KAUNAS UNIVERSITY OF TECHNOLOGY
MECHANICAL ENGINEERING AND DESIGN FACULTY

Ragavan Thiyagarajan

INVESTIGATION OF ROLLOVER PROTECTION IN INDIAN BUSES

Master's Degree Final Project

Supervisor
Assoc. prof. dr. Lukoševičius Vaidas

KAUNAS, 2017

KAUNAS UNIVERSITY OF TECHNOLOGY

MECHANICAL ENGINEERING AND DESIGN FACULTY

INVESTIGATION OF ROLLOVER PROTECTION IN INDIAN BUSES

Master's Degree Final Project

Vehicle Engineering (621E20001)

Supervisor
Assoc. prof. dr. Lukoševičius Vaidas

Reviewer
Assoc. prof. dr. Robertas Keršys

Project made by
Ragavan Thiyagarajan

KAUNAS, 2017

KAUNAS UNIVERSITY OF TECHNOLOGY

MECHANICAL ENGINEERING AND DESIGN FACULTY

Ragavan Thiyagarajan

Vehicle Engineering (621E20001)

"INVESTIGATION OF ROLLOVER PROTECTION IN INDIAN BUSES"

DECLARATION OF ACADEMIC INTEGRITY

6 June 2017

Kaunas

I confirm that the final project of mine, **Ragavan Thiyagarajan**, on the subject "Investigation of Rollover Protection in Indian Buses" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis.

I fully and completely understand that any discovery of any manifestations/case/facts of dishonesty inevitably results in me incurring a penalty according to the procedure(s) effective at Kaunas University of Technology.

(name and surname filled in by hand) *(signature)*

KAUNAS, 2017

KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT

Study programme: VEHICLE ENGINEERING

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Investigation of Rollover Protection in Indian Buses

2. Aim of the project

To investigate about rollover protection in Indian buses with the help of AIS 031 and ECE R66 regulations and to propose suitable changes to amend AIS 031 regulations.

3. Structure of the project

- Identifying about the severity of rollover accidents in buses with the help of literature review based on the researches done by previous authors.
- Studying about different types of testing methods proposed in AIS 031 and ECE R66 regulations and choosing a best method to carry out rollover tests in buses.
- Choosing a suitable bus model specially designed for Indian roads.
- Designing the chosen model using CAD software's.
- Calculation of different parameters as mentioned in ECE R66 and AIS 031 regulations which are used to conduct the rollover test in buses.
- Analytical calculations on the designed model using CAE software's.
- Discussion about the results and proposing suitable changes to amend AIS 031 regulations.

4. Requirements and conditions

- AIS 031, ECE R66 regulations.
- CAD Software - CATIA
- CAE Software - ANSYS

5. This task assignment is an integral part of the final project

6. Project submission deadline: 2017 June 6.

Student	Ragavan Thiyagarajan	________________
	(Name, Surname of the Student)	(Signature, date)
Supervisor	Assoc. Prof. dr. Lukoševičius Vaidas	_______________
	(Position, Name, Surname)	(Signature, date)

Ragavan Thiyagarajan. Investigation of Rollover Protection in Indian Buses. *Master's* Final Project / supervisor assoc. prof. dr. Lukoševičius Vaidas; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Research field and area: Technological Science, Transport Engineering (03T).

Keywords: *Bus accidents, Rollover, India, AIS031, ECE-R66, Catia, Ansys.*

Kaunas, 2017. 60 p.

SUMMARY

Accidents are considered as one of the worst-case scenarios that can cause severe damage and injuries. Accidents do happen anywhere, anytime and are unpredictable in nature. However, accidents cannot be avoided but on the other hand can be prevented to a certain extent. While travelling in bus is considered as one of the safest mode of transportation for passengers whether in city or intercity lines, question arises whether bus structures could be safe enough to withstand the impact created during an accident. The severity of a bus accident is high because buses carry a huge number of passengers than cars and bikes. This is true in developing countries like India where many passengers travel by buses than cars.

Rollover is a type of accident in which the vehicle tips over to its side or roof and it is considered as one of the most dangerous type of accidents since the number of passengers who are at risk is considerably high than other type of accidents like frontal impact or rear impact accidents. Also, the average fatality rate is about 35 to 40 passengers per accident which is higher than other cases with an average fatality rate of 5 to 10 passengers per accident.

To increase the occupant safety during an accident it is much desired to develop a bus super structure that should have enough strength to withstand the impact. The Automotive Industry Standard ‘AIS031’ specifies the requirements and methods to calculate the strength of superstructures. This is also associated with the Economic Commission for Europe ‘ECE-R66’ regulations.

