_{BC}) \quad (\text{Eqn. 3.11})$$

$$EI\theta = EI \frac{dy}{dx} = \frac{F_{C1}xx^2}{2} + C_1 : + \frac{F_{E1}x(x-L_{CE})^2}{2} : - \frac{F_Bx(x-L_{BC})^2}{2} \quad (\text{Eqn. 3.12})$$

$$EI\delta = EIy = \frac{F_{C1}xx^3}{6} + C_1x + C_2 : + \frac{F_{E1}x(x-L_{CE})^3}{6} : - \frac{F_Bx(x-L_{BC})^3}{6} \quad (\text{Eqn. 3.13})$$

Case 2. Bumper beam is subjected to Point load at one of its end part.

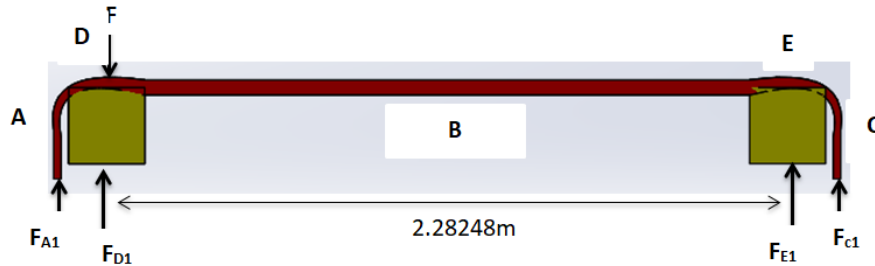


Figure 3. 9. Bumper Beam under point load at one of its end part

To find deflection, consider the section X in the first part of the bumper beam (i.e., in length AD) at a distance x from the right load C.

Horizontal Plane (y –axis) deflection: The summation of horizontal forces is: -

$$\sum F_V = -F_D + F_{A1} + F_{D1} + F_{E1} + F_{C1} = 0 \quad (\text{Eqn. 3.14})$$

The summation of moments at D is: -

$$\sum M_{(E)} = F_{C1}x_{L_{EC}} + F_{D1}x_{L_{DE}} - F_{Dx}L_{DB} + F_{A1}x_{L_{EA}} = 0 \quad (\text{Eqn. 3.15})$$

Bending moment, slop and deflection:

$$EIxB.M. = EI \frac{d^2y}{dx^2} = F_{C1}xx \div +F_{E1}x(x - L_{CE}) \div -F_Dx(x - L_{DC}) \quad (\text{Eqn. 3.16})$$

$$EI\theta = EI \frac{dy}{dx} = \frac{F_{C1}*x^2}{2} + C_1 \div + \frac{F_{E1}*(x-L_{CE})^2}{2} \div - \frac{F_D*(x-L_{DC})^2}{2} \quad (\text{Eqn. 3.17})$$

$$EI\delta = EIy = \frac{F_{C1}*x^3}{6} + C_1x + C_2 \div + \frac{F_{E1}*(x-L_{CE})^3}{6} \div - \frac{F_D*(x-L_{DC})^3}{6} \quad (\text{Eqn. 3.18})$$

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 introduction

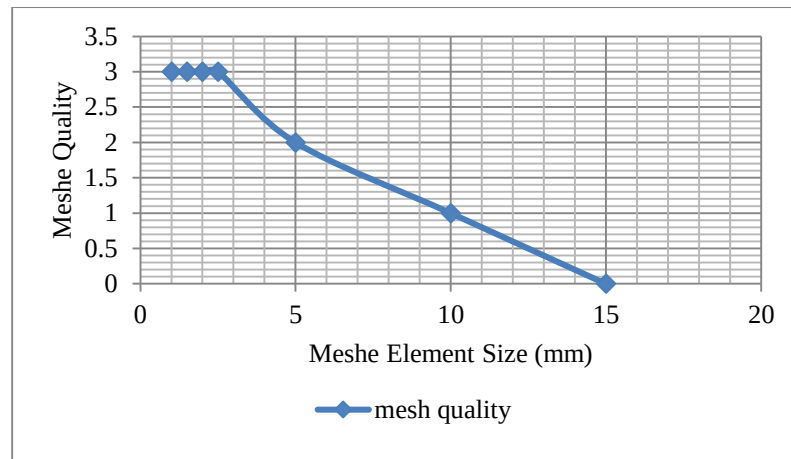
In this paper, the investigations on the energy absorption of bishoftu bus bumper beam and crash box are done through considering of the analytical and numerical results. The result and discussions are identified based on the scientific view, simulation results and the current work result perspectives.

4.2 Finite Element Analysis

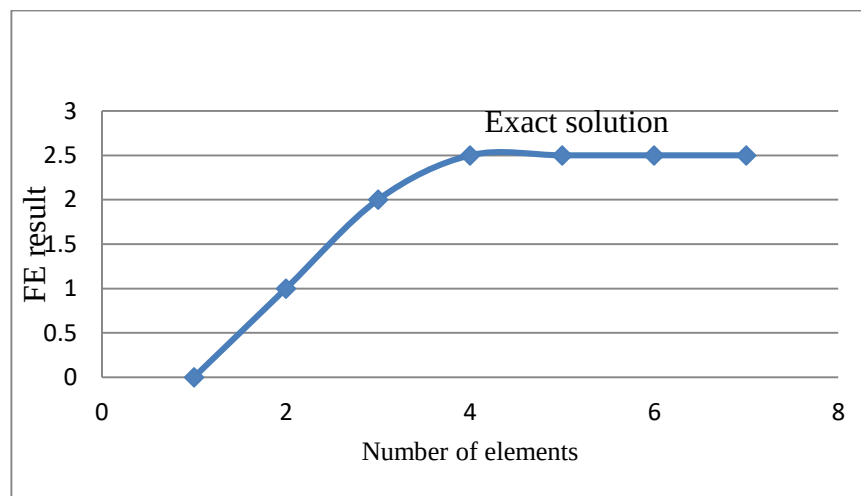
The software ANSYS 2022 workbench is used to comprehend the distribution of the stress along the bumper beam and crash box and to calculate the maximum deflection value, which is utilized to calculate energy absorption capacity. The geometric shape, material qualities, physical restraints, and loading situation are all determined throughout the modeling phase. ANSYS 2022 is used in this work to analyze static deflection, which is used to calculate energy absorption, and SOLID works 18 is used for modeling utilizing analytical governing equations.

4.3. Mesh Generation

One of the most important components and the initial stage in the finite element method is mesh generation. The process of meshing involves breaking the model down into a number of distinct components, or elements. The component is fragmented into a number of little pieces in this step since the forces' effects are not the same for each component. Information about each element type's level of freedom and physical characteristics is provided. Bus topology optimization was done with regard to the bumper beam and crash box using automatic 1st order element type and 2.5mm element size meshing. As a result, the mesh is succeeded in producing a fine and high-quality mapped mesh. The SOLIDWORK 18 model is imported into the ANSYS 2022 workbench for this inquiry, and meshing is then carried out. The tried meshes are shown in Figure 4.1 along with their flow direction or quality.



a) Mesh element size Vs meshing quality



b) Convergence of the FE result Vs Number of elements

Figure 4. 1. a) Mesh element size Vs meshing quality and b) convergence of the FE results Vs Number of elements

Figure 4.1a showed that the meshing quality is constant when the meshing element size decreases from 2.5 mm to zero. The quality of the mesh is defined by using different meshing sizes from 15mm to 1mm. After 2.5mm size, this becomes the same simulation result and selected 2.5mm mesh quality. As a result, fine smoothing and a 2.5mm mesh element size are selected. In addition, the above figure 4.1b showed the convergence of the solution that describes after the number of element 4, the result of FE is constant and go straight horizontal.

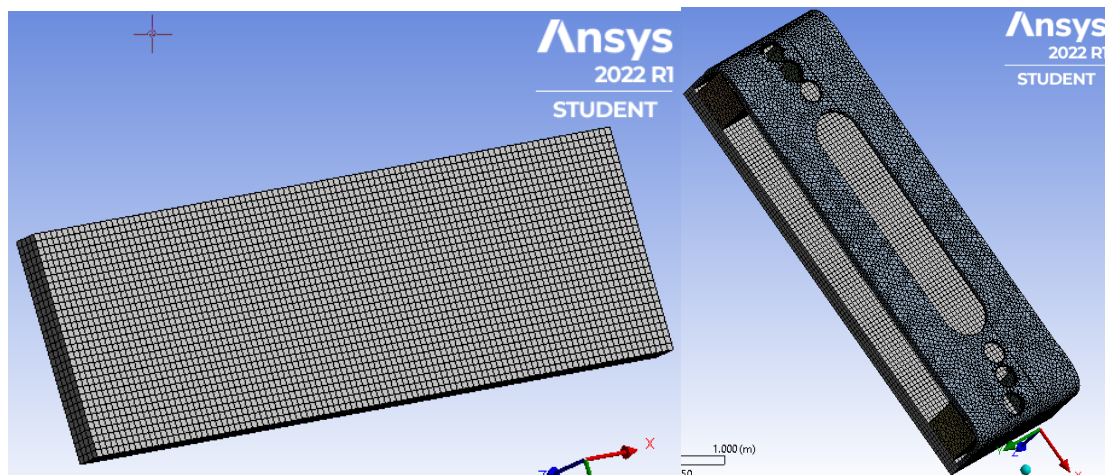


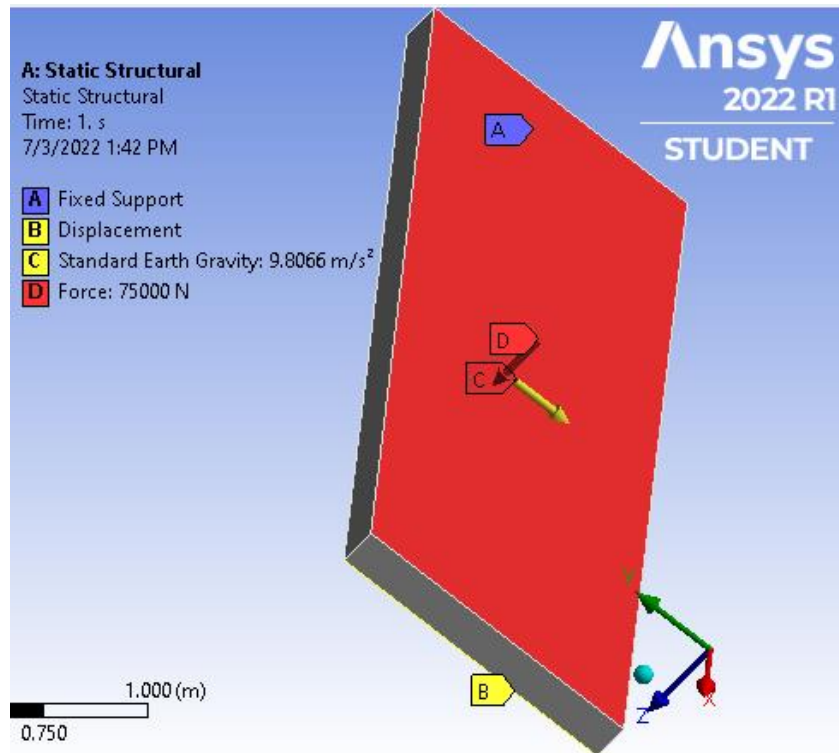
Figure 4. 2. Finite element models and mesh of Bus front part with and without bumper beam as well as crash box

4.4. Load Applications and Boundary Conditions

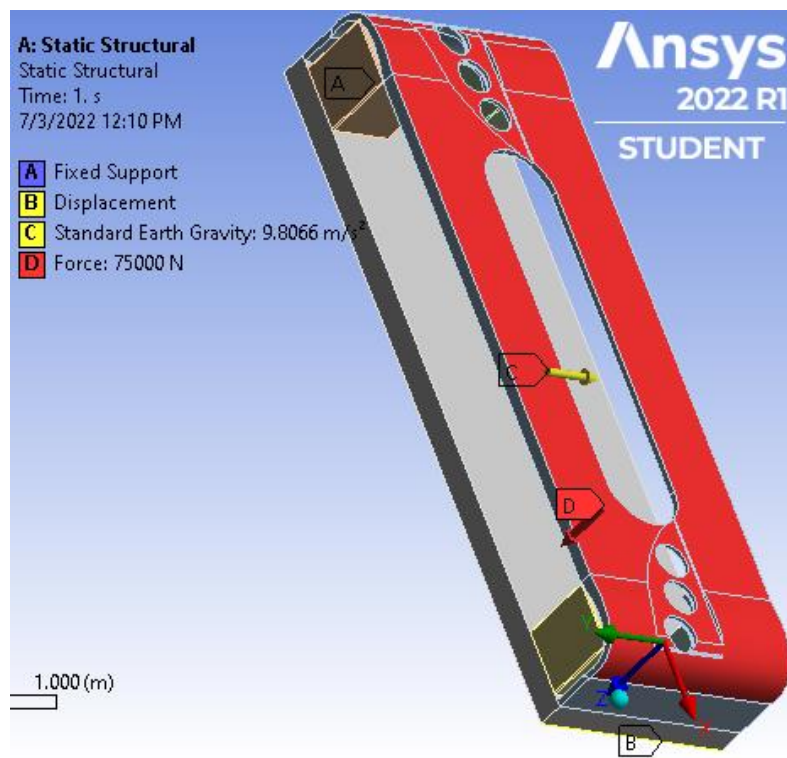
Boundary and loading conditions are applied to enable the solution of the resulting system equation. Due to the variable collision point in the model, various loads are given to the bumper beam and crash box. The load applied and boundary conditions are given in table 4.1.

Table 4. 1. Loading conditions applied on assembly of bumper beam and crash box.

