Analysis and Improvement of the Rollover Crashworthiness for Locally Built Isuzu Bus Using FEM

Elias Girma Suldolo

A Thesis Submitted to department of Mechanical Engineering,

School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Award of the Degree of Master of Science in Automotive Engineering

Office of Graduate Studies

Adama Science and Technology University

November, 2022

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled “Analysis and Improvement of the Rollover Crashworthiness for Locally Built Isuzu Bus Using FEM” 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.

Elias Girma Suldolo	______________	____________________
Name of student	Signature	Date

RECOMMENDATION

I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "Analysis and Improvement of the Rollover Crashworthiness for Locally Built Isuzu Bus Using FEM" prepared under my/our guidance by Elias Girma Suldolo submitted in partial fulfilment of the requirements for the degree of Mater's of Science in Automotive Engineering. Therefore, I/we recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Amana Wako (PhD)	_______________________	________________
Advisor	Signature	Date
__________________________	_______________________	________________
Co-advisor	Signature	Date

APPROVAL PAGE OF MSc THESIS

I/we, the advisors of the thesis entitled "Analysis and Improvement of the Rollover Crashworthiness for Locally Built Isuzu Bus" and developed by Elias Girma Suldolo; hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Amana Wako (PhD) ______________________ _______________

Advisor Signature Date

_________________________ ______________________ _______________

Co-advisor Signature Date

We, the undersigned, members of the Board of Examiners of the thesis by Elias Girma Suldolo have read and evaluated the thesis entitled "Analysis and Improvement of the Rollover Crashworthiness for Locally Built Isuzu Bus Using FEM" and examined the candidate during open defence. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of Master of Science in Automotive Engineering

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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)

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ACRONYMS

CATIA V5	Computer-Aided Three Dimensional Interactive Application Version 5
CDS	Crashworthiness Data System
COG	Centre of Gravity
DOE	Design of Experiment
DRTWBs	Dual Rectangular Thin Walled Beams
ECBOS	Enhanced Coach and Bus Occupant Safety
ECE	Economic Commission For Europe
FEM	Finite Element Method
HD	Higher Deck
NASS	National Automotive Sampling System
PRA	Protectable Rollover Accident
RTWBs	Rectangular Thin Walled Beams
D2R	Deformable to Rigid
FMVSS	Federal Motor Vehicle Safety Standard
CRIS	Controlled Rollover Impact System
MPVs	Multipurpose Passenger Vehicles
SWR	Strength-to-weight ratio
IGES	Initial Graphics Exchange Specification

NOMENCLATURE

A	Acceleration (mm/s^2)
$E_{i,}$	Internal energy (kJ)
E	Young's modulus (MPa)
E_d	Damping energy (kJ)
E_{hg}	Hourglass energies (kJ)
E_k	Kinetic energy (kJ)
E_s	Interface sliding (dissipated contact energy) (kJ)
F	Force of vehicles (N)
G	Acceleration Due to Gravity (m/s^2)
M	Momentum (kg.m/s)
M	Mass (kg)
SL	Shear strength
V	Velocity of vehicles (m/s)
W_{ext}	Work done by the external forces (kJ)
ρ	Mass density(kg/m^3)
B	The perpendicular distance of the vehicle's vertical longitudinal centre plane (VLCP) to the axis of rotation
H	The vehicle distance between the vehicle COG at free fall position
Θ	Unstable equilibrium angle
E_{total}	Total energy(kJ)
E_{rw}	Rigid wall energy (kJ)
E_{kin}^{0}	Initial kinetic energy (kJ)

E_{int}^{0}	Initial internal energy(kJ)
T	Time (sec)
$eratio$	Energy ratio

ABSTRACT

Bus is the most popular and favourite road transport user's way and has an important role for transporting people, goods and property, short and long distances all around the world. The number of buses in Ethiopia is growing significantly every year to meet the needs of passengers. In Ethiopia passengers are usually use Isuzu bus for traveling because of its availability and economically inexpensive. Isuzu buses are manufactured in Ethiopian local garages from Isuzu open back trucks. Bus rollover crashes have been claimed many lives, cause much property loss and injured more victims in Ethiopia. The infrequent rollover crash incidence when compared to other crash types like complete frontal and side crash has lessened the severity caused in rollover. There are no standards which enforce the built-up process of locally made Isuzu buses, and each Isuzu bus garage uses different dimensions, sizes and materials according to the owner's requisite. In a rollover accident, deformation, buckling, and breakage of Isuzu bus structures threaten the lives of passengers. Isuzu bus manufacturers are responsible to design and model a superstructure with a strong structure to absorb sufficient load and rollover safety. The Economic Commission for Europe (ECE R66) are the law on bus safety and security is necessary to prevent bus rollover. This thesis work focuses on Analysis and Improvement of the Rollover Crashworthiness for Locally Built Isuzu Bus are expected to increase safety of the passenger which uses Isuzu bus locally called Isuzu "Kitkit" for daily activities. By modelling the Isuzu bus using CATIA, performing rollover test on the bus model using LS DYNA software, identifying the critical zones crash on the bus to modify the identified critical crash zone of the bus, and test the effect of the modified bus for better rollover crashworthiness. From the result obtained 9.86% of energy absorption has improved, 29.2% impact force have reduced, and 34.5% intrusions of bus superstructure to the passenger compartment have been improved from existing Isuzu bus by the modification made. The analysis of Isuzu bus FE simulation regarding ECE Regulation number 66 gives very fruitful results as experimental full scale rollover test.

Keywords: CATIA, Crashworthiness, ECE R66, Isuzu Bus, LS-DYNA, Rollover, Superstructure.

CHAPTER ONE

INTRODUCTION

1.1. Background and introduction

Buses provide an essential service and bring enormous social benefits especially for pregnant women, people with disabilities, older people, ethnic minorities, and those on lower incomes. Buses connect communities and offer sustenance for people without other forms of transport. They boost economic growth; enable access to work, education, food, and healthcare; and reduce congestion and greenhouse gases (Alston, 2021).

Transportation in Ethiopia has started in 1942 GC, when fascist Italy was driven out of Ethiopia, by accumulating vehicles and spare parts used by the invader. Isuzu Motors starts in Tokyo Ishikawajima ship building and engineering co.., Ltd. and Tokyo gas and Electric Company commenced Isuzu Motors from Isuzu River in 1934 and it was named Isuzu Motors in Japan. Most of researchers studied on passenger load, crawling effect, seat design, and air conditioning of public bus (Kassu Jilcha, 2020).

Rollover crash accidents account for 36 percent of the deaths of passenger cars and small trucks. Front seat occupants are vulnerable to head, neck and thoracic injuries resulting from impact with the collapsing roof structure (Kulak, 2014).

The following categories of rolling hazards are irrational, but they provide an opportunity to assess the severity of the various rollover hazards and the definition of :-

a) “safe rollover hazard”: *Turn on side:* the bus rolls, (turns in the opposite direction or turns into a small ditch, but stops at its side. The revolution angle is between 60 ° -120 °, no movement), *rolling down from the road* :(means minimum half, maximum two rotations. The rotation is between 180-720° angles), and *severe rollover*: **(**means the bus rotates more than two rotations. The angle of rotation is more than 720,
b) Protectable rollover accidents (PRA): where bus passengers may be present and will be protected to reduce the rate of death and injury. Turn on side and rolling down from the road are categorized as PRA (Hungary, 2015).

1.1.1. Rollover

Rollovers are complex and violent accident in nature and often reflect the interaction of chauffeur, bus, and environmental causes. Buses that have a higher centre of gravity tend to be less resistant to rollover compared to smaller vehicles. Fatal rollover crashes are most of the time speed related. From the crash data of NHTSA, 40 percent of serious rollover crashes encompass extreme speeding (Chen, 2010).

Figure 1.1. Isuzu bus rollover

Source: https://ethiopianmonitor.com/wp-content/uploads/2021/10/accinent-in-SNNP-R-e1633443648585.jpg

Figure 1.1 displays, the bus with plate number 3-03348, was carrying about 44 passengers who were going from City of Arba Minch to Jinka Town was rollover. Eight people were killed and over a dozen more injured (SNNP Communication Office, 2021).

Figure 1.2. Bus rollover

As shown above in figure 1.2 twenty passengers were killed after a public bus rolled over in a ditch in the Amhara region. The bus, which was traveling from Bahir Dar, was en route to Sekota Town. Police are not sure how many people were on the bus, identified by Code 3:

11300 Amh plate number, said Deputy Inspector, head of the Traffic office at the Dahna regional police department. Pictures of the incident showed a damaged public bus inside a ditch. No other vehicles were involved in the crash (Monitor, 2022).

ECE Regulation number 66 consists of 5 methods of rollover testing. First method is real test of rollover, followed by rollover test using body sections, quasi-static loading test of body, quasi-static calculation based on testing of components and lastly computer simulation of rollover test on full bus (Mustafa et al., 2013). In this thesis, as an equivalent approval method, use computer simulation of full vehicle rollover test. Basically, large vehicle superstructures didn’t had severe deformation after having frontal, rear or side impact but, this type of vehicle is fragile to rollover accidents.

1.1.2. Transportation in Ethiopia

Ethiopia is located in the Horn of Africa and covers an area of about 1,221,900 square kilometers; which are almost equal to France, Germany and the United Kingdom combined. Ethiopia is found also geographically located at 3 -15°N and 33 - 48°E. Ethiopia's altitude ranges from 1,500 to 3,000 m above sea level (Kassa, 2015).

Ethiopia is one of those developing countries with low level of income accompanied by high rate of population growth. Due to low level of urbanization and the poor performance of the economy, transport could be said to be at its infantry stage in Ethiopia. The modalities of transport mobility are limited. Natural walking transport and modes of transport of animals account for a larger proportion, with a very low proportion for automobile transport. According to the 1994 census, the population is estimated at 63 million nowadays the population of Ethiopia are estimated at 110 million. There are 926 urban centres in the country out of which only 302 urban centres are designated with municipal status (Central Statistical Authority). Among urban centres, Addis Ababa is the biggest and most populous urban centre, accounting one third of the total population of all the urban centres (Ministry of Federal Affairs, July 2002).

In general, the major transport problems in Ethiopia include among others: Shortage and low quality of transport services and facilities, Poor quality of roads, pedestrian walkways, High rate of congestion and hence high rate of accidents, and Lack of lane animal, bicycle ride and pedestrian walking (Samson, 2006).

1.1.3. Bus transportation in Ethiopia

Among the many means of public transport available in Ethiopia, buses are the most popular means of transport in the countryside and cities. Skybus, Odabus, Goldenbus, Anbesabus Abaybus, Awashbus, Zemenbus and Selambus are some comfortable bus companies, and operate between Addis Ababa and a few other major cities around the country.

Ethiopian-built buses (Isuzu "Kitkit") become popular means of transportation; in which they can be manufactured in local garages in cities. These buses are domestically produced from imported Isuzu dump truck (Isuzu truck cabin), the loading bridge is disassembled and converted into passenger bus by inserting the passenger seat and cover structure with related accessories as show in figure 1.3 below. However, so many criticisms are heard on the bus design structural strength, seats, framework material and dimensions of these Isuzu NPR or FSR buses where passengers are facing discomfort, fatigue, stress and fatal injuries as well as death at the moment of rollover accident (Kassu Jilcha, 2020).

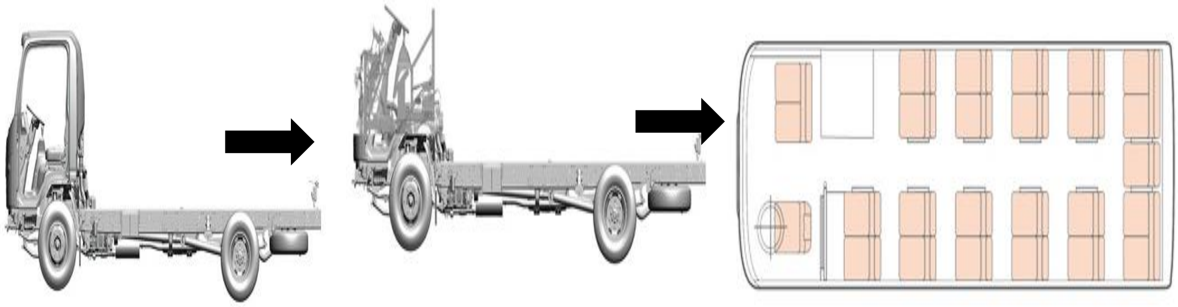

Figure 1.3. Body building process of Isuzu bus

Source: https://i.imgur.com/HYd9lKU.jpg

1.2. Statement of the Problem

Bus rollover crashes have claimed many lives and injured even more passengers throughout the world. Bus specially Isuzu buses are the most affordable and accessible form of public transport in Ethiopia. These buses so called (Isuzu "Kitkit") are becoming common way of transportation which can be made-up in native garages of the country. There are no standards which enforce the built-up process of locally made Isuzu buses, and each Isuzu bus garage uses different dimensions, sizes and materials according to the owner's requisite. In a rollover accident, deformation, buckling, and breakage of Isuzu bus structures threaten the lives of passengers. The structural strength, material and dimensions of Isuzu buses manufactured at local garages do not comply with ECE R66 regulations, which are used as a standard for manufacturing buses in more than 200 countries. As the result, passengers face minor injuries, serious injuries and even deaths during a bus rollover accident occur. Full scale rollover tests are very expensive to Ethiopian vehicle building garages and instrumenting the vehicle correctly is complicated. Therefore, computer simulation is becoming more and more important to make the project process fast and cost effective. For the above problems this thesis work are present in “Analysis and Improvement of the Rollover Crashworthiness for Locally Built Isuzu Bus” by modelling the Isuzu bus superstructure with CATIA software, simulating rollover crash test on Isuzu bus model, and analysing the result using LS-DYNA software. Then, improve the superstructure of locally built Isuzu bus for better rollover crashworthiness and improve the passenger’s safety.

1.3. Objectives

In this section the general and specific objectives of the thesis are given.

1.3.1. General objective

The general objective this thesis is to analyse and improve rollover crashworthiness of Locally Built Isuzu Bus using FEM .

1.3.2. Specific objectives

The main objective of this thesis achieved through the following specific objectives:-

- To model the Isuzu bus using dimensions collected from garages by CATIA
- To perform rollover test on the bus model using LS DYNA software
- To identify the critical zones crash on the bus
- To modify the identified critical crash zone of the bus
- To test the effect of the modified bus for better rollover crashworthiness

1.4. Significance of study

The major importance of this thesis is presented as benefits and beneficiaries.

1.4.1. Benefits

The analysis and improvement of rollover crashworthiness in locally built Isuzu bus helps to reduce the loss of property, improve passenger safety, improve the service life time of Isuzu bus and, improve the bus body and structural strength.

1.4.2. Benificiaries

After completing this project work, it could be beneficial for: vehicle manufacturers, government organizations related to bus transportation, non govermetal public transport organizations, vehicle owners specially bus and community of the country who use bus for day to day activity as a whole get benefitted from this thesis work.

1.5. Scope of the thesis

The scope of the thesis is to model the existing Isuzu bus by using CATIA software and performing the rollover test with ECE R 66 regulation by LS-DYNA software, then analysing the result from the existing Isuzu bus test. Then, modification made on the superstructure of the Isuzu bus to increase the rollover crashworthiness.

The following activities are included in this work.

- Reviewing different literature on rollover analysis of the public transportation buses.
- Isuzu bus modelling with CATIA and analaysing the model by LS DYNA softwares
- Selecting appropriate materials for superstuctures and body parts of the bus
- Improving the superstructure of the bus for better crashworthiness

This thesis work can be applied on public transportation vehicles such as transit bus, school bus and coaches. It doesnot work for two and three wheeler, pickups and industrial vehicles because their structural mounting mechanism, shape and size of the vehicle.

1.6. Limitations

The limitations of locally built Isuzu bus rollover analysis and improvement are:

- Experimental rollover crash test on the bus superstructure
- Experimental rollover crash test of whole Isuzu bus
- Lack of high-performance computer for LS DYNA simulation
- The electric power fluctuation in Adama Science and Technology University since, the bus rollover simulation takes more than 1 weeks to finish the analysis.

1.7. Organization of the thesis

The thesis is organized with the following chapters; **Chapter one** Introduction this chapter introduces the background of the study, statement of the problem, objectives, significance, beneficiaries, limitations and scope of the study. **Chapter two** literature review, the second chapter include review literatures that deals with concepts, past studies and information related to the bus rollover analysis. **Chapter three** materials and methods, this chapter explains research methodology including materials used and methods to be followed to accomplish the thesis work. **Chapter four** modelling and simulation of bus structure using ls dyna, this chapter concers about modeling the super structure of Isuzu Bus using CATIA and analysis of rollover crashworthines and modification analysis. **Chapter Five** result and discussion in this chapter, the numerical analysis results, model modification, and validation can be discussed.   **Chapter Six** conclusion and recommendation, this chapter presents concluding remarks with key findings of the present investigation with a recommendation and future research scopes.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

In this chapter, available previous works related to this study are reviewed. The reviewed literatures concern about rollover analysis in buses and related areas.

The concept of crashworthiness is a study of the vehicle's ability to avoid occupant injuries in an accident. It measures the ability of structures and all their components to protect residents in survivable accidents. Crashworthiness is a measure of the structural ability of a vehicle to plastically deform and maintain sufficient occupant survival space in the event of a collision with a moderate deceleration load (Georgiou et al., 2018).

The most common types of crash tests are shown on Figure 2.1 below. Front impact test, Front offset crash test, Side impact test and Roll over test (Ambati, 2012).

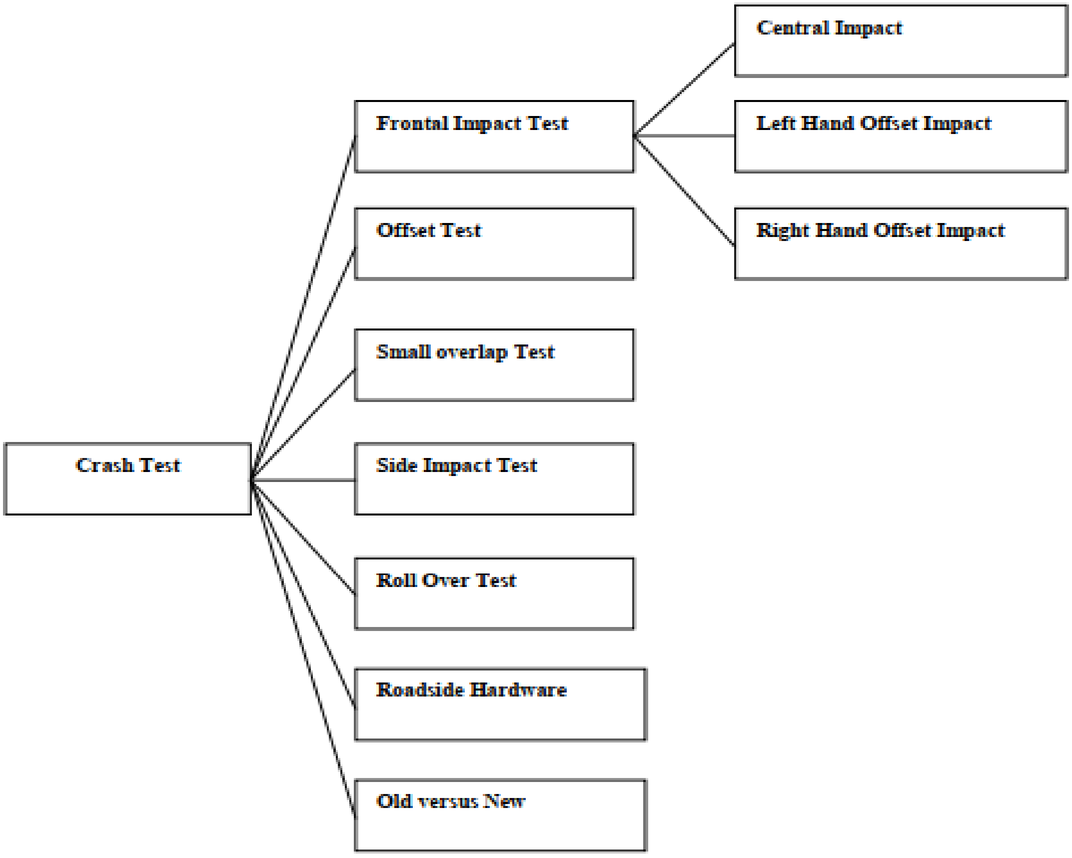

Figure 2.1. Classification of crash tests

2.2. Bus accident

Even in Europe, bus manufacturers are increasingly focused on occupant safety in rollover accidents. Spanish data from 1995 to 1999 show a 4% rollover rate for all bus accidents on the highway, and the risk of death from rollover is five times higher than the risk of any other crashes. A number of Fatality Analysis Reporting System (FARS) also showed that rollover occurred less frequently than all other types of car accidents, but the chances of death and serious injury in rollover type accidents are high. (Liang et al., 2012).

The data collection focused on the rollover accident of all bus categories. Table 2.1 gives a general overview about bus accidents collected until the end of 2014. The data are grouped into three regions, considering 7 basic accident categories (rollover, frontal collision, rear and side collision, direct fire, combined accident, collision with train, and special accidents) (Mátyás, 2015).

Table 2.1. Bus accidents data

Type of accident	Rollover	Frontal collision	Rear and side collision	Direct fire	Combined accident	Collision with train	Special accidents	Total
Hungary	176	335	28	65	11	6	19	645
Europe	168	96	7	13	28	12	5	324
World	201	124	2	20	146	15	17	525
Σ	545	555	37	98	185	33	41	1494

This research describes injury mechanisms for bus rollover accidents and divided them into four different groups defined as follows (Latifi, 2014).

- **Intrusion.** Due to large scale structural deformations and the loss of the survival space, structural elements impact or crush the bodies of the occupants.
- **Projection.** Due to the uncontrolled movement of the occupants in the bus, their bodies collide with the structural parts of the bus.
- **Partial Ejection.** During the rollover process, parts of the occupant can be thrown out of a broken or fallen window and crushed by a rolling bus.
- **Complete Ejection.** When a bus rolls over, occupants can be thrown out of broken or fallen windows and crushed by rolling buses.

According to the Ethiopian Federal Police Commission, road accidents have claimed 1,848 lives in six months; the country reported 20, 672 road accidents between July and December, 2020. Addis Ababa alone have registered 15, 844 accidents and 192 deaths. A total of 5, 211 people had sustained injuries (2, 646 serious injuries, 2,565 minor injuries) due to the vehicular accidents. The accident also caused destruction to vehicle and property worth more than 495.2 million birr. Data were collected from all district and two city officials, with the exclusion of Tigray region due to the security situation in the region (Fana, 2021).

2.3. Standards review

A crash test is a form of destructive testing usually performed in order to ensure safe design standards in crashworthiness and crash compatibility for various types of vehicle like small, medium and heavy duty (bus) and its related systems and components for the sake of getting the performance of vehicle use specific objects such as rigid walls, cables, concrete barriers, guardrail systems, etc. to testt vehicles at different angles and under different collision conditions. This is done either numerically or experimentally (Yadav, 2014).

Two major safety standards for roof integrity and rollover protection of bus are currently used around the world. The first one is the Federal Motor Vehicle Safety Standard 220 (FMVSS220). FMVSS 220 establishes performance requirements for rollover performance of school buses, but it is also commonly used for all other types of buses. The other safety standard, used for crashworthy evaluation of buses, is the Economic Commission for Europe Regulation 66 titled “Unified Technical Regulations on Body Strength of Large Passenger Cars” (ECE-R66). ECE-R66 is currently the most popular bus safety standard used in the world, and it has been accepted by over 40 countries (Bojanowski, & Kulak, 2011). There are also other rollover and roof crush testing standards as discussed below.

2.3.1. Controlled rollover impact system (CRIS)

This is a tractor unit and trailer with a rear-mounted device for holding the vehicle as shown in figure 2.3 below. You can adjust the mount to drop the vehicle from a certain height and give it a defined vertical velocity. However, there is no direct measurement of the horizontal or vertical speed of the vehicle at impact. The traveling speed of the semi-tractor/trailer controls the horizontal speed of the vehicle at impact.

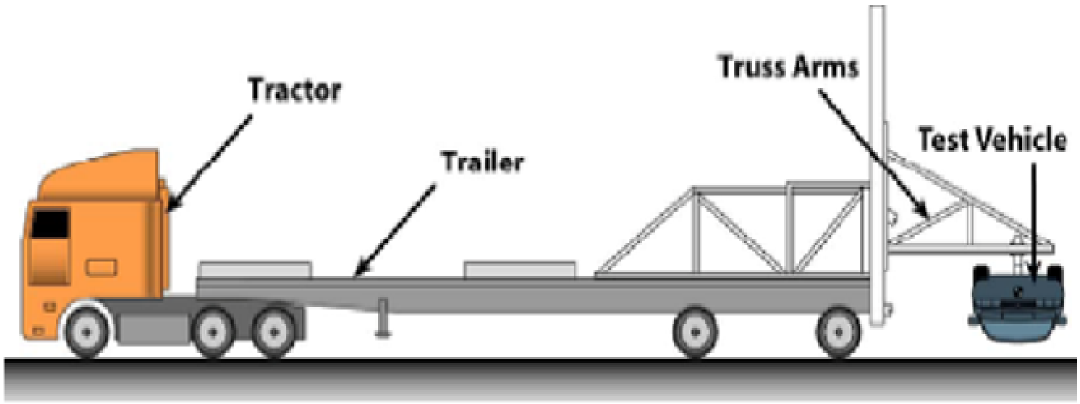

Figure 2.2. Experimental CRIS test (Jeong, 2008)

2.3.2. Federation of motor vehicle safety standards and IIHS No.216

FMVSS No. 216a is most common are which regulates minimal roof strength design in the vehicles. Compliant with FMVSS No.216a, urging manufacturers to improve roof design. The standards and their relevant information are summarized here as follows.

FMVSS No. 216a

The first standard for testing vehicles strength at event of rollover accident is called FMVSS no. 216a. Prior to FMVSS No. 216a, it is called the FMVSS 216, in the early 1970s. The code determines the strength of passenger car based on the ratio of the vehicle gross weight and resistance force (SWR). The rating was applicable for (GVWR) of 2,722 kg (6,000 lb.) or less and the SWR specified in FMVSS No. 216 was 1.5, meaning that a passenger car roof should withstand a load of at least 1.5 times the vehicle unloaded weight. The standard has been revised several times since its inception. It has been expanded to multipurpose passenger vehicles (MPVs), changed quasi-static test procedures, and updated to FMVSS No. 216a, which received the most attention in 2009.

FMVSS no. 216a was finalized on April 30, 2009, specifying multi-year phased implementation compliance requirements from 2012 to 2015. This means that full compliance for all designated vehicle fleets must be achieved by the 2016 model. One of the important requirements specified in the standard involves roof strength measured in the strength-to-weight ratio (SWR). SWR is a unitless metric that measures the roof strength of a vehicle based on its own weight. For example, with an SWR of 3.0, the roof structure of the vehicle can withstand 3.0 times the total vehicle weight of the vehicle under the test conditions specified in FMVSS No. 216a.

Non-federal safety rating

The Insurance Institute for Highway Safety (IIHS) introduced a vehicle roof strength assessment system in 2009 based on the peak SWR of the roof crash test, similar to that required by FMVSS no. 216a. There are some differences between the IIHS test and the FMVSS test no. 216a like; the number of sides to be tested (i.e., one side for IIHS and both sides for FMVSS No. 216a), and no headroom maintenance criterion in IIHS's test. IIHS roof strength assessments fall into one of four levels based on peak SWR (good, acceptable, marginal, and poor) as shown on figure 2.5 The highest rating, "Good," requires at least an SWR of 4.0 (Kweon, 2020).

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As shown in figure 2.6 it is placed on roof top with 25° roll angle and 5° pitch angle. The rigid rectangular block or loading device is allowed to move 127 millimeters to achieve the specified resistive load when applied to the forward edge of a vehicle's roof. This procedure is named as quasi-static test where load is applied to frontal edge of roof structure to determine whether 1.5 times of vehicle weight can be tolerated within 127 mm displacement of the load device (Cassia, 2015).

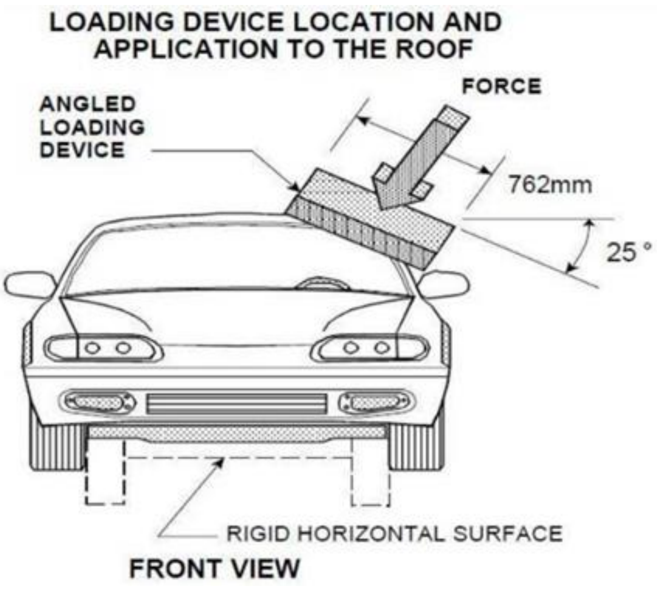


Figure 2.3. Roof crushes test set up for FMVSS 216 (Jeong, 2008).

Roof crush resistance

One measure of vehicle roof strength is the SWR, calculated from results of a laboratory roof crush test. The roof crush test pushes a metal plate against a side of the forward edge of vehicle's roof at a constant rate to a certain distance and the force applied to the metal plate is continuously recorded throughout the test. An SWR value is calculated by dividing an applied force by an unloaded vehicle weight as follows.

$$\mathrm{SWR} = \frac{\text{Applied Force}}{\text{Unloaded Vehicle Weight}} \tag{2.1}$$

Where: Applied force and unloaded vehicle weight are measured in the same unit such as Newton (N), or pounds-force (lbf) and, thus a calculated SWR is unit less.

2.3.3. ECE regulation no. 66

Passive safety of buses in rollover conditions is currently controlled by the ECE Regulation No. 66. The basic method of approval according to the ECE R66 is a fullscale rollover of the bus from an 800 mm ledge into a ditch with a concrete surface. Scheme of this process is shown in Figure 2.4.