In this study an intercity bus structure designed for India, specified as per the regulation norms of AIS031 and ECE R66 is chosen and modelled using CATIA software. The strength of the superstructure is calculated mathematically using the methods specified in the regulations and a new method of analytical calculation is done in which the rollover scenario is created with the help of ANSYS Workbench software. The results from the analytical method are compared with the mathematical calculations and a suitable recommendation to amend AIS031 regulation is suggested.

Ragavan Thiyagarajan. Tyrimo Apsaugos Virtimo Indijos Autobusai. *Magistro* baigiamasis projektas / vadovas doc. dr. Lukoševičius Vaidas; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino Fakultetas.

Mokslo kryptis ir sritis: Technologijos mokslai, Transporto inžinerija (03T).

Reikšminiai žodžiai: *Autobusų avarijų, virtimo, Indija, AIS031, ECE R66, Catia, Ansys.*

Kaunas, 2017. 60 p.

SANTRAUKA

Nelaimingi atsitikimai yra vertinamas kaip vienas blogiausio atvejo scenarijų, kurie gali sukelti rimtą žalą ir sužalojimų. Nelaimingų atsitikimų įvyksta bet kur, bet kuriuo metu ir yra nenuspėjamo pobūdžio. Vis dėlto nelaimingų atsitikimų neišvengiamas, bet kita vertus galima išvengti tam tikru mastu. Nors kelionės autobusu yra laikoma kaip viena iš saugiausių rūšies transportu keleiviams miesto ir tarpmiestiniai linijas, kyla klausimas, ar autobusų struktūrų gali būti pakankamai saugi, atlaikyti išorinius poveikius, sukurtų per nelaimingą atsitikimą. Autobuso avariją sunkumas yra didelis, nes autobusai atlikti labai daug keleivių nei automobiliams ir motociklams. Tai aktualu besivystančių šalių kaip Indija, kur daug keleivių kelionės autobusais nei automobiliais.

Virtimo yra avarija, jos pusės ar stogo apsivertus transporto priemonės tipas ir ji yra laikoma viena iš pavojingiausių nelaimingų atsitikimų tipą nuo keleivių, kuriems kyla pavojus yra labai didelės, nei kitos rūšies nelaimingų atsitikimų kaip priekinio smūgio ar užpakaline smūgine nelaimingų atsitikimų. Be to, vidutinis mirtingumo rodiklis yra maždaug 35-40 keleivių per avariją, kuris yra didesnis nei kitais atvejais, kai vidutinis mirtingumo lygis 5-10 keleivių per avariją.

Padidinti keleivių saugumą nelaimingų atsitikimų metu jis daug didesniu mastu plėtoti autobusų antstatą, kad turėtų turėti pakankamai jėgų atsilaikyti prieš poveikį. Automobilių pramonės standarto "AIS031" nurodo reikalavimus ir metodus apskaičiuoti antstatų stiprumą. Tai taip pat susiję su ekonomikos Komisijos Europoje "ECE-R66" nuostatai.

Šiame tyrime tarpmiestinių autobusų konstrukcija, skirta Indija, nurodytą pagal Reglamento normos, AIS031 ir ECE R66 yra pasirinkta ir sumodeliuoti CATIA programinės įrangos naudojimas. Kėbulo rėmų stiprumo apskaičiuojama matematiškai naudojant metodus, nurodytus reglamentus ir naują analizės skaičiavimo metodą, daroma, kuria virtimo scenarijų sukurtas ANSYS Workbench programinės įrangos pagalba. Analizės metodo rezultatai yra lyginami su matematinių skaičiavimų ir pasiūlė tinkamas rekomendacijas iš dalies keisti AIS031 reglamento.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Travelling by bus is considered as one of the safest mode of transportation and is widely preferred among passengers especially when it comes to an intercity travel. Operators and travel agents do prefer buses for intercity travels because of the fact, that it can carry a large number of passengers than other modes of road transports. This favourable reason among the operators because unfavourable when it comes to an accident where a large fatality rate occurs. Bus accidents are considered as one of the worst-case scenarios that can cause severe damage and injuries. Accidents do happen anywhere, anytime and are unpredictable in nature. However, accidents cannot be avoided but on the other hand can be prevented and are avoided to a certain extent.

The severity of a bus accident is high because buses carry an enormous number of passengers than other road transport modes like cars and bikes. This is true in developing countries like India where bus transport is an integral part of day to day life and a vast number of passengers travel by buses than cars. Buses in India and other developing countries are designed keeping in mind the population of such countries. Theses buses where designed to carry a substantial number of passengers when compared to buses in Europe and other places. According to Volvo's product specifications data the B7R coaches built for Europe has a passenger capacity of 37+D whereas the same variant for Indian market has a passenger capacity of 49+D which is 12 passengers more than the European market. Hence in case of an accident the number of passengers and the fatality rate is higher in Indian variants than the European one.