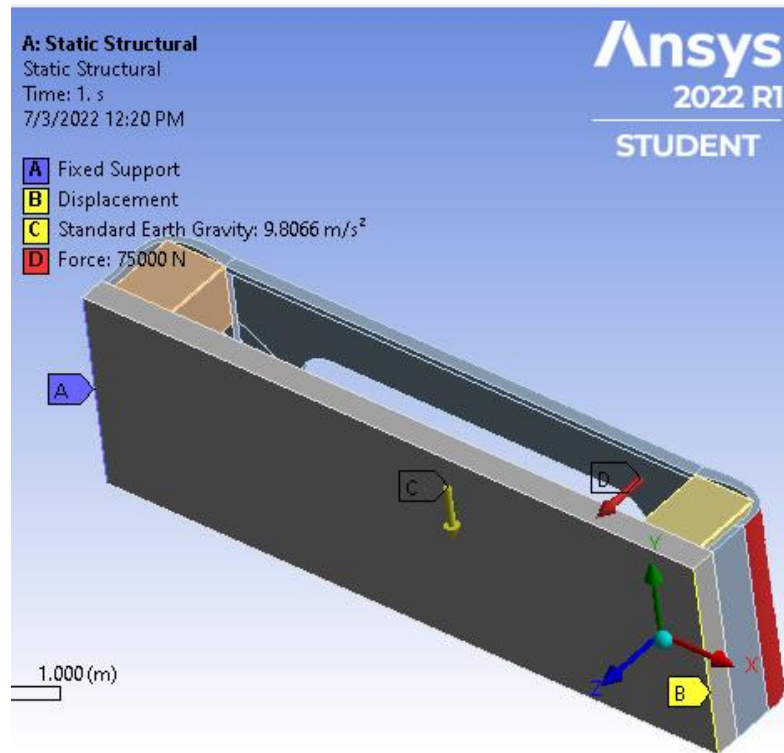
Part Name	Applied load (N)	Contact/Constrain
Bumper beam	75,000	Fixed to the crash box
Bumper beam	75,000	Fixed support to bus
Crash box	75,000	Fixed support to bus



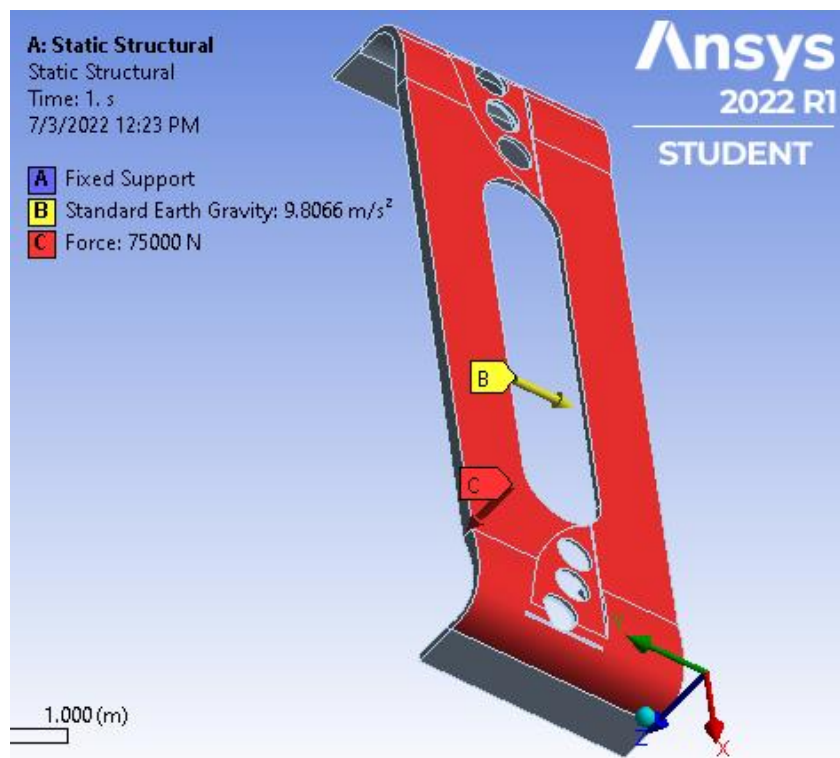
a) Isometric view loading condition on bus front part



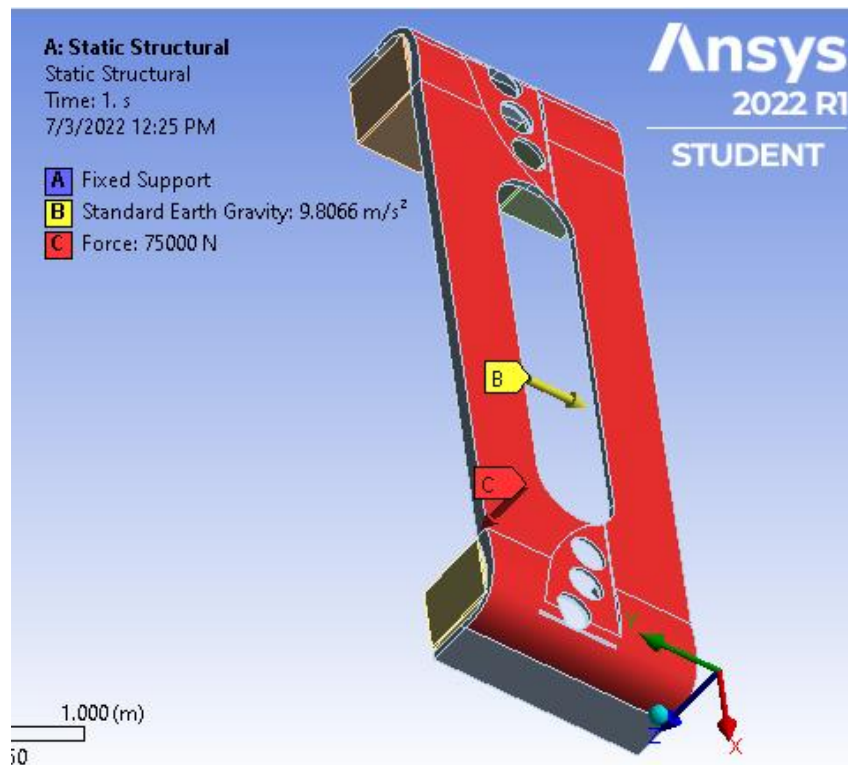
b) Isometric view loading condition on bus front part with bumper and crash box



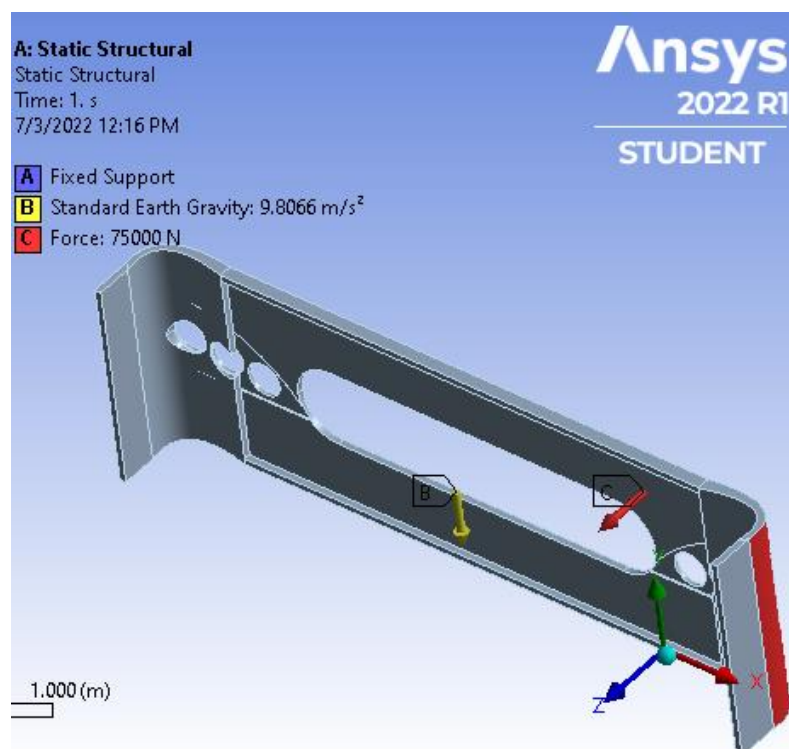
c) Irregular view loading condition on bus front part with bumper and crash box



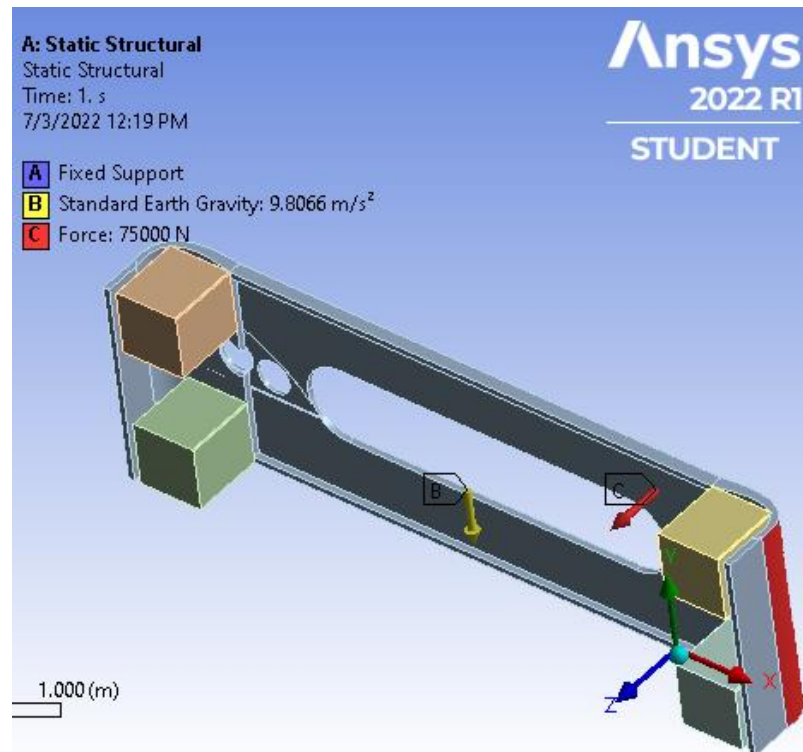
d) Isometric view loading condition on bus bumper



e) Isometric view loading condition on bumper with crash box



f) Isometric view loading condition on bus



g) Isometric view loading condition on bumper with crash box

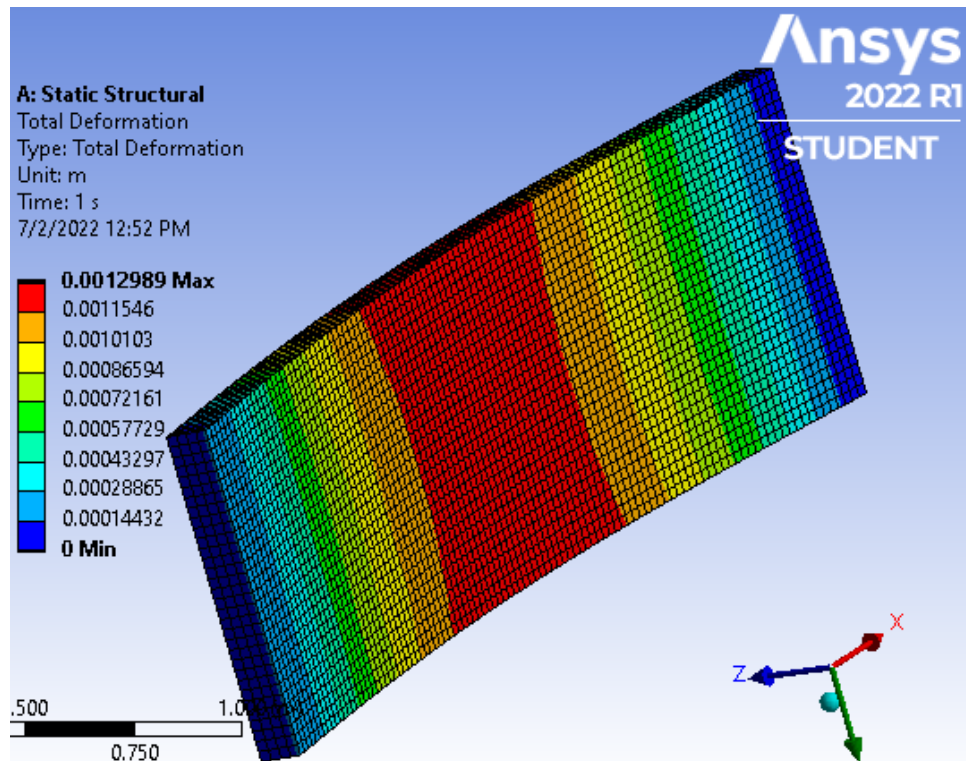
Figure 4. 3. Loading on bus front part bumper beam, and crash box

The observed from each figure are load applications and boundary conditions in the different position views of the parts and assembly of bishoftu front part with its bumper beam and crash box. In this load, application collision as well as gravitational loads is considered.

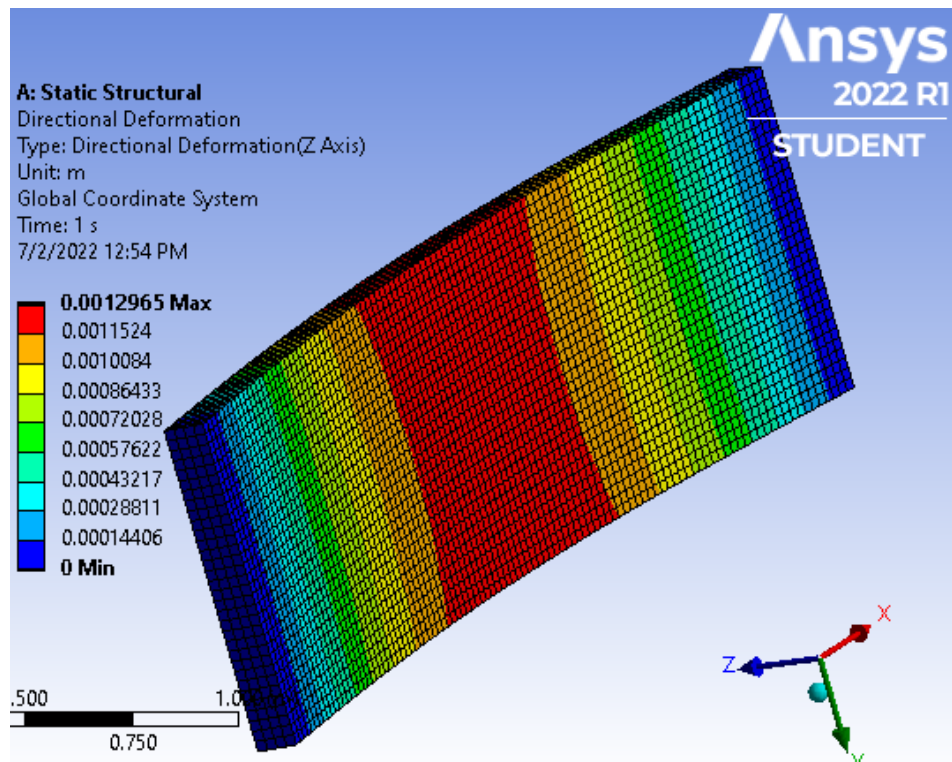
4.5. Finite Element Analysis on parts of Bishoftu Bus:

a) Frontal part of bishoftu bus

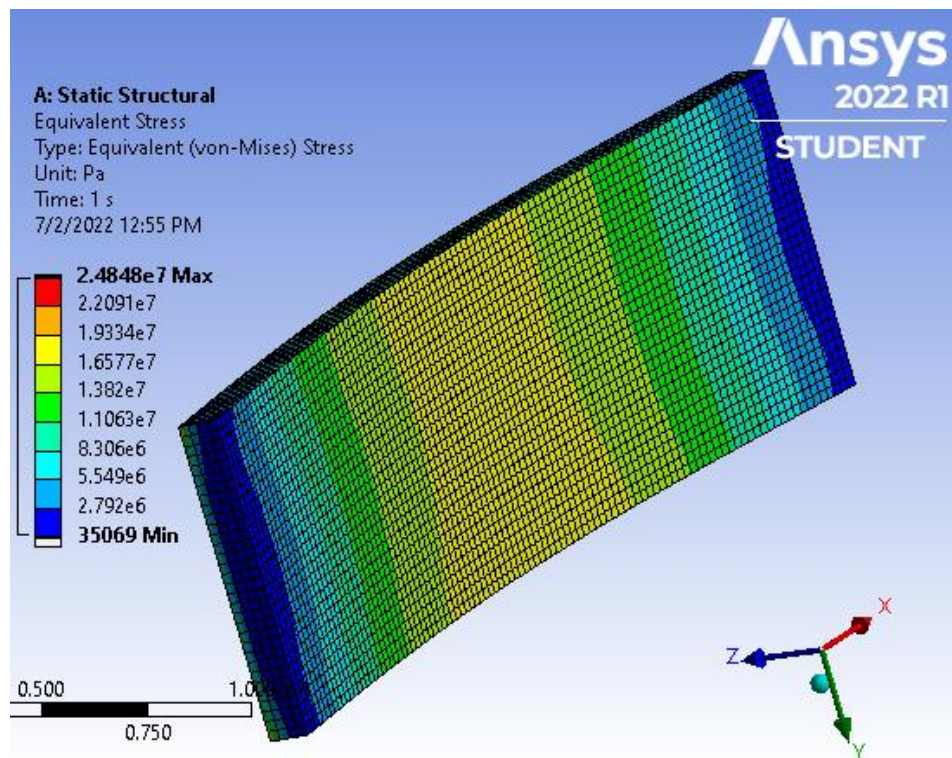
When a collision occurs at a low speed, the frontal portion of the bus is subjected to impact load. In this section, the impact load is applied directly to the bus's frontal region, analyzing the deformation, stress, and strain energy without taking into account the bumper beam and crash box energy absorber. The results obtained with ANSYS analysis on frontal portion of the bus are given in figure 4.4