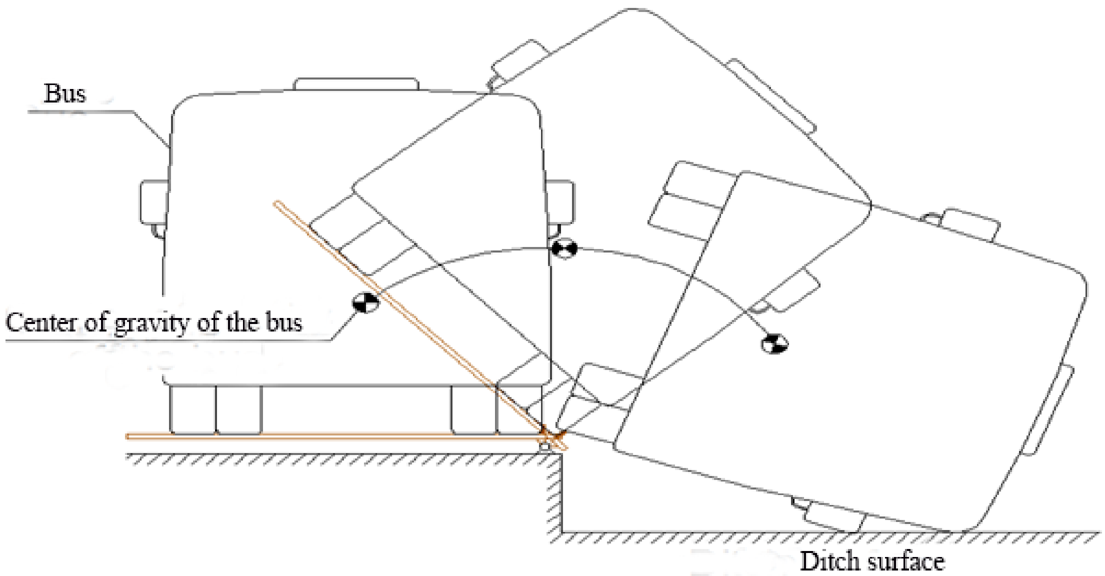


Figure 2.4. Scheme of the bus rollover trajectory of the centre of gravity movement (Wicaksono S. M., 2017)

The tilted platform design has also been standardized and must include support to prevent the vehicle from slipping into the ditch during rotation. If the width of the vehicle's tracks is different, these supports should be adjusted so the longitudinal vertical symmetry plane of the bus is parallel to the axis of rotation. In addition, the platform should not allow the test object to move along its longitudinal axis.

Passive safety estimation criterion is the preservation of the contour of the residual survival space as shown figure 2.5 in the course of and after the collision with the ditch surface (Rogov, 2020).

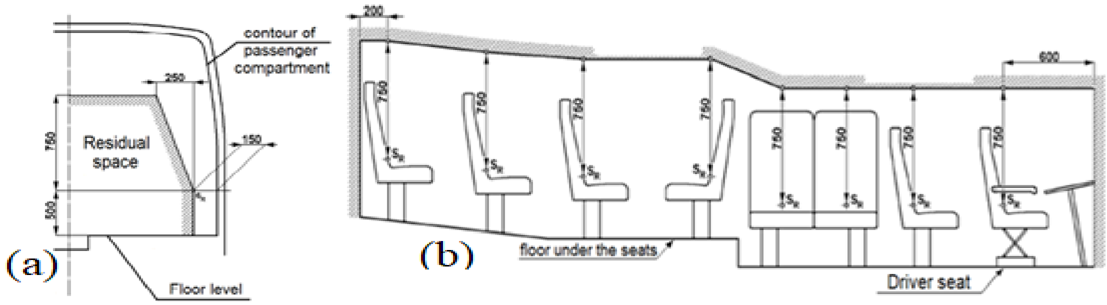


Figure 2.5. Dimensions of residual survival space: a) transverse and b) longitudinal planes (Wicaksono S. M., 2017)

The pass-fail criteria established by ECER66 are based on the concept of residual space (RS). Residual space is defined as the space that must be maintained to provide a survival zone for passengers and drivers.

2.3.4. Federal motor vehicle safety standard 220 (FMVSS 220)

Federal Motor Vehicle Safety Standard 220 (FMVSS 220) establishes performance requirements for school bus rollover protection, but is also frequently used as a required safety standard for the other types of buses in the USA. The FMVSS 220 concept is to statically apply a force equal to 1.5 times the Unloaded Vehicle Weight (UVW). The force is applied symmetrically to the roof through a flat, rigid rectangular plate at a load rate of no more than 12.7 mm/s (0.5 in/s). For vehicles exceeding 10,000 lb gross vehicle weight (GVW), the road bed should be 12 inches shorter and 36 inches wide than the roof of the test vehicle. For vehicles with GVW of 10,000 or less, the load application plate should be 5 inches longer and 5 inches wider than the vehicle roof dimensions. The vehicle passes the test if the maximum vertical displacement does not exceed 130.2 mm (5.125 in) and all emergency exits operate during load and after force is released as shown in figure 2.6 below (Gepner, 2014).

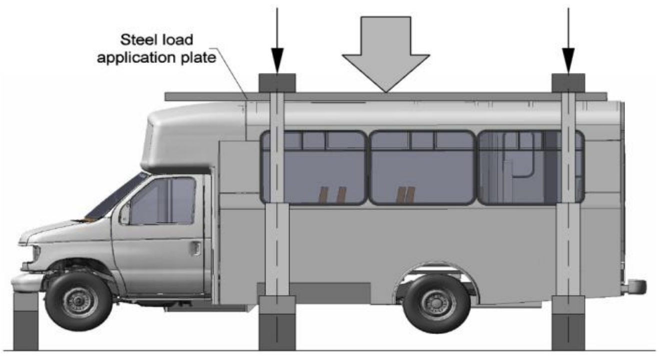


Figure 2.6. Test setup for FMVSS 220 school bus rollover protection

2.4. Vehicle structure building materials

This paper review different literature of automotive materials. Steel has superior mechanical, physical, chemical and thermal properties compared to many other materials. These features make them the best candidates for many applications. Due to its variability in strength level and excellent formability, steel is considered an ideal material for the automotive industry. Modern vehicle demands for better fuel economy, lower ozone emissions and higher safety requirements have led to new developments in steel grades with higher strength and better formability. The basic concept of 3rd generation advanced high strength steel (AHSS) is to utilize the mechanical properties of 1st and 2nd generation AHSS at a cost that is neither too high nor too low (Meknassi, 2021).

This article provides information on the nomenclature, structure and properties of steels used in the automotive industry. The development of new types of steel continues to take into account the needs of the automotive industry in steel production. The significant mass production and competitiveness of this industry require low production costs and improved safety in traffic accidents through technological innovation. This paper summarizes information on the nomenclature, structure and properties of steels used in the automotive industry. Recommendations are introduced for the development of compositions and appropriate treatments that improve mechanical and plastic properties (Tontchev, 2010).

For many years, steel has been a key material in the automotive industry. Steel has a wide range of yield strength with a high modulus of elasticity. Steel is also considered the most preferred material in the automotive industry due to its low cost. Steel's advantages include the potential for weight reduction using a new generation of high-strength steel that offers fuel efficiency, improved safety, good recyclability and formability properties. This article discusses current trends, applications, and recent progress in the use of different types of steel in the automotive industry. Recently, the development of next-generation steels such as AHSS (Advanced High Strength Steel) is also on-going (Singh, 2016).

As publication of the international academic journal Trans & Motauto world presented, Composite materials are materials created by combining existing materials and utilizing knowledge of physical metallurgy. They consist of at least two components. The first continuous component, the matrix acts as a binder, and the second discontinuous component (dispersed particles, fibers or layers) acts as a reinforcing agent. Automakers strive to continuously reduce vehicle weight while improving durability and safety. Closely monitor vehicle consumption and related emissions. Composite materials have multiple properties that greatly meet today's automotive requirements, such as fatigue resistance, high strength and modulus of elasticity, crack propagation resistance, high impact strength and toughness, fire resistance, vibration absorption capacity, and surface quality, corrosion resistance, ballistic properties, electrical conductivity and possibility of use in renewable sources. But, the main disadvantages of composite materials are their high price and production complexity (Kender, 2020).

This article presents a journal of materials showing the response to compression of laser welded square tubular absorbers made from two steel grades, DOCOL 1000DP and DOCOL 1200MDocol 1000DP and DOCOL 1200M are commercial cold rolled steels widely used in new designs of automotive, safety and structural body parts. The crashworthiness of the model square tube absorber is estimated based on the parameters of absorbed energy, average force, impact force efficiency coefficient, and absorption specific energy. Square tube absorbers made of DOCOL 1200M steel have been found to have higher potential mechanical energy absorption capacity than DOCOL 1000DP absorber. Moreover, crushing tests show that laser-welded joints in 0.6 mm sheets made of DOCOL 1000DP and DOCOL 1200M steels disclose higher cracking toughness. In turn, Strength tests at various strain rates have confirmed that the strain rate sensitivity of the DOCOL 1000 DP steel is higher than that of the DOCOL 1200 M steel, and that the high ductility properties of both steel grades are improved under high strain rate load conditions (Prochenka, 2021).

2.5. Previous work on bus rollover analysis

East Asian Transportation Association studied the methodology of undertaking rollover simulation to a bus, although only to selected body part section. They used Software to develop a FEM. As stated in ECE R66 regulation, simulation was conducted in model structural section which includes window pillars, the rooftop structure and beams. The results were presented in the form of structural deformation and energy vs. time history (Rahman, 2011).

Research published by Journal of Mechanical Science and Technology in china, This article presents a rollover impact analysis using LSDYNA software and bus frame optimization methods using rectangular thin-walled beams (RTWB) and double rectangular thin-walled beams (DRTWB). A bus frame with tires, suspension, and platform structures is created in the Car Frame program. In the numerical analysis example, it was confirmed that the frame model, which reduces simulation and calculation costs, matches the detailed model well, and in the numerical optimization example, it was confirmed that the frame model can provide high rollover impact resistance and lightweight bus structure. Therefore, the frame model can effectively replace the detailed model for overturning impact analysis and optimization (Bai, 2019).

The rollover analysis article demonstrates an attempt to increase the strength of the Volvo b9r bus frame structure while reducing structural weight using rollover-aware DOCOL materials. This material uses low carbon mild steel, also uses DOCOL material, and compares the results using LS DYNA as the FE solver (Veeresh, 2018).

King Saud University Advanced Manufacturing Institute, Saudi Arabia present paper provides the results of a safety evaluation of buses 3D structure in the unfortunate case of rollover during an accident. Finite element and structure analysis techniques using LS DYNA were applied to evaluate bus safety during rollover; and to provide design recommendations to reinforce its structure. The analysis included both static and dynamic calculations and hyper works were used for pre and post processing. The static calculations were used to develop a bus cross section that is capable to absorb more energy from the rollover crash test and to study the complete structure and parapet bus sections. These are necessary to identify weakness areas and establish redesign recommendations to improve bus safety. The dynamic calculations were used to simulate rollover bus crashes and find residual areas with intrusion with the bus structure (Elseufy, 2013).

Journal of Mechanical and Civil Engineering (IOSR-JMCE), paper proposes a new method for designing a bus body structure is designed and modelled in 3D modelling software Pro/Engineer. The original body is redesigned by changing the thickness and reducing the number of elements so that the total weight of the bus is reduced. The material currently used for construction is steel. It is replaced by composite materials Kevlar and S 2 Glass Epoxy. Since the density of steel is greater than that of composite materials, it is replaced with composite materials to reduce the weight of the structure. Structural and dynamic analysis is performed on both structures using three materials to determine the strength of the structure. Analysis was performed in ANSYS (Chinta, 2014).

The study published in this journal is a numerical rollover test of a bus superstructure using ANSYS software. Testing was performed according to ECE R66. They presented a successful design process for structures that passed rollover tests. For verification, a rollover test of the bus section was performed and compared with the results of FE. This test did not take into account the weight of the passenger (turgut GÜRSEL, 2010).

This study presents an experimental numerical study of bus rollover, the numerical study is performed using LSDYNA, and the authors present the distribution of energy absorption during numerical rollover. Experimental rollover is presented in this paper, although no reference to the numerical model is made (Zhang, 2012).

The International Journal of crashworthiness provides a review of the literature on rollover accidents. This is by no means a complete overview of all available literature. However, it covers many of the most frequently cited papers. This study mainly focused on research findings related to passenger cars. In this review, the rollover impact study was characterized based on the Haddon matrix to provide a broad perspective on the rollover crashworthiness state. First, the rollover crash characteristics were defined from the perspective of the vehicle. Second, the research results were reviewed from the perspective of vehicle (design evaluation), human (injury evaluation), occupant protection system (tool that controls the interaction between passengers and vehicle), and environmental factors (road and weather characteristics conditions). Third, it was classified into statistical (field data), experimental, and computational analysis according to the research method (Seyedi et al., 2020).

This paper explores a novel Local Functional Graded Thickness (LFGT) side strut and Minimum Deformation Search (MDS) method to improve the rollover crashworthiness of buses. According to the ECE R66 standard, the most severe deformation of the bus's traditional side pillars occurred when the bus rolled over at a large impact angle. To reduce deformation, the LFGT tube is designed to attach to sidewall pillars. In addition, the properties of the LFGT tube under large impact angles are analysed by radial basis functions. Based on the characteristics, the MDS method has been proposed to improve the impact safety when the bus body rolls over (Jin, 2021).

This article introduces bus structure modelling and its strength analysis, and evaluates the requirements of ECE Regulation No. 66 according to the finite element method, taking into account the non-linearity of materials and geometry. The analysis includes strength simulations in the form of rollover tests performed according to the requirements set out in the rules. This article introduces the results of dynamic analysis using the finite element method (Karliński et al, 2014).

Changing the bus's engine from combustion to electric motor resulted in an increase in the weight of the bus due to the large weight of the electric motor and its ancillary components. Weight should be reduced by using lighter materials. The lightweight bus frame and superstructures must be tested for its performance in a rollover crash as the crash is classified as a highly fatal crash. This paper aims to simulate the behaviour of a three-material in electric bus frame in a rollover accident using finite element method (FEM). Then, the simulation results of the three materials are compared to obtain the material with the best performance (Satrijo, 2020).

This journal updates on most of the existing rollover flexible devices have been made with a view to testing their flexibility, reliability, durability and the strength of crash reconstruction. The results show that the Jordan Rollover System (JRS) provides better power over repeat dynamic testing in all respects than Back Drop Test, Dolly SAE J2114 or FMVSS 208 test flow, System rollover system with rollover impact controlled rollover, screw rollover system button (Chirwa et al, 2010).

SAE International introduces the Soil Roll Test as a vehicle rollover test method in which a vehicle is pushed into a puddle to measure its rollover properties. Some of the difficulties encountered in the tipping test include proper soil maintenance, for example, under conditions of fluctuating humidity and uniformity of the pool soil, to ensure consistent repeatability of the results. Protecting the instrumentation on the test vehicle from ground impact while the vehicle is rolling can also be a challenge. Therefore, sled test methods without a soil pool that can simulate a soil trip rollover test with a soil pool are helpful in ensuring repeatability of results and maintenance of on board equipment (Fukushima et al, 2013).

This article presents the findings of research on rollover collisions and resulting injuries. Degree of injury, type of injury, body area injured, frequency of injury, and mode of injury are all indicated. The study included statistics on both blocked and unrestricted residents, and showed that displaced residents often received more serious injuries than the occupants. There are a number of conclusions being drawn about motor vehicle properties in relation to injuries (Hight, 2018).

A study carried out on improvement of a numerical method for bus rollover test simulations. Authors investigated different modelling techniques ranging from beam elements with rigidity curves, to a complete detailed shell element model. No validation effort has been presented by the authors, and every presented model produced diverging results. Increasing computing power and parallelization capabilities introduced into the FE codes made it possible to develop and utilize more advanced FE models, improving the accuracy of the results, without sacrificing computing speed. Up to date, multiple researchers have utilized very complex FE models (with size over 1 million finite elements) in research on bus crashworthiness (Valladares, 2010).

An article performs a computer finite element study on the influence of the superstructure configuration on coach performance when subjected to the ECE-R66 rollover. Using the baseline FE coach model the authors derived seven different FE models considering structural configurations, such as closed rings, wall to floor connections, column structure and waist rail location. Conclusions highlight that all of the investigated configurations, with the exception of the location of the waist rail, had a large influence onto the rollover performance (Li et al, 2012).

The scientific study concerning on the effects of bus structure rollover crash numerical analysis. The authors concluded that the skin structure of the bus has a large influence onto the outcomes of the FE ECE-R66 rollover simulation. No validation efforts were presented in this paper (Li, 2012).

The effect of applying foam to bus structures to increase crashworthiness in the event of a rollover accident was studied. Although foam was applied to the structural beams to reduce the deformation of the bus, the results were insignificant (0.25%). No validation effort of FE model was presented in the discussed paper (Özcanli, 2014).

This research looked at the aging effect, such as corrosion and deterioration of mechanical properties, on rollover crashworthiness of buses. The authors used available data on the mechanical properties of corroded metals and applied these properties to an existing finite element bus model. Conclusions show that aging effect has a significant influence onto the vehicle rollover crashworthiness and reduces bus occupant safety (Iskandar et al, 2013).

A paper presented comprehensive analysis of the rollover testing for Para transit buses. Authors showed an extensive validation and verification procedure for a development of bus FE model. Verification was performed through analysis of energy balance. Hierarchical validation was carried out through series of validation experiments on bus components. A new measure of bus deformation during rollover (Deformation Index, DI) was introduced and used as a quantifier for bus deformation ((Bojanowski, 2013).

This paper deals with structural analysis of bus superstructure undergoes rollover event. Bus superstructure with varying beam profile size will undergo rollover simulations analysis. The purpose of this work is to analyze structural response of bus superstructure in terms of deformation, stress and strain under several loadings and constraining conditions. These rollover simulations were performed in accordance with Regulation 66 of the European Economic Commission (ECE R66). The validation procedure using a simple simulation window rolls over to ensure that the results are synchronized with the real problem (Mustafa et al., 2013).

As explained in this paper there are some major causes of vehicle rollover like; weather the most obvious weather condition associated with a vehicle overturn is strong winds. In situations with a high center of gravity, strong winds are more likely to overturn the vehicle. Avoidance this type of accident occurs when the driver tries to avoid a hazard on the route and turns too sharply, which could lead to a rollover. Rollover situations usually result from initial evasive maneuver modifications, resulting in cumulative pendulum motion that can increase or decrease as the vehicle moves in a straight line. Brakes for the driver to have maximum control of the vehicle, it is very important that the brake system works properly. Anti-lock Braking Systems (ABS), Electronic Braking Systems (EBS) and Electronic Stability Programs (ESP) all help in avoiding vehicle rollover, as they can automatically adjust the braking pattern for each wheel, possibly giving the driver greater control. Cornering most vehicle rollovers occur while cornering. Due to the higher center of gravity and lower rollover threshold, entering a corner at excessive speed will cause the vehicle to roll over and roll over. Driving Error there are many factors that can result from driving errors or inadequate training. If you misjudge the size of the curve, the vehicle may enter the curve too quickly. And other causes such as, Excess speed, unbalanced Load, Jack-knifing (equipment failure), over steering, Road design, incorrect Suspension settings, and under-inflated tyres (Swamy, 2019).

In recent years, many researchers have been working on bus structure optimization has become a popular topic within the scientific community. These authors performed a multi-objective optimization for bus body structure on a large and well validated FE model. Based on sensitivity analysis, they selected critical structural variables for the optimization process.

Bus weight, torsional stiffness, intrusion into residual space and stress values were used by the authors as a response functions. The optimization process resulted with a 2.7% weight reduction, increase in torsional stiffness of 0.4% and a maximum stress reduction of 13.8% (Su, 2011).

Buses are the most cost-efficient and flexible form of public transport, requiring minimal investments to launch new lines or routes. Medium-size buses for transportation of passengers become particularly popular because they provide more freedom, for both carriers and passengers; furthermore, they are environmentally friendly and economical. However, the growing number of used buses is accompanied by raising the traffic events where these vehicles are involved. Of all road accidents caused by buses, bus rollovers represent the greatest loss due to the potentially high case fatality rate per accident (Pravilonis, 2020).

The Journal of International Automotive Technology presents research on the crashworthiness of bus bodies that comply with ECE R66 regulations when the bus undergoes rollover testing. They proposed a lightweight design for the bus body that can improve the energy consumption and operational cost in addition to the crashworthiness optimization (Kongwat, 2020).

On the research studied the dynamic response of a passenger bus subjected to an impact loading and the modal behaviour of the bus has been analysed through numerical Finite Element Analysis (FEA) formulations (Lopes, 2021).

In railroad passenger car, as an illustration, researchers studied the crashworthiness of railroad vehicles subjected to rollover crashes through numerical and experimental analyses. Indeed, they carried out experiments to analyse the collision and to propose modifications improving crashworthiness of the studied vehicle (Baykasoglu, 2013).

Injury research centre of America present, real-world data were from the 2001 to 2005 National Automotive Sampling System Crashworthiness Data System. A total of 10,941 drivers who were aged 18 years or older involved in frontal collision crashes were eligible for the study. A gender-specific logistic regression model was developed to analyze the association between MVC injuries (car accidents) and the presence of obesity in drivers. Computer models of obese subjects were constructed and collision simulations were performed to confirm the findings from the actual data. According to real-world data, obese men were at significantly higher risk of injury, especially serious injuries, in areas of the upper body such as the head, face, chest, and spine than men of normal weight. A U-shaped relation was found between body mass index (BMI) and serious injury in the abdominal region for both men and women (p, 0.05 for both BMI and BMI2). In the high-BMI range, men were favourite to seriously injured than were women for all body regions except the extremities and abdominal region (all p,0.05 for interaction between BMI and sex). The results of the computer simulation were in good agreement with the actual results. They conclude that obese men are at a much higher risk of injury in the upper body area during MVC (Zhu, 2010).

This paper presents a computer simulation of a bus rollover. The bus structure was modeled to represent the actual mass distribution of the bus. Two conditions were tested: bus when empty and when fully loaded. Simulation results for both empty and full buses show that the buses do not meet safety standards UNECER66. Examining an empty and full bus, they found that the structure of the bus was not strong enough because it violated safety standards for the remaining space. The most important part of the bus's structure is the connection between the roof rack and the frame and the floor. Results were validated by comparison with other tests performed by other researchers (Wicaksono, 2017).

2.6. Summary of literature review

Meanwhile, full-scale rollover tests are very expensive and instrumenting the vehicle correctly for rollover crash test is not easy. Computer simulations are becoming more important in automotive industries to make design process fast and affordable. From the literature review above, researchers used FE simulation tools to assist in the design process of vehicle rollover simulations and protect vehicle occupants. As indicated in the reviewed research publications, most of the rollover simulation is used for introduction of the finite element analysis of bus rollover and standards used in built-up process of the buses.

Now a day vehicle rating systems address crashworthiness and strength issues. Vehicle evaluation companies use both computer FE analysis and experimental simulation to rank vehicles.

Some large industrial research centres perform bus rollover analysis on experimental full-size buses and compare it to computer finite element analysis. The results of both computer simulations are almost the same as to the experimental result.

2.7. Research gap

The numerical FE simulation to the rollover crashworthiness of buses is relatively new and not fully explored research area. In case of rollover in Isuzu bus the passenger's safety risk will increase badly due to low structural strength and minor safety accessories equipage, so special emphasis should be taken. Most of the researches reviewed are focuses in locally built Isuzu bus rollover aerodynamical effectiveness analysis and, their results focus on suggesting modification should be made in order to improve shape of the bus to the safety of the buses. In Europe and America some papers are present in analysis of bus rollover crashworthiness, and modification were also made and analysed but, the modifications were not satisfactory to protect the occupant and the driver at the event of crush. Moreover in Ethiopian made buses like Isuzu "kitkit" there is no directly related research have been done concerning rollover crashworthiness to safeguard the Isuzu bus passengers during rollover accident. There is no experimental rollover test research done to Isuzu bus in Ethiopia due to lack of resources. This thesis work are motivated on improvement of the rollover crashworthiness of locally built Isuzu buses using FEM for better rollover crashworthiness and enhance the passenger's safety.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Introduction

This chapter discus about materials and methodology used to complete the thesis work of analysis and improvement of the rollover crashworthiness on locally built Isuzu bus.

3.2. Materials

The materials and equipment required for this thesis work are listed in table 3.1 given below.

Table 3.1. Materials and Tools

No.	Materials	Specifications
1.	Measuring Tape	• Measuring tape is a type of hand tool typically used to measure distance or size. It is like a much longer flexible ruler consisting of a case, thumb lock, blade/tape, hook, and sometimes a belt clip • A tape measure will have imperial readings, metric readings or both. • In my case used to measure length and size of locally built Isuzu bus.
2.	Vernier Calliper	• Vernier Calliper is a measuring and layout tool typically used for measuring linear dimensions • It provides an accurate measurement of inside, outside dimensions, depth, and thickness. • In this case it is used to measure inner, outer dimensions, depth and thickness of Isuzu bus structures.
3.	(CATIA V5)	• CATIA is a complete multi-platform solution for computer-aided design, manufacturing, engineering, and 3D software • the software is ideal for creating solids, surfaces, assemblies, drawings, fabrication and analysis • CATIA is used to improve productivity, improve mechanical design quality, create unified design , create manufacturing databases, and eliminate manual inaccuracies in drawings and irregularities between drawings.

	• In this thesis CATIA used for modelling bus structural parts.
4. LS DYNA	• LSDYNA is a multifunctional explicit and implicit FE program for the simulation and analysis of highly nonlinear physical phenomena associated with real problems. Usually, these phenomena cause large deformation in a short time, e.g. crashworthiness simulations. • The significant features of LS-DYNA are: the fully automatic definitions of contact areas, the large library of constitutive models, the large library of element types, and the special implementation for the automobile industry. • The LS-DYNA software contains: a pre-processing FE builder, an LS-DYNA solver and a post-processing LS-PREPOST.

3.3. Methods

In order to accomplish the objectives, there were several steps which followed while the project was under way as shown in figure 3.1. The methods that followed were including of:

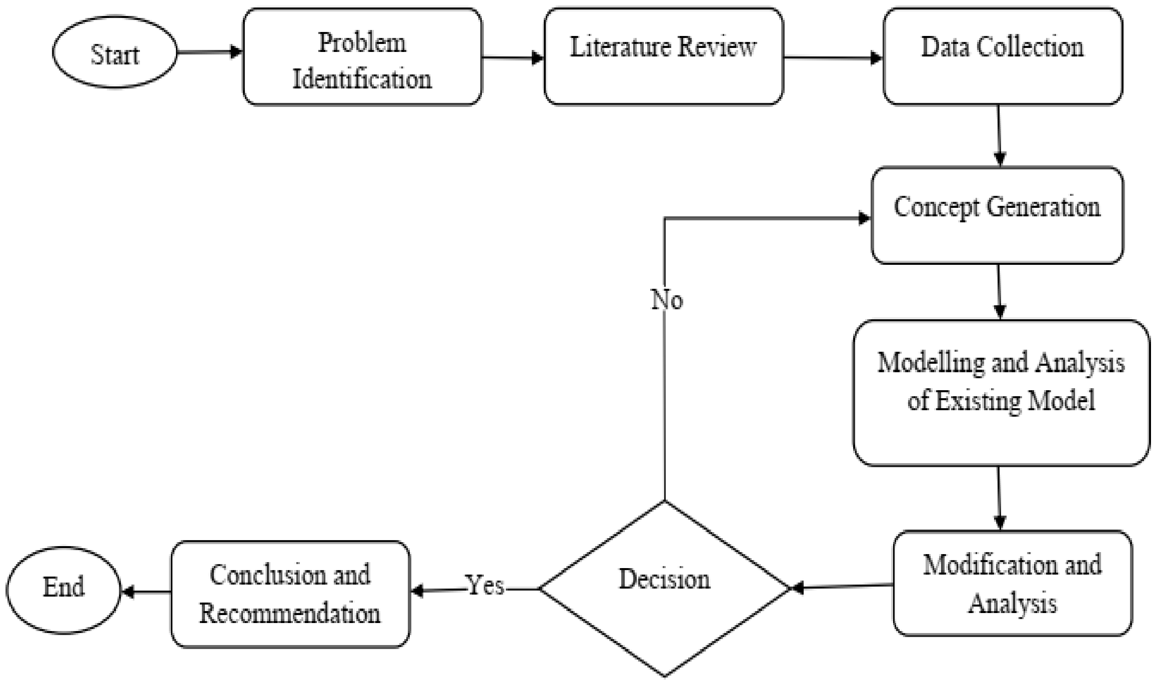


Figure 3.1. Block diagram of the thesis methodology.

3.3.1. Problem identification

A clearly specified list of problems is the most suitable basis for identifying potential solutions. Bus specially Isuzu bus is the most affordable and accessible type of public transportation in Ethiopia. These buses (Isuzu Kitkit) are becoming common way of transportation where they can be made-up in native garages of the cities. These buses are manufactured on-site by dismantling the normally imported Isuzu truck cabs and loading decks, converting the trucks into passenger buses, and adding passenger seats and covers with properly structured accessories. The design structural strength, seats, framework material and dimension of these Isuzu buses have no standard like ECE R66 or any other standards. Passengers are facing serious injuries as well as death at the time of crashes such as rollover impacts..

3.3.2. Data collection

Data collection is the process of collecting and measuring information about variables of interest, in an established systematic manner that allows answering stated research questions, test hypotheses, and evaluate results. Thus primary data which are useful to determine the overall dimensions of the locally built Isuzu bus dimensions, capacity of the bus and required material, physical and mechanical properties of materials for the Isuzu bus going to be developed were collected.

3.3.2.1. Primary data

Primary data collection is the process of gathering data through surveys, interviews, or experiments.

Data from Isuzu bus building garage

The tables below shows the data from interview and questionaries' form Endalkachew, Cherenet, Demelash and Mohammed Isuzu bus building Garages Adama, and Teddy Isuzu bus Building Garage Addis Ababa, Ethiopia.

For measurement of critical dimensions for this project work measuring tape and Vernier Calipers have been used. Ethiopian transport authority allows truck owners to change the truck (especially Isuzu open back truck) in to passenger buses so called "Isuzu kitkit" according to the specification given by the authority.

Table 3.2. Endalkachew Garage Isuzu bus specifications

Overall Dimension of Isuzu Bus	Width : 2.3 m Length : 7 m Height : 2.8 m
Capacity	From 23 - 29 Passengers
Wheel Base	4.26 m, depends on Isuzu truck
Maximum Speed	121 km/h
Fuel Tanker Capacity	200L
Model	6HK1-TCN
Engine type	Turbocharged and inter cooled, depends on Isuzu truck
Number of cylinder	6
Maximum Torque(Nm@r/min)	706@1450, depends on Isuzu truck
Maximum Horse Power(hp@r/min)	236@2400, depends on Isuzu truck
Gross weight	4,200 kg to 4,300 kg
Truss element Thickness	2 mm
Number of seat	29 maximum
Front axle width	2.1 m
Rear width	2.3 m
Material used for frame	Hollow Rectangular structural steel.
Material used for roof rack	Hollow Circular structural steel.

The above table 3.2 shows the major specification of Isuzu bus from Endale Garage Adama, Ethiopia. Endalkachew garage is found in Adama around Barecha. The data have been gathered by personal interview and questionaries' with the mechanics and owner of the garage.

Table 3.3. Mohammed garage Isuzu bus specification

Overall Dimensions of Isuzu bus	Width = 2.6 m Length = 7.3 m Height = 2.10 m
Capacity	From 23 – 29 Passengers, depends on Isuzu truck and customers need.

Wheel Base	4.28 m, depends on Isuzu truck
Maximum Speed	121km/h, depends on Isuzu truck
Fuel Tanker Capacity	200L, depends on Isuzu truck
Engine type	Turbocharged and inter cooled, depends on Isuzu truck
Number of cylinder	6
Maximum Torque(Nm@r/min)	230 (23.5) / 1,400 – 3,200, depends on Isuzu truck
Maximum Horse Power(hp@r/min)	236@2400, depends on Isuzu truck type
Gross weight	4,100 kg to 4,300 kg
Truss element Thickness	2 mm
Number of seat	29 maximum
Frontal width	2.14 m
Rear width	2.6m
Material used for frame	Hollow Rectangular structural steel
Material used for roof rack	Hollow Rectangular structural steel

The table 3.3 shows the material and dimensional specification of Mohammed garage Adama Ethiopia. The data have been collected from Mr Mohammed who is the owner of the garage by method of interview, and personal survey and measurement.