Rollover is a type of accident in which the vehicle tips over to its side or roof and it is considered as one of the most dangerous type of accidents since the number of passengers who are at risk is considerably high than other type of accidents like frontal impact or rear impact accidents. In case of rollover the vehicle ends up by lying on its side or roof due to the rotation that occurs during the accident. The vehicle rotates minimum one quarter turn or more turns on its side. Although rollover accidents occur less frequently then other types of accidents the average fatality rate according to Matyas Matolcsy's research [1] is about 22 to 25 passengers per accident which is higher than other cases with an average fatality rate of 5 to 10 passengers per accident. However, this fatality rate in case of Indian buses will go higher up to 35 passengers per accidents owing to the fact of larger passenger carrying capacity of these buses.

Another important thing to consider in case of rollover accident is that rollover can lead to other type of accidents and damages to bus structures. Since the buses are rotating one or more quarter turns the fuel tanks of the buses gets ruptured and can led to fire accidents which will risk the lives of entire passengers and crew. About 2-5% of rollover accidents results in fire accidents [2] causing it difficult to rescue the passengers. The below figure shows a bus superstructure after fire accident caused by rollover of bus to its side.

Figure 1. 1 Damaged Bus Structure due to Rollover and Fire [2]

While travelling by bus is considered as one of the most preferred and the safest mode of transportation for passengers whether in city or intercity lines, question arises whether bus super structures could be safe enough to withstand all kind of impacts created during an accident. This is of utmost important in case of roll over where the entire superstructures of the buses are considered. The knowledge about safety of bus transportation is now a day increasing among the passengers and it is the manufactures responsibility to satisfy these needs. Bus manufactures are working hardly to improve the design a super structure to be able to withstand all kinds of accidents.

This thesis work is an investigation of the bus super structure of an Intercity coach specially designed for Indian market. The coach chosen for this investigation purpose is Ashok Leyland's 'Luxura' which is manufactured by the Indian bus maker Ashok Leyland from the year 2014 to present. The chosen bus is investigated as per the safety norms specified by AIS031 regulations and is associated with the help of ECE R66 regulations. The model is modelled using CATIA software and the strength of the superstructure is calculated mathematically using the methods specified in the regulations and a new method of analytical calculation is done in which the rollover scenario is created with the help of ANSYS Workbench software. The results from the analytical method are compared with the mathematical calculations and some suitable recommendations are suggested to amend AIS031 regulation.

1.1 INTRODUCTION TO AIS031

In order to ensure the safety of passengers travelling by bus the Automotive Research Association of India (ARAI) in association with the Automotive Industry Standard Committee (AISC) published the Automotive Industry Standard 'AIS031' regulations named 'Automotive Vehicles-The Strength of Superstructures of Large Passenger Vehicles' on December 2004. Automotive Industry Standard AIS031 is applied to single decked vehicle constructed for the carriage of more than 13 passengers or above excluding the driver. The main scope of this regulation as mentioned by the Automotive Industry Standard Committee is [3]:

'The superstructure of the bus is shall be so designed and constructed as to eliminate to the greatest possible extent the risk of injury to the occupants in the event of an accident'.

The AIS031 standard is a part of bus body code and it specifies the strength required by the superstructures to protect the occupants from all kind of impacts created during the accidents. AIS031 is prepared with considerable assistance using the ECE R66 regulations published by the Economic Commission for Europe on October 1995 and its amendment revised on September 1997 [3].

1.1.1 AIS 031 Testing Methods

According to the AIS031 regulations the superstructure of the bus should be strong enough to protect the passengers from all kind of impacts that are created during the case of an accident. In order to determine the strength of the super structure, each type of vehicle is verified based on one of the following four methods mentioned in AIS031 regulations [3].

1. A rollover test on a Complete Vehicle
2. A rollover test on a Body Section or Section representative of a Complete Vehicle
3. A Pendulum test on a Body Section or Sections
4. A Verification of strength of superstructures by Calculation.

These tests on super structures of the vehicle must be done by the vehicle body/bus manufactures or by a test agency and the results of these tests should be submitted to the committee for approval. A detailed description of the superstructure with its dimensions, used materials and its attachments to chassis frame shall be submitted to the committee. A detailed drawing of the vehicle and the interior parts which have a direct influence on the superstructure strength should be submitted for calculation and approval purpose. The superstructure is certified to be safe only if it satisfies the below two conditions:

1. No displaced part of the vehicle intrudes into the residual space after the tests has been done and
2. No part of the residual space projects outside the deformed structure.