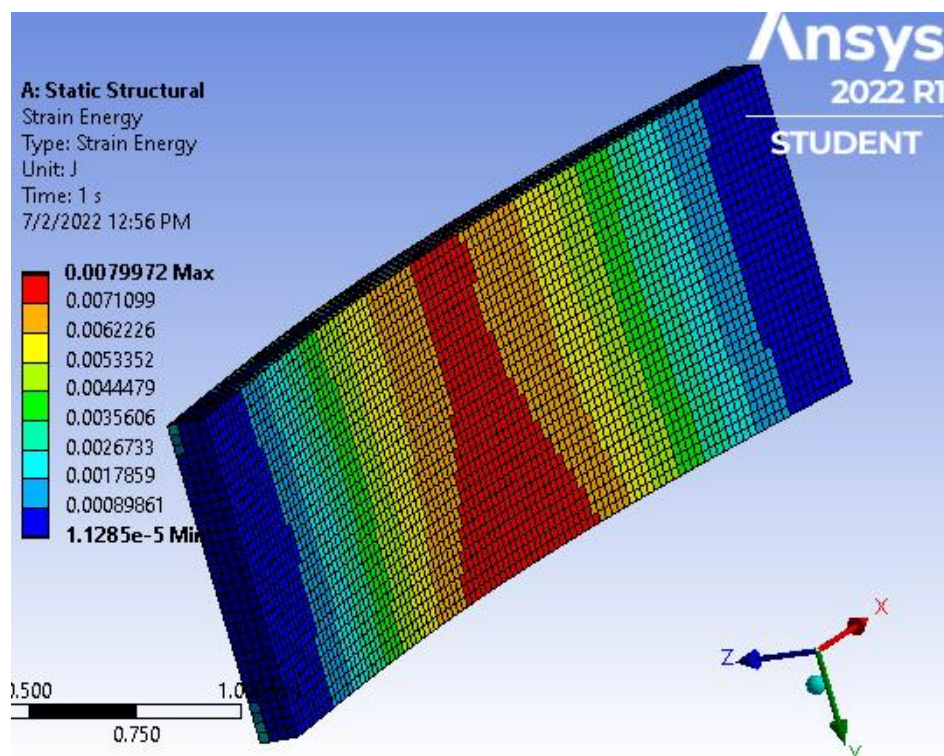
a) Total deformation on bus front part



b) directional deformation on bus front part



c) Von-Mises stress on bus front part



d) Strain energy on bus front part

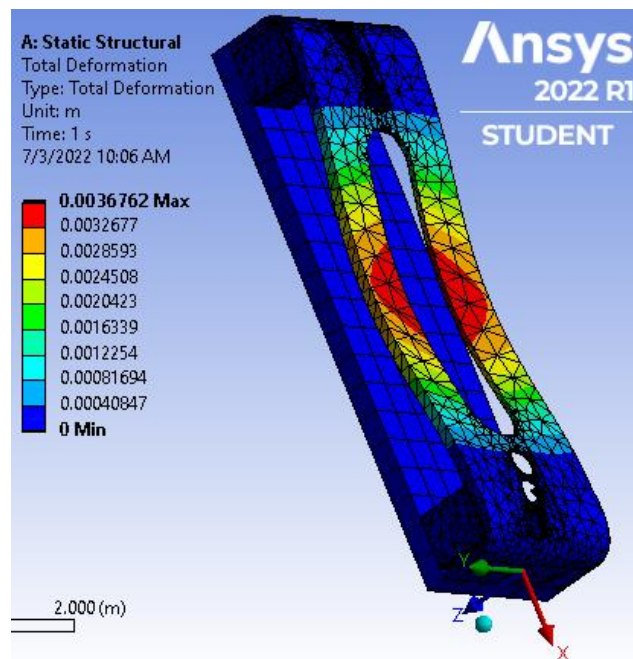
Figure 4. 4. Total deformation, directional deformation, Von-Mises stress and strain energy on bus front part

The analysis is done directly on the front face of bus without considering bumper beam and crash box. The observed from each figure are the simulation results of ANSYS software.

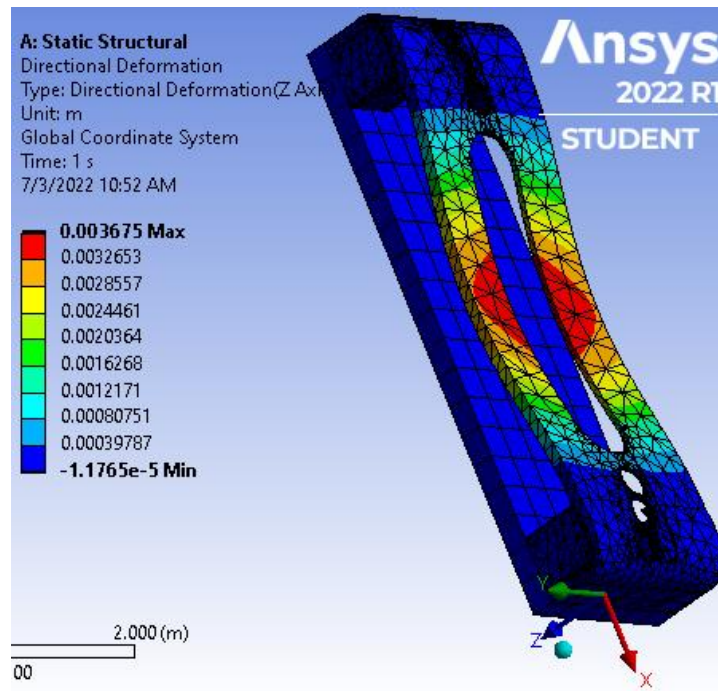
Since, the collision load is concentrated to the center and the bus collides with its full front face, the deformations, stresses, and strains are highest at the center of bus front part and decreased to its end portions. The observed results in the figures 4.4 a, b, c, and d are total deformation, directional deformation, Von-Mises stress and Strain energy which have the maximum values of 0.0012989m, 0.0012965m, 24.848 MPa 0.0079972J respectively. Therefore, from this simulation results it is concluded to focus the results, which occurred at the center of the part.

c) Bishoftu bus frontal part with bumper beam and Crash Box

When a collision occurs at a low speed, the frontal portion of the bus is subjected to impact load. The impact load is applied directly to the bus bumper beam while taking into account the bumper beam and crash box energy absorber to analyze the deformation, stress, and strain energy. The results obtained with finite element analysis on frontal face of the bus are shown in the figure 4.5.

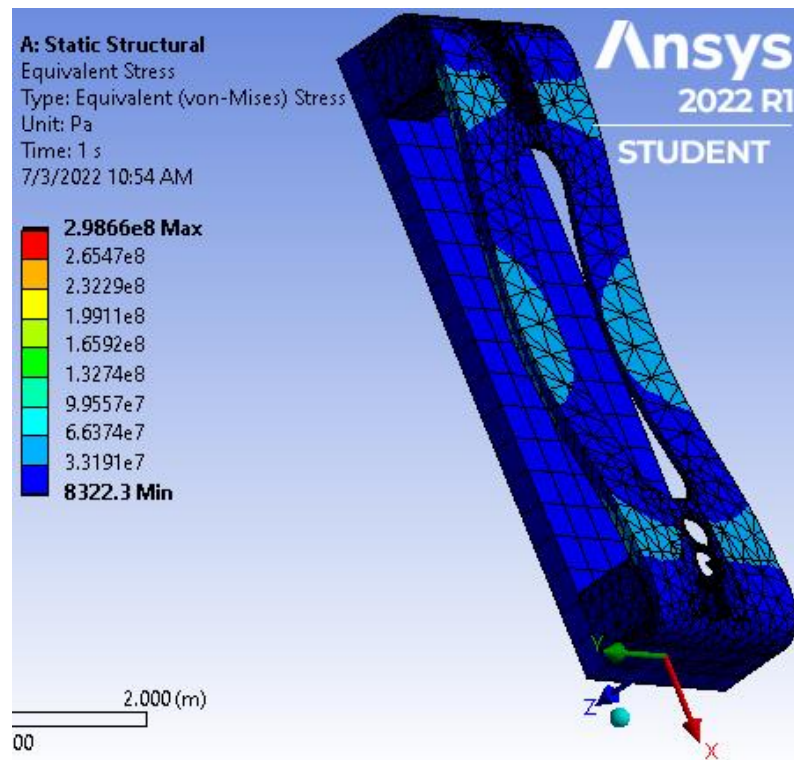


a) Total deformation on bus front part with bumper beam and crash box

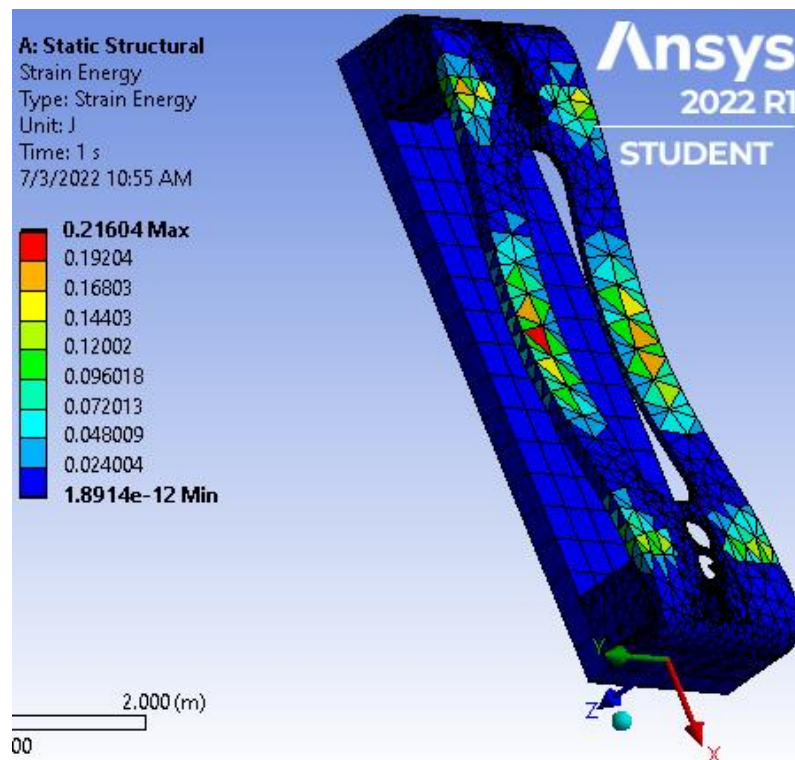


b)

c) Directional deformation on bus front part with bumper beam and crash box



d) Von-Mises stress on bus front part with bumper beam and crash box



e) Strain energy on bus front part with bumper beam and crash box

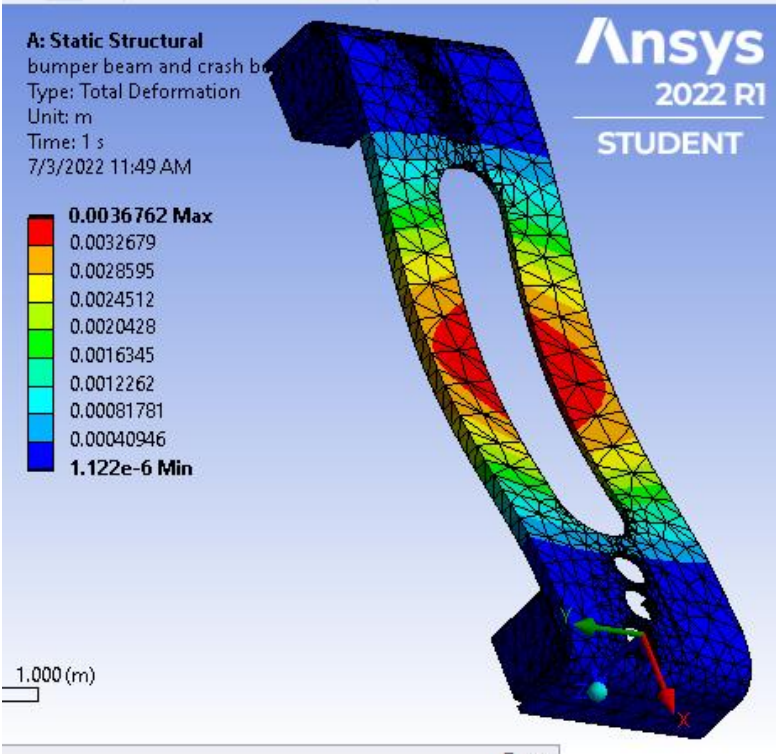
Figure 4. 5. Total deformation, directional deformation, Von-Mises stress and strain energy on assembly of Bus front part with bumper beam and crash box

The analysis is done on the front face of bus with considering bumper beam and crash box. The observed results from each figure are the simulation results of ANSYS software. Since, the collision load is concentrated to the center and the bus collides with its full face of bumper beam, the deformations, stresses, and strains are highest at the center of bumper beam and decreased to its end portions. The observed results in the figures 4.5 a, b, c, and d are total deformation, directional deformation, Von-Mises stress and Strain energy which have the maximum values of 0.0036762m, 0.003675m, 298.66 MPa 0.21604J respectively. The maximum values of total deformation, directional deformation, von-Mises stress, and stain are largest when bumper beam and crash box are considered. Therefore, this result shown that bumper beam and crash box has more advantage to absorb deformation, stress and strain during the collision of the bus rather than transmit the collision effect to the bus front part.