Table 3.4. Demelash Isuzu bus Building garage specification

Overall Dimensions of Isuzu bus	Width = 2.7 m Length = 7.6 m Height = 2.26 m
Capacity	23 Passengers
Wheel Base	4.26 m, depends on Isuzu truck type
Maximum Speed	121km/h, depends on Isuzu truck type
Fuel Tanker Capacity	200L, depends on Isuzu truck
Engine type	Turbocharged and inter cooled, depends on Isuzu truck type
Number of cylinder	6
Maximum Torque(Nm@r/min)	230 (23.5) / 1,400 – 3,200, depends on Isuzu truck type

Maximum Horse Power(hp@r/min)	236@2400, depends on Isuzu truck type
Gross weight	4,000 kg to 4,400 kg
Truss element Thickness	1.5- 2 mm
Number of seat	23 maximum
Frontal width	1.98 m
Rear width	2.7m
Material used for frame	Hollow Rectangular structural steel
Material used for roof rack	Hollow Rectangular structural steel

The statistics of the above table 3.4 claimed from Demelash Isuzu bus building garage Adama Ethiopia. The data of materials and structural dimensions have collected by personal measurement, and interviewing the owner Mr Demelash and the employees of the garage.

Table 3.5. Cherenet garage specification

Overall Dimensions of Isuzu bus	Width = 2.5 m Length = 7.8 m Height = 2.1 m
Capacity	From 23 – 29 Passengers
Wheel Base	4.28 m
Maximum Speed	121km/h
Fuel Tanker Capacity	200L
Engine type	Turbocharged and inter cooled
Number of cylinder	6
Maximum Torque(Nm@r/min)	230 (23.5) / 1,400 – 3,200
Maximum Horse Power(hp@r/min)	236@2400
Gross weight	4,000 kg to 4,200 kg
Truss element Thickness	2 mm
Number of seat	29 maximum
Frontal width	1.92 m
Rear width	2.5m
Material used for frame	Hollow Rectangular structural steel

Material used for roof rack	Hollow Rectangular structural steel

The specified information and data of the above table 3.5 collected from Cherenet garage Adama Ethiopia. The data gathered from garage employees and supervisor by interviewing and questionnaires', and also personally measuring the dimensions of structural parts of the bus.

Table 3.6. Teddy Isuzu bus building garage specifications

Overall Dimensions of Isuzu bus	Width = 2.6 m Length = 7 m Height = 2.10 m
Capacity	29 Passengers
Wheel Base	4.26 m
Maximum Speed	121km/h
Fuel Tanker Capacity	200L
Engine type	Turbocharged and inter cooled
Number of cylinder	6
Maximum Torque(Nm@r/min)	230 (23.5) / 1,400 – 3,200
Maximum Horse Power(hp@r/min)	236@2400
Gross weight	4200 to 4,500 kg
Truss element Thickness	2 mm
Number of seat	29 maximum, based on Isuzu Truck types
Frontal width	1.96m
Rear width	2.6m
Material used for frame	Hollow Rectangular structural steel
Material used for roof rack	Hollow Circular structural steel

The table 3.6 show the specification taken from Teddy garage Addis Ababa, Ethiopia, the data gathered by observation and measuring the structural dimension of the bus parts and interviewing the garage workers and by questionnaire questions.

Vehicle (bus) registration data

The following vehicle registration data claimed from transport communication information technology directorate. The information is from 2009 to 2013 Ethiopian calendar by type and number in the regions registrations.

The bus with seat number greater than eleven are the category of Isuzu bus (Isuzu Kitkit) considered, the figures below are the the number of buses registered in every regions of Ethiopia from 2009 to 2013 E.C.

Where AA= Addis Ababa City Administration, AM= Amhara Region, AF= Afar Region, BN= Benishangul-Gumuz Region, DD= Dire Dawa City Administration, SO= Somalia Region, TG= Tigiray Region, GM= Gambela Region, HA= Harari Region. SN= South Nations Nationality People Regional State, and OR= Oromia Region.

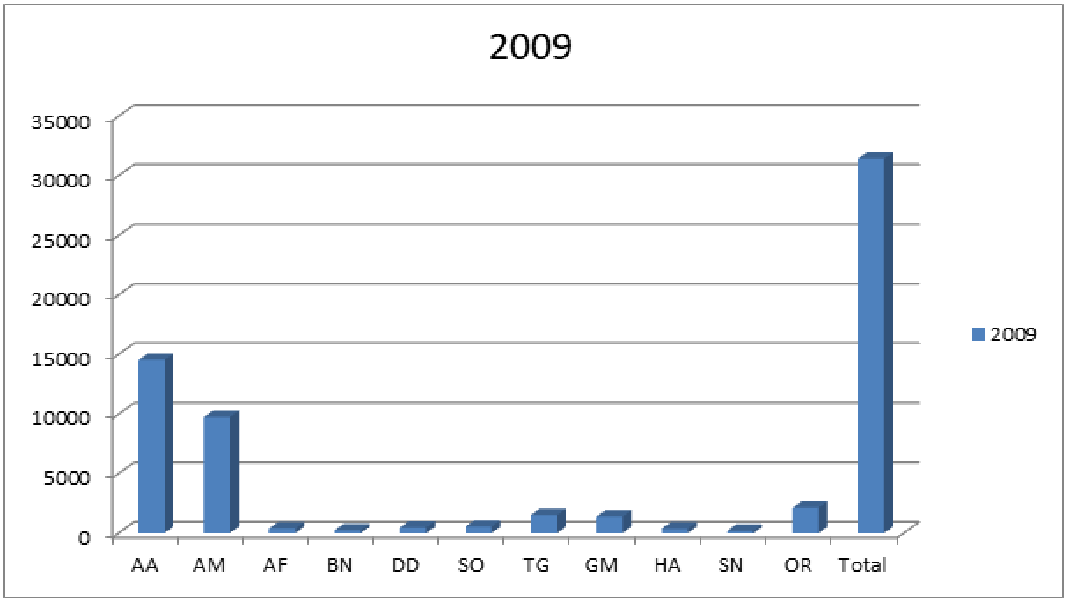


Figure 3.2. Bus registration in 2009 E.C

In 2009 E.C totally 31,423 buses have registered in Ethiopia out of this 14,524 buses registered in Addis Ababa which take the most number, and with 178 buses Southern Nations Nationality And Peoples Region registered the lowest number of buses.

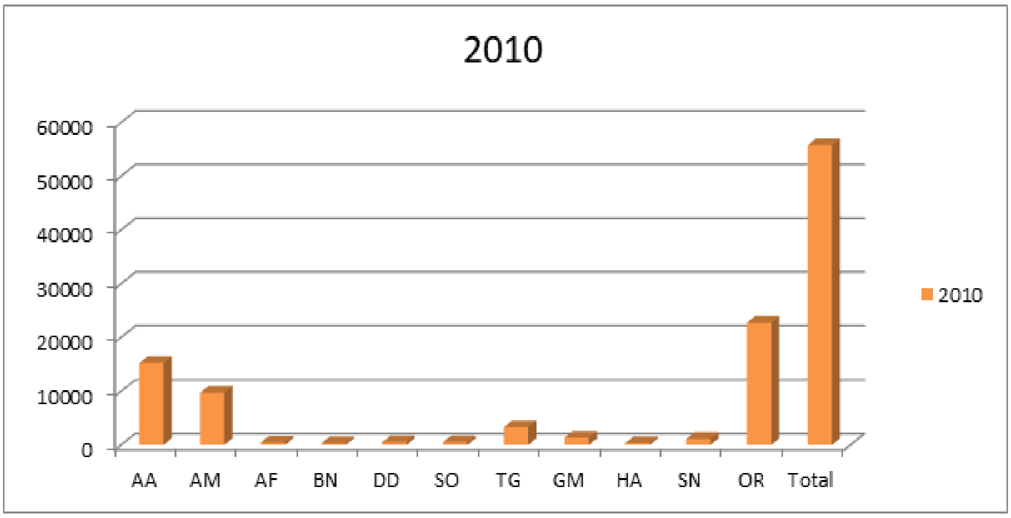


Figure 3.3. Bus registration in 2010 E.C

In 2012 E.C totally 55,797 buses have registered in Ethiopia, from this Oromia region have registered 22,772 buses, which is the highest number of buses registered and Benishangul-Gumuz region registered the lowest number with 325 buses.

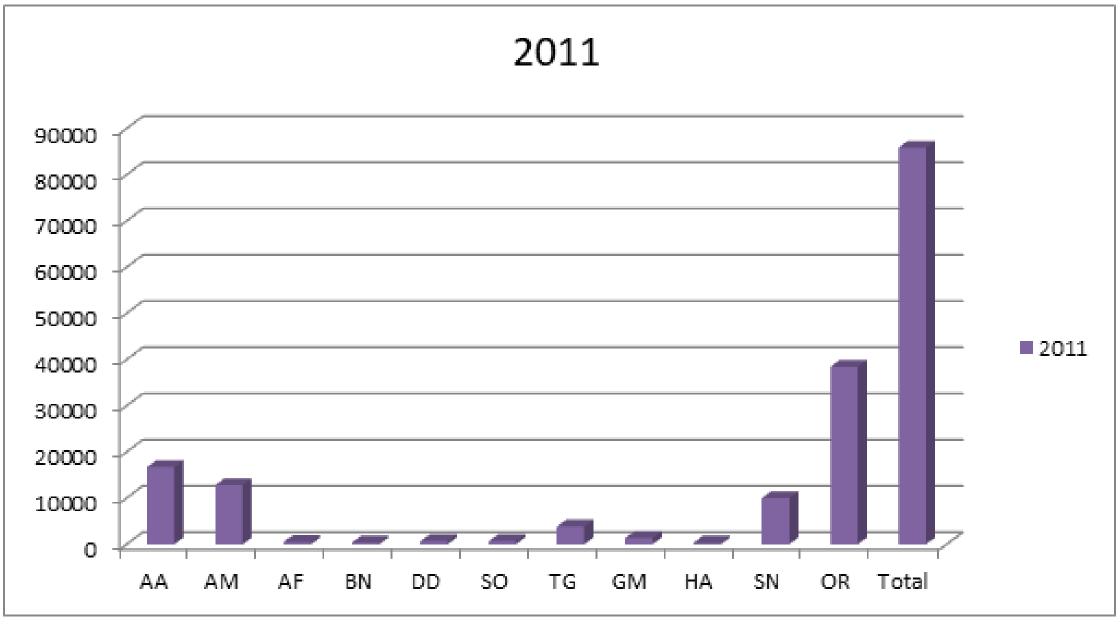


Figure 3. 4. Bus registration in 2011 E.C

Figure 3.4 shows registration data in 2011 E.C total 85,892 buses number of buses registered in Ethiopia out of these buses 38,439 buses registered in Oromia region, which is the leading region by registering highest number of buses and Benishangul-Gumuz region placed in the least place by registering only 378 buses.

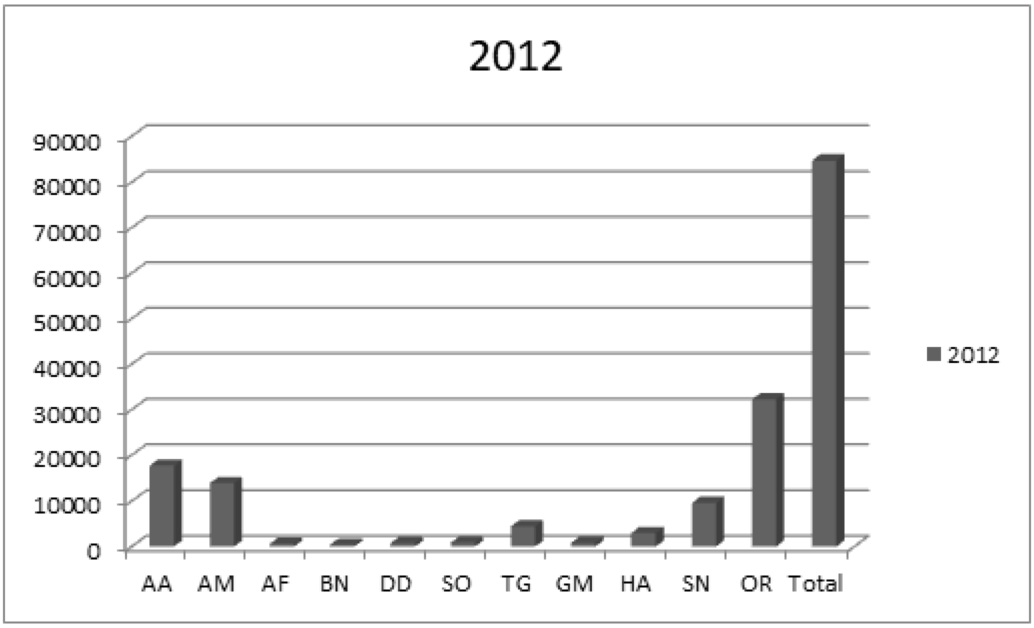


Figure 3.5. Bus registration in 2012 E.C

As shown in figure 3.5 in 2012 E.C registered buses in Ethiopia totally is 84,700 buses, out of these buses 32,289 buses are registered in Oromia region which is the highest number registered in the Country, the lowest number registered is 467 buses in Benishangul-Gumuz region.

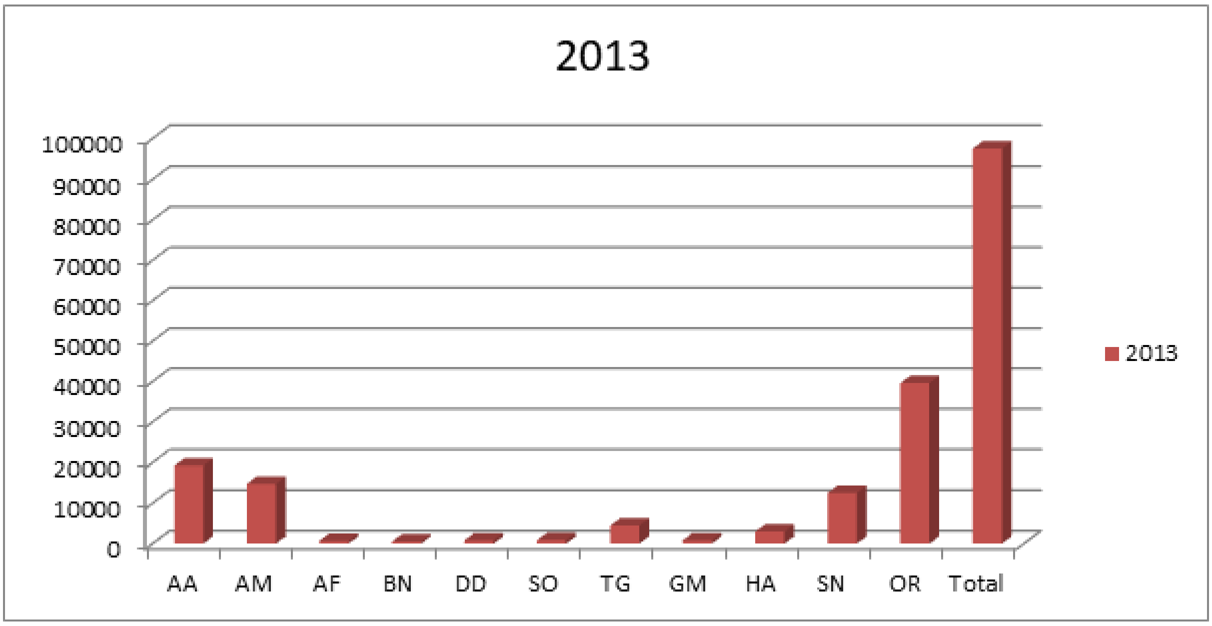


Figure 3.6. Bus registration in 2013 E.C

As shown in figure 3.6. in 2013 E.C registered buses in Ethiopia is 97,520 busses, from this busses 39,631 are registered in Oromia region which put this region placed in first place, and Benishangul-Gumuz registered lowest number of buses with 526 buses.

In general from 2009 to 2013 E.C the number of bus registration in Ethiopia are increasing very fast and, from these registered buses the Izuzu bus (Isuzu Litkit) take the major type of bus registered.

Bus accident data in Ethiopia

Bus accident data from 2009 to 2012 E.C are presented in figure below. The accidents are shown as death, severe injuries, minor injuries, and property loss.

As shown in figure 3.7 the number of death increases from 2010 to 2012 as injures, property loss decreases in Ethiopia. There are many reasons for the increase of death, the low strength of the structure of buses and lack of protective safety equipment are considered to be the main causes.

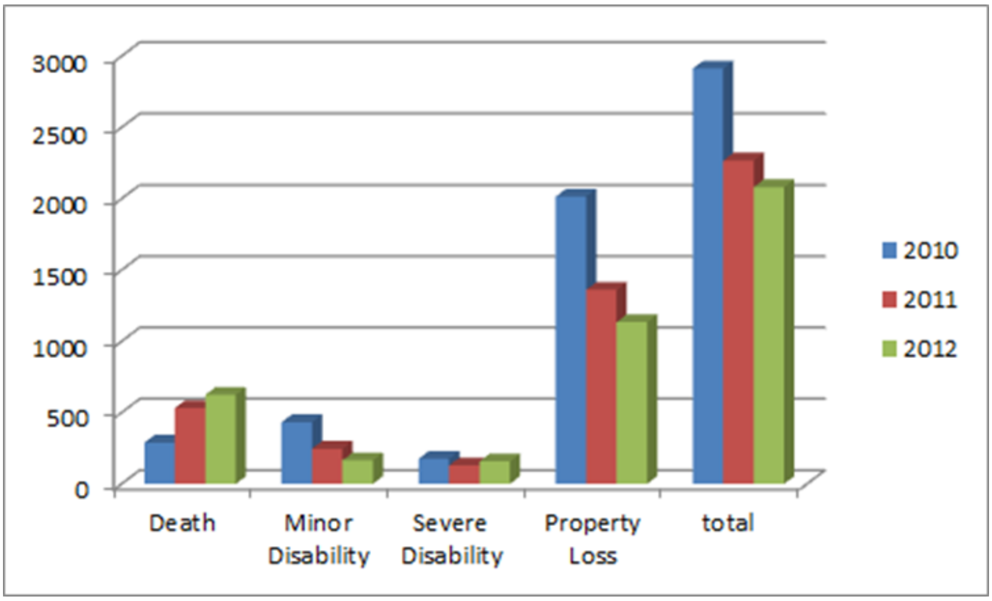


Figure 3.7. Bus accident data in Ethiopia from 2010 - 2012 E.C

3.3.2.2. Secondary Data

Secondary data include censuses, information from literature review, organizational records and data that was originally collected for other research purposes. These types of data have been discussed in chapter two.

3.3.3. Concept Generation

In bus structure rollover crashworthiness different concepts have been generated to improve the bus strength during rollover crash like superstructure reinforcement, material changing and increasing the number of pillars. In the next chapter we will discuss in detail about this.

3.3.4. Modelling and simulation of bus structure using LS DYNA

The modelling and analysis of the structure of the existing model of locally built Isuzu bus was carried out by using some attractive software's. The Isuzu bus modelled in on CATIA software and model quality is cheeked by LS-pre post and the analysis will be done using LS-DYNA processor

3.3.5. Modification and analysis

By observing the crashworthiness behaviour of the existing model Isuzu bus, modifications and designs were made on critical points of the bus. Then the modified parts were analyzed separately by LS DYNA.

3.3.6. Decision

In this stage, the response of modifications is inspected using engineering analysis and decision made. If the result were acceptable the next stage of the project will take place but if not, the modification is re-designed

3.3.7. Verification parameters

Without experimental data, the appropriateness of the values obtained on a computational model accurately represented by verification process. In case LS DYNA simulation, verification can be made by checking the quantity of energy balance, deformations, kinematics, kinetics and other quantities (Gulavani, 2014). There are some parameters used to verification like Energy balance, and Energy ratio.

Energy balance

The main task of the model verification is an assessment of the numerical error in the simulation. Besides the error introduced from discretization of FE model, there are multiple other factors influencing the error within the solution. The importance of these factors is assessed, in the present research, mainly by checking the energy balance within the simulated time period. It is required, that all energy components should follow the laws of conservation of energy, and that all non-physical energy forms were kept at minimum.

$$E_{total} = E_{kin} + E_{Int} + E_{si} + E_{rw} + E_{damp} + E_{hg} = E_{total}^{0} + W_{ext} \tag{3.1}$$

$$E_{total}^{0} = E_{kin}^{0} + E_{int}^{0} \tag{3.2}$$

Where:

E_{total} - Total energy

E_{kin} - Kinetic energy

E_{Int} - Internal energy

E_{si} - Sliding interface energy

E_{rw} - Rigid wall energy

E_{damp} - Damping energy

E_{hg} - Hourglass energy

W_{ext} - External work

E_{kin}^{0} - initial kinetic energy

E_{int}^{0} - initial internal energy

Energy ratio

The ratio of the total energy to the sum of ‘initial total energy’ and ‘external work done ‘is called the energy ratio

$$eratio = \frac{E_{total}}{W_{ext}+E_{i}^{0}+E_{ke}^{o}} \tag{3.3}$$

Where:

$eratio$ - Energy ratio

An energy ratio with value of equal to 1 shows more stable and reliable FEA result, but most of it is difficult to achieve such value. If e>1, which mean that artificially energy is added in the model and rises the total energy values, as a results instability occur, most of the time the rises of total energy is due to a numerical instability or through initial penetration. If e<1, which indicates that the total energy reduces because of artificially absorbed energy, either by excessive hour-glassing or during stabilization of an ill-conditioned contact surface. Since it is difficult to obtain energy ratio equal to unity so, the acceptable value of the ratio is 1.00 +/- 0.07 (Ls-dyna support, 2022).

Hourglass energy

The hourglass energy mode is a non-physical, non-energetic, strain-free and stress-free strain mode. Hourglass mode occurs only in solid elements, cases and thick cases that have not been integrated (single-point integration). LSDYNA has various algorithms for hourglass mode inhibition. Hourglass energy can cause a zero-energy model. If the hourglass Energy is less than 5% of the total energy, the finite element model is reliable. Triangular shells and tetrahedral solid elements do not have hourglass modes but have drawbacks with regard to overly stiff behaviour in some applications (dynasupport, 2021).

In locally built Isuzu bus rollover simulation the core parameters such as energy balance, absorbed energy, impact force, deformation and structural response are going to be studied briefly.

CHAPTER FOUR

MODELLING AND SIMULATION OF BUS STRUCTURE USING LS DYNA

4.1. Introduction

In this chapter locally built Isuzu bus structure according to the dimensions of the Ethiopian Isuzu bus building garages modelled by CATIA V5 software and the existing Isuzu bus rollover analysis using LS-DYNA are discussed.

Figure 4.1. Isuzu bus (Isuzu Kitkit)

The figure 4.1 shows existing Isuzu passenger bus with a seating capacity of 29 which manufactured in Ethiopia. It is very popular bus in Ethiopia for city-to-city public transport. Picture taken from Mohammed garage Adama.

4.2. Simulation technique of the rollover test for locally built Isuzu buses

The global scheme of the developed technique for the simulation of local built Isuzu bus rollover test is shown hereafter. The flow diagram of this technique is shown on figure 4.2. Once the geometry defined, the finite element model of the bus structure was developed. Material and section definitions are introduced in the next step. Then the initial and boundary conditions like the tilt table were modelled to hold the bus in it, the residual space was designed in a way that the passengers stay safe during rollover crash according to ECE regulation number 66. Positioning the locally built bus in tilt table to freely fall in to the dry fixed ditch by gravitational force, contact between the parts can be encoded, introductions of gravitational force on the bus to freely fall into the dry 800mm dip ditch, and changing deformable material parts to rigid material property up to the bus touches the fixed wall ground. Then, Isuzu bus rollover crash simulation was done and the result were analysed. Finally, modifying the existing Isuzu bus on critical crash zone, verifying n and validating using ECE R-66.

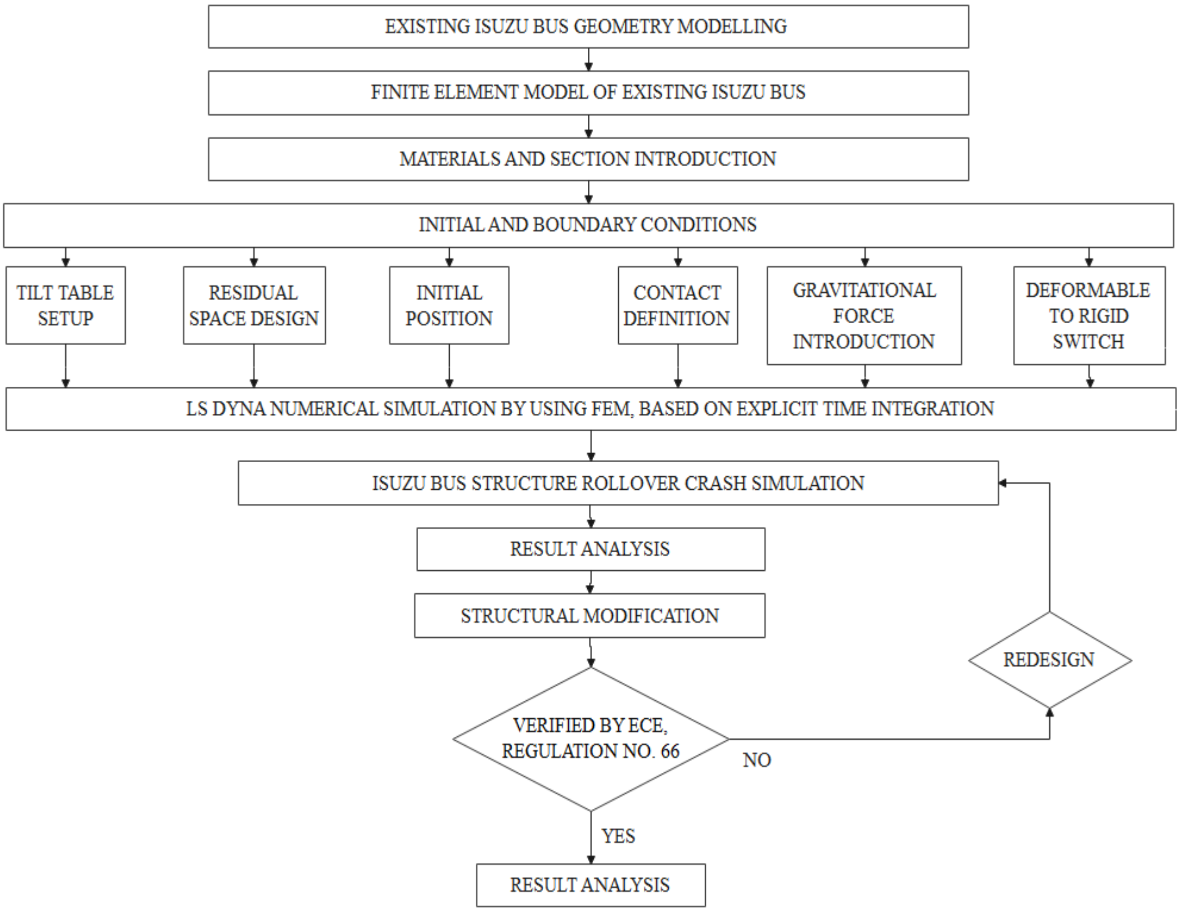


Figure 4.2. Flow diagram of the rollover test simulation

4.3. Locally built Isuzu bus models used for simulation

Existing locally built Isuzu bus superstructure modelling according to the specifications gathered from local garages using CATIA V5 software.

Figure 4.3. Isuzu bus building process

Figure 4.4. Different sizes of HRS

Figure 4.3 shows locally built Isuzu bus body structure building process in local garage. Traditionally, the most common material selection for manufacturing bus body structure would be steel, in various forms. Some time, other materials have come into use, the majority of which have been covered here are hollow rectangular steel.

As shown in figure 4.4 the prime reason for using steel in the body structure is its inherent capability to absorb impact energy in a crash situation. And also most bus building garages use mild steel for body cover so called 'Lamera'. The method of constraining (joining) used in these garages is arc welding.

Every local Isuzu bus building garages use different materials and different dimensions. The dimensions and size of the bus is according to the needs of the owner.

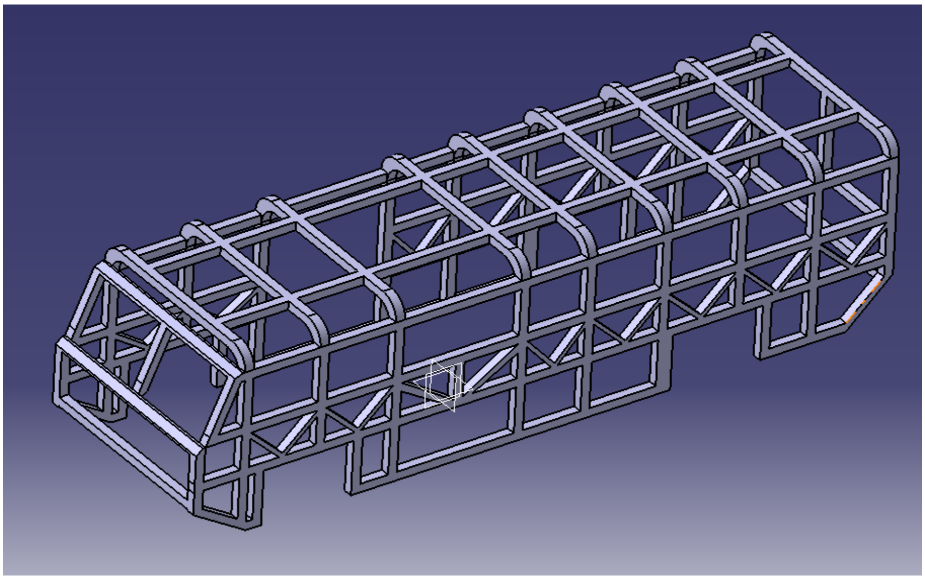


Figure 4.5. Isuzu bus superstructure model

There are some good reasons for using a CATIA to support the mechanical design function:

- To rise in the fabrication.
- To acquire better the quality of the mechanical design.
- To uniform design standards.
- To eliminate errors caused by manual copying of drawings and irregularities between drawings.