Where Residual Space is the space or volume to be preserved in the passenger compartment [1] during and after the structure has been subjected to one of the test methods mentioned in above page. Hence it is clear that in case of an accident the volume occupied by the passengers should be protected with utmost importance and care. The dimensions of the residual space for a single deck vehicle as mentioned by the AIS031 standard is shown in below figure in accordance with the lateral side of the vehicle.

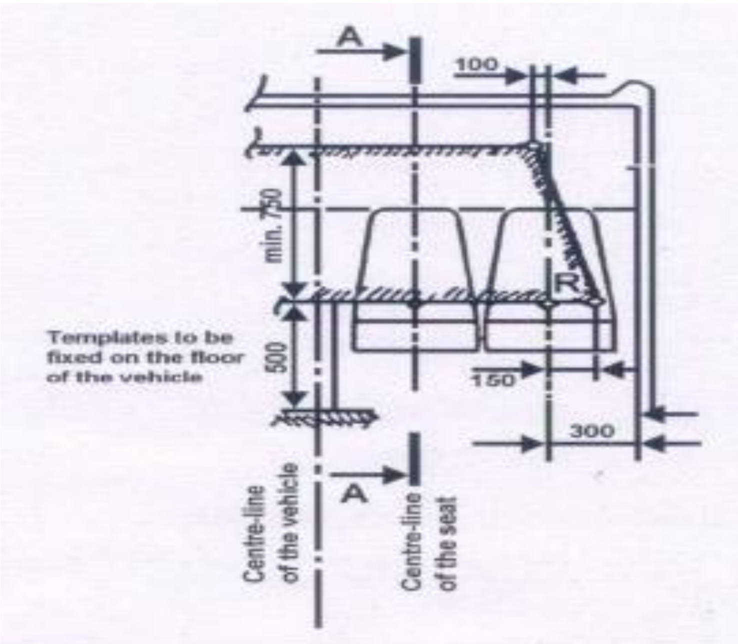


Figure 1. 2 Residual Space of the Bus mentioned by AIS031 [3]

[1] The space intended for passenger's use excluding the space occupied by toilets, bars and kitchenettes.

1.2 INTRODUCTION TO ECE R66

The Economic Commission for Europe founds that there is a greater need and awareness among manufactures and passengers for enforcing a regulation on rollover protection of buses due to a series of rollover accidents that happened in Europe during those times. A regulation to monitor the manufacturing of bus super structure is a much needed one, based on which the superstructure strength of the buses and other articulated vehicles can be determined thereby making a structurally strong bus structures for safer travels. This made the Economic Commission for Europe to implement the 'ECE R66' regulations named as 'Uniform Provisions Concerning the approval of Large Passenger Vehicles with regard to the Strength of their Superstructure' on January 1987 as the first regulation of its kind for rollover protection of vehicles.

The ECE R66 regulations is applied to single deck rigid or articulated vehicles[2] belonging to categories M2 or M3[3] used for carrying more than 22 passengers, whether seated or standing, in addition to driver and crew. This regulation as per the request from manufactures in recent time is amended on May 2009 is also applied to double deck vehicles belonging to categories M2 or M3. The main scope of the ECE R66 regulation as mentioned by the Economic Commission for Europe is [4]:

"The superstructure of the vehicle shall have the sufficient strength to ensure that the residual space during and after the rollover test on complete vehicle is unharmed".

This regulation now a day is a widely used one across the world for rollover protection investigation and as a successful model for other countries to enforce their own regulations for rollover protection. For example, the Automotive Industry Standard 'AIS031' of India is prepared with considerable assistance using the ECE R66 regulations published by the Economic Commission for Europe on October 1995 and its amendment revised on September 1997 [3]. The ECE R66 regulation is continuously updated based on the new technological development and actual requirements. Some of the amendments includes the updated version enforced on October 1995, September 1997, February 2006 and May 2009.

---

[2] Vehicles which consists of two or more sections which articulate to each other, the passenger compartments of each section intercommunicate so that the passengers can move freely between them; the rigid sections are permanently connected so that they can separated only in a workshop.

[3] Vehicles used for the carriage of passengers, comprising more than eight seats and having a mass not exceeding 5 tonnes (M2) or mass exceeding 5 tonnes (M3).

1.2.1. ECE R66 Testing Methods

A strong superstructure is an essential one to ensure the occupants safety in case of rollover and other type of accidents. The ECE R66 regulations proposes five different methods to determine the strength of the superstructure. These methods can be used separately and can be used to compare results from one to another method. These testing methods includes [4]:

1. Rollover Test on a Complete Vehicle as the basic approval method
2. Body Section Rollover Test as an equivalent approval method
3. Quasi Static Loading Test of Body Section as an equivalent approval method
4. Quasi Static Calculation based on Testing of Components as an equivalent approval method
5. Computer Simulation of Rollover Test on complete Vehicle as an equivalent approval method.