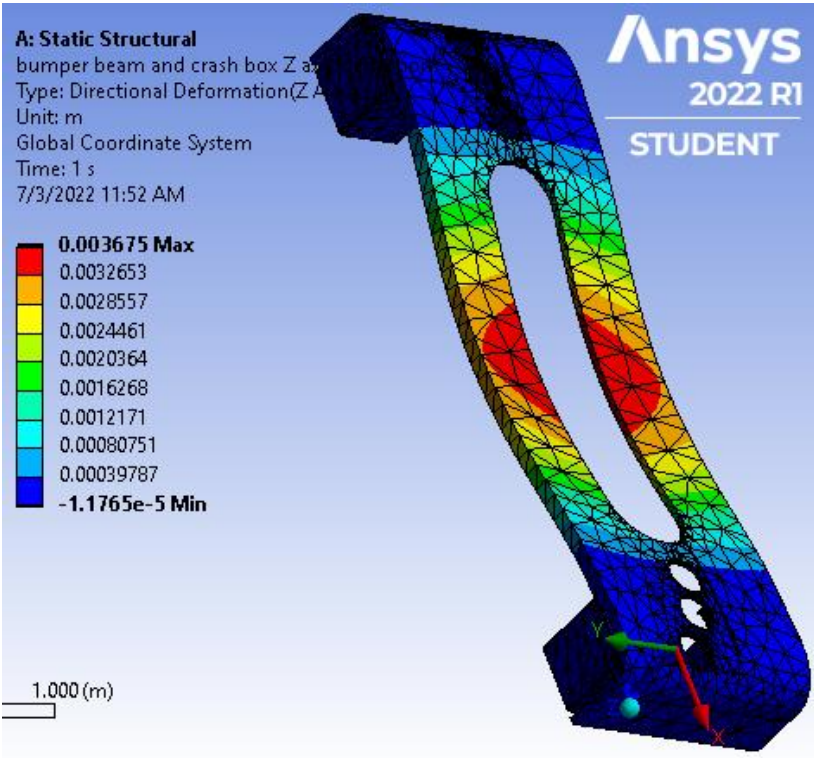
f) Bus Bumper Beam and Crash Box Energy Absorber parts

This section applies identification studies to the bumper beam and crash box from the overall assembly finite element findings in order to study the deformation, stress, and strain energy

of the bumper beam and crash box directly. As a result, the following findings from all bus bumper beam and crash box finite element analyses are shown in figure 4.6:



a) Total deformation on bumper beam with crash box



b) Directional deformation on bumper beam with crash box

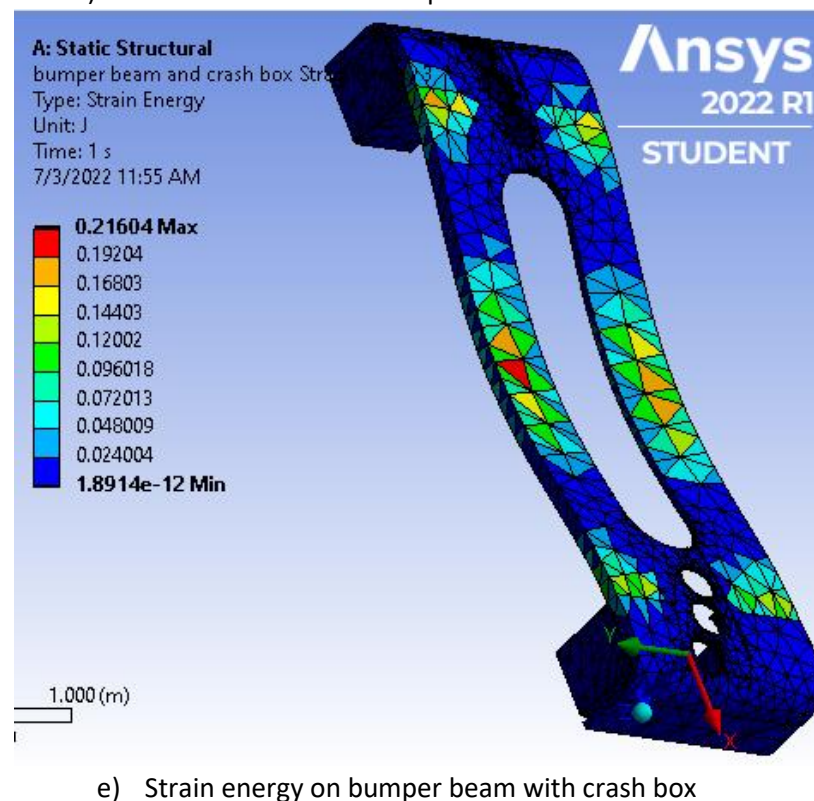
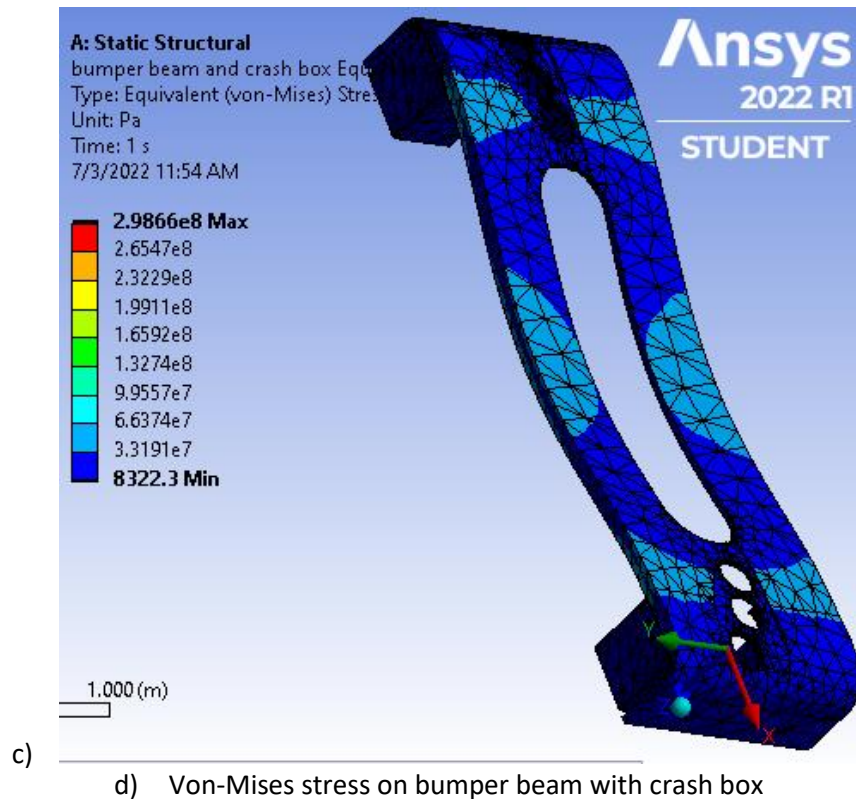


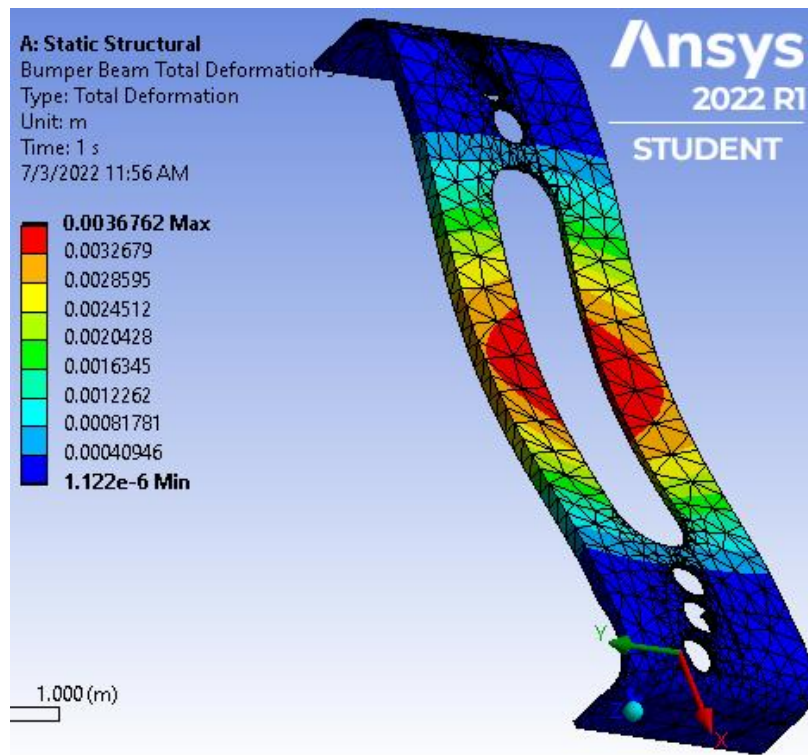
Figure 4. 6. Total deformation, directional deformation, Von-Mises stress and strain energy on assembly of bumper beam and crash box

The analysis is done with considering only the bumper beam and crash box. The observed results from each figure are the simulation results of ANSYS software. In this also the

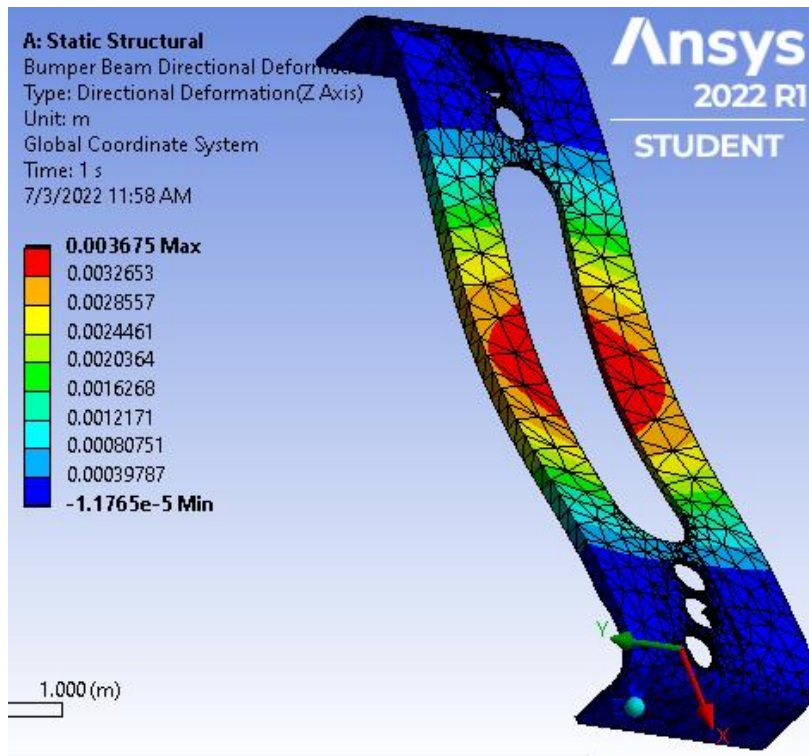
deformations, stresses, and strains are highest at the center of bumper beam and decreased to its end portions. The observed results in the figures 4.6 a, b, c, and d are total deformation, directional deformation, Von-Mises stress and Strain energy which have the maximum values of 0.0036762m, 0.003675m, 298.66 MPa 0.21604J respectively. The maximum values of total deformation, directional deformation, von-Mises stress, and stain are largest even though the analysis is only on the bumper beam and crash box. The results also shown that the maximum absorption occurred on the bumper beam and crash box. Therefore, this result shown that bumper beam and crash box has more advantage to absorb deformation, stress and strain during the collision of the bus to protect the bus front part from damage.

g) on bus bumper Beam

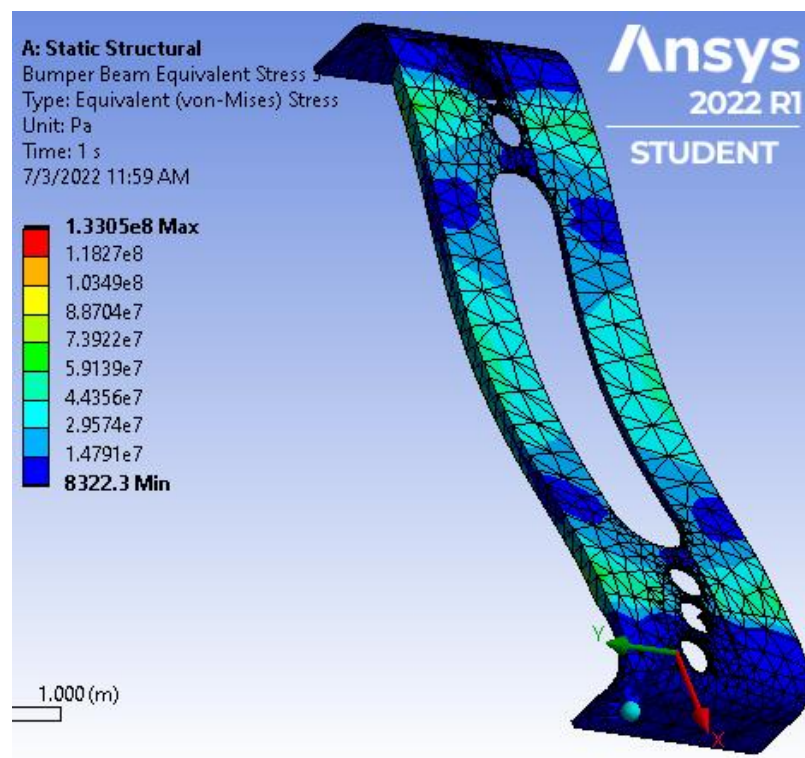
By using identification analyses on the bumper beam from the findings of the entire assembly finite element analysis, the deformation, stress, and strain energy of the bumper beam are directly studied in this section. As a result, the following results are shown in figure 4.7 below for the bumper beam of the bus:



a) Total deformation on bumper beam



b) directional deformation on bumper beam



c) Von-Mises stress on bumper beam

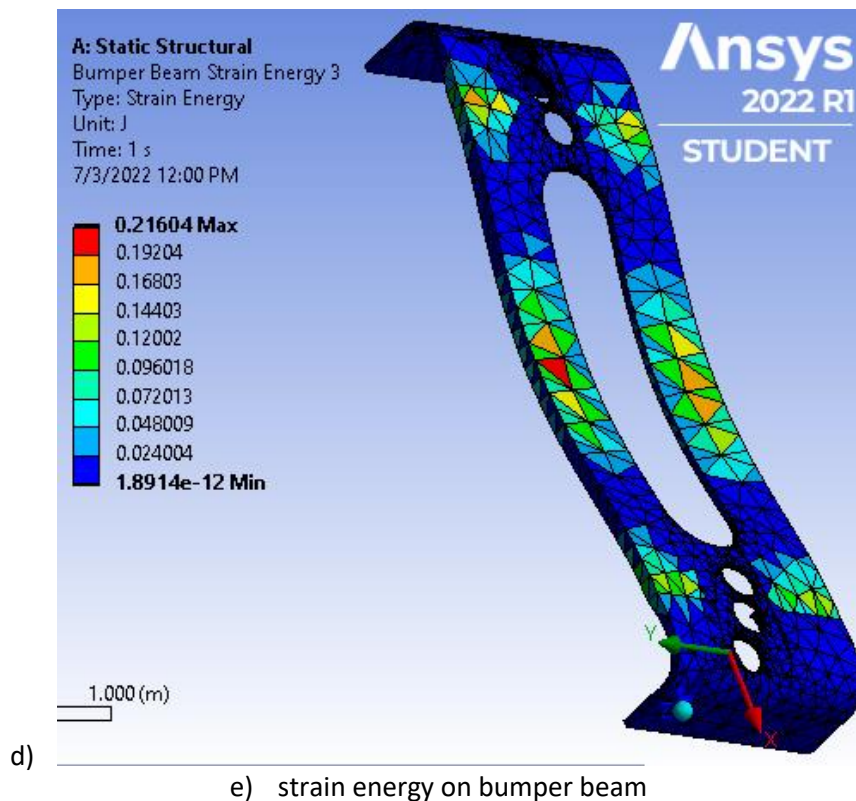
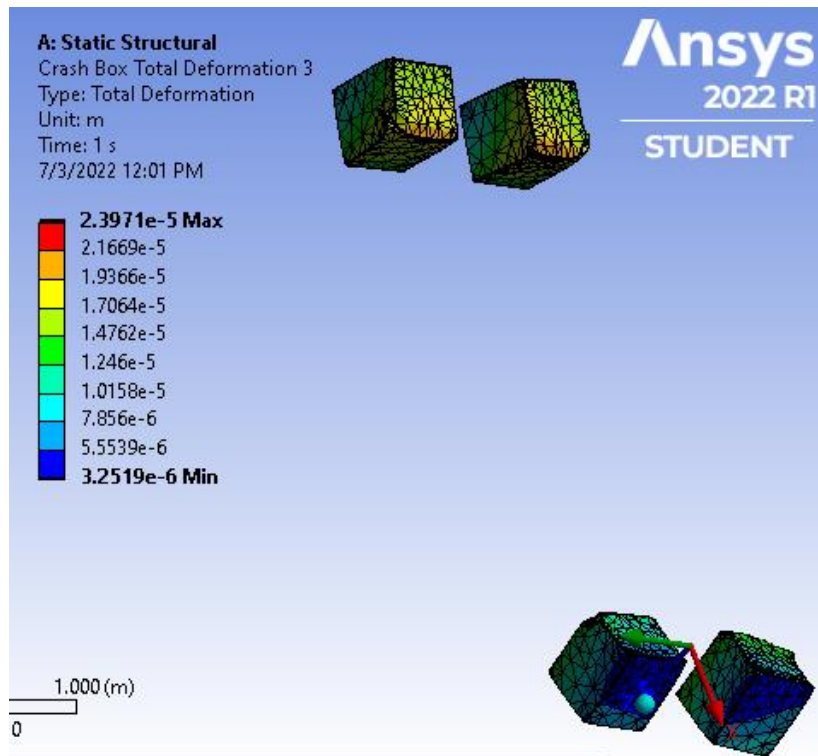