In general, plans of parts are drawn up to have an accurate idea of how the model is made. Components created in the parts module were imported into the assembly module and using the "insert component" command, and all these components were combined to form the required assembly. (Madhuvanesan M. M., 2021). The different views of assembly and the drawing generated in CATIA V5 are as shown above

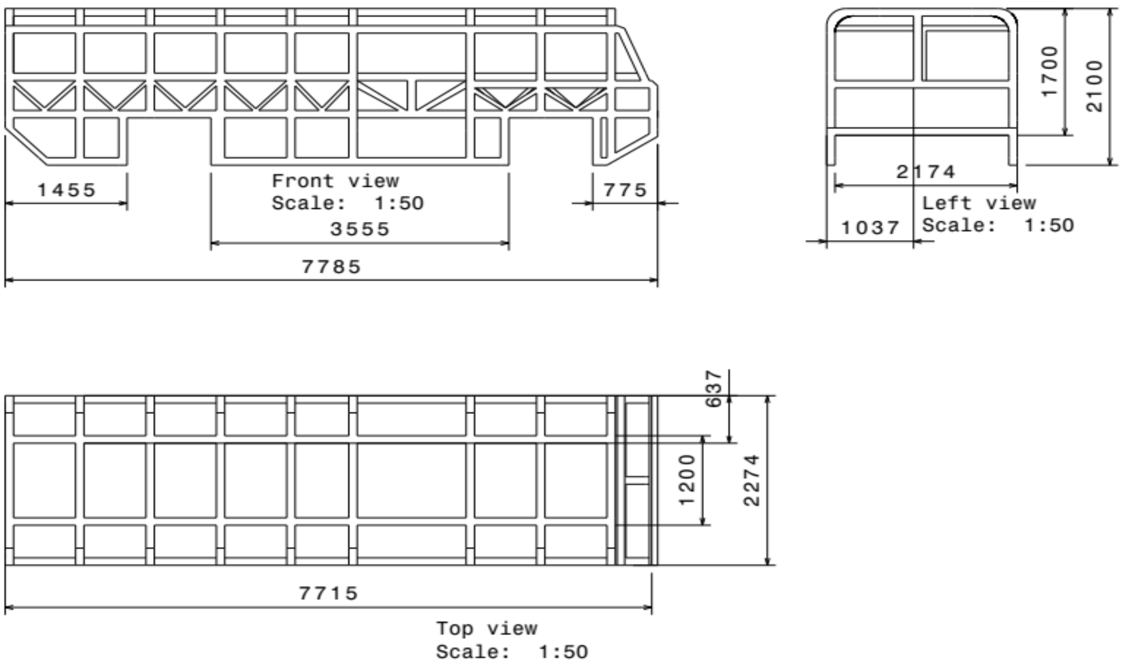
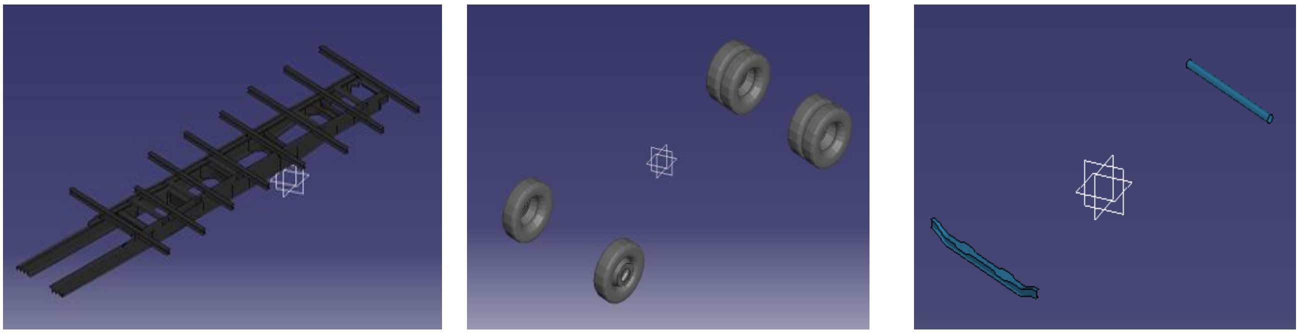


Figure 4.6. Isuzu bus superstructure model dimensions

As shown in figure 4.5 and 4.6 the modelling of the Isuzu passenger bus structure is made with data collected from Adama and Addis Ababa Ethiopia garages Isuzu passenger bus body builder. Before measuring the structure, drawing of the bus structure is made. This helps for easy placement of the measured length on the corresponding members on the drawing. During the data collection of the structure, all members of the structure are measured with length measuring tape.



a) Chassis b) Tires (wheels) c) Axels

Figure 4.7. Isuzu bus chassis, wheels and Axels model

As shown in the figure 4.7 a) the chassis modeling used for locally built Isuzu bus, b) the tire used for bus modeling front (two tires) and rear (four tires), and axles (front and rear axles) used for bus.

After modeling the above main components locally built Isuzu bus, the next procedure is to assemble the separated components in to one full mode using Ls Dyna software to reduce crossed edges and penetrations.

The modelling of the bus structure is made with Catia V5 software. The bus structure is made with steel beams of rectangular hollow section, with different size. The sizes of rectangular hollow section used are 100x50x6.3mm, 70x50x3 mm, 50x30x3 mm, 40x40x2.5mm and 70x50x2 mm. All dimensions are in millimetres. Before importing into LS DYNA the modelled parts should be saved in to an Initial Graphics Exchange Specification (IGES) mode.

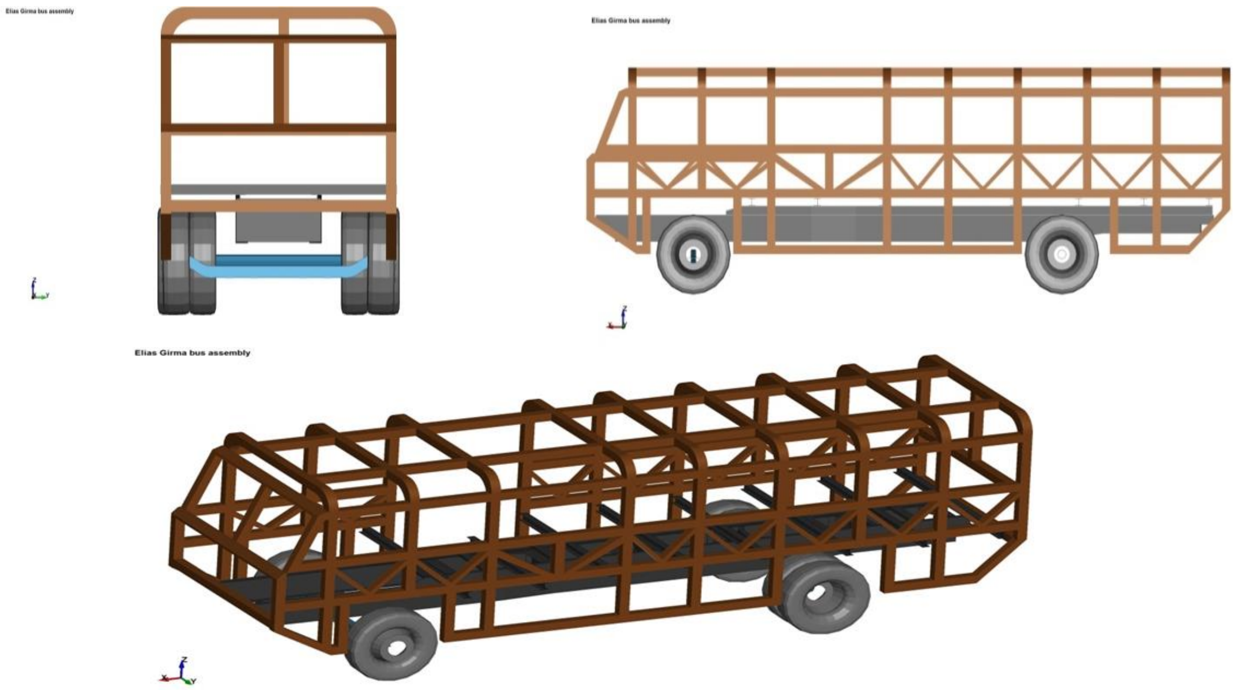


Figure 4.8. Side, Front and Isometric view of Isuzu bus model assembly

Figure 4.8 explains the modelled parts of Isuzu bus assembly in LS DYNA side, front and Isometric views after this, meshing and constraining the model follows.

4.3.1. Meshing the Model

The IGES mode files imported from CATIA to LS DYNA were meshed and checked for errors. The mesh generation is take place separately for each part. Defining how the Isuzu bus parts should be broken down into finite pieces for computational process. As shown in figure 4.9 below.

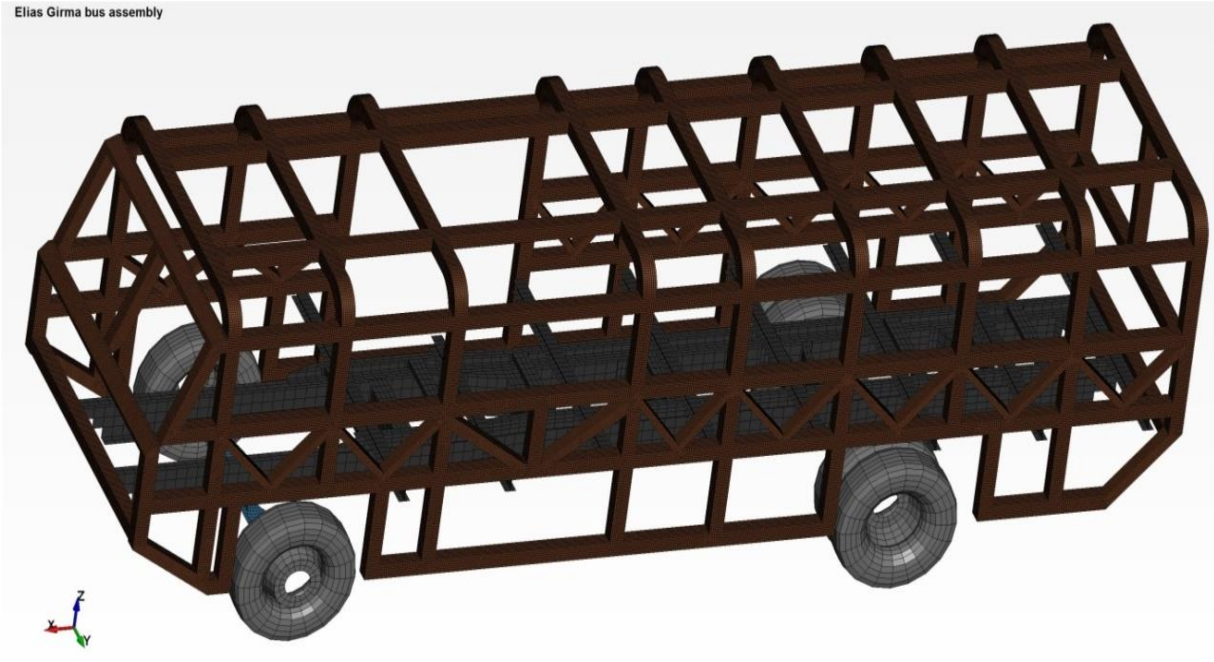


Figure 4.9. Meshed Isuzu bus

4.3.2. Element Formulation

Most of the shell elements have been modelled using a fully integrated element type 16. Default element formulation in LS-DYNA (type 2 Belytschko-Tsay), although computationally efficient, suffers from an effect called hourglass. Hourglass deformations are nonphysical, zero energy deformations, that are direct a consequence of under-integrated element formulations. LS-DYNA has multiple algorithms for mitigating hourglass modes, either stiffness based (types 4, 5) or viscosity based (type 1, 2, 3).

The element sizes for whole bus superstructure model are between 2mm and 12mm. usually smaller mesh means more accurate results, but the computing time gets significant as well. for a balance between computing time and accuracy. The total numbers of elements for the whole meshed model were 377003 and node 378201

Element quality check

To get reasonably accurate results, it is always essential to generate a structured mesh with worthy quality parameter. Table 4.1 explain different quality parameters like skew, aspect ratio, included angles, Jacobian, stretch etc., are the measures of how far a given element deviates from ideal shape. Square means all angles 90 degree and equal sides, while equilateral triangle is all angles 60 degree and equal sides.

Table 4.1. Element quality check

Quality Name	Minimum. Value	Maximum. Value	Allowable	Violated (%)
Min side length	0	0	3	0(0%)
Max side length	0	0	30	0(0%)
Aspect Ratio	1	9.77	5	10(0.000818%)
Warpage	0	180	15	331(0.0271%)
Min Quad Angle	20	90	45	214(0.0175%)
Max Quad Angle	0	0	135	0(0%)
Min Tria Angle	0	0	30	0(0%)
Max Tria Angle	0	0	120	0(0%)
Taper	0	0	0.7	0(0%)
Skew	0	58.6	45	44(0.0036%)
Jacobian	-0.0617	1	0.6	643(0.0526%)
Char. Length	0	0	1	0(0%)
Area	0	0	5	0(0%)
Feature angle	0	0	30	0(0%)
Time Step	0	0	1e-06	0(0%)
#quads(%):376394(99.8%),		#trias(%):642(0.17%),		#total of failed(%):0(0%)

4.3.3. Model Check

After meshing each part of the model, checking for initial penetration and crossed edges in LS DYNA. Initial penetration is a term used frequently to describe the amount of penetration that exists between a node and its closest master segment (in the case of classic node/ segment treatment) or between two interacting segments (in the case of `segment-based` treatment) during the initialization of the problem. The case where an edge of an element crosses another shell element mid surface, or face on a solid element is not a penetration in a classical sense in LS-DYNA. But these mesh errors might lead to severe problems when running an analysis in LS-DYNA so it is very important that such modelling is avoided

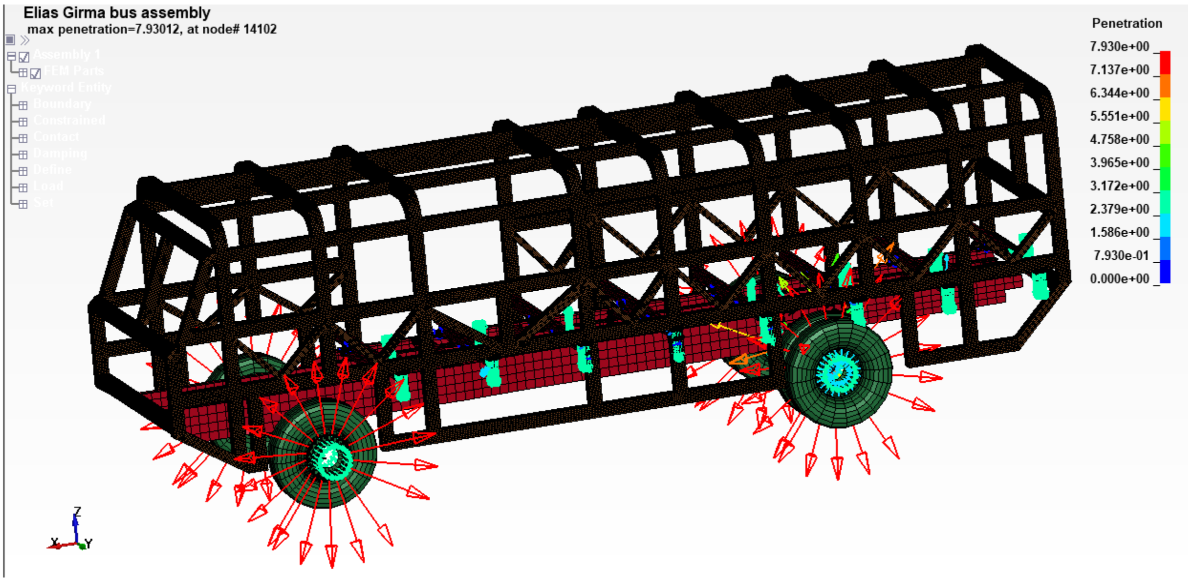
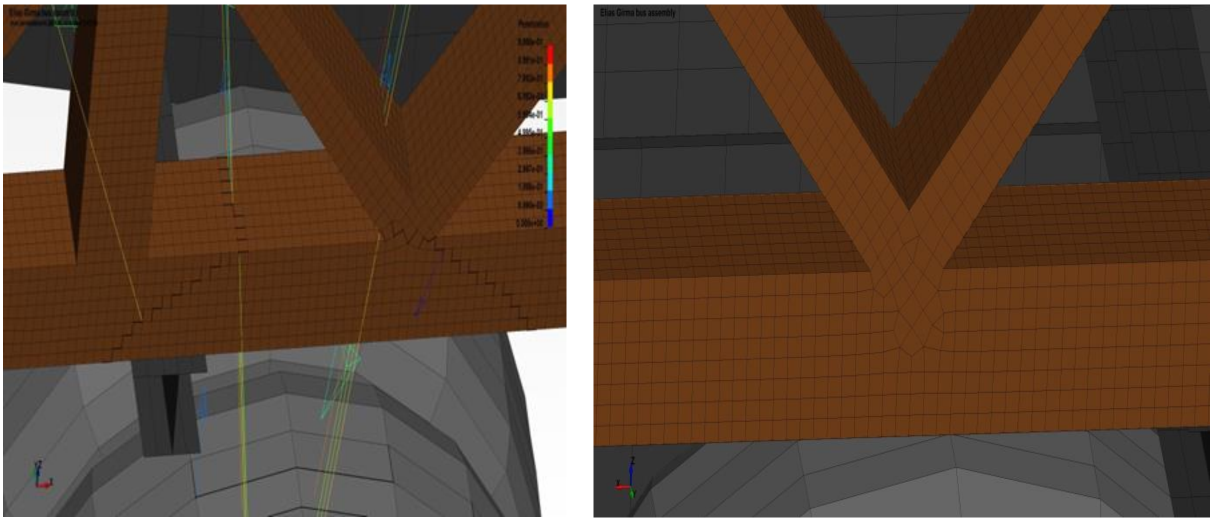


Figure 4.10. Model check (penetration and crossed edge)

The existence of first cycle penetration in the exposure definitions without interference, i.e. after problem initialization, has some adverse effect on the quality of the simulation as shown above in figure 4.8 LSDYNA tries to eliminate any intrusions and penetrations that may exist in the first cycle by exerting force on the nodes involved.



a) before b) after

Figure 4.11. Penetration a) Before and b) after removing initial penetration

As shown in figure 4.11. LS DYNA software removes initial penetration automatically but this causes distortion of the original shape at the locations where the penetration is detected, and the node coordinates after deletion can still penetrate other neighbouring segments and lead to instability problems. So, manually removing like re-meshing and merging node to node are the finest way to remove initial penetration.

4.4. Analysis Setup

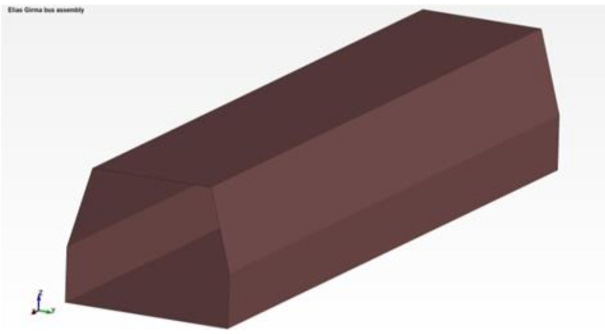
4.4.1. Residual Space specification

ECE R66 concentrates on the ability of a vehicle to sustain its residual space in a rollover crash. The residual space (survival space) is not expected to be intruded by structural deformations resulting from a rollover crash, for regulation approval. The specifications for the residual space viewed as wireframe trapezoid, from cross section were as follows:

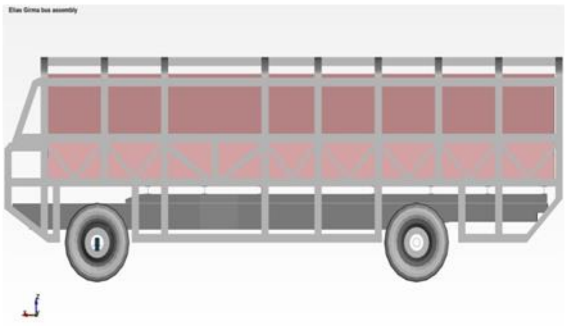
- The lower edge line shall be at 500 mm above the floor under the seat.
- The lower edge point shall be at 150 mm from the inside surface of the wall.
- The upper edge line shall be at 750 mm from the lower edge line.
- The upper edge point shall be at 250 mm from the line perpendicular to the lower edge point

a) 3D view residual space inside the bus

b) Front view residual space inside the bus



C) Residual space



D) Side view of residual space inside the bus

Figure 4.12. Residual space specifications

Figure 4.12 shows the residual space model 3D, front and side view inside the Isuzu bus model in which the passengers assumed to be safe. According ECE R66 specification the residual space are inserted.

Table 4.2. Residual space dimensions of Isuzu bus model.

SN	Dimension of residual space	Description of dimension	Length
1	Lower edge length	2,274 mm – (2 x 150 mm)	1,974 mm
2	Upper edge length	2,274 mm – (2 x (150+250	1,474 mm
3	Height	As specified in ECE R66	750 mm
4	Longitudinal length	According to body section	7,060 mm

In table 4.2 The Isuzu bus model residual space dimensions are discussed. Thin rigid beam frames were used for modelling the residual space, which were mounted on rigid part under the floor. Null material was assigned to the residual space, thus the stiffness connection between these frames was voided

4.4.2. Tilt table modelling according to ECE R-66

The full-scale vehicle is placed stationary and slowly tilts into an unstable equilibrium position on the table. The rollover test begins in this unstable vehicle position with zero angular velocity and the axle passes through the wheel contact points. By this time, the vehicle trips over into ditch, having a horizontal dry and smooth concrete ground surface with a nominal depth of 800 mm as shown in figure 4.13 and figure 4.14.

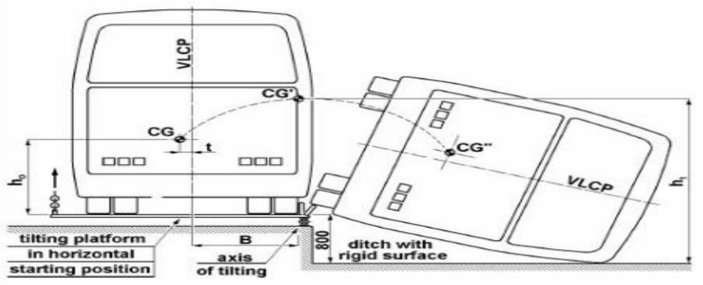


Figure 4.13. Rollover per ECE R 66

Figure 4. 14. Tilting Platform model

To reduce the computing time, the testing model was rotated in advance to reach a point just before unstable position. The boundary condition is that the vehicle model is tilted without shaking or dynamic effects until it reaches unbalanced equilibrium and begins its rollover.

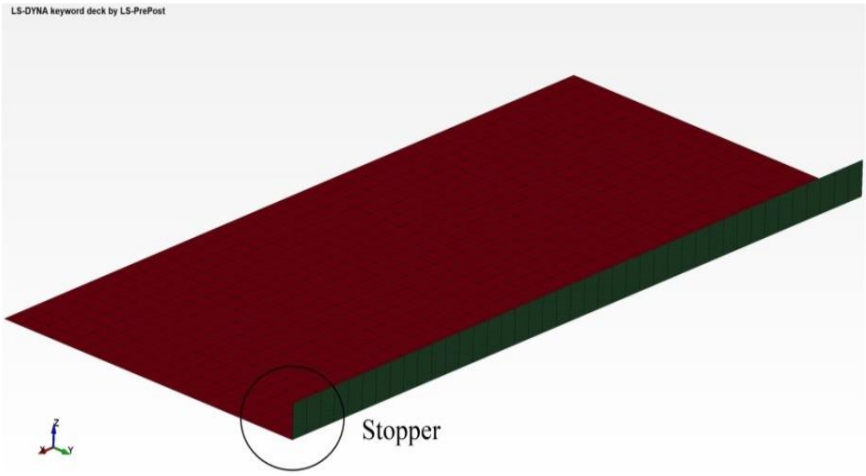


Figure 4.15. Stopper on tilt table

As presented in Figure 4.15 at the edge of the incline a stopper has been inserted to support the wheel so that the bus turns away from the incline without moving along its longitudinal axis and to hold the side of the wheel. The stopper is 20 mm in thickness. LS DYNA Finite Element (FE) model of tilt table and stopper device is defined as RIGID material.

The tilting table is 12,000 mm in length, 2 mm thick and 3,000 mm wide at the edge it is connected to stopper which is 100 mm in height and 20 mm in width. The rigid wall is 12,500 mm, 2 mm thickness and 3,500 mm in width 800 mm below tilt table.

4.4.3. Selection of Constitutive Material Models Used

Constitutive material models used in this research along with the list of components modelled using given material definition is listed below in table 4.3.

Table 4.3. Constitutive material models used in FE models of locally built Isuzu bus

Material Model	Vehicle components
001 *MAT_ELASTIC	Wheels
009 *MAT_NULL	Residual space profile (survival space)
020 *MAT_RIGID	Tilt table
024 *MAT_PIECEWISE_LINEAR_PLASTICITY	Chassis structural elements and bus superstructure (roof and frame)

MAT_ELASTIC

During the FE bus model development this material definition was used to model non-structural parts of the traveller compartment, such as rubber door seals, rubber wheel, wall covers, and water ballast dummies used to compensate for passenger weight (Hallquist, 2007).

MAT_NULL

Shell elements defined with this material are not included into element processing by LS-DYNA solver (Hallquist, 2007). To take advantage of that feature, the residual space profile (used only for visualization purposes), was modelled with MAT_NULL definition.

MAT_RIGID

MAT_RIGID presents a very convenient way of defining parts within the model as rigid bodies. In some applications it is a good choice to approximate a part of the model as a rigid body, since its definition is bypassed in the element processing and results in increased calculation speed (Hallquist, 2007). Rigid bodies are also commonly used in LS-DYNA for joint definition such as JOINT_REVOLUTE and JOINT_CYLINDRICAL keywords. The tilt table, used for rollover test procedure, was modeled using the material rigid definition.

MAT_PIECEWISE_LINEAR_PLASTICITY

Most of the steel and aluminium structural elements in the developed FE models were modelled using MAT_PIECEWISE_LINEAR_PLASTICITY material definition. Elements of the chassis, such as frame and vehicle body panels, were defined as MAT_024 on the locally built Isuzu bus as listed in table 4.4 below. Structural elements of the passenger compartment, such as cage frame, and steel bus skin, were added to the model also using MAT_024 definition (Hallquist, 2007).

Table 4.4. Isuzu bus model parts material properties

Vehicle part	Material name	Mass density (kg/mm^3)	Young's Modulus (KN/mm^3)	Poisson's ratio	Yield Stress (KN/mm^3)	Shear Modulus (KN/mm^3)	Tangent modulus
axles	steel	7.80e-006	210	0.3	0.25	-	1
Chassis	Structural steel	7.80e-006	207	0.28	00.61	-	
Frame	HSS	7.750e-006	190	0.27	0.366	-	1250
Wheels	Rubber	1.190e-006	4	0.15		-	
Residual space	Null	7.80e-006		0.3	-	-	-
Inclined plate	Aluminum	2.6989e-006	68	0.36	-	25	-
Fixed rigid plate	Concrete	2.0000000	14	0.21	-	-	-

4.4.4. Section Definition

In the section definition, the element formulation, integration rule, nodal thicknesses, and cross sectional properties are defined. Most vehicle components thicknesses were defined by section shell and the rest with solid element. For shell elements the value of the thickness are determined based on their density and mass value as show in table 4.5 below.

Table 4.5. Thickness of bus model components

Isuzu Bus component	Thickness (mm)	Isuzu Bus component	Thickness (mm)
Chassis	6	Residual space	1
Superstructure	2	Tilt table	2
Tire	10	Stopper	20
Axle	20		

4.4.5. Contact Definition

The keyword *CONTACT provides a way of treating interaction between disjoint parts. During FEM crash calculations, it is often the case that modelled parts come in contact. In order to prevent two objects penetrating each other, a contact handling algorithm is necessary to be implemented into the FEM software. Contact treatment algorithms are critical for large deformation problems, and accurate contact modelling is very important. Many contact types are currently available in commercial FEM software. Contact algorithms in LSDYNA can be separated into two groups; penalty based contacts and constrained based contacts (LSTC, 2014).

Most of the contacts algorithms, used for crash applications, are penalty based contacts. The principle of classical penalty contact definition in LS-DYNA requires the user to define "slave" nodes (ex. node sets, parts, past sets) that should be prevented from penetrating "master" segments (ex. segment set, parts, part sets). A search algorithm is implemented in LS-DYNA software in search for possible penetrations. Once a penetration is detected, a penalty force, proportional to the depth of the penetration is applied to the "slave" node in order to eliminate detected penetration (LSTC, 2014).

Since the penalty force is proportional to the depth of the penetration, it is often described as a tension-only spring, attached to the penetrating "slave" node. The resultant reaction force, coming from the contact spring, is also distributed over neighbouring nodes that belong to the "master" segment in order to follow the laws of conservation of momentum. The contact spring stiffness is a product of a user defined penalty factor and a stiffness value, defined as a minimum stiffness from either master segment or slave node (Du Bois, 2010).

Currently, AUTOMATIC_SINGLE_SURFACE contact algorithm is the most commonly used in impact simulations. It considers contact between all parts defined within the slave part set, as well as their self-contact. This contact is considered to be reliable and accurate (LSTC, 2014). The whole bus parts with each other used this contact type for the simulation.

*CONTACT_AUTOMATIC_SINGLE_SURFACE contact algorithm was used to define contact between all parts in developed FE models. Friction coefficient for this contact type was set equal to 0.15 representing steel to steel contact. (LSTC, 2014).

*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE is a suggested contact form since, in crash simulations, the location of parts relative to each other cannot always be predicted as the model experiences enormous deformations. As mentioned before, automatic contacts check for penetration on either side of a shell element. a contact between concrete rigid wall and bus. A separate contact entity was created for tiers and tilt table contact with a friction coefficient set to 0.7 representing rubber to steel contact as shown in table 4.6 below.

Table 4.6. Contact master and slave

No.	Contact type	Slave	Master
1.	Automatic surface to surface	Tire	Tilt table
2.	Automatic surface to surface	Tire	Stopper
3.	Automatic single surface	Whole vehicle	None
4.	Automatic surface to surface	Whole vehicle	Rigid plate

4.3.6. Constraints

The joining process of the existing Isuzu bus (Isuzu Kitkit) are usually arc welding which is easily available joining process in every garages. Figure 4.16 show the joining process of locally built Isuzu bus.

Figure 4.16. Isuzu bus joining process

After meshing the individual parts of Isuzu bus model, interactions have been defined between them. These connections are defined among the surfaces of dissimilar parts and control the transmission of forces and moments between separate members. Kinematic linkages have been well-defined for different parts of the vehicle. The constraint between two deformable parts was given by the keyword CONSTRAINED_NODAL_RIGID_BODY in Entity creation. Also to connect rigid to deformable body CONSTRAINED_EXTRA_NODE_SET is used by creating node set from deformable body. Constrained spot-weld and joint generalized is also used for this project to join two separate parts.

4.3.7. Centre of Gravity of the Bus

The position of the centre of gravity (CG) is essential in determining the reference and the total energy to be absorbed in the rollover test.

Table 4.7. Centre of Gravity dimensions of bus model

Section	Distance
The front edge from the CG	3807 mm
The rear edge from the CG	3973 mm
The CG from the VLCP	1254 mm
Height of the CG (h)	1090 mm

The rollover simulation only started after the body section roll passed the angle of stability in an unstable equilibrium position to save cost and processing time. Moreover, mass scaling and deformable-to-rigid switching functions in LS-DYNA were utilized for the same purpose. The location of CG was used to determine the unstable equilibrium angle given by the equation below.

$$\theta = \text{arccosine}\left(\frac{h}{\sqrt{(h^2+(B\pm t)^2)}}\right) \tag{4.1}$$

Whereby h is the height of CG, B is the perpendicular distance of the vehicle's vertical longitudinal centre plane (VLCP) to the axis of rotation, and t is the perpendicular distance of the CG from VLCP.