Method 1 is accepted as a standard method of testing superstructures whereas other methods are considered as equivalent approval methods. Method 5 is a new advanced method in which the entire rollover testing is done with the help of computer software's thereby eliminating the usage of a physical model for rollover testing. Method 5 is a real-time example of advancement of computer technologies in the field of vehicle testing. In this thesis, method 5 is used to perform rollover analysis using ANSYS Workbench software.

A detailed drawing of the vehicle layout, its bodywork, and interior arrangements of the vehicle should be submitted by the vehicle manufacture or the testing agency conducting the rollover test to the approval committee. The superstructure is certified to be safe only on the satisfaction of following conditions [4]:

1. No part of the vehicle which is outside the residual space during the start of the test (e.g. pillars, safety rings, luggage racks) shall intrude into the residual space during the test and
2. No parts of the residual space shall project outside the contour of the deformed space. The contour of the deformed structure shall be determined sequentially between every adjacent window and/or door pillars.

An important thing to consider here is that any structural parts which are originally inside the residual space (e.g. Vertical handholds, Partitions, Kitchenettes, Toilets) can be ignored while evaluating the intrusion inside the residual space.

The main aim of these regulation is to protect the passengers compartment or Residual space from the impacts created during the rollover accident. The residual space is thus designed with care as per the dimensions mentioned by ECE R66 regulations. This residual space may vary depending upon the height & other dimensions of the vehicle but a general residual space dimension is shown in the below figure.

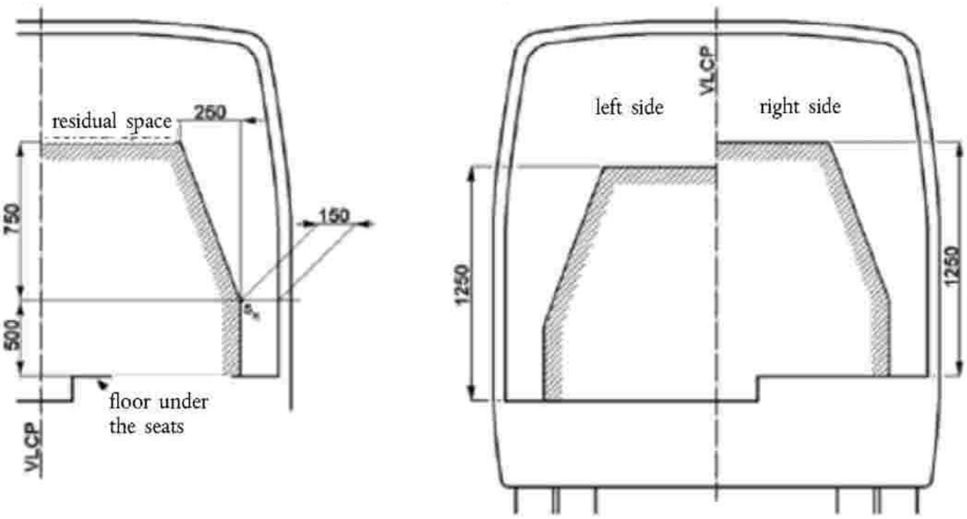


Figure 1. 3 Residual Space Mentioned in ECE R66 [4]

1.3. COMPARISON BETWEEN AIS 031 AND ECE R66 REGULATIONS

The AIS 031 regulation is formulated by considering the road and other conditions of the Indian Subcontinent whereas the ECE R66 is based on the conditions of European Union. However, both has some similar features and testing methods and the main aim of both regulations is to determine whether the superstructure is strong enough to withstand all kind of impacts created during bus rollover. The AIS 031 regulation is enforced from December 2004 which is seventeen years after the implementation of ECE R66 regulation on January 1987. It is noted that while formulating the AIS 031 regulations considerable assistance is derived from ECE R66 regulations [3]. In both regulations, the Residual space is given much importance than other factors.

The testing methods in both the regulations is the same with some considerable variations between them. The AIS 031 regulations has four types of testing procedures in which the methods 1, 2 are the same as methods 1, 2 in ECE R66 regulations. While method 3 of AIS 031 conducts test with the help of a pendulum the same method is done with the help of quasi static loading in method 3 ECE R66 regulation. The fourth testing method of ECE R66 and AIS031 is a physical calculation of the testing components in which a quasi-static calculation is done in the former one. Method 5 which is a new method of rollover testing is available in ECE R66 regulations which is done with the help of advanced computer simulation software's. This method is used in this study to determine the rollover strength of the bus superstructure using ANSYS Workbench software. The general requirements for computer simulation and ways to do the simulation are explained in Appendix A. No such testing method is found in the AIS 031 regulations.