Figure 4. 7. Total deformation, directional deformation, Von-Mises stress and strain energy on bumper beam

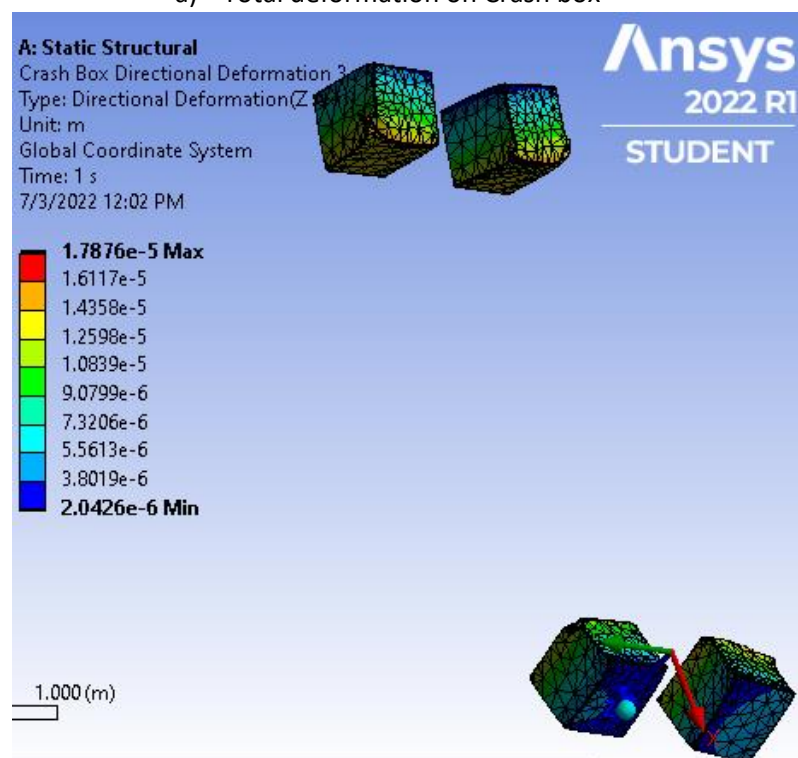
The analysis is done only on the bumper beam. The observed results from each figure are the simulation results of ANSYS software. In this also the deformations, stresses, and strains are highest at the center of bumper beam and decreased to its end portions. The observed results in the figures 4.7 a, b, c, and d are total deformation, directional deformation, Von-Mises stress and Strain energy which have the maximum values of 0.0036762m, 0.003675m, 298.66 MPa 0.21604J respectively. The maximum values of total deformation, directional deformation, von-Mises stress, and stain are largest even though the analysis is only on the bumper beam. The results shown that, the maximum absorption occurred on the bumper beam of bus. Therefore, this result shown that bumper beam has most advantage to absorb deformation, stress and strain energy during the collision of the bus to protect the damage of the bus crash box and front part

h) on bus crash box

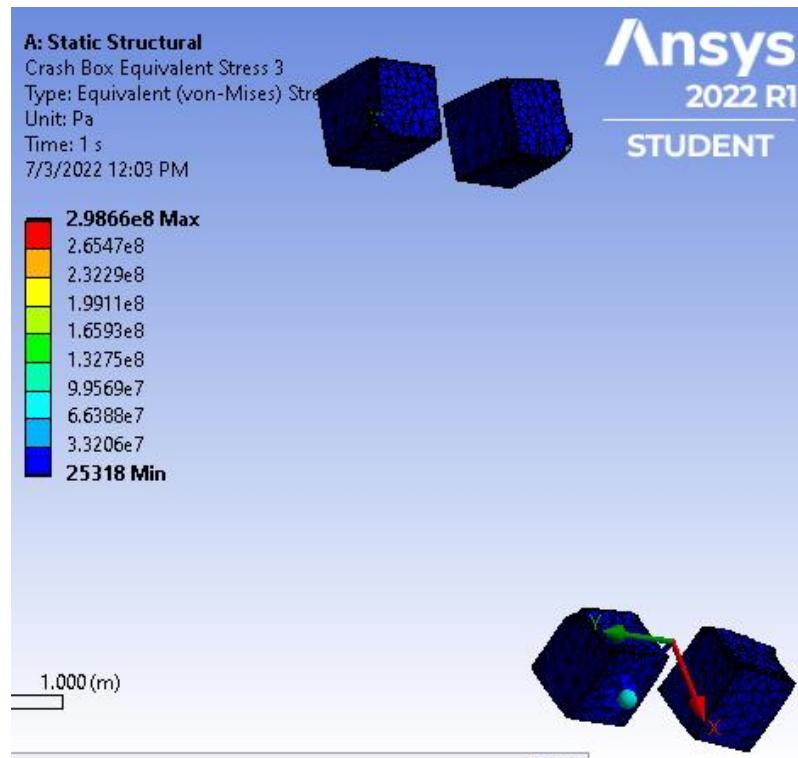
This section applies identification studies to the crash box based on the results of the total assembly finite element analysis to assess the deformation, stress, and strain energy of the crash box directly. As a result, the following results from the crash box of bus finite element studies are shown in figure 4.8 below:



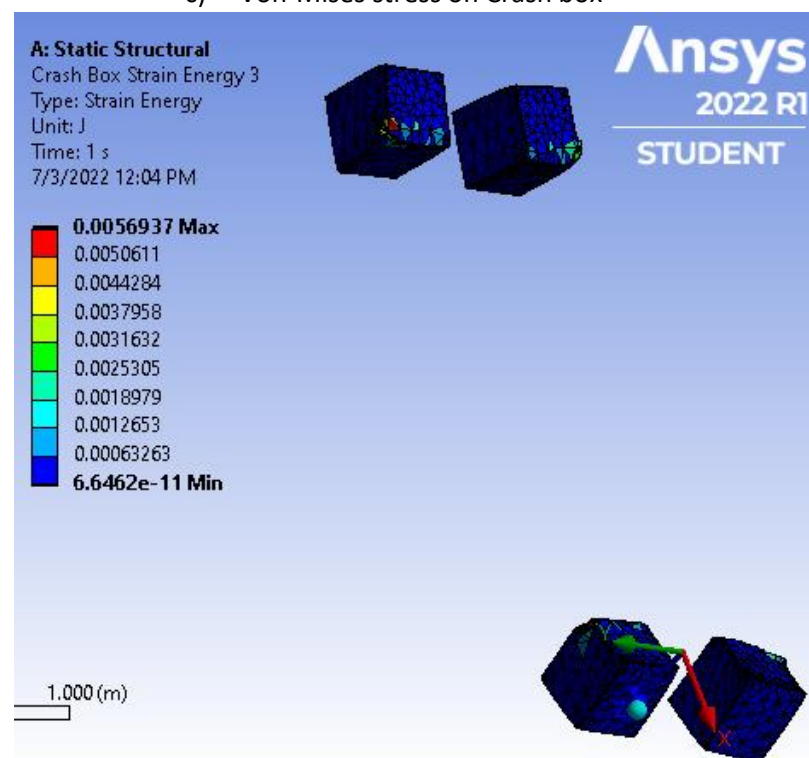
a) Total deformation on Crash box



b) directional deformation on Crash box



c) Von-Mises stress on Crash box



d) strain energy on Crash box

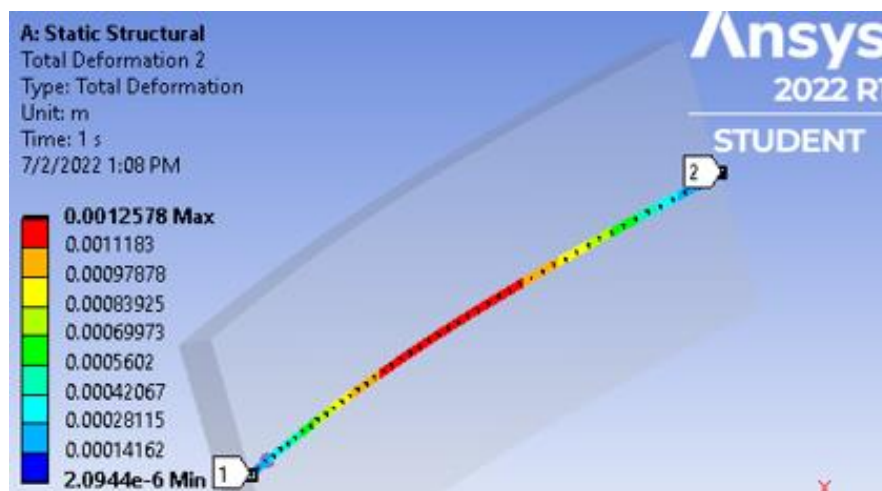
Figure 4. 8. Total deformation, directional deformation, Von-Mises stress and strain energy on crash box

The analysis is done on the crash box. The observed results from each figure are the simulation results of ANSYS software. Since, more absorption is observed on the bumper

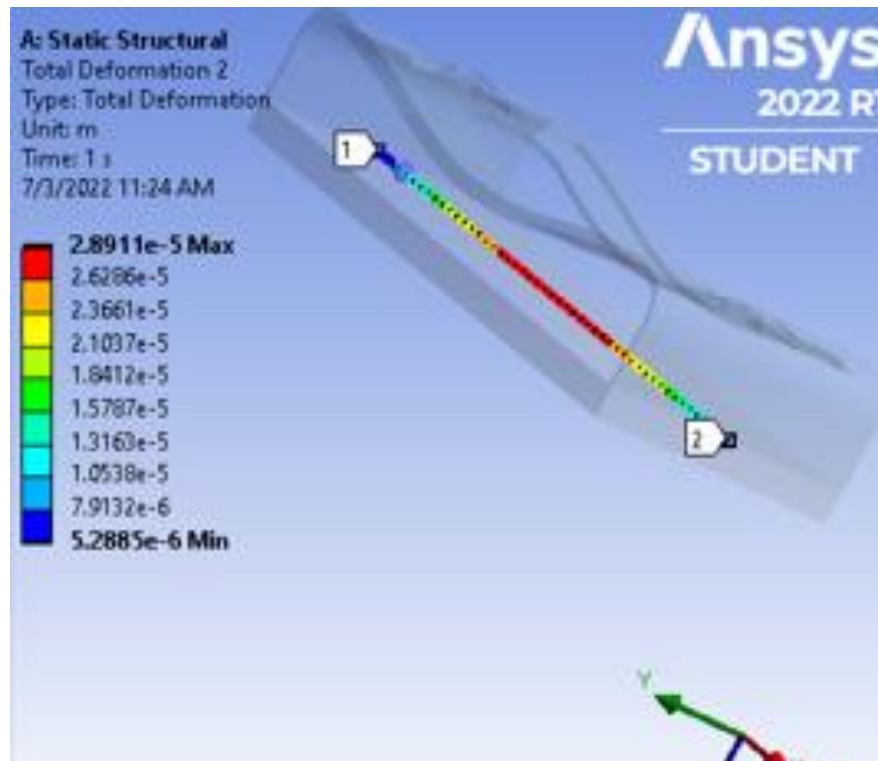
beam, the the results of absorption analysis of deformations, and strains are lower than results occurred on bumper beam and the value of stress is constant. The observed results in the figures 4.8 a, b, c, and d are total deformation, directional deformation, Von-Mises stress and Strain energy which have the maximum values of $2.397 \times 10^{-5} \text{m}$, $1.7876 \times 10^{-5} \text{m}$, 0.003675m , 298.66 MPa , 0.0056937J respectively. The maximum values of total deformation, directional deformation, von-Mises stress, and stain are largest even though the analysis is only on the bumper beam. The results also shown that the maximum absorption occurred on the crash box is lower than bumper beam absorption. Therefore, this result shown that the energy absorption decreases from bumper beam to crash box and bumper beam has most advantage to absorb deformation, stress and strain energy during the collision of the bus to protect the damage of the bus crash box and front part

4.6. Comparison without and with Bumper Beam and Crash Box

This part of the study confirms the bus's front part deflection, stress, and energy absorption capacities both with and without the bus's bumper beam and crash box. The lateral static analysis are the main focus. To confirm the developed stress and safty of the parts, the stresses are also compared with the yield strength of the chosen material and stated as follows.



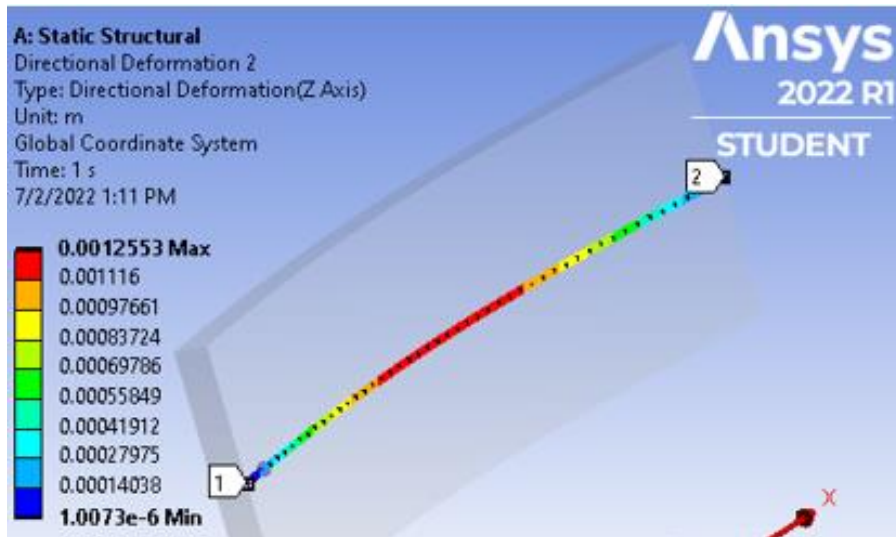
a) Total deformation of front part without the bumper beam and crash box



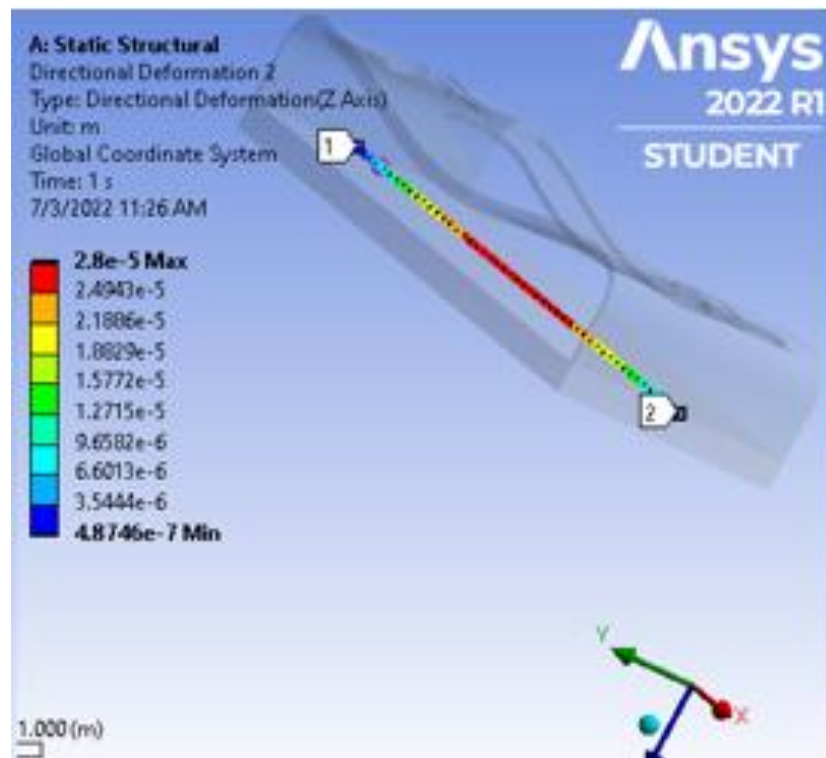
b) Total deformation of front part with the bumper beam and crash box

Figure 4. 9. The difference of total deformation values

The analysis is done on front part of the bus without and with bumper beam and crash box. The observed results from each figure are the simulation results of ANSYS software. The observed total deformation results in the figure 4.9 a, and b are 0.0012578m , and $2.8911 \times 10^{-5}\text{m}$ respectively. Since, more deformation is absorbed on the bumper beam and crash box, the total deformation is smaller on the front part of the bus. Therefore, this result shown that the total deformation decreases from bumper beam to crash box then to front part of bus. The bus front part decreases its total deformation by $1.228889 \times 10^{-3}\text{m}$ using bumper beam and crash box. So, it is concluded that the bumper beam and crash box has most advantage to absorb total deformation during the collision of the bus to protect the damage of the bus front part.



a) Directional deformation of front part without the bumper beam and crash box



b) directional deformation of front part with the bumper beam and crash box

Figure 4. 10. Directional deformation values

The analysis is done on front part of the bus without and with bumper beam and crash box. The observed results from each figure are the simulation results of ANSYS software. The observed directional deformation results in the figure 4.10 a, and b are 0.0012553m, and 2.8×10^{-5} m respectively. Since, more directional deformation is absorbed on the bumper beam and crash box, the directional deformation is smaller on the front part of the bus. Therefore, this result shown that the directional deformation decreases from bumper beam

to crash box then to front part of bus. The bus front part decreases its directional deformation by $1.2273 \times 10^{-3} \text{m}$ using bumper beam and crash box. So, it is concluded that the bumper beam and crash box has most advantage to absorb directional deformation during the collision of the bus to protect the damage of the bus front part. For more information, see figure 4.11.