Weight of the Bus Specification

The table 4.8 below explains the weight distribution in locally built Isuzu bus in every component of the vehicle. The mass of engine, transmissions suspension and other missed component in this model are considered as rigid box element in the centre of gravity to get overall weight of locally built Isuzu bus.

Table 4.8. Weight of the bus specification

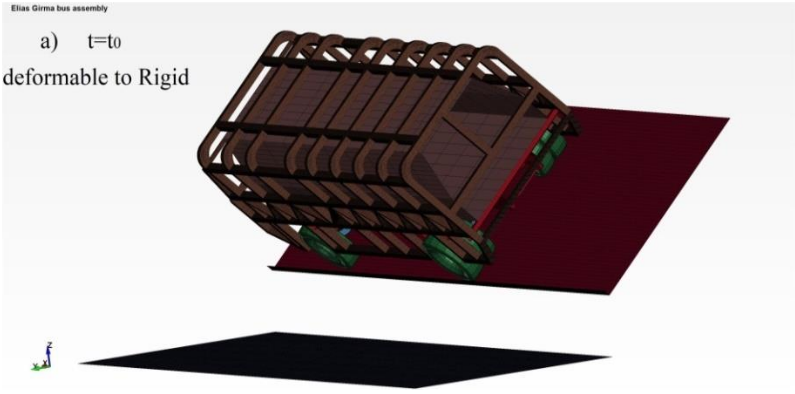
No.	Parts	Weight in kg
1.	Chassis and missing parts	1,428 kg
2.	Wheels	502 kg

3.	Axels	856 kg
4.	Superstructure	844 kg
5.	Cover, decorates, seats and glasses	890 kg
6.	Passengers	29 x 75 kg = 2,175kg
7.	Luggage	29 x 25 kg = 725 kg
8.	Total gross weight	7,420kg

4.3.8. Deformable To Rigid Switch

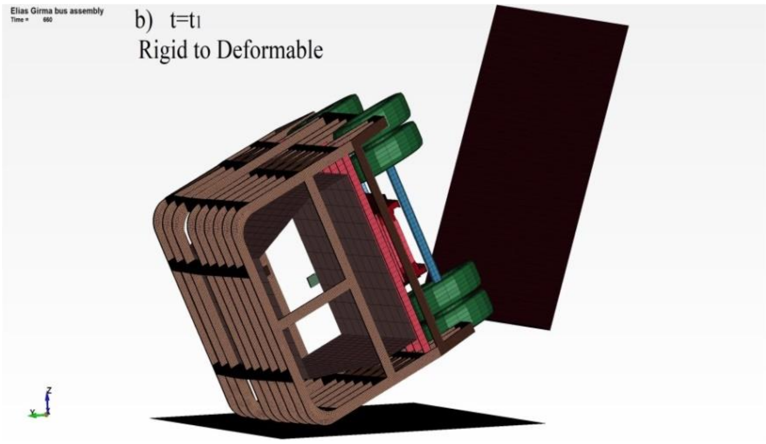
Ideally, the initial conditions for the rollover simulation should include bus at rest at the moment of unstable equilibrium. The freefall analysis is important in order to obtain detailed impact conditions, such as translational and rotational velocity components, as well as bus orientation. Unfortunately, the freefall period, from the moment of reaching the unstable equilibrium to the moment of impact, is usually above 1.5 sec. This time depends largely on definition of unstable equilibrium, and tires friction coefficient. This is relatively long time when compared to the duration of the impact which in turn does not exceed 0.5 sec and kinetic energy, accumulated during freefall, is dissipated, excluding minor vibrations, within 0.5 sec.

From the computational point of view, the freefall period is very expensive, due to lack of any structural deformation during that time. A “Deformable to Rigid” (D2R) switch implemented in LS-DYNA is an attractive solution to this problem. The “Deformable to Rigid” switch allows the user to change material properties of the selected parts from deformable to rigid material characteristics at any given time instance. It is beneficial when the FE model undergoes rigid translations or rotations without any deformations (Sur, 2011). Since rigid components are omitted from calculation of the element centered variables, the application of this switch results in a vast increase in computational speed of FE model as well as increase of the time step for the period of its rigid body movement (Hallquist, 2007). The rollover procedure is an ideal example for application of a deformable to rigid switch. The initial period of the rollover, the bus falling from the tilt table (Figure below a, b and c), can be easily approximated by the rigid body movement, leaving only tires definition as deformable.



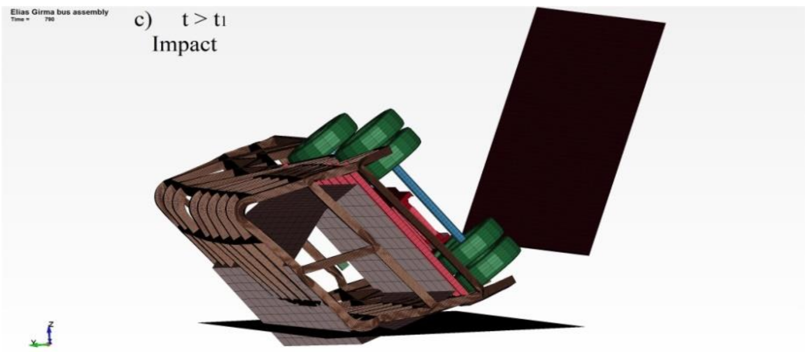
a) Initial place of the bus (from deformable to rigid switch)

As presented in figure 4.15 a) at this position, the material of the deformable parts of the vehicle switches to rigid material to increase computational speed of FE model for given time period up to the vehicle near to touch the rigid plate.



b) Time right before the impact (from rigid to deformable switch back)

At this time, the vehicle part materials that have switched from rigid transform to deformable material property with deformation. To obtain detailed impact situations, like translational and rotational velocity part



c) Impact

Figure 4. 17. a) Initial place of the bus (from deformable to rigid switch), b) Time right before the impact (from rigid to deformable switch back) and c) Impact

At this point, the entire model is deformable for the impact with the rigid concrete pad. The rigid model achieved a computational speed increase of 20 times, as compared with the deformable model. This allowed the bus to go through the entire rollover procedure with the minimal use of computational resources.

4.3.9. Boundary Conditions

To simulate a complete vehicle rollover, all loads and boundary conditions that occur in a real crash event need to be modelled. A vehicle is subjected to gravitational acceleration in real life rollover; the simulated model should roll over under the existence of gravitational acceleration. Friction forces between the tires and the road surface play an important role in how the vehicle behaves on impact, so these have to be accounted for in the simulation.

Then the model was set in tilting table as shown figure 4.18 ditch is modelled as fixed rigid plate. Tilt table was modelled by shell elements and defined as rigid material. The tilt table was constrained in all degrees of freedom and E is applied.

$$E = 0.75Mgh \tag{4.4}$$

Where E- energy, M- mass of the vehicle, g – gravity and h – the vehicle distance between the vehicle COG at free fall position, and the vehicle COG which is kinematically rotated up to the ground rigid plate contact position.

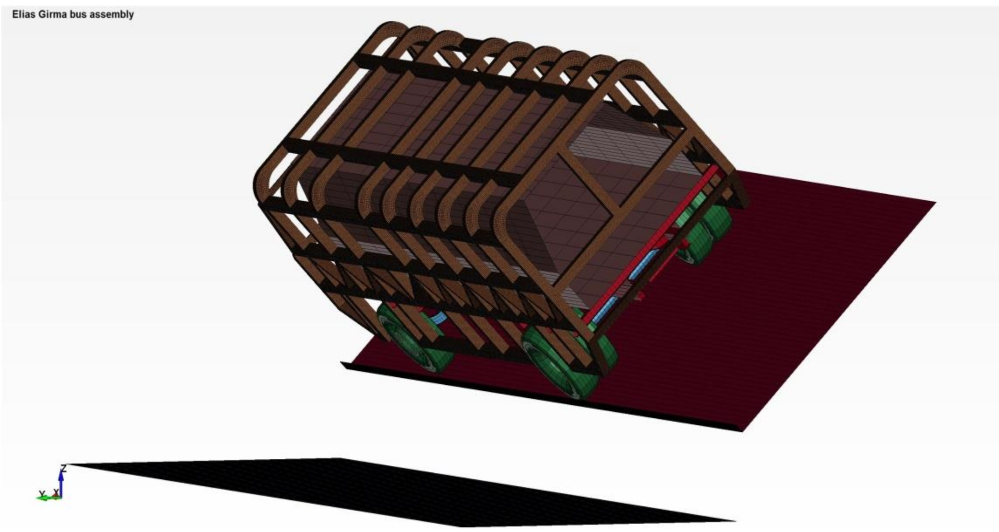


Figure 4. 18. Rollover test setup

Research presented in this thesis has been carried out on Intel(R) Core(TM) i7-8700 CPU @ 3.20GHz 3.19 GHz processor and RAM 8 GB Computing systems. Bus structural rollover simulations presented in this thesis have been completed using HP desktop at the Adama Science and Technology University (ASTU) Automotive Laboratory, Ethiopia.

Due to the transient, nonlinear and impact character of the rollover test simulation explicit time integration solver in LS-DYNA was used for rollover simulations. LS DYNA R11.1.0 version released at 2019 used for this simulation and the simulation runs for 92 hours for total 1.6 sec termination time the automatic deformable to rigid switch up to 0.92 sec, the automatically the material switch to deformable.

4.3.10. Missing Components

The mass of Engine, power transmission, suspension and seats were added in its rigid box elements, the mass of A/C unit, AC duct, Luggage rack, tool & battery box, compressor, side mirrors, radiator were distributed on a box close to its COG. Finally after the FE model generation, mass balancing was done to bring the global COG as close as possible to the physically calculated COG. Residual space is joined to the high stiffness region on the axle which does not disturb the structural strength in any manner (Kumar, 2012). The axle is rigid and mass is added at suitable places.

4.4. Modification on Existing Isuzu Bus

4.4.1. Introduction

Modification, as the term suggests, are changes that are made to a vehicle. These changes are introduced to a stock vehicle to alter its appearance or performance or both (bankbazaar, 2017). The Isuzu bus is a key part of public transportation, whereas in a bus rollover coincidence the deforming superstructure extremely threatens the lives of the travellers and the crew in the bus. In Ethiopia the main public transportation medium is locally built Isuzu bus (Isuzu Kitkit). During rollover of Isuzu bus the injury and death rate of passengers increasing. So, improving the superstructure of the Isuzu bus is more important to protect the passengers from intrusion and deformation of the superstructure to the survival space of the bus to decrease the injury and death rate of the travellers and drivers team.

4.4.2. Passenger Safety

Bus can carry much more passengers than any others vehicles at one time. The issue that we concern here is about safety of passengers if accidents happened. Usually, buses are not equipped with extra safety features such as safety belt and air bag. Hence, bus superstructure needs to be strong enough to withstand load from accident impact. Therefore, it can provide better survival space for passengers (Mustafa et al., 2013).

Isuzu bus (Isuzu Kitkit) is an effective solution for mass transportation and to reduce road congestion. Isuzu bus is a practical mode of transport for various age groups in the society, is cheap and highly connected between cities. However, despite its popularity, the safety of Isuzu bus is a major concern.

Bus accidents cause deaths to innocent victims and frequently grab the major media outlets. Bus accidents are due to human errors, technical failure of the bus and due to the surrounding infrastructure. Hence it is important to study the causes of these accidents and study how to improve safety. Driver tiredness and driving behaviours also play significant roles in guaranteeing high level of safety of busses (Azman, 2020).

Traveller wellbeing is an essential criterion to be used in evaluating the quality of public transport services and a critical effect in occupants' choice of traffic mode. The major challenges of the Isuzu bus locally manufactured in Ethiopia was the less consideration given by the bus body builders for the passengers' safety in line with crash test, safety and health consideration. So much complaints are heard on the design of the seats framework material and dimension of these Isuzu buses in which passengers are suffering death and serious injuries specially long distance travellers during bus accident. In addition to this, there is absence in strong standards to control the bus superstructure manufacturing have been implemented to enhance the safety of the passengers (Kassu Jilcha, 2020). To improve the strength of the structural framework of Isuzu bus, modification is necessary.

4.4.3. Design Modification on Superstructure of the Bus

Roof beams are the major energy absorbing parts of bus superstructure during rollover. A lightweight optimization, allowing for the bus rollover crashworthiness design in the sideways wall division, and the roof division of bus frame are evaluated based on energy absorption ability in order to specify the design variables. With the purpose of improving both the deformation of the bus frames versus the vehicle's residual space and the body skeleton density of the bus structure.

The superstructures for bus were built in local garages were not pass the ECE R66 regulation due to low strength of framework materials and mountings. One of the factors that play an vital role is steel profile in each superstructure beam. Cant-rail beam and horizontal beam profile will be varied in order to determine the profile size that can contribute to superstructure strength.

4.4.4. Materials and Section of Superstructure

The purpose of this material and thickness modification is to select the best material to the critical crush zone and to check the selected material strength, energy absorbing capacity and deformation.

In recent years, safety and environmental friendliness have got more of the attention of the automotive industries. These characteristics are important for the mass transportation vehicles, such as buses and coaches and also the economic aspects come to picture which try to reduce the operational costs of the fleet, by using vehicles with reduced fuel consumption. The materials selected for this analysis modification is metal coated DOCOL AHSS steels are advanced high-strength steels that are hot-plunge steel enclosed for corrosion resistance. Using this material in structural and security components gives vehicles with reduced weight without disregarding people's safety and corrosion resistance (Veeresh G Meti A. P., 2018).

Vehicles structural high fatigue resistance can be get from high tensile strength material. The structure of the bus must withstand high peak load at the time of rollover, this can be achieved with high yield strength material and good plastic material. Bus superstructural parts have complex geometry to achieve this steel with good formability and strong mechanical properties choosing DOCOL steel can give excellent fatigue resistance manage high peak load during rollover impact as shown in table 4.9 below. Advanced high strength steels allow making bus frame with good stiffness and easy to process (SSAB, 2022).

Table 4.9. DOCOL general advantages

No.	Advantages	Explanation
1.	Safe and lightweight	Achieve better crash performance with strong, optimized AHSS profiles, creating both intrusion-free and energy-absorbing structures.

2.	The strongest steel	Increase car structural durability, toughness, and fatigue resistance with high tensile strength steels – up to 2000 MPa ultimate tensile strength.
3.	Excellent welding	Use conventional welding processes to create strong AHSS joints for improved torsional stiffness and car responsiveness.
4.	Economical and sustainable	Replace costly and CO2-intensive aluminum and carbon-fiber composites with some of the most CO2-efficient AHSS steels available today

AHSS (advanced high strength steel) steels for car applications

- Structural body parts: Parts such as sill reinforcements and cross-members must have both high-energy absorption capabilities and low weight. Stiffness can be maintained with optimized shape. Suitable steel grades are DOCOL Dual Phase (DP), Martensitic (M) or Press-Hardening steel (PHS) grades.
- Chassis: High-strength steels provide chassis with excellent formability and fatigue resistance properties. Suitable steel grades are DOCOL Complex Phase (CP) grades.
- Door beams: The high-strength levels of AHSS steel result in major weight reductions when upgrading side impact beams. Suitable steel grades Considered are DOCOL Martensitic (M) grades.
- Seating: Car seats provide a critical safety structure for occupants. Advanced high steel steels can be used throughout the seat frame, significantly reducing their weight while meeting or exceeding current safety requirements (SSAB, 2022).

Table 4.10. DOCOL material properties

No.	Property	Values
1.	Thickness (mm)	1 - 1.6
2.	Yield Strength (MPa)	1070
3.	Ultimate Yield Stress (MPa)	1220
4.	Uniform Elongation at Break (%)	43.9
5.	Density In (kg/mm3)	7.87xe-6
6.	Young’s Modulus E (GPa)	207
7.	Poisson's ratio	0.28

As shown in table 4.10 general DOCOL 1200 DP material property are presented. DOCOL steel DP 1200 the steels are annealed at temperatures between 750°C and 850°C, depending on the grade of steel, and then are hardened by quenching in water. Tempering is the next stage, in which the steel is heated to 200-400°C and then acquires its final structure to which the steel owes it toughness and good formability. This unique annealing procedure produces a tempered martensitic structure that responsible for the greater strength of the steel. Both annealing and tempering are takes place in an inert atmosphere to stop the steel from oxidizing, and the steel strip runs through a pickling bath between quenching and tempering, in order to remove the thin oxide film made in the quenching process.

DOCOL are Cold Rolled Steel which is Ultra high-strength steel (UHS). Property values are for DOCOL thicknesses 0.5 - 1.6 mm. DOCOL 1200 are made from Iron (98%), Aluminium (0.04%), Carbon (0.17%), Manganese (1.6%), Niobium (0.015%), Phosphorus (0.15%), silicon (0.5%) and sulphur (0.002%) (matweb, 2022).

Since locally built Isuzu busses are subjected to bending during rollover and side impact accidents, three point bending tests are conducted to directly measure the tube's strength. This test is vital because it analyses DOCOL AHSS steel tubes under local buckling. Local bucking is an important design feature for DOCOL ASS tubes that have large width to thickness ratios.

These three point bending tests will be tested experimentally using an electro mechanical MTS machine. Using this machine, the influence of axial and shear forces will be minimized. The machine will apply a vertical load at the tube's midspan resulting in the specimen forming a plastic hinge in the mid span. Most of the moment and deformation is concentrated in the midspan (Armaghani, 2014).

4.4.5. Three point bending test of roof beam

Boundary conditions for roof beam three point bending testing in LS DYNA

The following boundary conditions should be fulfilled to accomplish the three point bending test of roof beam for modified locally built Isuzu bus material strength.

- ❖ The CONTROL_TERMINATION time is set as 0.1 sec, Settings of several control cards are also necessary to be addressed in composite beam material test are;

- ❖ CONTROL_ACCURACY, INN=4: The invariant node numbering for shell and solid elements are toggled on. Setting INN=4 minimize the sensitivity of updating of the orientation of the material coordinate system, as the material coordinate system is automatically updated following the rotation of element coordinate system.
- ❖ CONTROL_BULK_VISCOSITY, Q1=0, Q2=0, TYPE=-2: The shell bulk viscosity may aid stability in compressive mode of response.
- ❖ CONTROL_SHELL, LAMSHT=1: The laminate shell theory corrects for the incorrect assumption of uniform constant shear strain through the thickness of the shell.
- ❖ CONTROL_HOURGLASS, IHQ=4, QH=0: Hourglass modes are non-physical, and zero energy mode of deformation for non-fully-integrated elements, therefore producing no Stress and strain. Type 4 offers stiffness based hourglass deformation modes, aiming to minimize nonphysical stiffening of the response and at the same time effectively inhibiting hourglass modes (Mahadevan & Liu, 1996).
- ❖ DATABASE: DATABASE_D3PLOT and DATABASE_ ASCII_ GLSTAT,MATSUM RNFRC shou be ordered to get results
- ❖ CONTROL_ACCURACY, INN=4: The invariant node numbering for shell and solid elements are toggled on.
- ❖ CONTROL_BULK_VISCOSITY, Q1=0, Q2=0, TYPE=-2: The shell bulk viscosity may aid stability in compressive mode of response.
- ❖ CONTROL_HOURGLASS, IHQ=4, QH=0: Type 4 offers stiffness based hourglass deformation modes, aiming to minimize nonphysical stiffening of the response and at the same time effectively inhibiting hourglass modes (LSTC, 2018) .

The material properties used for this test are DOCOL AHSS DP 1200 as shown in table 4.9 frame and roof material properties. At LS DAYNA material library MAT_024_PIECEWISE_LINEAR_PLASTICITY material definition

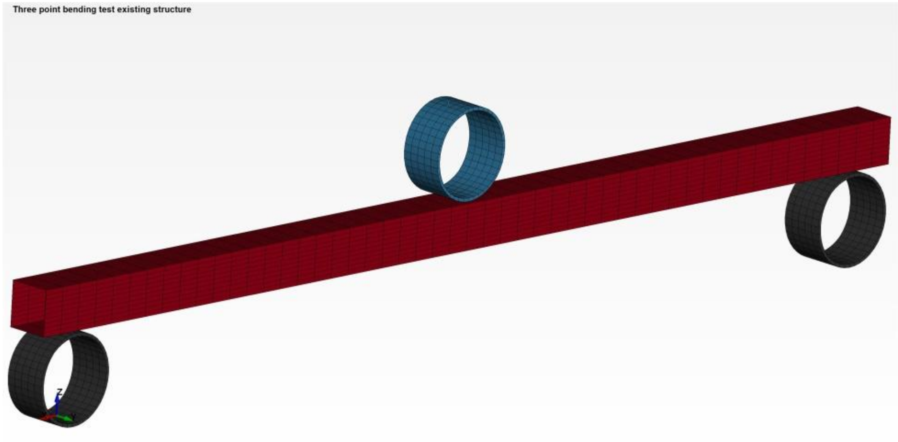


Figure 4. 19. Three point bending test setup of roof beam structure using DOCOL material

As showing in figure 4.29 the roof beam placed between two supports at the end and at midspan there is vertical punching sphere. Vertically load is applied in roof beam structure to test material strength using DOCOL AHSS steel DP 1200 to examine the strength, deformation, and impact force with different thickness then to compare the result.

And thickness used for this test simulation is according to DOCOL dual Phase 1200 from 1mm up to maximum value which is 1.6 mm.

CHAPTER FIVE
RESULT AND DISCUSSION

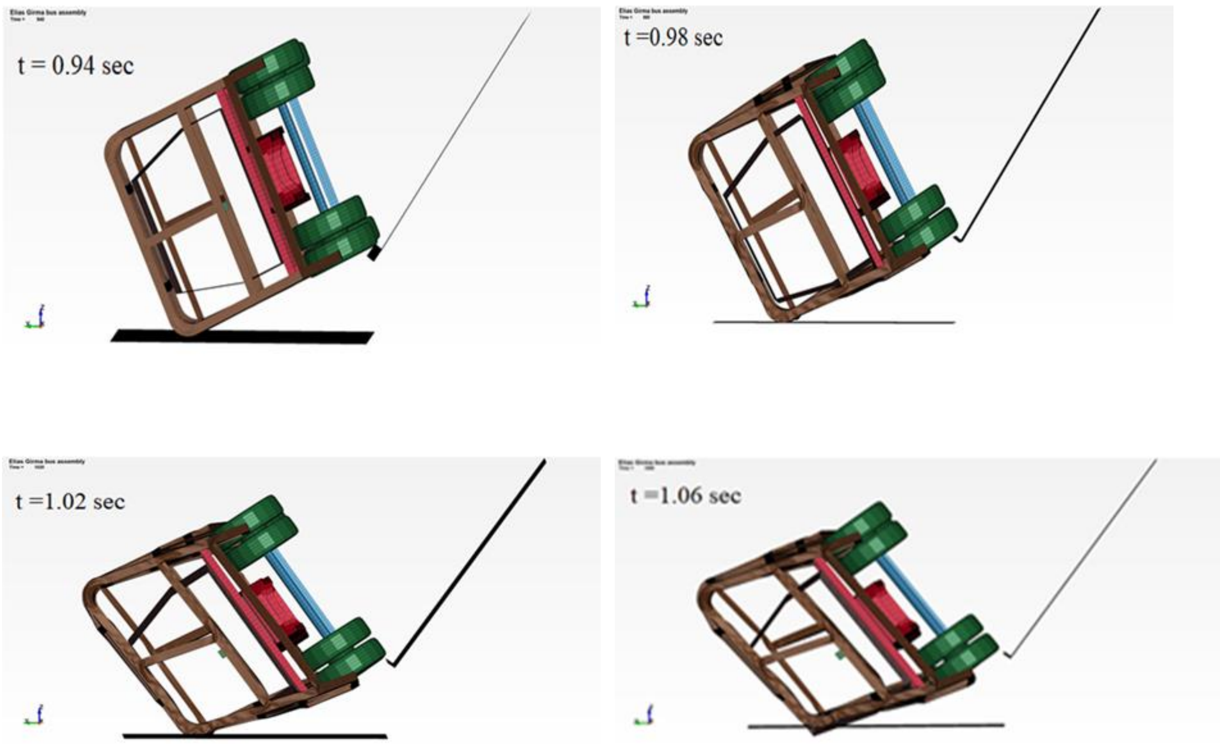
5.1. Introduction

In this chapter, the results of the simulation of the locally built Isuzu bus rollover analysis for existing and modified bus model were discussed. The results are validated using comparative analysis carried out between the modified and existing Isuzu bus. The verification method also discussed for LS DYNA simulation.

5.2. Result and discussion of existing Isuzu bus model

5.2.1. The analysis of the locally built Isuzu bus distortion

The FE model of Isuzu bus was used to simulate rollover test according to the ECE-R66. The depth of the ditch was set at the level of 800 mm, as required by ECE-R66.



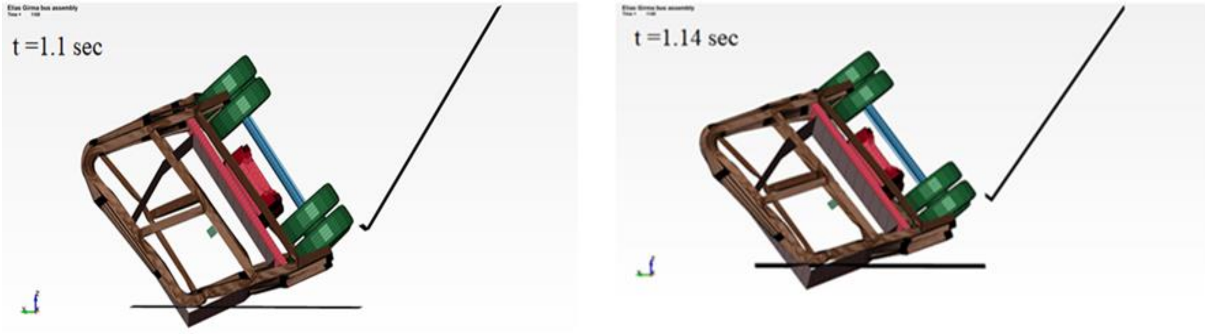


Figure 5.1. Sequential picture of deformation of the existing Isuzu bus at time steps

The first contact with the ground took place along the cant-rail like other severs rollover accidents. The time travelled between the first contact with the ground and start of collapse (period of elastic-plastic deformation) is very short.

As shown in Figure 5.1. sequential pictures showing behaviour of deformation of the Isuzu bus through time steps are illustrated. At t = 0.94 sec the bus comes into contact with the ground, when t = 0.98 sec the bus starts absorbing energy by elastic-plastic deformation leaving the residual space unharmed , then at t= 1.02 sec the vehicle star bending at roof and frame zones. At time t = 1.06 sec the residual space starts to compromised by the side wall entering the residual space. Most of the deformation was developed in hinges located in the frontal part of the body at the waist-rail and at the cant-rail (located at the wall to roof connection). The critical time for maximum deformation occurred at t = 1.1 sec. Starting from t = 1.14 sec upward impact energy transferred to the lower frame and, the bus starts sliding and spring back occurs at pillars.

a) Real rollover crash b). FE rollover analysis

Figure 5.2. Distortion of (a) Real rollover accident, and (b) FE rollover analysis

As figure 5.2 shows the FEA of rollover simulation of locally built Isuzu bus vs the real rollover crushes. As it was seen from the pictures the simulation result is much similar with the real crush. As shown in the picture, of the real crash the superstructures of the bus are very weak that, lead to failure in roof and body parts of the vehicle which, increases the severity of the accident.

5.2.2. Total Energy Balance Graph

The rollover procedure is an ideal example for application of a deformable to rigid switch. The initial period of the rollover, the bus falling from the tilt table can be easily approximated by the rigid body movement, leaving only tires definition as deformable. Since ECER66 rollover test procedure requires to lock the suspension of the tested vehicle before dropping it off the tilt table, the D2R switch was also applied to suspension components.

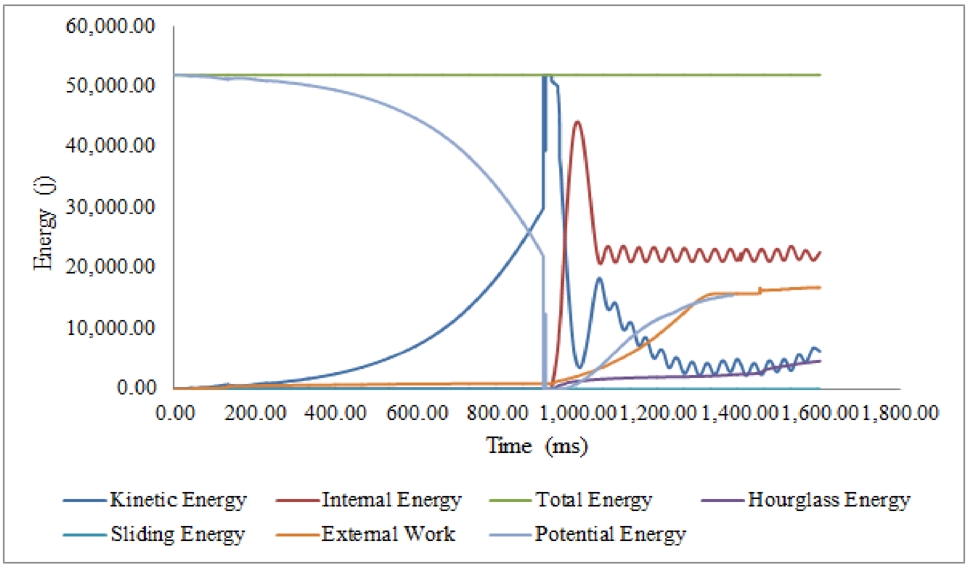


Figure 5.3. Energy balance curve for the rollover simulation with the deformable-to-rigid switch

Energy is neither created nor destroyed but it can change from one form to another, as shown in the figure 5.3. in rollover process the potential energy accumulated in the elevated bus is transferred into its kinetic energy in a form of translational and rotational velocity on impact. After the impact with the concrete ditch the structure deforms until the point where the COG of the bus reaches the lowest level. From vertical distance that the bus COG travels from the point of unstable equilibrium to its lowest position up to the impact point. At this point collected kinetic energy is transferred into internal energy in the deformed bus structure and to other forms of energy such as friction and vibrations.

5.2.3. Internal Energy

As discussed on the above the initial potential energy (total energy) of the bus is converted to internal, kinetic sliding and external work (energy due to vibration and friction).