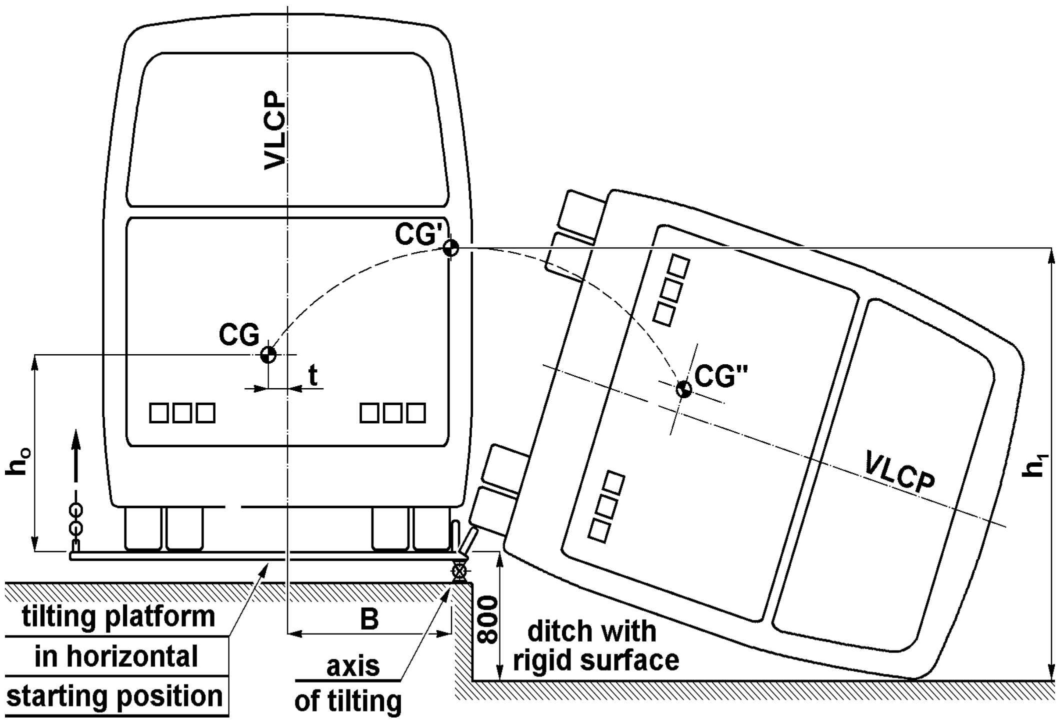


Figure 1. 4 Rollover Test on Complete Vehicle [3,4]

Both AIS 031 and ECE R66 regulation proposes a rollover test on a complete vehicle as a basic approval method which is done by keeping the vehicle in a tilting platform with blocked suspension and then tilting it slowly on its lateral side to reach its unstable equilibrium position. The vehicle is now tipped over into a ditch made up of concrete ground surface and having a depth of 800mm [3,4]. In both the regulations the superstructure is certified to be safe only if the residual space is unharmed and unaffected before and after the testing.

2. LITERATURE REVIEW

The research study done by Matyas Matolcsy "The Severity of Bus Rollover Accidents" [1] shows that roll over is the most severe type of bus accident as it causes an average fatality rate of 22 fatalities per accident. According to the author, the severity of rollover accidents can be specified into two ways based on the number of causalities and based on the circumstances of the rollover accidents. Four major types of injuries are occurred during this accident like intrusion, projection, partial and total ejection. The author also mentions that the surrounding geometry of the accidents also needed to be considered while doing rollover analysis. Most of the roll-over accidents occurs as turn on side, into a ditch and roll over from roads. This study is carried out purely on experimental procedures and no computer software's were used.

The research carried out by SCOE, University of Pune, India "Rollover Analysis of Passenger Bus as per ASI031" [2] clearly states that the super structure of the bus needs to be strong enough to ensure minimum damage and absorbs maximum impact energy. The author also mentions that rollover is considered as one of the most severe type of accidents as it can lead to other type of accidents like fire accidents. This is because the bus rolls on its side during a rollover accident which causes the fuel tank to rupture and causing fire after rollover. In this paper, the authors designed the numerical model of bus super structure as per the requirements of ASI031 standards followed by numerical simulation of rollover test using finite element methods. The author mentions that if the damage to structure in rollover is severe the occupants are exposed to elevated risk of life.

A research was done by product development department of TEMSA [5] about the rollover of buses "An Investigation on the Rollover Cross worthiness of an Intercity Coach, Influence of Seat Structure and Passenger Weight". In this study, an explicit dynamics ECE R66 roll over crash analysis of a stainless-steel bus under development is carried out and the strength of the bus is assessed with respect to the ECE R66 regulations. Also in this study, different considerations like passenger weight, luggage weight which are not mentioned in the regulations are considered. LS DYNA is used as the nonlinear explicit solver and LS-PREPOST as pre-processor.