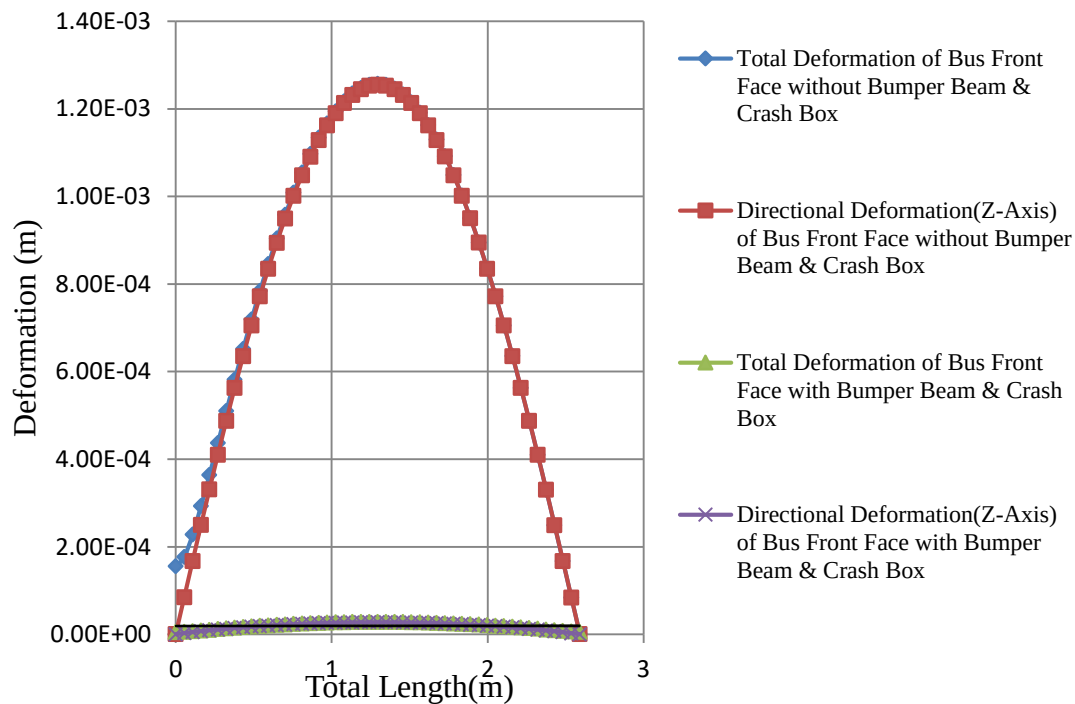
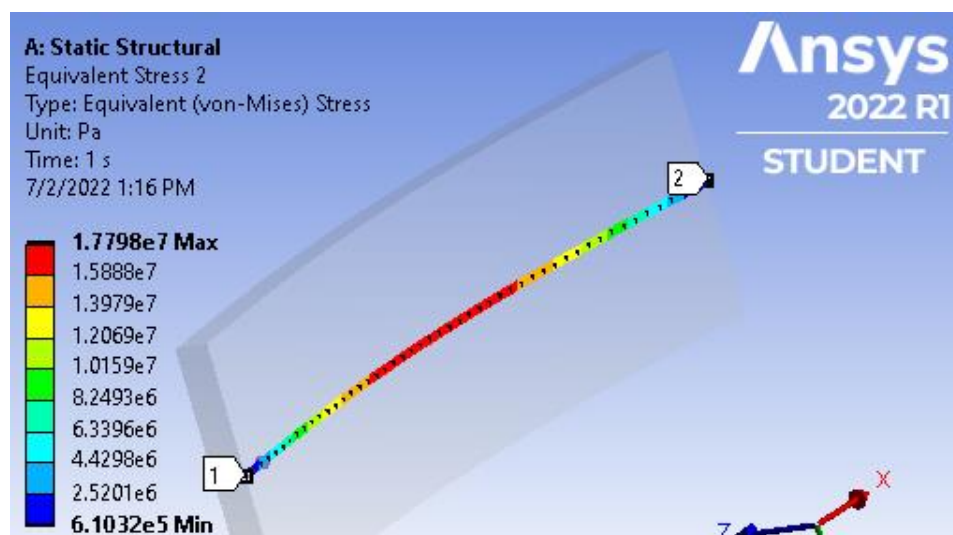


Figure 4. 11. Total Deformation and Directional deformation



a) Von-Mises stress of front part without the bumper beam and crash box

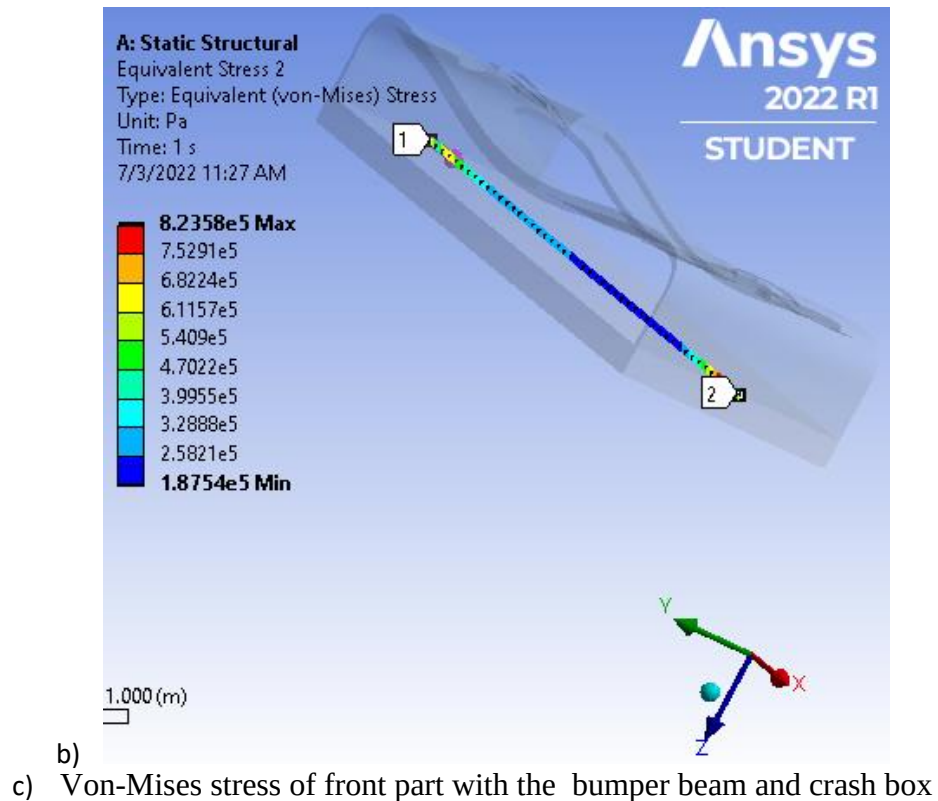


Figure 4. 12. The difference of von-mises stress values

The analysis is done on front part of the bus without and with bumper beam and crash box. The observed results from each figure are the simulation results of ANSYS software. The observed von-Mises stress results in the figure 4.12 a, and b are 17.798 MPa and 0.82358 MPa respectively. Since, more von-Mises stress is absorbed on the bumper beam and crash box, the von-Mises stress is smaller on the front part of the bus. Therefore, this result shown that the von-Mises stress decreases from bumper beam to crash box then to front part of bus. The bus front part decreases its von-Mises stress by 16.9MPa using bumper beam and crash box. So, it is concluded that the bumper beam and crash box has most advantage to absorb von-Mises stress during the collision of the bus to protect the damage of the bus front part. For more information, see figure 4.11.

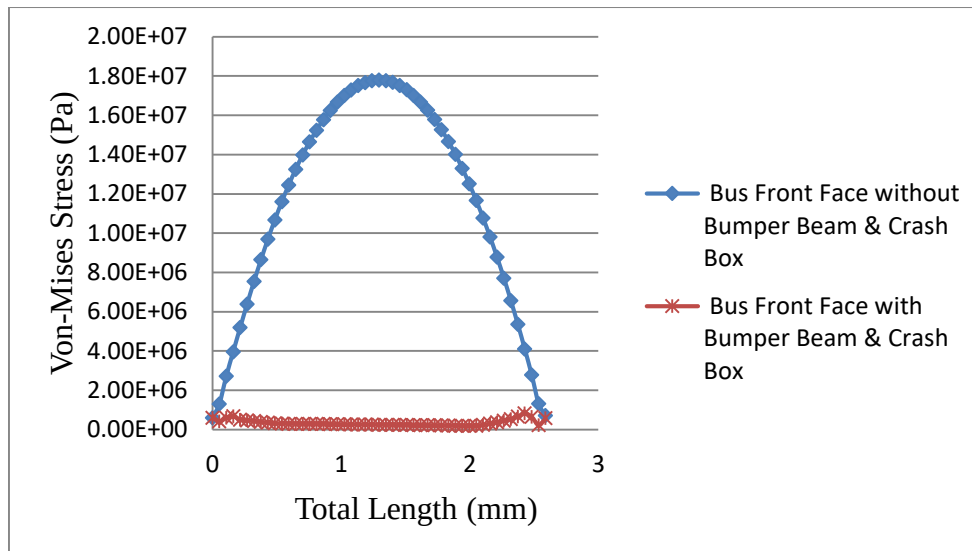
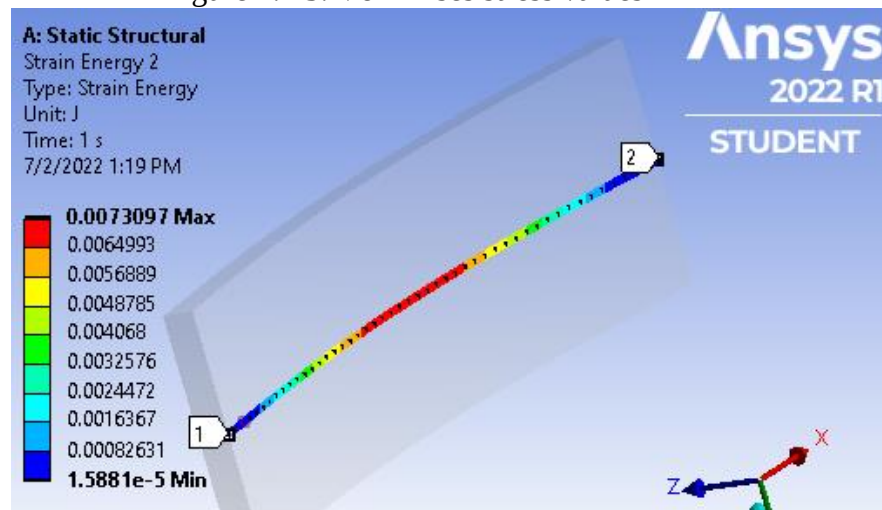
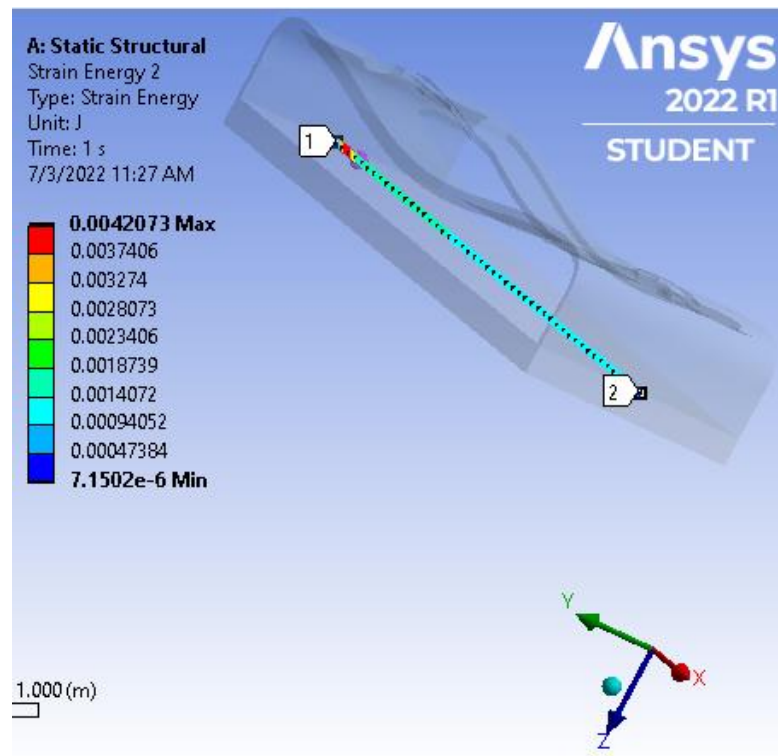


Figure 4. 13. Von-mises stress values



a) strain energy of front part without the bumper beam and crash box



b) strain energy of front part with the bumper beam and crash box

Figure 4. 14. The difference of strain energy values

The analysis is done on front part of the bus without and with bumper beam and crash box. The observed results from each figure are the simulation results of ANSYS software. The observed strain energy results in the figure 4.14 a, and b are 0.0073097J and 0.0042073J respectively. Since, more strain energy is absorbed on the bumper beam and crash box, the strain energy is smaller on the front part of the bus. Therefore, this result shown that the strain energy decreases from bumper beam to crash box then to front part of bus. The bus front part decreases its strain energy by $3.1024 \times 10^{-3} \text{J}$ using bumper beam and crash box. So, it is concluded that the bumper beam and crash box has most advantage to absorb strain energy during the collision of the bus to protect the damage of the bus front part. For more information, see figure 4.11.