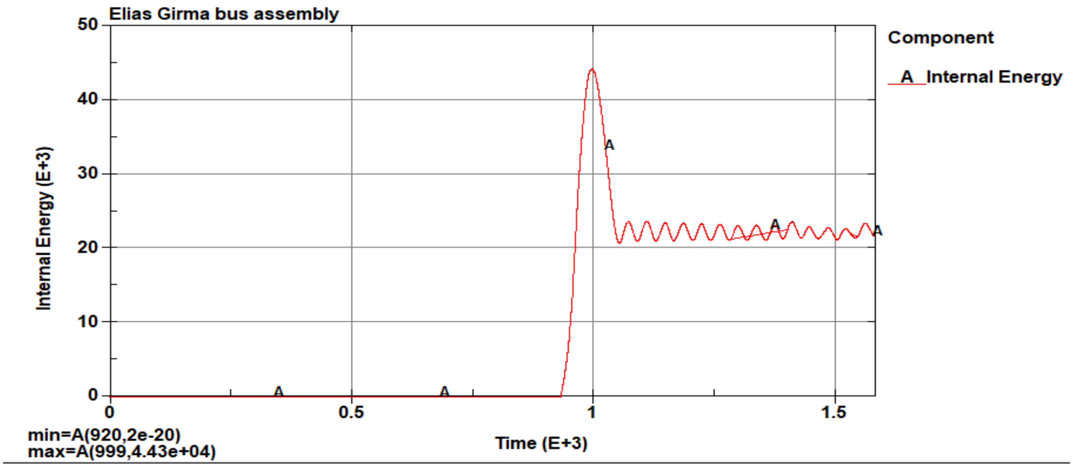


Figure 5.4. The bus absorbed internal energy curve

As shown in figure 5.5. shown above the maximum energy is absorbed by the bus structure with a value of 44.3 kJ at time 999 millisecond, which accounts 85.2% of the total energy. The remaining 14.8% of energy is converted in to other form of energy like sliding, hourglass energy and external work.

5.2.4. Impact Force between the Bus to the Ground

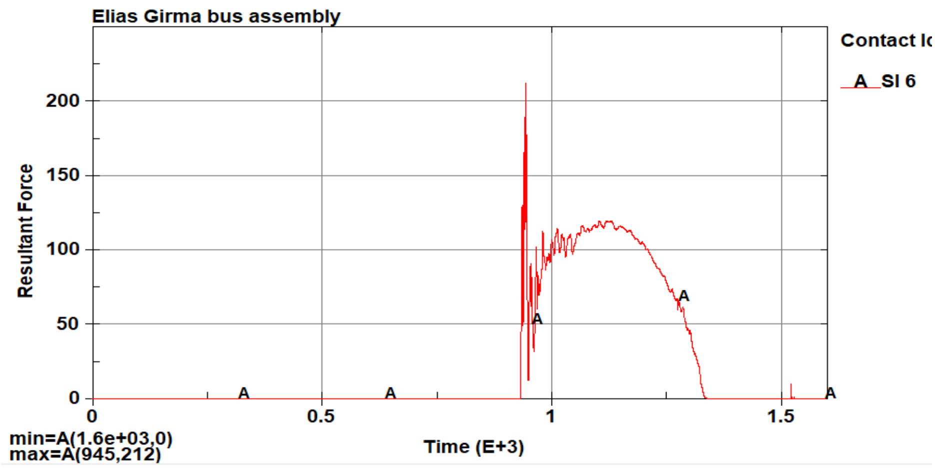
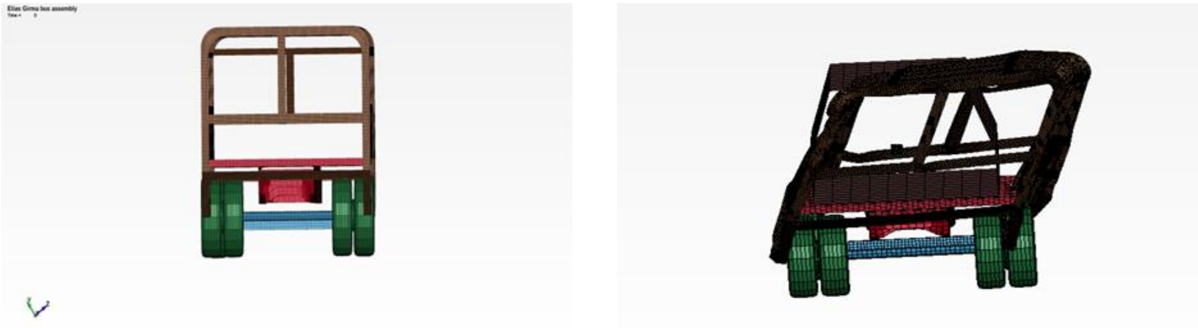


Figure 5.5. Contact Force of the bus to the ground

As shown in the above figure 5.3. the contact force is zero up to 945 ms this is because of the bus upper part (roof) do not touch the ground up to that time there is no contact force. When the time reaches 945 ms the maximum contact force occurs with a value of 212 kN. The fluctuation shows that the rebounding effect of the bus frame

5.2.5. Deformation Isuzu Bus Structure

The deformation patterns of Isuzu Bus to evaluate the structural responses of the models simulation results are present as explained in figure 5.6 below a) before rollover crash takes place and b) after the rollover crash, the bus superstructure passed the survival space in which, the passengers assumed to be safe during rollover crash. Therefore, the existing Isuzu bus superstructures are not crashworthy.



a) Before rollover b) After rollover

Figure 5.6. structural deformation before and after rollover crash.

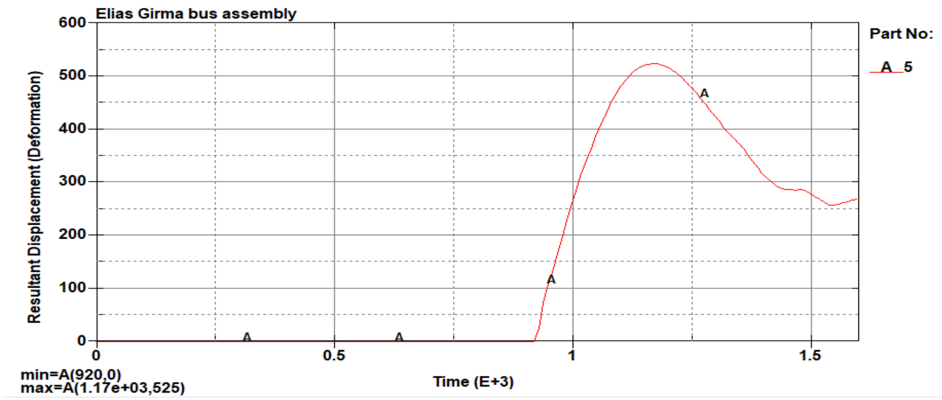


Figure 5.7. The deformation result of the existing Isuzu bus superstructure.

From time is 0 sec to 0.92 sec there will be no deformations because all parts of the vehicle are switched to rigid. The maximum deformation in a bus superstructure at t =1.17 sec is 525 mm. the bus superstructure intruded into passengers compartment with 525 mm, which failed to fulfil the ECE R-66 regulation.

5.2.6. Velocity of the Isuzu Bus

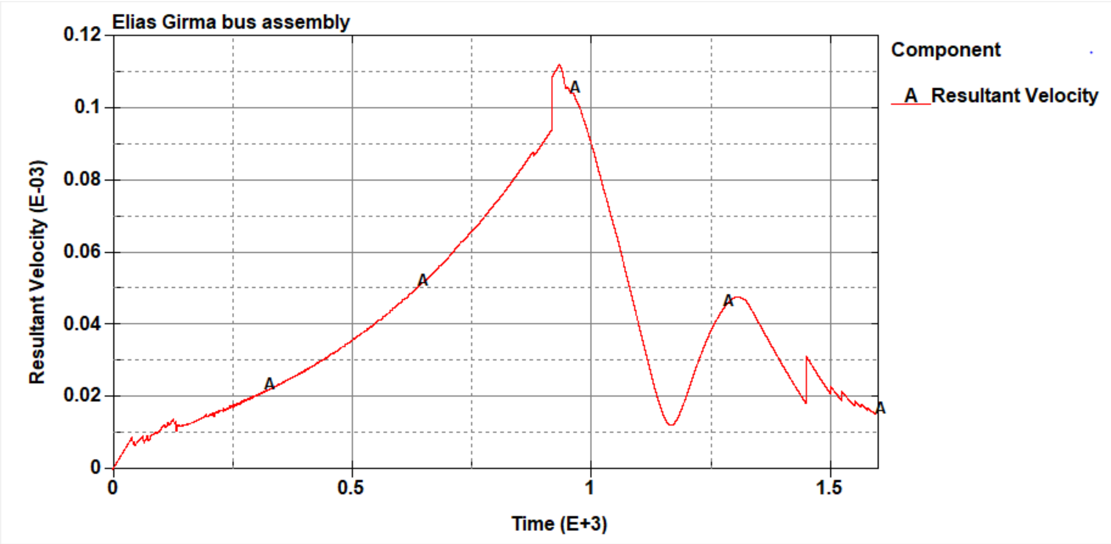


Figure 5. 8. The resultant rollover velocity of Isuzu bus

After the bus placed in a stable position, the bus slowly starts to fall down to the concrete rigid planar. When the bus almost touch the contact with rigid ground the maximum velocity can be reached, then afterwards from touching with rigid ground the bus start to bounce.

5.2.7. Verification

5.2.7.1. Energy Ratio

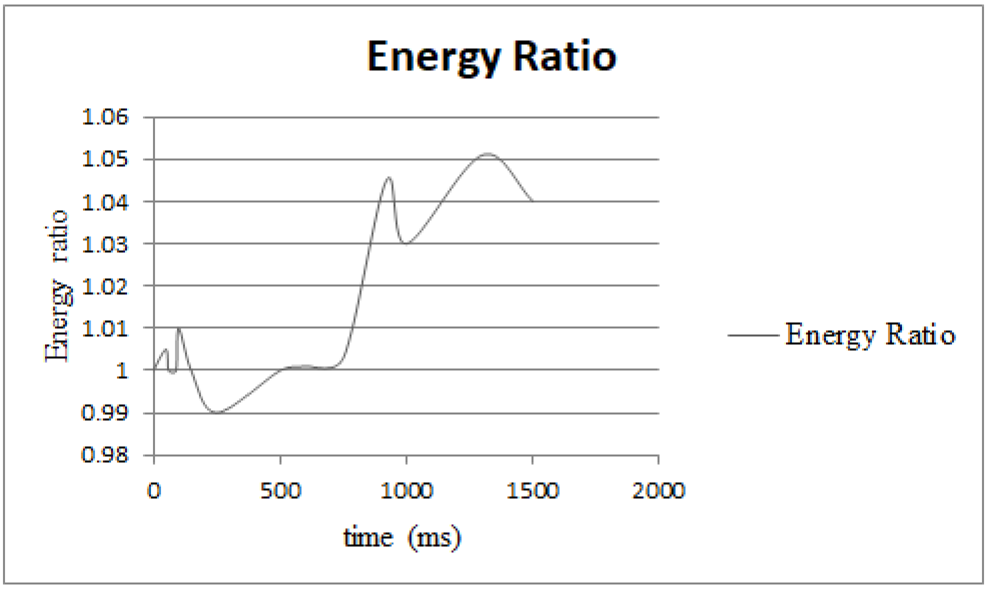


Figure 5. 9. Energy ratio of the simulation

The above discussed values are validated by the energy ratio, which is equal with the ratio of the total energies to the sum of other energies. From the Figure 5.9, it can be observed that the energy ratio value ranges between 0.99 and 1.052. This range is within 1+/- 0.07. So the results are in the acceptable range.

5.3. Three Point Bending Test Result of Roof Beam

The three point bending tests of roof beam sample test have been tested and analysed using LS DYNA with the same dimensions and thickness only changing the material properties of both existing (structural steel) and modified (DOCOL 1200DP steel). The result show that DOCOL have better energy absorbing ability with small deformation, and lower impact force than the existing Isuzu bus making material (structural steel). Also DOCOL have relatively smaller mass compared to that of structural steel.

For the purpose of strength analysis and mass percent increase due to difference in thickness the DOCOL 1200 DP steel material Isuzu bus roof beam three point bending test are represented in graphs at regular interval of time with different thicknesses as shown below. Judgments were going to be made by observing the impact analysis results like force, stress, displacement (deformation) and strain values at different thicknesses.

5.3.1. Deformation

The deformation values are obtained by measuring the relative displacement from two nodes of the roof beam. With this measurement the value of deformation graph of the roof beam at different thickness was shown in figure 5.10 below.

The materials with high thickness deform less than the material with less thickness and mass of the material increases indirectly contributes to the increases in fuel consumption of the vehicle. As deformation increases the energy absorption increases but this result in structure intrudes in to passenger’s compartment. Also decreasing thickness means increase in stress in the materials and decrease the strength of the structure.

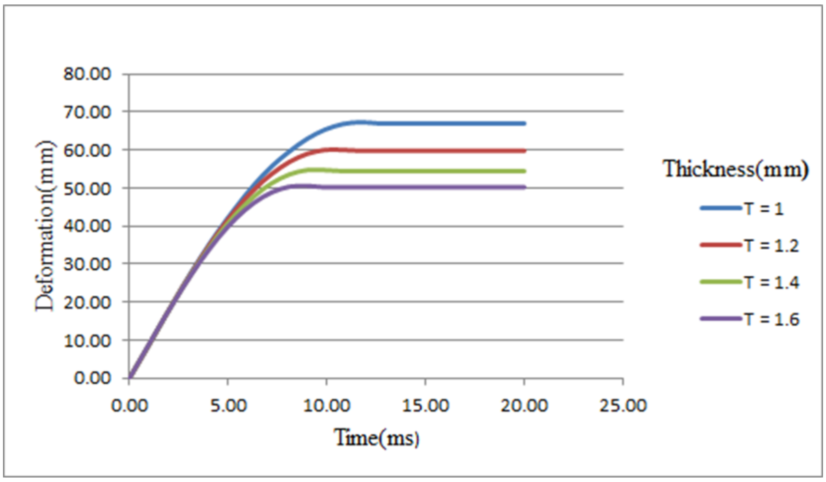


Figure 5. 10. Deformation values of different thickness of roof beam.

5.3.2. Impact Force

Impact force is a force that gives an impact or a strong impact in a relatively short time, occurs when two bodies crash each other. This crash is the result of one object dropping onto another object.

The Impact force increases with increasing the thickness of the roof beam, this result in increasing the mass of the roof beam.

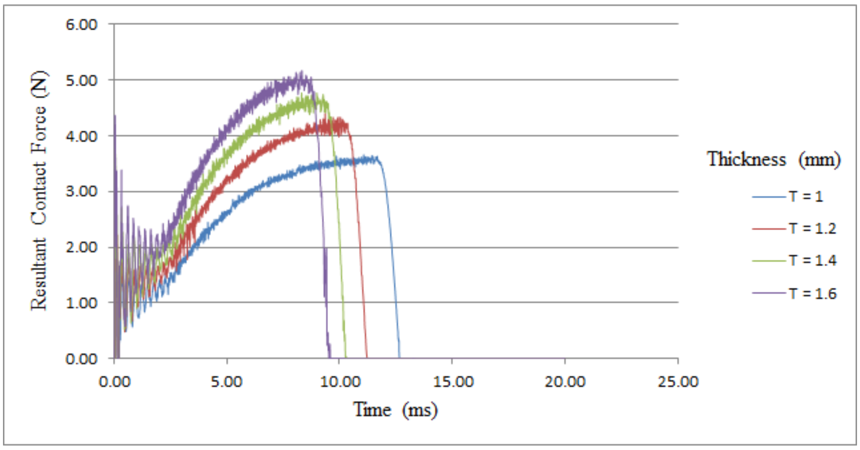


Figure 5. 11. Impact force curves of different thicknesses

5.3.3. Energy Absorbed

As we see in figure below as the thickness increases deformation decreases which result in internal energy absorbed decreases. The materials with smaller thickness are more suitable for energy absorption.

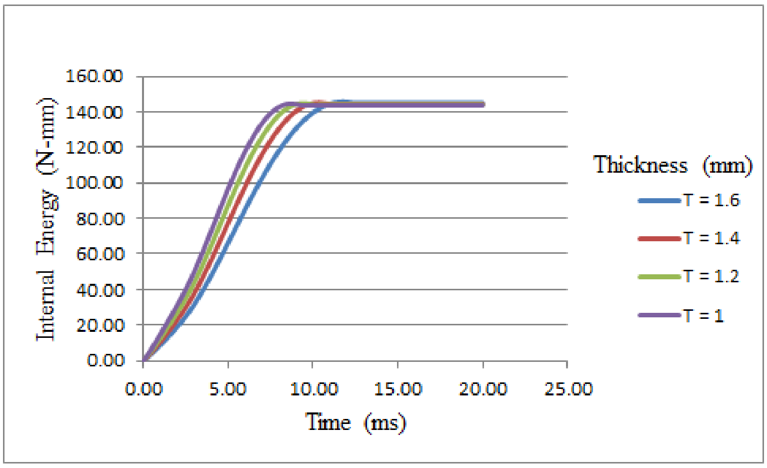


Figure 5. 12. Energy absorption curves of roof beam

From the above results it can be concluded that neither a beam with less thickness nor with higher thickness is better. The main purpose of this investigation is to select a lightweight roof beam without losing the impact behaviour.

For rollover crashworthiness modification analysis of Isuzu bus the average thickness is more reliable in terms of mass, energy absorption and deformation. The roof beam thickness 1.4 mm is the best from the thicknesses explained above.

5.3.4. Effective von mises stress

Von Mises stress is a value used to determine if a given material will yield or fracture. It is mostly used for ductile materials, such as metals. The von Mises yield criterion states that if the von Mises stress of a material under load is equal or greater than the yield limit of the same material under simple tension then the material will yield.

When a body, in an initial state of equilibrium or undeformed state, is subjected to a body force or a surface force, the body deforms correspondingly until it reaches a new state of mechanical equilibrium or deformed state. The inner body forces are the result of a force field such as gravity, while the surface forces are forces applied on the body through contact with other bodies.

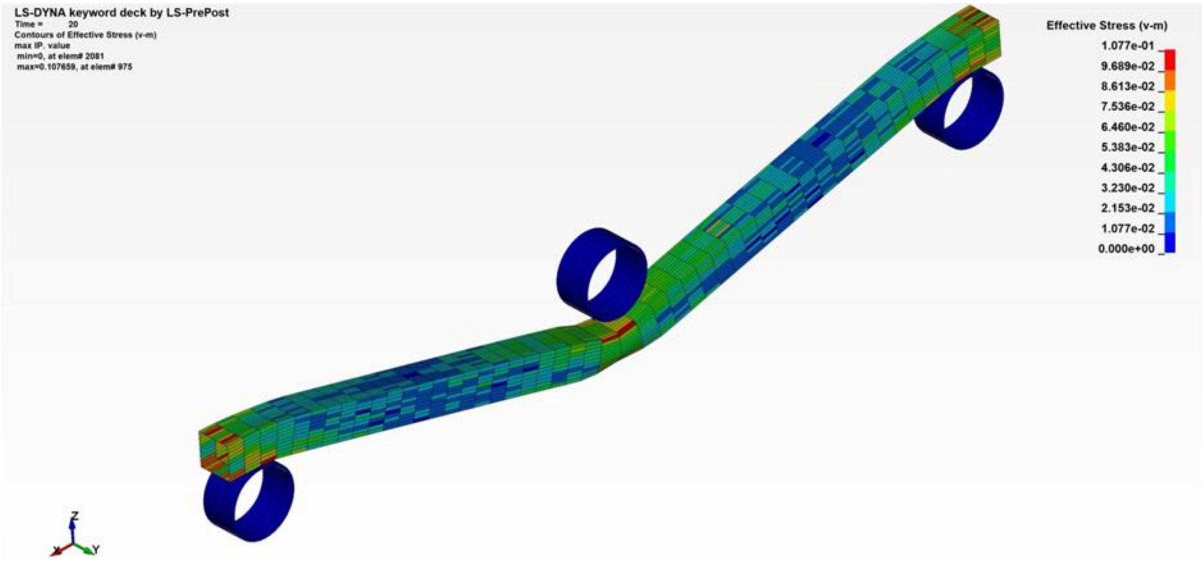


Figure 5. 13. Contours of Von Mises stress distribution for maximum stress value

As presented in figure 5.13, the maximum von Mises stress distribution is shown at the point of contact of roof beam and the puncher.

5.4. Mass Precent Increase

The value obtained from LS DYNA shows the existing Isuzu bus superstructure has a mass of 844 kg and gross laden weight of the vehicle is 7,300 kg.

The modified bus superstructure has a mass of 428.938 kg at thickness is 1 mm; When we use the superstructure thickness 1.2 mm the mass of the superstructure is equals 514.726 kg. At the thickness of superstructure is 1.4 mm; the mass of the superstructure is equals 600.513 kg. And when thickness of superstructure is 1.6 mm; the mass of the superstructure is equals 686.501 kg.

Table 5. 1. Mass percent increase in the bus

No.	Thickness of the superstructure (mm)	Weight of superstructure (kg)	Mass percent increase (%)
1.	1	428.938	0
2.	1.2	514.726	2 %
3.	1.4	600.513	3.7 %
4.	1.6	686.501	5.5 %

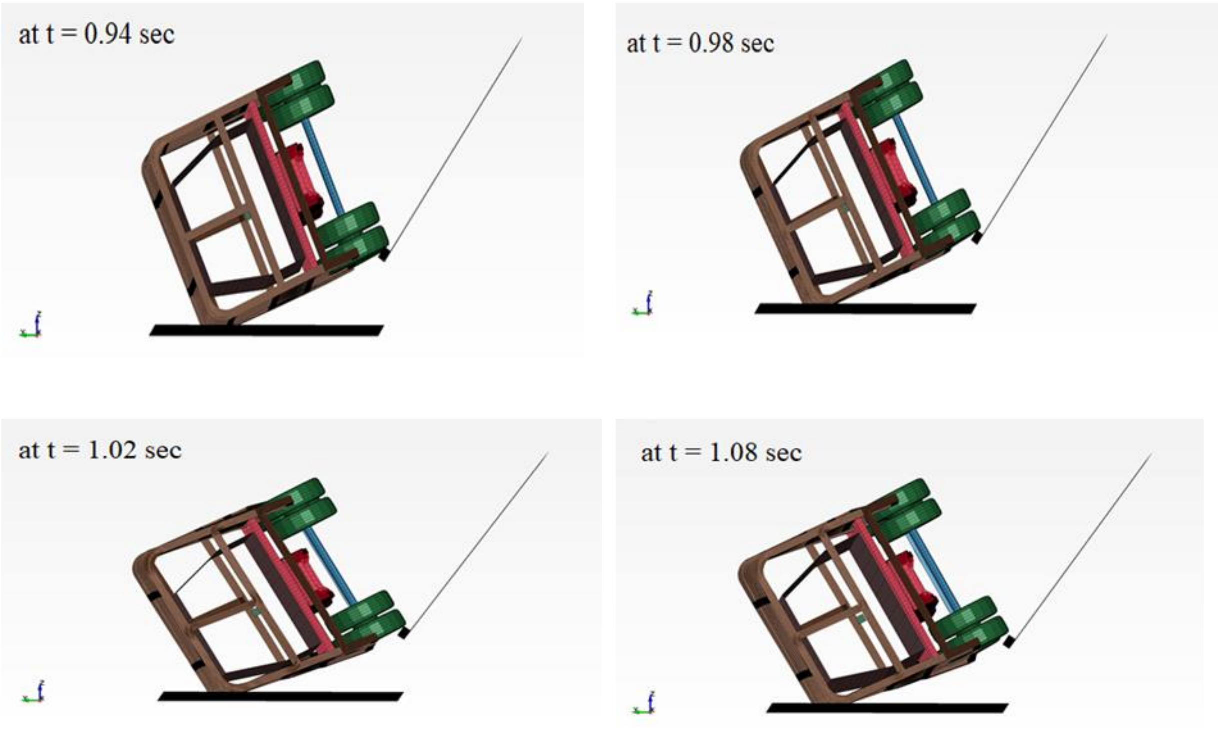
As we can see in table 5.1 in the bus superstructure thickness 1.6 mm the mass percent is 5.5 % which have significant effect on fuel consumption of the vehicle, so that this thickness is not acceptable for this modification. The superstructure thicknesses 1.2mm and 1.4 mm have mass perecent increase value 2 % and 3.7 % respectively which are acceptable. But the bus superstructure thickness 1.2 mm has more deformation and impact force compare to the bus superstructure thickness 1.4 mm. So, the bus superstructure thickness 1.4 mm is most suitable in terms of mass percent, deformation and impact force.

The chosen bus superstructure thickness 1.4 mm is used for modified Isuzu bus rollover analysis then the result can be discussed and compared to the existing Isuzu bus rollover analysis results.

5.5. Result and Discussion of Modified Isuzu Bus

In this section the result of the modified Isuzu bus rollover analysis can be discussed.

5.5.1. The Analysis of the Modified Isuzu Bus Distortion



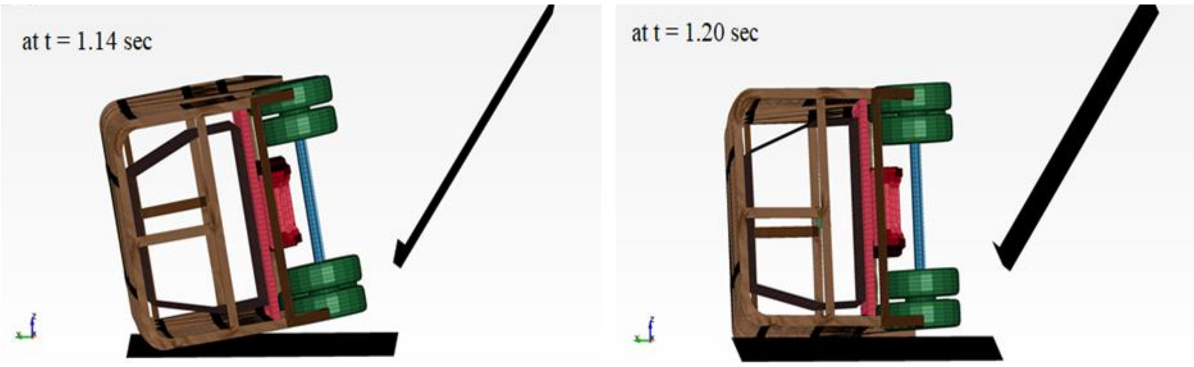


Figure 5.14. Deformation of the modified Isuzu bus through time steps

As shown in figure 5.14. Successive pictures showing behaviour of deformation of the existing Isuzu bus through time steps are explained. At t = 0.94 sec the bus comes into contact with the ground, when t = 0.98 sec the bus starts absorbing energy by deformation and start bending at roof and frame zones leaving the residual space unharmed , then at t= 1.02 sec the vehicle reaches its maximum deformation. When t = 1.20 sec the bus starts to slide and then bounce. At time Starting from t = 1.08 sec and upward impact energy transferred to the lower frame and, the bus starts sliding and bouncing back occurs.

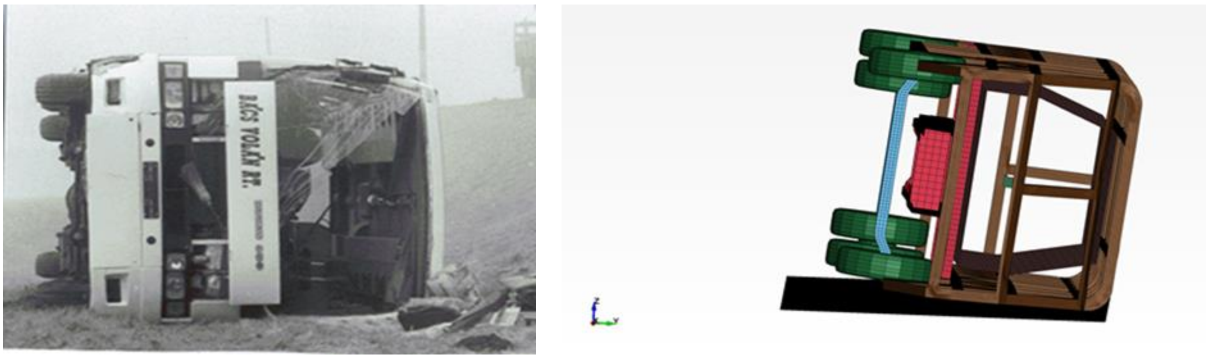


Figure 5.15. Strong superstructure assures the survival space

As shown in figure 5.15 it is obvious that the existing Isuzu bus superstructure is weak, cannot assure a survival space for the passengers. The modified bus approved vehicle rolled down on the same slope of which maintain the residual space which have strong superstructure.

This new modified bus rollover analysis does not violate the ECE regulation number 66. As it was defined in regulation those in rollover accidents the passengers should be protected, and the survival space shall be maintained.

5.5.2. Total Energy Balance Graph

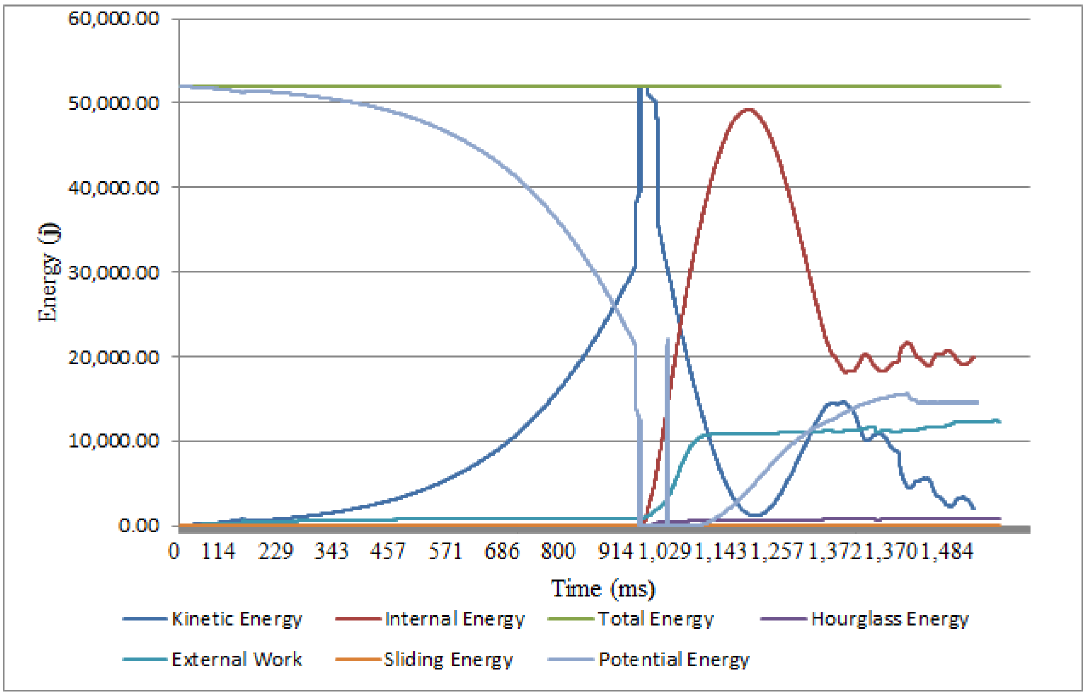


Figure 5.16. Energy balance curve of modified Isuzu bus during rollover

According to the law of conservation of energy, energy cannot be created or destroyed, although it can be changed from one form to another. As shown in figure 5.16 a stationary bus at the top of a tilt table. As the car rolled down to the fixed ground, its kinetic energy increases and its potential energy decrease.

The plot of kinetic energy shows that, initially the value of kinetic energy is zero. That's because initially there was no velocity in the bus. When the simulation started, the velocity of the body started to increase due to gravity. This in turn, increases kinetic energy. It becomes maximum when just at the time when the body faced impact with the surface. After first impact the velocity of the body decreases dramatically resulting a sharp decrease in kinetic energy. After first impact, the body started to drop on the surface showing fluctuation in kinetic energy.