Four different type of analysis based on the base line, with passenger mass, with luggage mass, and with seat are investigated. The conclusion of this study clearly mentions the need of a seat restraint system. Belted occupants are likely to avoid the severe injuries that happen during roll over. Also, it is noted that an increase in mass like passenger mass, seat and luggage mass also causes an increase in intrusion.

“A comparative analysis of bus roll over protection under the existing standards” is a comparative research done by C.C. Liang and L.G. Nam [6]. The analysis is done based on two regulations-one is the Economic Commission of Europe’s ECE R66 regulation and the other one is American Federal Motor Vehicle Safety Standards (FMVSS 220) to prevent catastrophic roll-over accidents. However, the scope of those two regulations does overlap for some group of vehicles. Thus, this study firstly presents a physical meaning comparative analysis of the ECE R66 with the FMVSS 220.

The LS-DYNA 971/MPP was used for numerical analysis. The analysis models were constructed by the eta/FEMB that is a pre-processing module integrated in the LS-DYNA 971 package. Great differences were found between the rollover strength of bus superstructures depending on which regulations are followed. The results also demonstrate that the passenger compartment and residual space are more violated and more dangerous under the lateral rollover testing condition of the ECE R66 than the other.

The conclusion of this study shows that under lateral roll over passenger and residual space were more violated and are dangerous. The focus of absorbed energy is 57.16% for side walls in ECE R66 regulations whereas in FMVSS 220 it is 50.01% for the roof. Hence this study shows that side walls are the focus area for ECE R66 regulations whereas roof is the main area for FMVSS 220 regulations.

The study carried out by Vehicle Safety Institute of Granz University of Technology [7] on the name “Enhanced Coach and Bus Occupant Safety”. This research is done using the MADYMO software. The Bay section of the bus is also considered in this study and the roll over model is designed along with the bay section. Also, the passenger masses are considered. To make the study more realistic 50% Hybrid III dummies are used. The study is carried out in three methods one with the unrestrained passenger dummies and the other two includes the seat restraint systems like 2 point and 3-point seat belts. The study concludes by making some recommendations to coach. The roof cross beams are used as a stable structure whereas the interiors can be optimized for minimum impacts. Also, the study states the passenger mass is an important thing to consider while investing the rollover of buses. As the number of passengers increases the absorbed energy increases. The absorbed energy increases also with the height of centre of gravity.

The study carried out by Rahul Mahajan and Rishi Shah "Automated Process Tool for Pre-and Post-Processing of Bus Roll Over Analysis in compliance with AIS031/ECE R66" [8] a much-improved approach to cut down the simulation time is proposed. The simulation cost and cycle time is minimized by reducing the number of iterations of the process. An automated study flow is developed using Altair Hyper Study process without compromising quality. This automated study flow ensures to prepare final model for solving with minimum user intervention thereby reducing the model setup time as per the regulatory requirements. This process created by the author helps in reducing the time model setup and post processing time during certification.

The study done by Ajinkiya Patil and Prof. S.R. Pawar of BVDUCOE, Pune "Roll Over Analysis of Sleeper Coach Bus by Virtual Simulations in LS-DYNA" [9] a study on sleeper coach roll over is done. The roll over mechanism is assumed to be same as that of the buses with seats (AIS 031). The author also did an analysis on the road accidents happened in India during the year 2011 in which bus accidents accounts for 9.4 percentage of the total 92.4 percentage of accidents. Out of these 9.4 percentage most of the accidents are due to roll over type of accidents making it the major concern for passenger safety.

The study carried out by Dr. Matolcsy Matyas of GTE Hungary, "Passenger's Ejection in Bus Rollover Accident" [10] discovers a new kind of problem that researchers need to consider. Based on the requirements of roof and bus super structures as mentioned by ECE R66/AIS 031 regulations the severity of the rollover accidents have been reduced. However, a new problem with the ejection of passengers from the bus remains unsolved. Two types of ejections the partial and full ejections happen during the rollover accidents in which the side windows are used as emergency exits to eliminate the passengers. In this paper, the author proves that the side windows are not needed as emergency exits. Also, the author shows that wearing safety belts has more disadvantages than advantages in rollover accidents because as the passengers are wearing their seatbelts they are hanging in a very unusual position which make it even difficult to evacuate them. Different efforts are undergoing to solve this problem however the complex nature of the problem makes it difficult to solve. A feasible way to solve this newly recognized issue is proposed by the author in this paper.