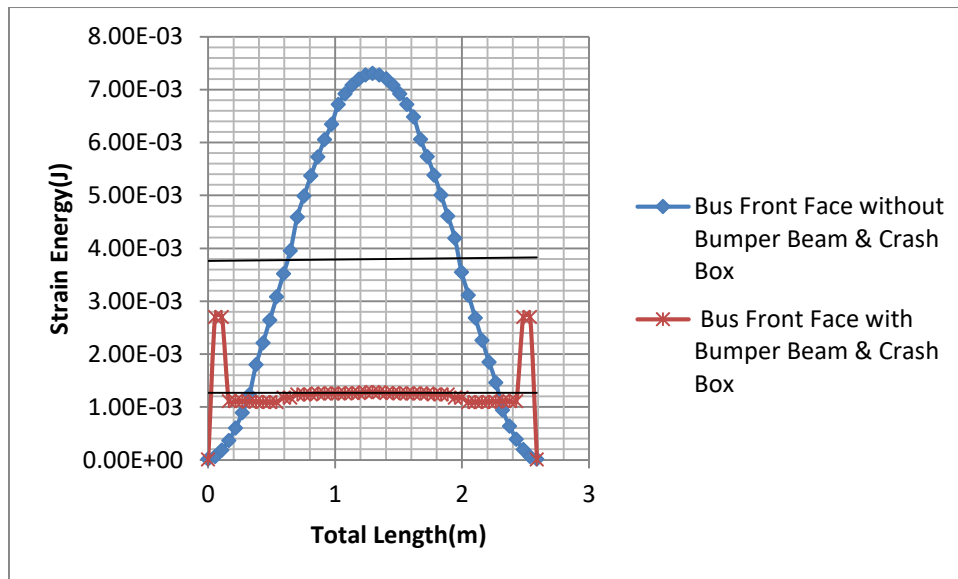


Figure 4. 15. Strain energy

The graph demonstrates that the bus front face is subjected to the least amount of deformation, stress, and strain with the presence of bumper beam and crash box because more energy is absorbed on bumper beam and crash box. As a result, the percentage of deformation, stress, and strain energy of the bumper beam and crash box are reduced, as illustrated in figure 4.16-19.

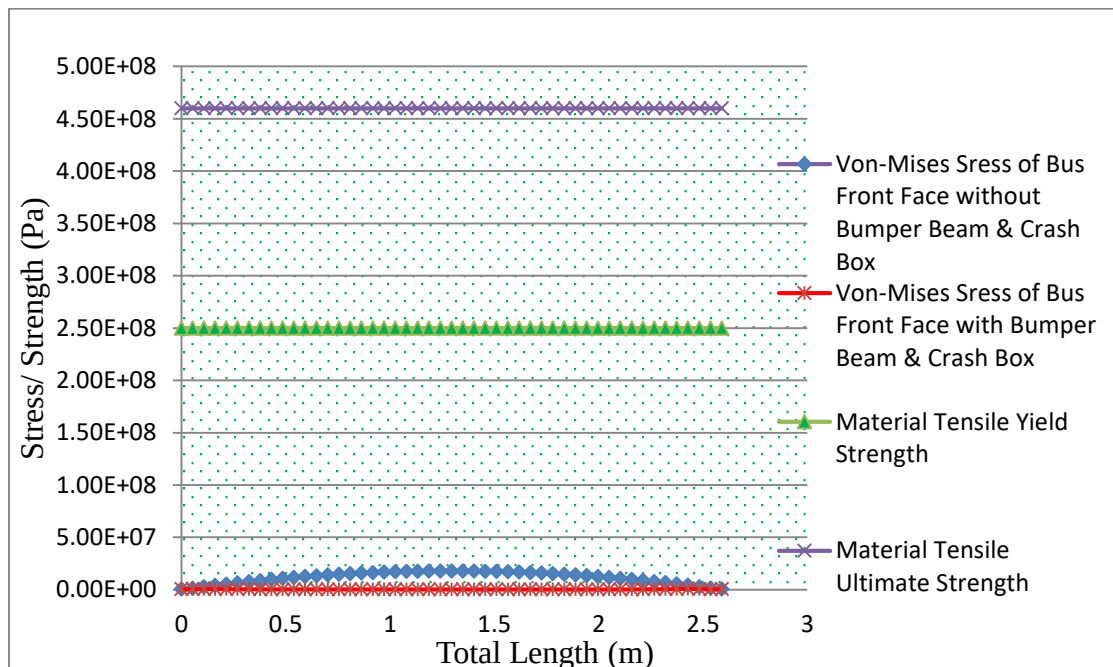


Figure 4. 16. Von-Mises stress and Yield strength

The analysis in figure 4.16 shown that the comparison and effects of the bumper beam and crash box on the strength of the material. The graph obviously shown that the material

ultimate strength is greater than tensile strength and the analyzed von-Mises stresses are below the tensile strength of the material, which indicates the analysis is in good safety factor. Moreover, the von-Mises stress on the front part of the bus is minimum when the bumper beam and crash box is considered.

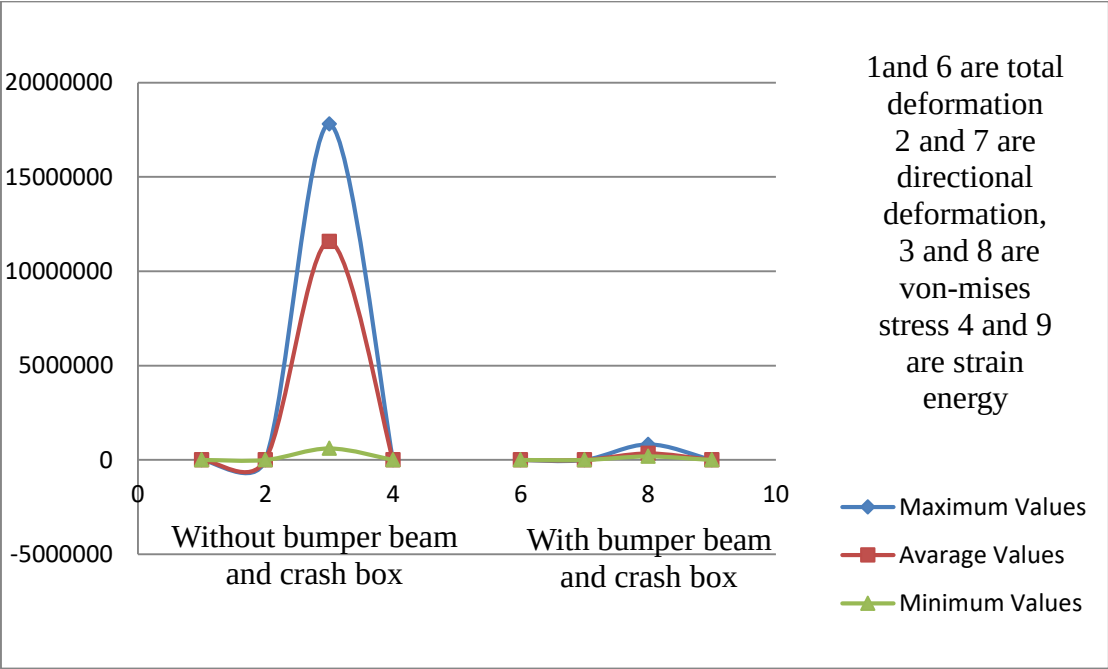


Figure 4. 17. Bumper beam and crash box effects on front part of bus

The analysis in figure 4.17 shown that the comparison and effects of the bumper beam and crash box on the total deformation, directional deformation, von-Mises stress and strain energy. The graph obviously shown that the parameters effect values on bus front part without bumper beam and crash box are greater than with bumper beam and crash box.

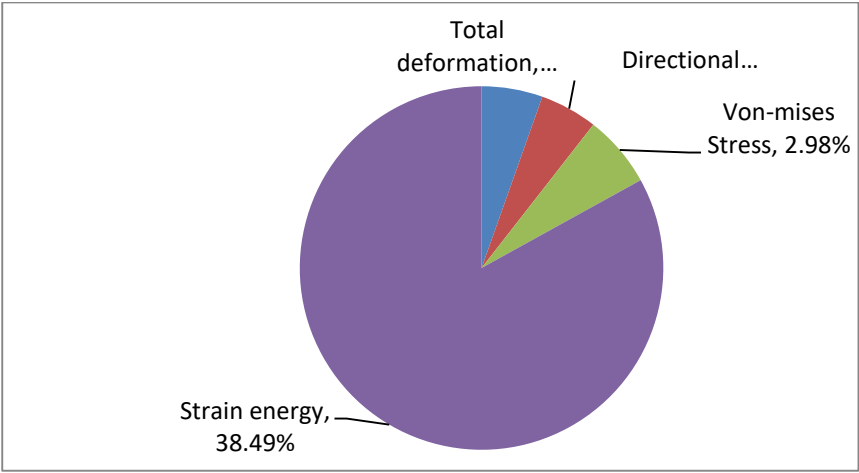


Figure 4. 18. Strain energy, deformation, and stress on bus frontal part using average effect of bumper beam and crash box

The analysis in figure 4.18 shown that the comparison and effects of the bumper beam and crash box on the average total deformation, average directional deformation, average von-Mises stress and average strain energy. The graph obviously shown that the advantage of the parameters effect values on bus front part with bumper beam and crash box are 2.52% total deformation, 2.37% directional deformation, 2.98% von-Mises stress and 38.49% strain energy.

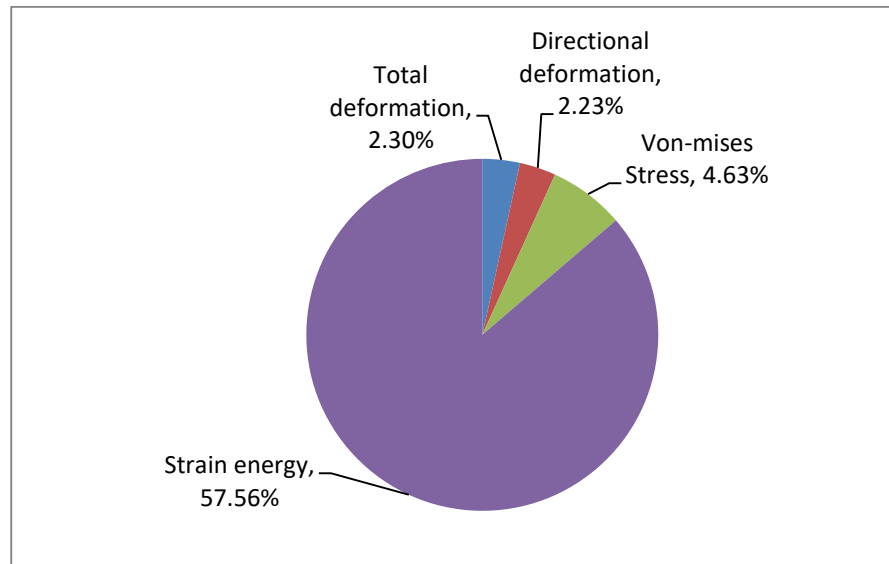


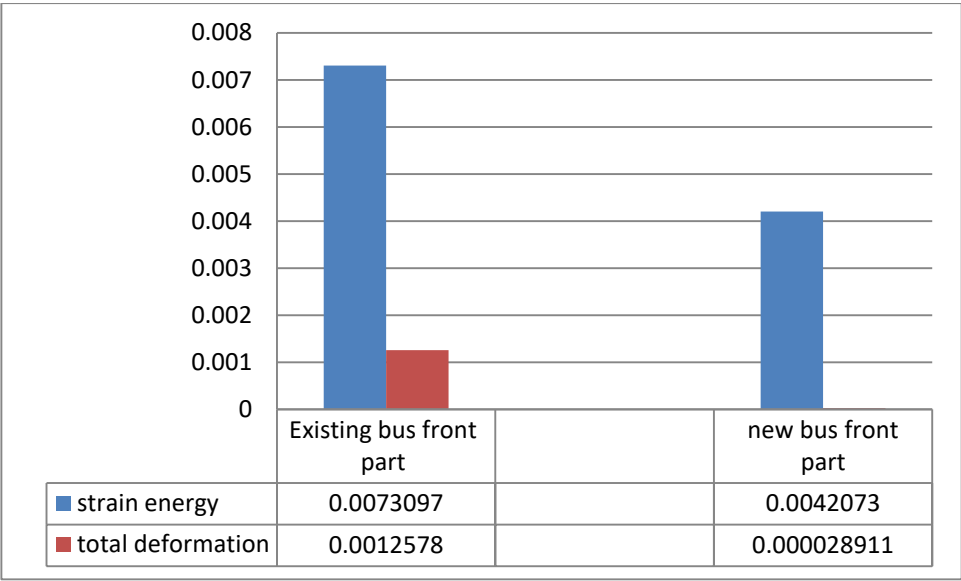
Figure 4. 19. Strain energy, deformation, and stress on bus frontal part using maximum effect of bumper beam and crash box

The comparison and effects of the bumper beam and crash box on the maximum total deformation, maximum directional deformation, maximum von-Mises stress and maximum strain energy are shown in figure 4.19. The graph obviously shown that the maximum advantage of the parameters effect values on bus front part with bumper beam and crash box are 2.30% total deformation, 2.23% directional deformation, 4.63% von-Mises stress and 57.56% strain energy.

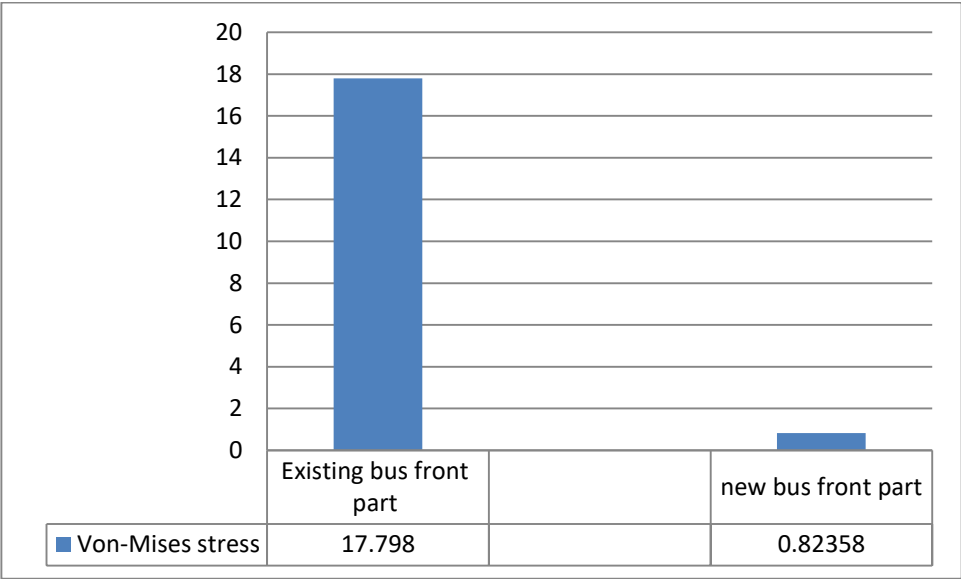
4.7. Validation of bumper beam and crash box energy absorption

Validation of energy absorption on the bishoftu bus bumper beam and crash box is analyzed by comparing the existing bus front part absorption with the new bus front part absorption since it is new design and no experimental and published papers for bushoftu bus bumper beam and crash box. The figure 4.20 indicates the difference of bus front part deformation, von- Mises stress and strain values without and with bumper beam and crash box. So, the results of the graph shown at a) compared deformation and strain energy values of existing and new front part of the bus and b) compared von-Mises stress values of existing and new

front part of the bus.



a) strain and deformation validation of existing bus and new bus front part



b) Von-Mises stress validation of existing bus and new bus front part

Figure 4. 20 validation results of energy absorption on bishoftu bus front part

CHAPTER FIVE

5.1 Summary

The most important thing to do to enhance energy absorption performance is to add an impact load protection system to the front face to defend against adverse consequences that may result from vehicle collisions. Reverse C Profile (RCP) geometry, 18000 kg mass, 30 km/h bus crash speed, and PC/0.5 wt.% Nano Alumina (Nano composite foam) material are chosen for this study because they have an impact on the energy absorption of the bumper and crash of the frontal face of the Bishoftu Bus to prevent damage to the chassis and passengers.