5.5.3. Internal Energy Curve

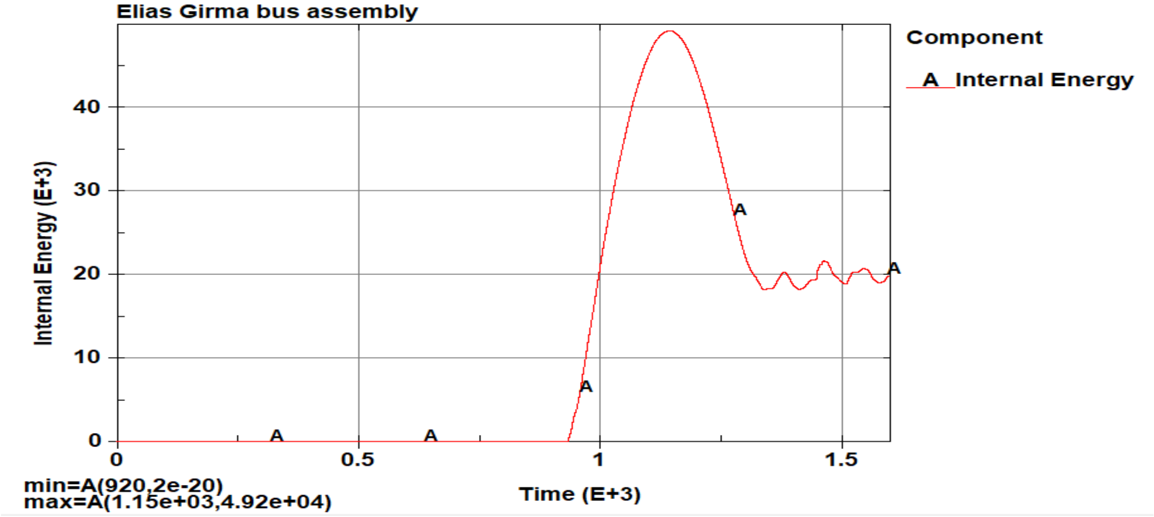


Figure 5.17. Modified Isuzu bus internal energy at event of rollover

The value of internal energy remains constant until the body faced first impact. Before first impact there was no change in the structure except kinetic energy and potential energy. But, after first impact the kinetic energy of the body was absorbed by the deformed members resulting sharp increase in internal energy

From initial potential energy (total energy) the energy converted to internal energy is equals to 49.2 KJ which is 94.6 % absorbed by bus super structure, the remaining 5.4 % energy have converted to sliding energy, hourglass energy and external work as shown in figure 5.17 curve.

5.5.4. Impact Force between the Bus to the Ground

Due to the material property of DOCOL and reduction of the vehicle weight the Impact force of the modified Isuzu bus are decreased.

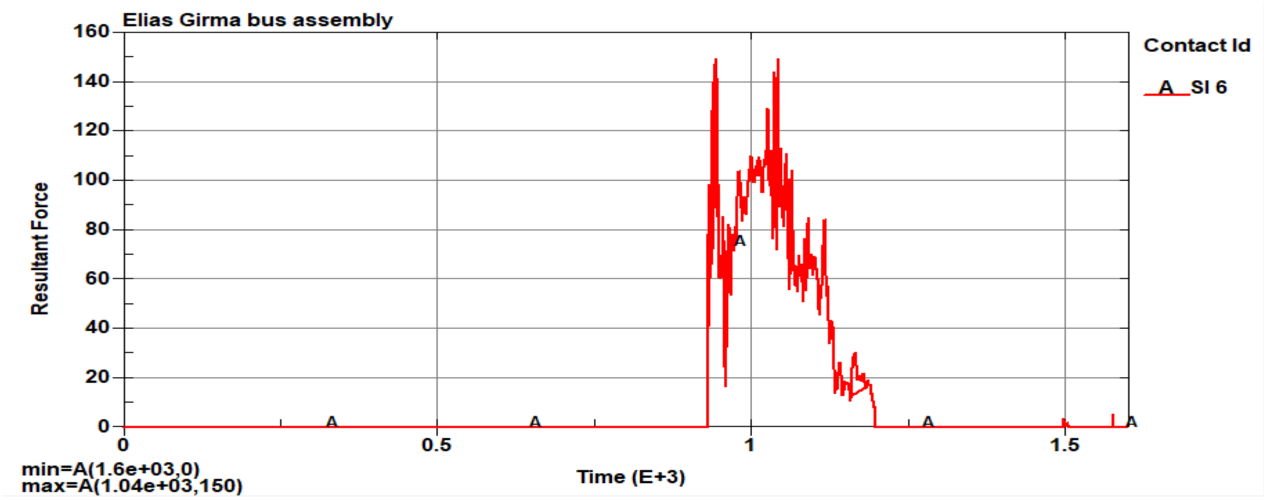
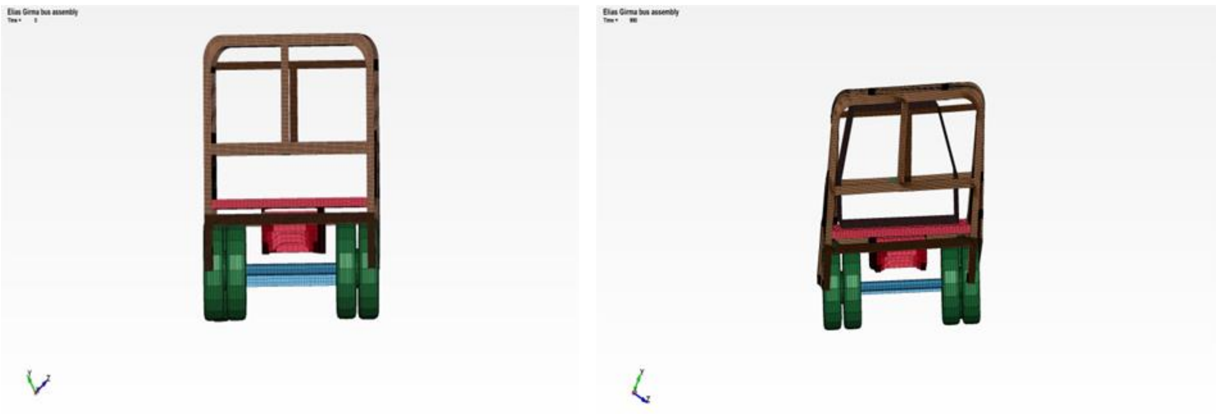


Figure 5.18. Modified Isuzu bus impact force

As shown in the above figure 5.18, the contact force is zero up to time equals 1040 millisecond, this is because of the bus structures does not touch the ground up to that time there is no contact force between the bus and rigid ground. When the time reaches 1040 millisecond the maximum contact force occurs with a value of 150 kN. Curve fluctuations indicate that the rebound effect of the bus structure on the ground.

5.5.5. Deformation of Isuzu Bus Structure



a) Before rollover crash b) After rollover crash

Figure 5.19. Modified Isuzu bus a) before and, b) after rollover crash

In figure 5.19 the modified Isuzu bus structure before and after rollover crash simulation are illustrated. The maximum deformation of the bus intrudes are 344 mm in roofs and frame joint point. According to the regulation ECE R-66 the residual space are safe with 56 mm displacement remaining to touch the residual space.

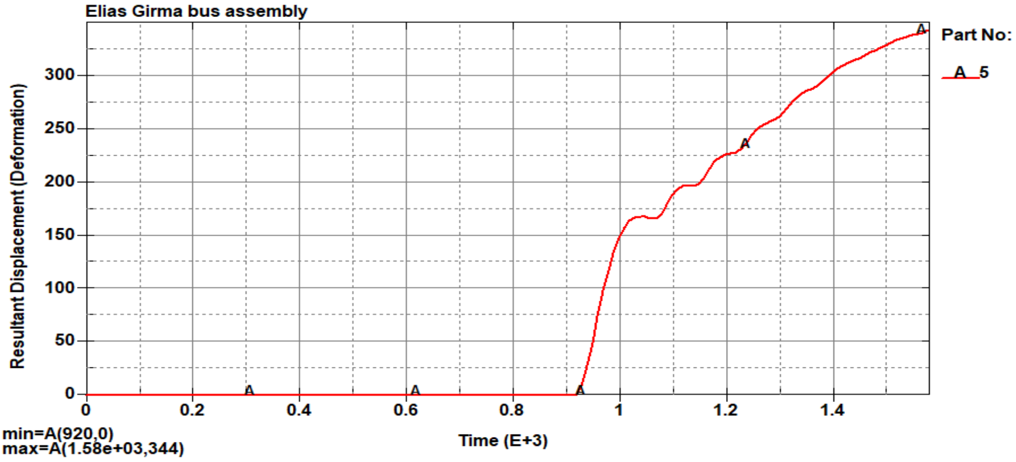


Figure 5.20. Resultant displacement Isuzu bus structure

The total resultant displacement of the modified Isuzu bus are shown in figure 5.20 the maximum deformation of the the bus structure found in roof and frame joint with the value of 344 mm which is safe according to ECE r-66 regulation, leaving residual space unharmed during the rollover crash anlysis

5.5.6. Velocity of the Modified Isuzu Bus

The velocity of the bus during rollover analysis illustrated in the curve

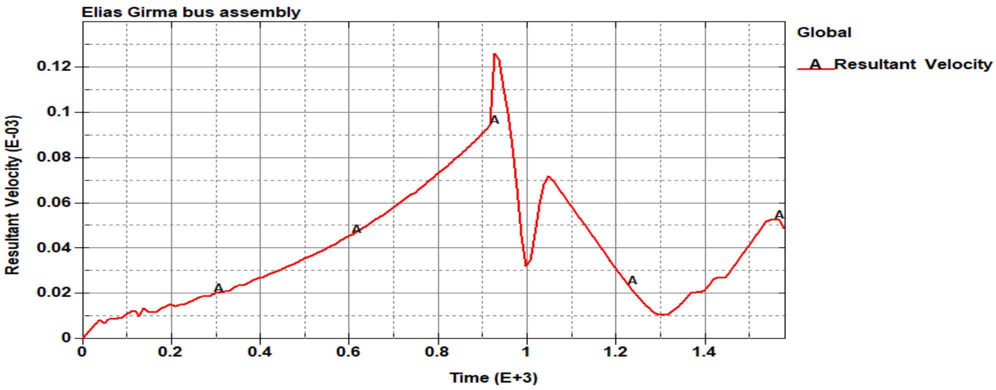


Figure 5.21. Resultant velocity of modified Isuzu bus

As explained in the curve of figure 5.21 at time 0 second the bus placed in an unstable position with initial velocity 0 m/sec, the bus slowly starts to rolls down to the concrete rigid ground using gravitational force. When the bus near to almost touch to the rigid ground the maximum velocity reaches, then afterwards from touching with rigid ground the bus start to bounce

5.5.7. Verification

5.5.7.1. Energy Ratio

From the energy balance curve it has been seen that the system energy is not fully conserved and this is due to zero energy form of some elements. All the processes in this universe are irreversible and some losses are always included which deviates energy ratio slightly from one. To be accepted the energy ratio value should be 1.00 +/- 0.07.

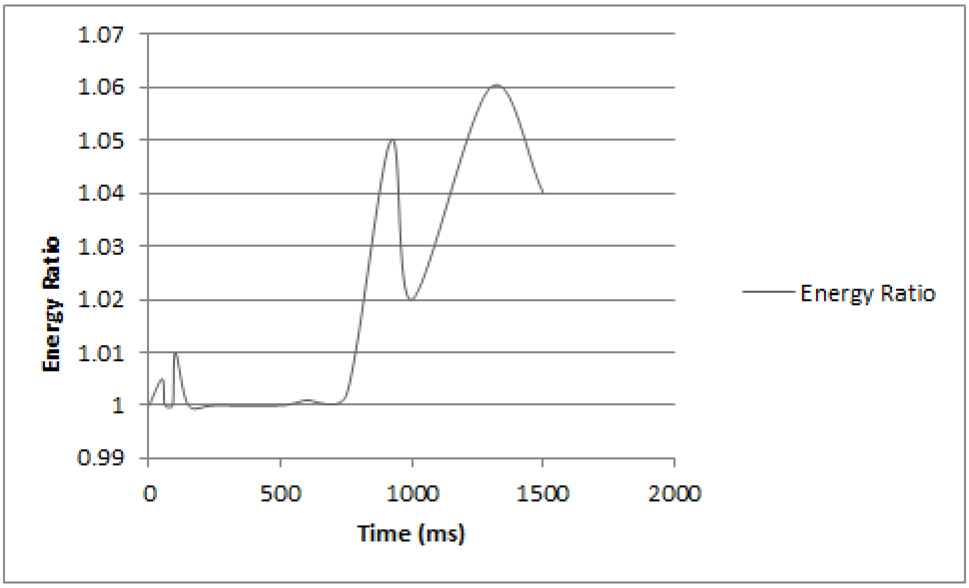


Figure 5.22. Energy ratio of the modified Isuzu bus.

As shown in the figure the energy ratio is between 0.99 and 1.06 which is on acceptable range for modified Isuzu bus rollover simulation

5.6. Comparison

Comparisons are used to evaluate and compare values between two or more viewpoints. The existing and modified Isuzu bus rollover simulation results are compared using the following parameters

- Energy absorption ability
- Force of impact
- Resultant Displacement (Deformation)
- The structural response,

5.6.1. Internal energy

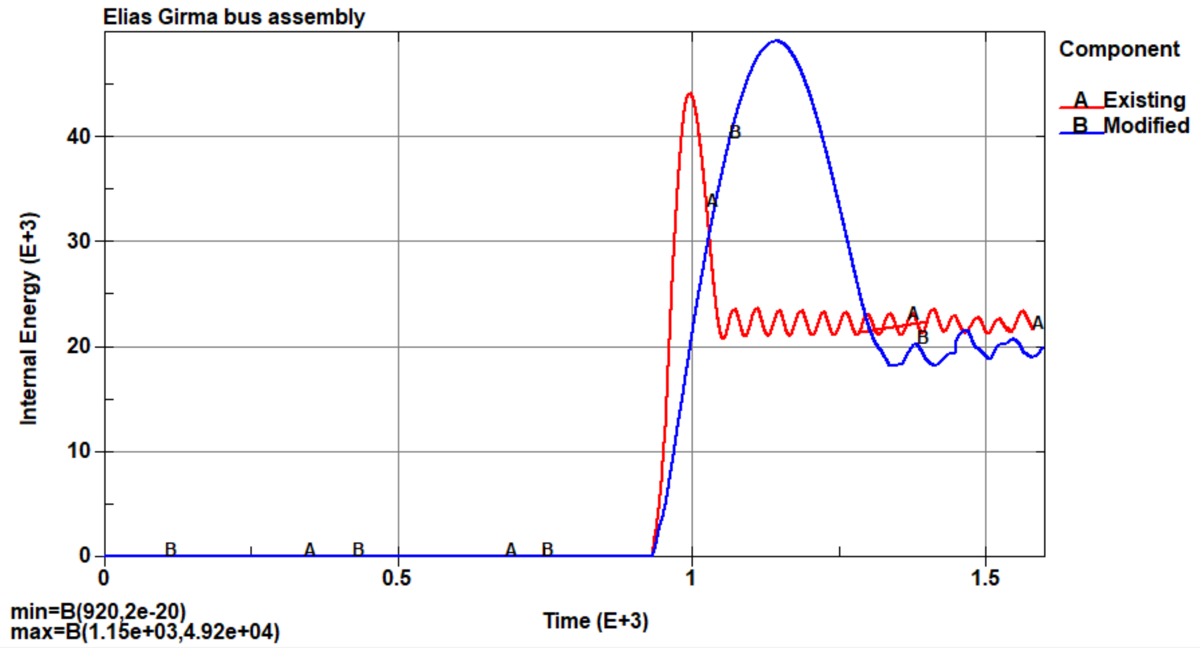


Figure 5.23. Internal energy of existing and modified Isuzu bus

The internal energy of the bus structure for the existing is 44.3 kJ where as for the modified is 49.2 kJ. This indicates that the modified bus structure absorbs additional energy of 4.9 kJ which accounts 9.96% improvement in energy absorption as shown in figure 5.23 above.

5.6.2. Impact force

From the figure 5.24 below, the impact force obtained by the existing is 212 kN whereas on the modified is 150 kN. so, a reduction of impact force with a value 62 N between the bus super structure and the ground by making the modification. This indicates 29.2% improvement on the impact force transferred to the occupants.

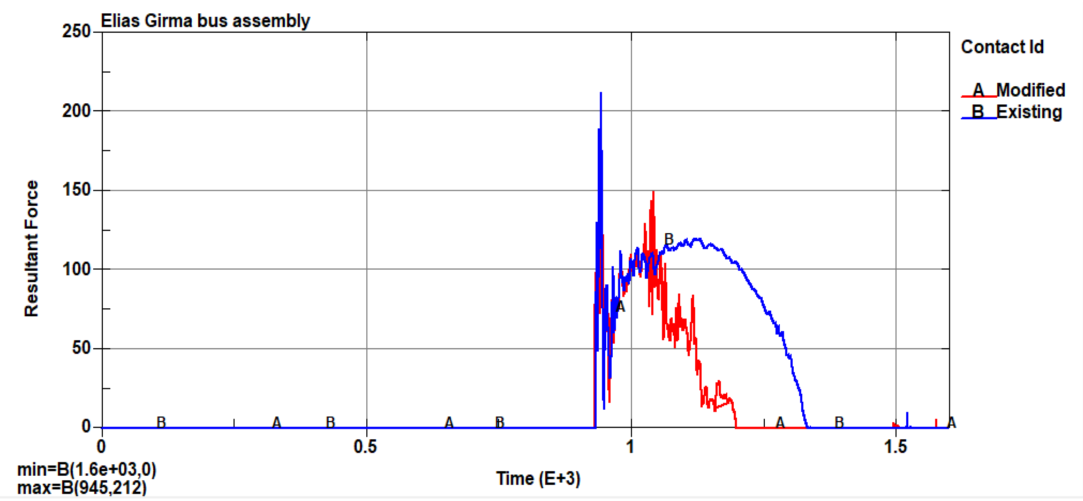


Figure 5.24. Impact force of existing and modified Isuzu bus

The higher the impact force increases the severity of the injuries during rollover. The material properties of the DOCOL allow the structure to have more energy absorption with low impact force.

5.6.3. Deformation

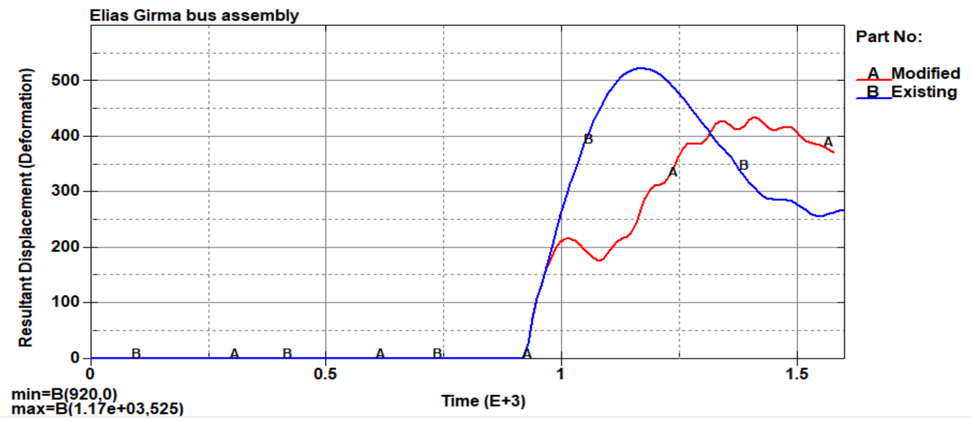


Figure 5.25. deformation of existing and modified Isuzu bus

The curve in the figure 5.25 shows the intrusion of the super structure in to the passenger compartment. From the figure, the deformation on the existing vehicle is 525 mm and the modified vehicle is 344 mm the difference is 181 mm. this indicates that the modification gives 181 mm (34.5%) more space to the passenger compartment, and this leaves the residual space untouched (safe) by bus superstructure according to ECE R-66 regulation.

5.6.4. Structural response

The modified superstructure of the bus does not reach (touch) the residual space as shown in the figure 5.26. this shows the superstructure is safe to the occupant. But the existing bus superstructure intrudes 125 mm in to the residual space this, violates the ECE R-66 regulations

a) Modified b) Existing

Figure 5.26. Structural response a) modified and b) existing Isuzu bus

The modified Isuzu Bus used DOCOL DP 1200 steel and the existing Isuzu bus structure are made of structural steel (mild steel) , as we can see from the above figure the modified Isuzu bus have high resistant to deformation and are more crashworthy. In contrast, the deformation of the modified bus was in acceptable limit according to the UN-ECE Regulation 66 preserving safe residual space for passengers.

5.7. Result summary

The Isuzu bus rollover crashworthiness results of the existing and modified bus are summarized in the table below

Table 5. 2. Result summary

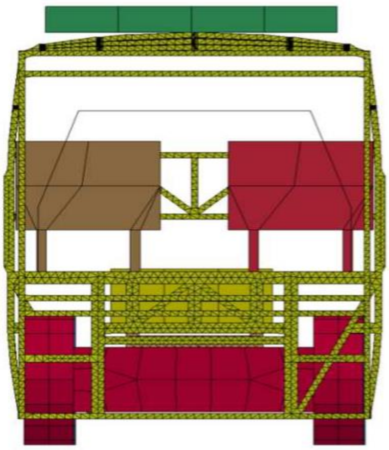
No.	Parameters	Existing	Modified	Change
1.	Energy absorbed	44.3 KJ	49.2 KJ	4.9 KJ
2.	Impact force	212 kN	150 kN	62 kN
3.	Maximum deformation	525 mm	344 mm	181 mm

From the table above the energy absorbed by modified Isuzu bus are advance 4.9 KJ more energy than the existing. The Impact force of the modified bus 62 kN less than the existing bus which prevent the passenger’s injury severity during rollover crash. The maximum deformations of the superstructure of modified bus are 181 mm less than the existing Isuzu bus superstructure. The modified Isuzu bus obey ECE R-66 regulation by keeping the residual space of the bus untouched when the bus rolled over.

5.8. Validation

A testing method for bus rollover, as European regulation ECE-R66 in which a bus is set on a platform above the ground by 800mm and pulled up by a crane at 1degree/sec to let the bus roll over as shown in figure 5.27.

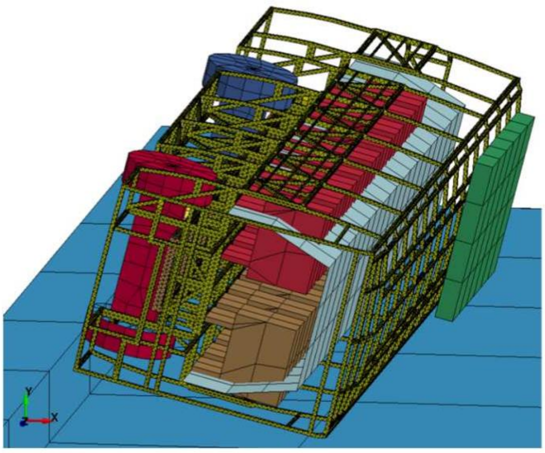
The data for these guideline test conditions was provided by the bus manufacturer, and additional higher-speed crashworthiness evaluations were compared to data from previous publications of similar class to locally built Isuzu buses.



a) Full-scale rollover test arrangement

b) FE analysis rollover test arrangement

Figure 5.27. General arrangement of a) full-scale b) FE analysis rollover test according to ECE R66



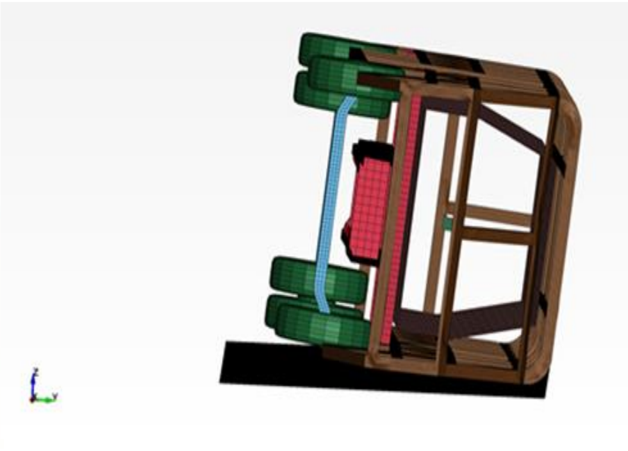


Figure 5.28. Shape deformation of the superstructure after rollover test.

As shown in figure 5.27. and 5.28. the full-scale vehicle should be rolled down from 800 mm height to a horizontal concrete surface without any dynamic effect. The axis of rotation is parallel to the longitudinal axis of the bus and the finite element analysis simulation is as same as the full-scale bus rollover test (Vincze-Pap, 2011)

The validation experiment showed that the bus model was subjected to maximum deformation at its superstructure. Hence, it can be concluded that intensive care should be drawn on the strength of superstructure during design process (Ali, 2010). The experimental and FE analysis of bus rollover are relatively the same and valid

CHAPTER SIX
CONCLUSION AND RECOMMENDATION

1.1. Summery

A dynamic full scale rollover test for the purpose of the experimental assessment, are either too expensive or time consuming. In the light of these problems, there is a need for a new, simple and reliable assessment tool. The objective of this thesis was to perform a preliminary study on feasibility of the development of the new simplified safety assessment protocol for rollover crashworthiness assessment of locally built Isuzu buses. The new protocol, development of a detailed FE model for the purpose of the numerical procedure, was developed based on the available resources and gathered knowledge, and was intended to be relatively simple and economically viable in our country.

This thesis begins with the analysis of the valuable data, available for bus accidents. The data obtained from federal police commission and local Isuzu bus body building garages, and literature reviews was analysed and compared. This analysis shows that the most dangerous accident scenario for buses is the vehicle rollover. Even though rollover was a rare event, over a half of serious and fatal injuries occurred when a vehicle rolled over during the accident. This observation has led researchers to focus on rollover as the most dangerous accident scenario for bus occupants. This effort resulted in the introduction of safety standards aiming to improve bus safety in case of the rollover accident. The discussed standards are the ECE-Regulation 66 accepted by over 40 countries in the world. The numerical rollover simulation of the locally built and modified Isuzu bus have been tested and analysed based on ECE-Regulation number 66.

1.2. Conclusion

The analysis of Isuzu bus simulation regarding UN-ECE Regulation 66 gives very useful and fruitful results. It can be concluded that the safe residual space for passengers inside bus during rollover impact is strongly dependent on some parameters like energy absorption capacity, Impact force, deformation and total mass of the bus. The strength of bus superstructure is the most important thing to be considered in the design process

In order to gather a better understanding of the energy distribution and deformation pattern during bus rollover, a developed FE models were subjected to the numerical rollover test following the guidelines of the ECE-R66. Based on these results, it was observed that due to their structure, the existing Isuzu buses are prone to a dangerous deformation pattern that results in the collapse of a roof beam structure during rollover test. This observation highlighted the significance of the strengthen roof beam structure and critical crash zones of the bus for a crashworthy behaviour during rollover. Hollow Rectangular Structural Steel (HRSS), which used for making the superstructure of the existing Isuzu bus. RHSS has failed to keep the residual space of the bus. The modified Isuzu bus use DOCOL 1200 steel which is a lightweight sill reinforcement made by cold forming in Docol martensitic steel provides good crash performance and is a cost effective solution.

The modified Isuzu bus absorbs 9.96% more energy than the existing Isuzu bus which is enough to maintain the survival space safe.

The impact force of the modified Isuzu bus has 29.2% less than the existing Isuzu Bus. This is because of DOCOL steel lightweight and good crash performance property.

The existing Isuzu bus has failed to obey ECE R-66 regulation; the deformation of the bus structure intrudes to the residual space of the bus. But the modified Isuzu bus improves with 34.5%, this passes the rollover regulation ECE-R66. The superstructure of the bus maintains the residual space safe. The major advantage of using DOCOL AHSS steel is the material absorbs more energy with small amount of deformation during crash. This corroborates that the total weight of the bus is not only significantly improved but also sees the ECE R66 standard.

1.3. Recommendations

Local Isuzu bus builder garages are encouraged to use the provisions of the Rollover Testing procedure in order to understand how to build safer Isuzu bus superstructures.

The materials used for bus body building are responsible for crashworthiness behaviour at the time of rollover; it should be strong enough to absorb energy.

The Ethiopian transportation minister should enforce the bus body builder garages to follow specific regulation to enhance the safety of the passengers during rollover crash.

Vehicular new technologies: Technologies like ABS (Antilock Braking System), TCS (Traction Control System), ESP (Electronic Stability Program), and other advanced technologies used to prevent bus rollover in locally built Isuzu bus should be mounted

1.4. Suggestions for future work

As presented in this thesis is the concept of the FE numerical rollover procedure intended to increase test efficiency, and to reduce cost associated with full scale rollover testing of locally built Isuzu buses. The following recommendations are given

- Reinforcement optimization

You can inspect and optimize roof panels, roof rails, window rails, waist rails, and floor panels to improve the impact resistance of the bus body during rollover.

- Number and Position of Pillars:

As the structural pillars absorb energy during roll over impact, it is necessary to optimize the number of pillars. More number of pillars will add unnecessary weight and less number of pillars will fail in roll over simulation

- Tubes Cross Section:

The strength of the structure is mostly depending on the cross section of the tubes used in the structure. If the bus is failing in rollover analysis, the strength of the structure can be increased by increasing cross section (Breadth, width or thickness) of crucial members in rollover analysis.