SOLIDWORKS 18 was used in this study to create the frontal bumper and crash box models. SOLIDWORKS 18 modeling, ANSYS 22 Workbench simulation, By modeling, analyzing, and simulating the impact load effect, the best energy absorber bumper and Crash-box model were created in order to enhance the energy absorption on the frontal face of the Bishoftu bus. By taking into account the impact of the bumper beam and crash box on the frontal face of the bus, the verification and validation of energy absorption was carried out. The highest results of deformation, stress, and strain energy on the frontal face of the bus are $1.26\text{E-}03$ m, $1.78\text{E}+07$ Pa, and $7.31\text{E-}03$ J, respectively, without taking into account the bumper and crash box. While the maximum deformation, stress, and strain energy on the frontal face of the bus are $2.89\text{E-}05$ m, $8.24\text{E}+05$ Pa, and $4.21\text{E-}03$ J, respectively, when the bumper and crash box are taken into account.

The validation are done in this work by considering Bishoftu bus front part energy absorption capacity and its capacity after designing bumper beam and crash box. But, verification is done depending on the analytical analysis which used to verify the work is done correctly.

Thus, the average percentage advantage of the bumper beam and crash box on strain energy, total deformation, and alternative stress are each 38.49%, 2.52%, and 2.98%, respectively. The maximal percentage advantage of the bumper beam and crash box is 57.56% for strain energy, 2.30% for total deformation, and 4.63% for alternative stress. As a result, the data also shows that using this specially built bumper beam and crash box on the front of the Bishoftu bus has the advantage of absorbing energy between 38.49% and 57.56%.

Therefore, it is recommended to take into account the bumper beam and crash box influence on maximum speed, average speed, and on both vehicle dynamic accidents in order to improve more energy absorption.

5.2 Conclusion

Design and analysis of the front bumper beam and crash box energy absorption on the Bishoftu bus were explored in this research work. Reverse C Profile (RCP) geometry, 18000 kg mass, 30 km/h bus crash speed, and PC/0.5 wt.% Nano Alumina (Nano composite foam) material are chosen in this study because they affect how much energy is absorbed by the bumper and by the vehicle's frontal face, protecting the chassis and the people inside. SOLIDWORK 18 and FEM (ANSYS 2022 Workbench) are used for the modeling and numerical analysis, respectively. The average advantage of the bumper beam and crash box on strain energy, total deformation, and alternative stress are each 38.49%, 2.52%, and 2.98%, respectively. The maximum advantage of the bumper beam and crash box is 57.56% for strain energy, 2.30% for total deformation, and 4.63% for Von-mises stress. Using this specially created bumper beam and crash box on the front of the Bishoftu bus has the advantage of energy absorption of 38.49% to 57.56%.

5.3 Recommendations

The study only focused at the slower-speed accident between the similar stationary bus and the Bishoftu bus. This thesis work highlights the collision load that affected the frontal aspect of the bus in the middle. Therefore, it is suggested to take into consideration the bumper beam and crash box influence on maximum speed, average speed, and on both vehicle dynamic accidents in order to improve more energy absorption. More research is required to determine the energy absorption on the bumper beam and crash box in accidents involving various load configurations and loading positions. It is recommended to model and simulate using alternative software to SOLIDWORK and ANSYS in order to obtain more accurate results for energy absorption.

5.4 Future Scope of Work

More research is required, taking into account the dynamical impacts of various materials. The study of energy absorbers can take into account the impacts of varying temperature, varying weights, varying load angles, and varying vehicle model crashes. In the investigation, bumper beam and collision box simulations at various vehicle speeds are also

required. Additionally, it is advised to research how a vehicle's energy absorber reacts to collisions with various objects. Additionally, it needs to be researched when a car crashes with objects of various shapes. Finally, different mechanisms other than bumper beam and crash box need to be examined when looking at the energy absorber.

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APPENDICES

Appendix I

Table A. 1. The strain energy finite element results of bus frontal face

No.	Length	Strain energy without bumper beam and crash box (in J)	Strain energy with bumper beam and crash box (in J)
1	0	1.59E-05	1.15E-05
2	5.40E-02	6.61E-05	2.70E-03
3	0.10792	1.86E-04	2.70E-03
4	0.16187	3.65E-04	1.11E-03
5	0.21583	6.03E-04	1.11E-03
6	0.26979	8.95E-04	1.11E-03
7	0.32375	1.23E-03	1.10E-03
8	0.37771	1.80E-03	1.10E-03
9	0.43167	2.21E-03	1.10E-03
10	0.48562	2.64E-03	1.10E-03
11	0.53958	3.08E-03	1.10E-03
12	0.59354	3.52E-03	1.18E-03
13	0.6475	3.96E-03	1.18E-03
14	0.70146	4.59E-03	1.24E-03
15	0.75542	4.99E-03	1.24E-03
16	0.80937	5.37E-03	1.24E-03
17	0.86333	5.73E-03	1.25E-03
18	0.91729	6.05E-03	1.25E-03
19	0.97125	6.34E-03	1.26E-03
20	1.0252	6.72E-03	1.26E-03

21	1.0792	6.92E-03	1.26E-03
22	1.1331	7.08E-03	1.26E-03
23	1.1871	7.20E-03	1.26E-03
24	1.241	7.28E-03	1.28E-03
25	1.295	7.31E-03	1.28E-03
26	1.349	7.28E-03	1.28E-03
27	1.4029	7.20E-03	1.26E-03
28	1.4569	7.08E-03	1.26E-03
29	1.5108	6.92E-03	1.26E-03
30	1.5648	6.72E-03	1.26E-03
31	1.6188	6.48E-03	1.26E-03
32	1.6727	6.06E-03	1.25E-03
33	1.7267	5.74E-03	1.25E-03
34	1.7806	5.38E-03	1.24E-03
35	1.8346	5.01E-03	1.24E-03
36	1.8885	4.61E-03	1.24E-03
37	1.9425	4.19E-03	1.18E-03
38	1.9965	3.55E-03	1.18E-03
39	2.0504	3.12E-03	1.10E-03
40	2.1044	2.68E-03	1.10E-03
41	2.1583	2.26E-03	1.10E-03
42	2.2123	1.85E-03	1.10E-03
43	2.2663	1.46E-03	1.10E-03
44	2.3202	9.39E-04	1.11E-03

45	2.3742	6.39E-04	1.11E-03
46	2.4281	3.88E-04	1.11E-03
47	2.4821	1.94E-04	2.70E-03
48	2.536	6.64E-05	2.70E-03
49	2.59	1.78E-05	1.15E-05

Table A. 2. The deformation finite element results of bus frontal face

Length	Total Deformation without Bumper Beam & Crash Box	Directional Deformation without Bumper Beam & Crash Box	Total Deformation with Bumper Beam & Crash Box	Directional Deformation with Bumper Beam & Crash Box
0	1.56E-04	1.28E-06	5.29E-06	5.41E-07
5.40E-02	1.77E-04	8.47E-05	5.99E-06	2.91E-06
0.10792	2.28E-04	1.68E-04	7.42E-06	5.29E-06
0.16187	2.94E-04	2.50E-04	9.10E-06	7.50E-06
0.21583	3.65E-04	3.31E-04	1.07E-05	9.45E-06
0.26979	4.37E-04	4.10E-04	1.24E-05	1.13E-05
0.32375	5.10E-04	4.88E-04	1.40E-05	1.30E-05
0.37771	5.82E-04	5.63E-04	1.56E-05	1.47E-05
0.43167	6.52E-04	6.36E-04	1.71E-05	1.62E-05
0.48562	7.20E-04	7.05E-04	1.85E-05	1.77E-05
0.53958	7.84E-04	7.72E-04	1.98E-05	1.90E-05
0.59354	8.46E-04	8.35E-04	2.10E-05	2.03E-05
0.6475	9.04E-04	8.94E-04	2.22E-05	2.14E-05
0.70146	9.59E-04	9.50E-04	2.32E-05	2.25E-05

0.75542	1.01E-03	1.00E-03	2.42E-05	2.34E-05
0.80937	1.06E-03	1.05E-03	2.51E-05	2.43E-05
0.86333	1.10E-03	1.09E-03	2.59E-05	2.51E-05
0.91729	1.13E-03	1.13E-03	2.66E-05	2.58E-05
0.97125	1.17E-03	1.16E-03	2.72E-05	2.64E-05
1.0252	1.19E-03	1.19E-03	2.77E-05	2.69E-05
1.0792	1.22E-03	1.21E-03	2.81E-05	2.73E-05
1.1331	1.24E-03	1.23E-03	2.85E-05	2.76E-05
1.1871	1.25E-03	1.24E-03	2.87E-05	2.78E-05
1.241	1.26E-03	1.25E-03	2.89E-05	2.80E-05
1.295	1.26E-03	1.26E-03	2.89E-05	2.80E-05
1.349	1.25E-03	1.25E-03	2.89E-05	2.80E-05
1.4029	1.25E-03	1.24E-03	2.88E-05	2.78E-05
1.4569	1.23E-03	1.23E-03	2.85E-05	2.76E-05
1.5108	1.22E-03	1.21E-03	2.82E-05	2.73E-05
1.5648	1.19E-03	1.19E-03	2.79E-05	2.68E-05
1.6188	1.16E-03	1.16E-03	2.74E-05	2.63E-05
1.6727	1.13E-03	1.13E-03	2.68E-05	2.57E-05
1.7267	1.09E-03	1.09E-03	2.61E-05	2.50E-05
1.7806	1.05E-03	1.05E-03	2.54E-05	2.43E-05
1.8346	1.00E-03	1.00E-03	2.46E-05	2.34E-05
1.8885	9.51E-04	9.50E-04	2.36E-05	2.24E-05
1.9425	8.95E-04	8.95E-04	2.26E-05	2.13E-05
1.9965	8.35E-04	8.35E-04	2.15E-05	2.02E-05

2.0504	7.72E-04	7.72E-04	2.03E-05	1.89E-05
2.1044	7.06E-04	7.06E-04	1.90E-05	1.76E-05
2.1583	6.36E-04	6.36E-04	1.77E-05	1.61E-05
2.2123	5.63E-04	5.63E-04	1.62E-05	1.46E-05
2.2663	4.88E-04	4.88E-04	1.47E-05	1.29E-05
2.3202	4.10E-04	4.10E-04	1.31E-05	1.12E-05
2.3742	3.31E-04	3.31E-04	1.15E-05	9.29E-06
2.4281	2.50E-04	2.50E-04	9.86E-06	7.32E-06
2.4821	1.67E-04	1.67E-04	8.18E-06	5.09E-06
2.536	8.44E-05	8.44E-05	6.86E-06	2.74E-06
2.59	2.09E-06	1.01E-06	6.31E-06	4.87E-07

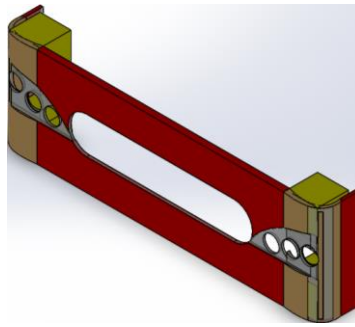
Table A. 3 Von-Mises stress finite element results of bus frontal face

Total Length	Equivalent(Von-Mises) Stress without Bumper Beam & Crash Box	Equivalent(Von-Mises) Stress with Bumper Beam & Crash Box
0	6.10E+05	6.06E+05
5.40E-02	1.31E+06	4.20E+05
0.10792	2.72E+06	5.96E+05
0.16187	3.97E+06	6.85E+05
0.21583	5.19E+06	5.11E+05
0.26979	6.39E+06	4.77E+05
0.32375	7.55E+06	4.32E+05
0.37771	8.65E+06	3.91E+05
0.43167	9.69E+06	3.57E+05
0.48562	1.07E+07	3.24E+05
0.53958	1.16E+07	3.07E+05
0.59354	1.25E+07	2.99E+05
0.6475	1.32E+07	2.94E+05

0.70146	1.40E+07	2.93E+05
0.75542	1.46E+07	2.90E+05
0.80937	1.52E+07	2.90E+05
0.86333	1.58E+07	2.85E+05
0.91729	1.63E+07	2.81E+05
0.97125	1.67E+07	2.77E+05
1.0252	1.70E+07	2.72E+05
1.0792	1.73E+07	2.67E+05
1.1331	1.75E+07	2.62E+05
1.1871	1.77E+07	2.57E+05
1.241	1.78E+07	2.53E+05
1.295	1.78E+07	2.49E+05
1.349	1.78E+07	2.46E+05
1.4029	1.77E+07	2.42E+05
1.4569	1.75E+07	2.40E+05
1.5108	1.73E+07	2.37E+05
1.5648	1.70E+07	2.34E+05
1.6188	1.67E+07	2.31E+05
1.6727	1.63E+07	2.27E+05
1.7267	1.58E+07	2.22E+05
1.7806	1.53E+07	2.17E+05
1.8346	1.47E+07	2.07E+05
1.8885	1.40E+07	1.99E+05
1.9425	1.33E+07	1.90E+05
1.9965	1.25E+07	1.88E+05
2.0504	1.17E+07	1.97E+05
2.1044	1.08E+07	2.38E+05
2.1583	9.81E+06	3.04E+05
2.2123	8.78E+06	3.72E+05
2.2663	7.70E+06	4.48E+05

2.3202	6.56E+06	5.35E+05
2.3742	5.36E+06	6.62E+05
2.4281	4.11E+06	8.24E+05
2.4821	2.78E+06	6.53E+05
2.536	1.33E+06	2.21E+05
2.59	7.09E+05	5.82E+05

Appendix II



a) Isometric view



b) Top view

Figure A. 1. 3D modeling of Bishoftu Bus Bumper and crash box, a) isometric view, b) top view



a)



b)

Figure A. 2. 3D part Modeling of Bishoftu Bus Bumper beam and Crash box a) front view and b) back view

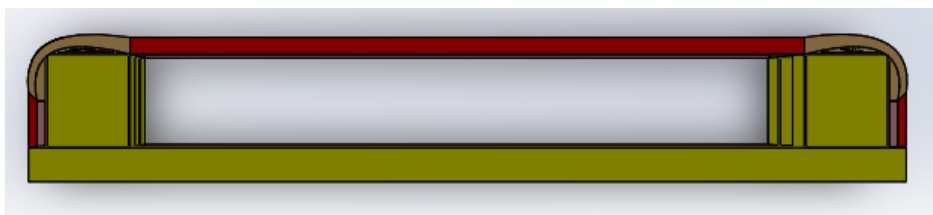


Figure A. 3. 3D modeling of Bishoftu Bus Bumper and crash box front view.

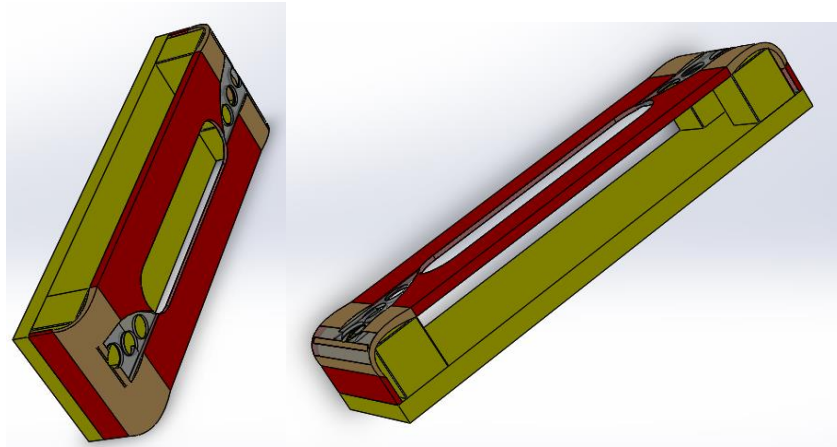


Figure A. 4. Assembled 3D modeling of Bishoftu Bus Bumper and crash box