- Seat belt for passenger restraining in Isuzu bus

In the event of an accident, wearing a seatbelt reduces the chance of death and the severity of the injury. Seat belts provide protection from injuries in the event of a rollover

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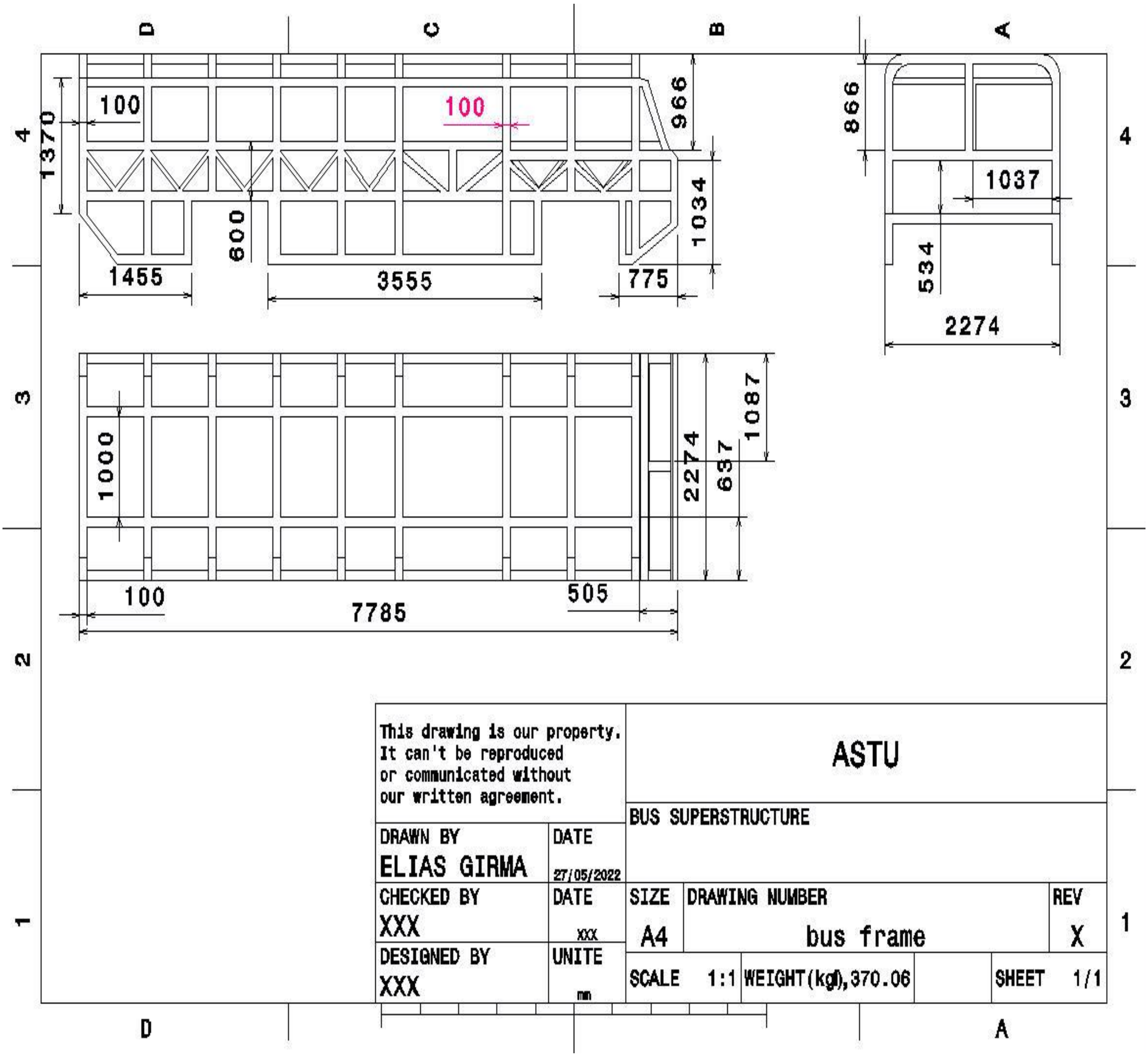
APPINDIEX

Appendix A. Bus Model Dimensions



Appendix B. Questionnaires for Isuzu Bus Building Garages

The following questionnaires have been presented to Mohammed, Teddy, Endalkachew, Demelash and Cherenet Garages and the ansewer are used for this thesis work as a data.

Survey On Local ISUZU Bus Body Builder Company's

1. Date:____________________________
2. Name of the organization:______________________

About the standard

3. Is there any national standard code for bus structure building and design?
   YES ☐ NO ☐
4. If the answer for number 3 is yes, which standard? What does it includes
   ____
   - Dimension ☐
   - Material ☐
   - Any other ☐ and specify_________________
5. Do you consider bus rollover regulations, if the answer is yes which regulation?
   ____
6. If the answer for number 5 is No, do all bus builder companies follow identical procedures?
   Yes ☐ No ☐
7. What type of buses do you make?
   City buses ☐ Intercity buses ☐ both ☐
8. If both, what is their major difference_____________________
9. Dimension of the Isuzu bus

Length	
Width	
Height	
Wheel base	
Truss element thickness	
Number of seat	
Passenger holding capacity	
What types of plate material used for frame and cover	
Gross weight	

Cherenet Garage Specification

Survey On Local ISUZU Bus Body Builder Company's

1. Date: 07 / 02 / 2022.
2. Name of the organization: Cherenet Garage.

About the standard

3. Is there any national standard code for bus structure building and design?

YES ☐ NO ☑

4. If the answer for number 3 is yes, which standard? What does it includes

____

- Dimension ☐
- Material ☐
- Any other ☐ and specify________________

5. Do you consider bus rollover regulations, if the answer is yes which regulation?

No

6. If the answer for number 5 is No, do all bus builder companies follow identical procedures?

Yes ☐ No ☑

7. What type of buses do you make?

City buses ☐ Intercity buses ☐ both ☑

8. If both, what is their major difference Size and the need of the owners.
9. Dimension of the Isuzu bus

Length	7.8m
Width	2.5m
Height	2.1m
Wheel base	4.28m
Truss element thickness	2mm
Number of seat	29 max 23 mini
Passenger holding capacity	23 - 29 passengers
What types of plate material used for frame and cover	-RHCS to roof -Mild steel to cover
Gross weight	4,000 to 4200 kg

Endalkachew Garage specifications

Survey On Local ISUZU Bus Body Builder Company's

1. Date: 12/02/2022
2. Name of the organization: Endalkachew Garage / Adama

About the standard

3. Is there any national standard code for bus structure building and design?

YES [ ]   NO [✓]

4. If the answer for number 3 is yes, which standard? What does it includes

____

- Dimension [ ]
- Material [ ]
- Any other [ ] and specify ____________

5. Do you consider bus rollover regulations, if the answer is yes which regulation?

No

6. If the answer for number 5 is No, do all bus builder companies follow identical procedures?

Yes [ ]   No [✓]

7. What type of buses do you make?

City buses [ ]   Intercity buses [ ]   both [✓]

8. If both, what is their major difference Size based on the Isuzu Trucks
9. Dimension of the Isuzu bus

Length	7m
Width	2.3m
Height	2.8m
Wheel base	4.26m
Truss element thickness	2mm
Number of seat	29 max
Passenger holding capacity	23-29 Passenger
What types of plate material used for frame and cover	Frame-RHSS Cover - Mild steel
Gross weight	4200to 4300kg.

Demelash Garage Specifications

Survey On Local ISUZU Bus Body Builder Company's

1. Date: 10/02/2022
2. Name of the organization: Demelash Garage, Adama

About the standard

3. Is there any national standard code for bus structure building and design?

YES ☐ NO ☑

4. If the answer for number 3 is yes, which standard? What does it includes

No

- Dimension ☐
- Material ☐
- Any other ☐ and specify

5. Do you consider bus rollover regulations, if the answer is yes which regulation?

6. If the answer for number 5 is No, do all bus builder companies follow identical procedures?

Yes ☐ No ☑

7. What type of buses do you make?

City buses ☐ Intercity buses ☐ both ☑

8. If both, what is their major difference No deference, It depend on Owners want.
9. Dimension of the Isuzu bus

Length	7.6m
Width	2.7m
Height	2.26m
Wheel base	4.26m
Truss element thickness	2.5 up to 3mm
Number of seat	23 maximum
Passenger holding capacity	23 passengers.
What types of plate material used for frame and cover	→ Frame used RHSS → Cover - mild steel
Gross weight	4,800 to 4,400kg

Mohammed garage specifications

Survey On Local ISUZU Bus Body Builder Company's

1. Date: 09/02/2022.
2. Name of the organization: Mohammed Garage, Adama

About the standard

3. Is there any national standard code for bus structure building and design?

YES ☐ NO ☑

4. If the answer for number 3 is yes, which standard? What does it includes

____

- Dimension ☐
- Material ☐
- Any other ☐ and specify____________________

5. Do you consider bus rollover regulations, if the answer is yes which regulation?

No

6. If the answer for number 5 is No, do all bus builder companies follow identical procedures?

Yes ☐ No ☑

7. What type of buses do you make?

City buses ☐ Intercity buses ☐ both ☑

8. If both, what is their major difference Size & seat capasity according to customers need.
9. Dimension of the Isuzu bus

Length	7.3m
Width	2.6m
Height	2.10m
Wheel base	4.28m ~~[illegible] 23-29 Passengers~~
Truss element thickness	2mm
Number of seat	23-29 passengers based on customer need.
Passenger holding capacity	29 maximum
What types of plate material used for frame and cover	Frame made from RHSS. & cover mild steel.
Gross weight	4100 to 4,300kg.

Teddy garage specification

Survey On Local ISUZU Bus Body Builder Company's

1. Date: 15 / 02 / 2022
2. Name of the organization: Teddy Garage, Addis Ababa

About the standard

3. Is there any national standard code for bus structure building and design?

YES ☐ NO ☑

4. If the answer for number 3 is yes, which standard? What does it includes

____

- Dimension ☐
- Material ☐
- Any other ☐ and specify____________

5. Do you consider bus rollover regulations, if the answer is yes which regulation?

____

6. If the answer for number 5 is No, do all bus builder companies follow identical procedures?

Yes ☐ No ☑

7. What type of buses do you make?

City buses ☐ Intercity buses ☐ both ☑

8. If both, what is their major difference Based on customer need & size of Isuzu truck type
9. Dimension of the Isuzu bus

Length	7m
Width	2.6 m
Height	2.10 m
Wheel base	4.26m
Truss element thickness	2mm
Number of seat	29 max
Passenger holding capacity	29 passengers
What types of plate material used for frame and cover	RHSS and mild Steel.
Gross weight	4,200 to 4,500kg

Appendix C. Five years traffic report by vehicle type

<u>የ ፌ ዴ ራ ል ፖ ሊ ስ ኮ ሚ ሽ ን</u>

<u>የ2008 አገር አቀፍ የትራፊክ አደጋ ስታትስቲክስ ሠንጠረዥ</u>

<u>የሚሸፍነው ጊዜ ከሀምሌ 1/2007 እስከ ሰኔ 30/2008 ዓ.ም.</u>

አደጋ የፈፀሙ ተሽከርካሪዎች ዓይነት

ተራ ቁጥር	አደጋው ያስከተለው ጉዳት	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	ድምር
		ተራ ብስክሌት	ሞተር ብስክሌት	አውቶሞቢል	ስቴሽን ዋገን	ፒክአፕ እስከ 10 ኩንታል	የጭነት ከ11 - 40 ኩንታል	የጭነት ከ41 -100 ኩንታል	የጭነት ከነተሳቢ	ቦቴ	ታክሲ	የሕዝብ እስከ 1200 መቀመጫ	የሕዝብ ከ13-45 መቀመጫ	የሕዝብ ከ46መቀመጫ በላይ	ልዩ ተንቀሳቃሽ መሳሪያ	ልዩ ተንቀሳቃሽ ከነተሳቢ	ጋሪ	ባቡር	ሌላ	ያልታወቀ	
1.	ሞት	40	140	62	84	317	302	399	190	91	874	311	309	77	51	29	109	-	44	26	3,455
2.	ከባድ የአካል ጉዳት	30	155	43	85	193	145	515	75	20	2,098	252	142	42	25	45	88	-	62	7	4,022
3.	ቀላል የአካል ጉዳት	17	101	34	58	108	99	207	47	9	1,524	177	84	34	24	25	90	-	93	6	2,737
4.	የንብረት ጉዳት	41	953	4,100	2,082	3,096	970	1,277	400	205	4,947	2,701	1,205	764	63	63	92	-	120	36	23,115
ድ ም ር		128	1,349	4,239	2,309	3,714	1,516	2,398	712	325	9,443	3,441	1,740	917	163	162	379	-	319	75	33,329

የ ፌ ዴ ራ ል ፖ ሊ ስ ኮ ሚ ሽ ን

የ2009 አገር አቀፍ የትራፊክ አደጋ ስታትስቲክስ ሠንጠረዥ

የሚሸፍነው ጊዜ ከሀምሌ 1/2008 እስከ ሰኔ 30/2009 ዓ.ም.

		አደጋ የፈፀሙ ተሽከርካሪዎች ዓይነት																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
ተራ ቁጥር	አደጋውዓ ያስከተለው ጉዳት	ተራ ብስክሌት	ሞተር ብስክሌት	አውቶሞቢል	ስቴሽን ዋገን	ፒክአፕ እስከ 10 ኩንታል	የጭነት ከ11 - 40 ኩንታል	የጭነት ከ41 -100 ኩንታል	የጭነት ከነተሳቢ	ቦቴ	ታክሲ	የሕዝብ እስከ 1200 መቀመጫ	የሕዝብ ከ13-45 መቀመጫ	የሕዝብ ከ46መ.በላይ	ልዩ ተንቀሳቃሽ መሳሪያ	ልዩ ተንቀሳቃሽ ከነተሳቢ	ጋሪ	ባቡር	ሌላ	ያልታወቀ	ድምር
1	ሞት	34	156	214	131	195	397	486	213	125	462	410	415	110	22	21	36		54	94	3,575
2	ከባድ የአካል ጉዳት	19	291	301	274	554	324	297	103	24	859	636	274	118	20	15	18		79	145	4,351
3	ቀላል የአካል ጉዳት	17	193	184	91	260	194	184	69	41	540	410	109	169	24	22	24		99	59	2,.689
4	የንብረት ጉዳት	57	241	4,264	1,873	3,941	2,300	1,792	829	114	6,066	3,374	1434	651	58	34	97		474	236	27,835
	ድ ም ር	127	881	4,963	2,369	4,950	3,215	2,759	1,214	304	7,927	4,830	2,232	1,048	124	92	175	0	706	534	38,450

የ ፌ ዴ ራ ል ፖ ሊ ስ ኮ ሚ ሽ ን

የ2010 አገር አቀፍ የትራፊክ አደጋ ስታትስቲክስ ሠንጠረዥ

የሚሸፍነው ጊዜ ከሀምሌ 1/2009 እስከ ሰኔ 30/2010 ዓ.ም.

2010ዓ/ም. የተሽከርካሪ - ዓይነት

	አደጋ - ያስከተለ - ጉዳት	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ጋሪ	[illegible]	ሌላ	[illegible]	ድምር
1	ሞት	19	201	182	129	269	370	434	195	123	266	536	625	103	24	19	35	0	148	142	3820
2	ከባድ የአካል ጉት	25	482	501	251	478	376	253	90	30	868	573	433	48	25	18	11	1	149	128	4740
3	ቀላል የአካል ጉዳት	26	215	220	156	282	227	157	63	45	663	357	176	80	17	16	22	0	254	97	3073
4	የንብረት ጉዳት	43	773	5798	1839	4756	2314	1646	825	54	4679	3236	2015	436	105	38	103	1	411	293	29365
	ድ ም ር	113	1671	6701	2375	5785	3287	2490	1173	252	6476	4702	3249	667	171	91	171	2	962	660	40998

የ ፌ ዴ ራ ል ፖ ሊ ስ ኮ ሚ ሽ ን

የ2011 አገር አቀፍ የትራፊክ አደጋ ስታትስቲክስ ሠንጠረዥ

የሚሸፍነው ጊዜ ከሀምሌ 1/2010 እስከ ሰኔ 30/2011 ዓ.ም.

		2011ዓ/ም የተሽከርካሪው ዓይነት																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
ተራ ቁጥር	አደጋው ያስከተለው ጉዳት	ተራ ብስክሌት	ሞተር ብስክሌት	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ቦቴ	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ጋሪ	[illegible]	ባጃጅ	ሌላ	[illegible]	ድምር
1	ሞት	28	238	136	104	256	348	402	161	121	358	599	532	193	22	14	32	1	-	81	112	3,738
2	ከባድ የአካል ጉዳት	34	378	500	240	468	320	238	112	25	768	646	246	64	17	10	15	-	-	105	138	4,324
3	ቀላል የአካል ጉዳት	12	143	375	202	220	158	140	40	23	517	305	129	62	16	13	17	-	-	155	60	2,587
4	የንብረት ጉዳት	48	552	6,288	2,055	3,984	1,919	1,727	599	134	6,641	3,532	1,360	647	74	48	68	-	-	192	354	30,22
ድ ም ር		122	1,311	7,299	2,601	4,928	2,745	2,507	912	303	8,284	5,082	2,267	966	129	85	132	1	-	533	664	40,87

የ ፌ ዴ ራ ል ፖ ሊ ስ ኮ ሚ ሽ ን

የ2012 አገር አቀፍ የትራፊክ አደጋ ስታትስቲክስ ሠንጠረዥ

የሚሸፍነው ጊዜ ከሀምሌ 1/2011 እስከ ሰኔ 30/2012 ዓ.ም.

ተራ ቁጥር	አደጋው ያስከተለው ጉዳት	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	ድምር
		ተራ ብስክሌት	ሞተር ብስክሌት	አውቶሞቢል	ስቴሽን ዋገን	ፒክአፕ እስከ 10 ኩንታል	የጭነት ከ11 - 40 ኩንታል	የጭነት ከ41 - 100 ኩንታል	የጭነት ከባድ	ቦቴ	[illegible]	የሕዝብ እስከ 1200 መቀመጫ	የሕዝብ ከ13-45 መቀመጫ	የሕዝብ ከ45 በላይ	[illegible]	[illegible]	ጋሪ	ባቡር	ባጃጅ	ሌላ	ያልታወቀ	
1	ሞት	63	265	126	123	177	227	397	146	143	438	542	289	158	54	46	81	3	49	84	166	3,577
2	ከባድ የአካል ጉዳት	33	398	553	238	301	376	285	82	23	588	739	165	76	28	20	20	-	54	111	196	4,286
3	ቀላል የአካል ጉዳት	22	180	339	123	161	131	75	38	16	379	273	157	70	23	23	17	-	42	130	48	2,247
4	የንብረት ጉዳት	76	303	7,934	2,065	3,160	1,981	1,456	403	198	5,267	3,895	1,134	1,041	106	73	62	-	45	166	342	29,707
ድ ም ር		194	1,146	8,952	2,549	3,799	2,715	2,213	669	380	6,672	5,449	1,745	1,345	211	162	180	3	190	491	752	39,817

Appendix D. Five Years Types and Number of Vehicle Registration

ከት/መረጃ ማዕከልና ኢንፎርሜሽን ቴክኖሎጂ ዳይሬክቶሬት

The collected data are from July 1/2008 up to June 30/ 2009 E.C from every region of Ethiopia

ከት/መረጃ ማዕከልና ኢንፎርሜሽን ቴክኖሎጂ ዳይሬክቶሬት

Type of Vehicles and Number in the Regions (up to Sene 2009) Registration

Descript	AA	AM	AF	BN	DD	SO	TG	GM	HA	SN	OR	Total
Ambulan	180	0	34	27	9	2	69	0	4	7	165	**497**
Automob	171523	1485	55	34	1967	558	927	228	1275	51	6376	**2E+05**
Bajaj	0	2132	2302	0	0	0		0	536	4671	5152	**14793**
Tri Cyle	0	40	0	0	0	0	0	0	0	27	16861	**16928**
Bus(< 12	25929	7146	442	260	1376	755	2799	0	0	50	126	**38883**
Bus(> 11	14524	9747	372	229	457	537	1521	1375	357	178	2126	**31423**
Combine	10	17	0	0	1	2	8	0	357	0	6322	**6717**
Dozer	0	0	3	0	0	1	5	0	20	0	252	**281**
Dry Carg	34446	1602	273	94	847	953	733	0	176	95	1067	**40286**
Dry Carg	105150	4099	224	92	3916	2152	4372	0	2	15	527	**1E+05**
Dual Pur	43253	3443	339	255	1104	515	1665	0	36	21	131	**50762**
Field Vel	43681	1590	298	138	426	912	1034	0	445	16	7168	**55708**
Grader	5	2	0	0	1	1		0	3	0	17517	**17529**
Forklift	145	0	3	0	6	0	2	0	317	0	19880	**20353**
Not Spec	18370	8121	25	16	214	263	187		0	50762	13480	**91438**
Gotach	5178	0	0	0	57	0	308	0	1699	0	1305	**8547**
Liquid C	5057	272	34	2	203	114	621	0	7	65	358	**6733**
Liquid T	0	11	0	0	0	0		0	336	0	2189	**2536**
Motor Bi	21509	26442	1048	3237	5761	1157	5705	2166	0	4	642	**67671**
Other	9766	442	35	1	89	33	524	1353	72	22	3	**12340**
Three wl	8	0	0	6	2	166	65	0	1	0	263	**511**
Three wl	506	0	0	1508	299	5145	5046	0	0	0	7	**12511**
Tractor	1027	281	46	124	20	0	184	0	0	1	239	**1922**
Trailer	23810	292	8	1	379	1	2485	0	0	0	13	**26989**
Vehicle v	367	135	14	1	109	27	62	0	0	0	164	**879**
Total	**5E+05**	**67299**	**5555**	**6025**	**17243**	**13294**	**28322**	**5122**	**5643**	**55985**	**1E+05**	**8E+05**

ከት/መረጃ ማዕከልና ኢንፎርሜሽን ቴክኖሎጂ ዳይሬክቶሬት

The collected data are from July 1/2009 up to June 30/ 2010 E.C from every region of Ethiopia

From Information Communication Technology Directorate												
Type of Vehicles and Number in the Regions (up to Sene 30.2010) Registration												
Descriptio	**AA**	**AM**	**AF**	**BN**	**DD**	**SO**	**TG**	**GM**	**HA**	**SN**	**OR**	**Total**
Ambulan	198	0	37	35	9	2	91	0	4	25	238	639
Automob	184227	1485	59	49	2057	558	1421	228	1275	16162	4796	212317
Bajaj	0	2132	2644	0	289	0	0	0	536	8721	34339	48661
Tri Cyle	0	40	0	0	0	0	0	0	0	27	0	67
Bus(< 12	26408	7146	448	324	1468	755	4768	0	0	709	14174	56200
Bus(> 11	15242	9747	449	325	514	537	3335	1375	357	1144	22772	55797
Combine	20	17	0	0	1	2	5	0	357	0	75	477
Dozer	16	0	3	3	0	1	5	0	20	0	0	48
Dry Cargo	37384	1602	289	101	890	953	1069	0	176	3070	7063	52597
Dry Cargo	109952	4099	229	98	4089	2152	4886	0	2	1195	1810	128512
Dual Pur	44954	3443	348	301	1157	515	2063	0	36	1435	372	54624
Field Veh	45081	1590	303	148	447	912	1185	0	445	117	5421	55649
Grader	7	2	0	0	1	1	4	0	3	0	1	19
Forklift	188	0	4	1	6	0	13	0	317	0	2	531
Not Speci	18154	8121	32	25	222	263	602	0	0	1534	6020	34973
Gotach	5598	0	0	0	59	0	572	0	1699	0	0	7928
Liquid Ca	6341	272	35	2	206	114	645	0	7	65	189	7876
Liquid Tr	0	11	0	0	0	0	0	0	336	0	117	464
Motor Bic	22931	26442	1152	4129	5891	1157	10744	2166	0	49409	29378	153399
Other	9912	442	36	1	88	33	494	1353	72	36	1763	14230
Three wh	12	0	0	24	2	166	888	0	1	0	4	1097
Three wh	375	0	0	1909	0	5145	9962	0	0	0	0	17391
Tractor	1059	281	46	134	21	0	265	0	0	7	503	2316
Trailer	25336	292	8	1	394	1	2793	0	0	0	302	29127
Vehicle w	543	135	15	1	113	27	115	0	0	0	0	949
Total	**553938**	**67299**	**6137**	**7611**	**17924**	**13294**	**45925**	**5122**	**5643**	**83656**	**129339**	**935888**

ከት/መረጃ ማዕከልና ኢንፎርሜሽን ቴክኖሎጂ ዳይሬክቶሬት

The collected data are from July 1/2010 up to June 30/ 2011 E.C from every region of Ethiopia

From Information Communication Technology Directorate

Type of Vehicles and Number in the Regions (up to Sene 30.2011) Registration

Descriptio	AA	AM	AF	BN	DD	SO	TG	GM	HA	SN	OR	Total
Ambulanc	253	0	38	44	7	14	164	0	4	28	365	917
Automobi	205773	1701	66	49	2246	609	1660	228	1275	80	6012	219699
Bajaj	0	4722	2889	0	2318	0	0	0	536	9307	48822	68594
Tri Cyle	0	37	0	0	0	0	0	0	0	27	0	64
Bus(< 12	27357	8805	465	347	1607	837	5201	0	0	12503	3024	60146
Bus(> 11	16698	12840	532	378	681	677	3886	1375	357	10029	38439	85892
Combiner	23	53	0	0	1	2	5	0	357	0	78	519
Dozer	17	0	3	3	0	1	5	0	20	0	0	49
Dry Cargo	41333	2396	301	102	993	1036	1163	0	176	102	1868	49470
Dry Cargo	115023	4591	240	103	4313	2348	5030	0	2	153	7188	138991
Dual Purp	47278	3907	380	310	1370	684	2188	0	36	1438	97	57688
Field Vehi	47059	1767	318	153	487	1037	1228	0	445	123	3299	55916
Grader	6	2	0	0	2	1	4	0	3	0	2	20
Forklift	237	0	4	1	8	0	18	0	317	0	2	587
Not Speci	18943	1462	34	48	248	0	396	436	1179	3118	7929	33793
Gotach	5756	0	0	0	67	2	613	0	1699	0	0	8137
Liquid Ca	6703	318	35	2	226	148	650	0	7	65	437	8591
Liquid Tra	0	14	0	0	0	0	0	0	336	0	187	537
Motor Bic	24700	40229	1181	4865	6689	1366	12358	2166	1178	54084	49903	198719
Other	10279	643	36	1	105	33	485	1353	72	38	2905	15950
Three whe	15	9625	0	39	7	233	1417	0	1	0	4	11341
Three whe	368	0	0	2259	0	6106	12953	0	0	0	0	21686
Tractor	1199	392	51	136	21	0	304	0	0	10	530	2643
Trailer	26326	349	8	1	417	1	2891	0	0	0	217	30210
Vehicle w	738	148	17	1	125	25	132	0	0	0	0	1186
Total	**596084**	**94001**	**6598**	**8842**	**21938**	**15160**	**52751**	**5558**	**8000**	**91105**	**171308**	**1071345**

ከት/መረጃ ማዕከልና ኢንፎርሜሽን ቴክኖሎጂ ዳይሬክቶሬት

The collected data are from July 1/2011 up to June 30/ 2012 E.C from every region of Ethiopia

From Information Communication Technology Directorate												
Type of Vehicles and Number in the Regions (up to sene 30.2012) Registration												
Descriptio	**AA**	**AM**	**AF**	**BN**	**DD**	**SO**	**TG**	**GM**	**HA**	**SN**	**OR**	**Total**
Ambulan	303	0	82	55	6	45	187	0	4	58	438	1178
Automob	222683	1786	83	53	2360	648	1994	322	1303	98	5258	236588
Bajaj	0	9308	3925	0	3086	0	0	0	4909	11325	55462	88015
Tri Cyle	0	0	0	0	0	0	0	0	0	0	0	0
Bus(< 12	28432	9197	493	375	1656	979	5656	2125	80	13300	27315	89608
Bus(> 11	17707	13953	678	467	786	871	4473	859	3000	9617	32289	84700
Combine	27	54	0	0	1	1	5	0	0	0	79	167
Dozer	16	0	3	3	0	1	4	0	0	0	0	27
Dry Cargo	44898	3597	338	105	1041	1104	1298	0	0	1577	1839	55797
Dry Cargo	119032	3653	259	108	4522	2604	5148	0	0	3612	7325	146263
Dual Pur	49234	4068	461	330	1569	989	2266	0	56	1701	2889	63563
Field Veh	48837	1835	371	160	507	1148	1282	330	300	149	3037	57956
Grader	5	2	0	0	2	1	4	0	0	0	2	16
Forklift	281	0	4	1	9	1	18	0	0	0	2	316
Not Speci	19955	1532	71	56	283	511	397	231	0	295	1650	24981
Gotach	5854	0	0	0	66	5	624	0	0	0	0	6549
Liquid Ca	6866	313	37	2	241	186	658	0	0	67	181	8551
Liquid Tr	0	14	0	0	0	0	0	0	0	0	171	185
Motor Bic	25726	45137	1355	6108	7656	1651	14405	2370	1076	76565	61386	243435
Other	10786	718	35	30	124	33	485	0	0	43	3796	16050
Three wh	16	42	0	50	9	250	1874	0	0	0	4	2245
Three wh	356	10311	0	2612	0	8523	16647	0	0	0	0	38449
Tractor	1325	401	54	138	21	0	317	0	0	16	526	2798
Trailer	27266	360	8	1	431	1	2913	0	0	1	377	31358
Vehicle v	835	153	20	1	134	27	145	0	0	0	0	1315
Total	**630440**	**106434**	**8277**	**10655**	**24510**	**19579**	**60800**	**6237**	**10728**	**118424**	**204026**	**1E+06**

ከት/መረጃ ማዕከልና ኢንፎርሜሽን ቴክኖሎጂ ዳይሬክቶሬት

The collected data are from July 1/2012 up to June 30/ 2013 E.C from every region of Ethiopia

From Information Communication Technology Directorate												
Type of Vehicles and Number in the Regions (up to sene 30.2013) Registration												
Descripti	AA	AM	AF	BN	DD	SO	TG	GM	HA	SN	OR	Total
Ambulan	322	0	90	56	6	45	187	0	4	65	590	1365
Automob	255793	1834	86	56	2413	648	1994	0	1303	104	5758	269989
Bajaj	0	11381	4608	0	3302	0	0	1439	4909	12901	65218	103758
Tri Cyle	0	0	0	0	0	0	0	0	0	0	0	0
Bus(<12 S	31330	9787	494	393	1666	979	5656	2125	80	13874	29068	95452
Bus(>11	19206	14802	713	526	860	871	4473	859	3000	12579	39631	97520
Combine	106	61	0	0	2	1	5	0	0	0	78	253
Dozer	16	1	3	3	0	1	4	0	0	0	0	28
Dry Cargo	52338	3825	351	109	1083	1104	1298	0	0	176	2187	62471
Dry Cargo	139376	3767	267	117	4670	2604	5148	0	0	233	8201	164383
Dual Purp	56063	4258	486	343	1704	989	2266	0	56	1712	3028	70905
Field Veh	53233	2066	389	164	524	1148	1282	0	300	206	3266	62578
Grader	6	2	0	0	2	1	4	0	0	0	2	17
Forklift	351	0	4	1	10	1	18	0	0	0	2	387
Not Speci	21185	1621	72	57	327	511	397	0	0	2540	2293	29003
Gotach	7235	0	0	0	67	5	624	0	0	0	0	7931
Liquid Ca	8307	331	39	2	244	186	658	0	0	67	184	10018
Liquid Tra	0	14	0	0	0	0	0	0	0	0	0	14
Motor Bic	28235	48997	1454	7385	8111	1651	14405	2643	1076	80466	63359	257782
Other	12526	778	35	39	137	33	485	0	0	44	4304	18381
Three wh	17	281	0	56	10	250	1874	0	0	0	9	2497
Three wh	350	13807	0	3111	0	8523	16647	0	0	0	0	42438
Tractor	1505	415	54	146	21	0	317	0	0	33	1015	3506
Trailer	32676	381	8	1	450	1	2913	0	0	1	408	36839
Vehicle w	1004	158	21	1	134	27	145	0	0	0	0	1490
Total	**721180**	**118567**	**9174**	**12566**	**25743**	**19579**	**60800**	**7066**	**10728**	**125001**	**228601**	**1339005**

ማሳሰቢያ፡- የአዲስ አበባ ተሽከርካሪ ከሁሉም ክፍለከተሞች የተሰበሰበው መረጃ መርጅ በሚደረግበት ጊዜ ካለፈው ቁጥር ጋር ሲነፃፀር ዝቅ በማለቱ ከ6ወር በፊት በተሰጠው መረጃ መሰረት እንዲሆን እንገልፃለን።