The study done by author Pankaj S. Deshmukh Wichita State University "Rollover and Roof Crush Analysis of Low Floor Mass Transit Bus" [11] describes about the Low floor transit buses which are now a day an integral part of the transportation system. The usage of transit buses increases to 30 percentage in the recent ten years. This study of the author deals with the development of a finite element model of bus and analysis of its roof crush and roll over in LS-DYNA. ADAMS view software is used to measure the bus velocity, acceleration and its angle with the ground before the impact and are used as input for LS-DYNA. The author proposes a new method in which a frame with mass 1.5 times greater than the mass of bus is used the loading element. The effect of passenger’s weight on bus super structures is also discussed by the author. Also, the dummy kinematics and injuries for various seated and standing positions are considered by the author in this study.

The study done by the authors of Hanbat National University Korea, “A Study on Cross Worthiness and Rollover Characteristics of Low Floor made of Sandwich Composites” [12] describes the results of numerical evaluation on cross worthiness and rollover of a bus made of composites. This sandwich composites are comprised of aluminium honeycomb core and glass fabric/epoxy laminate face sheets. Roll over analysis were conducted using the explicit finite element method and analysis code LS-DYNA3D with the lapse of time. The crash was conducted at a speed of 60 Kmph. Dynamic Analysis Program is used to calculate the angular and translational velocity and its angels. An additional modified Chang-Chang failure criterion is recommended by the author to predict the failure modes of the composite structures.

In his study “Impact of Bus Superstructure due to Rollover” [13] the author MD. Liaka Tali studies the deformation response of a typical bus structure during roll over. The author models a simplified box structure using finite element analysis and simulated using the requirements of ECE R66 regulations. Four simulations are conducted to get the dimensions of different members of bus structures. The author concludes that the failure of bus frame depends on the total mass of the bus and strength of the super structure.

The research done by A. Subic and J. He, S. Preston of Victoria University of Technology “Modal Analysis of Bus Roll Cage Structure for Optimum Rollover Design” [14] states about the improvisation of vehicle stability and cross worthiness during vehicle rollover. The author states that there is a need for efficient development process which consists of modelling and simulation using computers. An alternative research approach based on analytical and experimental modal analysis is done by the author to identify the dynamic characteristics of bus roll cage structure. As Per the author geometric parameters are the most influential characteristics in rollover simulation.

The study done by Ashok Leyland Technical Centre, India "Bus Rollover Simulation using Body Sections in RADIOSS" [15] describes about the passenger protection in case of rollover accidents. A body section was tested using ASI031 regulations and is accordingly simulated in CAE. The method proposed by the author in turn reduces the computer resources needed. The author designs the bay section which consists of one door or window pillar on each side of the wall element, a section of roof, a section of floor and under floor structures. Radioss explicit solver is used by the author for simulating the structure from component to body level.

In his research "Rollover Analysis of Bus Body Structure as per ECER66/ASI031" [16] the author D. Senthil Kumar analysed about rollover in a VOLVO bus designed for India. The author designs the FE model of complete bus structure using first order shell elements, mass elements, spring and rigid elements with an average edge element length of 10mm in critical regions and 30mm in non-critical regions. The modelling and model setup of the entire bus is carried out by the author in Hypermesh and Hypercrash respectively and the simulation is done using RADIOSS explicit solver.

From the above literature review, it is clear that rollover should be considered as one of the most important type of accidents although it occurs less frequently. The severity of rollover accidents and the average fatality rate makes it as one of the dangerous type of accidents compared to other types. The superstructure of the bus should be designed and tested according to the specifications mentioned in ECE R66 and AIS 031 regulations. The residual space must be unharmed before and after the testing which is the only means to identify whether the superstructure is strong enough or not to withstand all kind of impacts. Also, from the above studies, it is noted that a computer simulation on rollover protection is preferred than the physical rollover testing, because the later includes a lot of time, money and human power. Thus, in this thesis work a physical rollover testing is simulated with the help of computer simulation and thereby the superstructure strength is identified.

3. THEORETICAL BACKGROUND

Rollover, considered as one of the most catastrophic type of accident which causes great damage to bus structures and severe injuries to both passengers and crew members. While there are many regulations to determine whether the superstructure is strong enough to withstand all kinds of impacts during an accident question still arises how a super strong bus with a certified superstructure undergoes rollover and what makes rollover a severe type of accidents then compared to other accidents. The answers to this question lies in a few factors like human, road conditions, climate and other environmental conditions.

3.1. CAUSES FOR ROLLOVER ACCIDENTS

Every rollover accidents that is happening all around the world differs from each other in a unique way because each accident happens due to its own conditions and have its own kind of reasons. This complexity in reasons makes rollover a catastrophic type of accidents than other accidents. Although rollover occurs due to a unique kind of reasons the more common type of factors that causes rollover is listed below [16,17]:

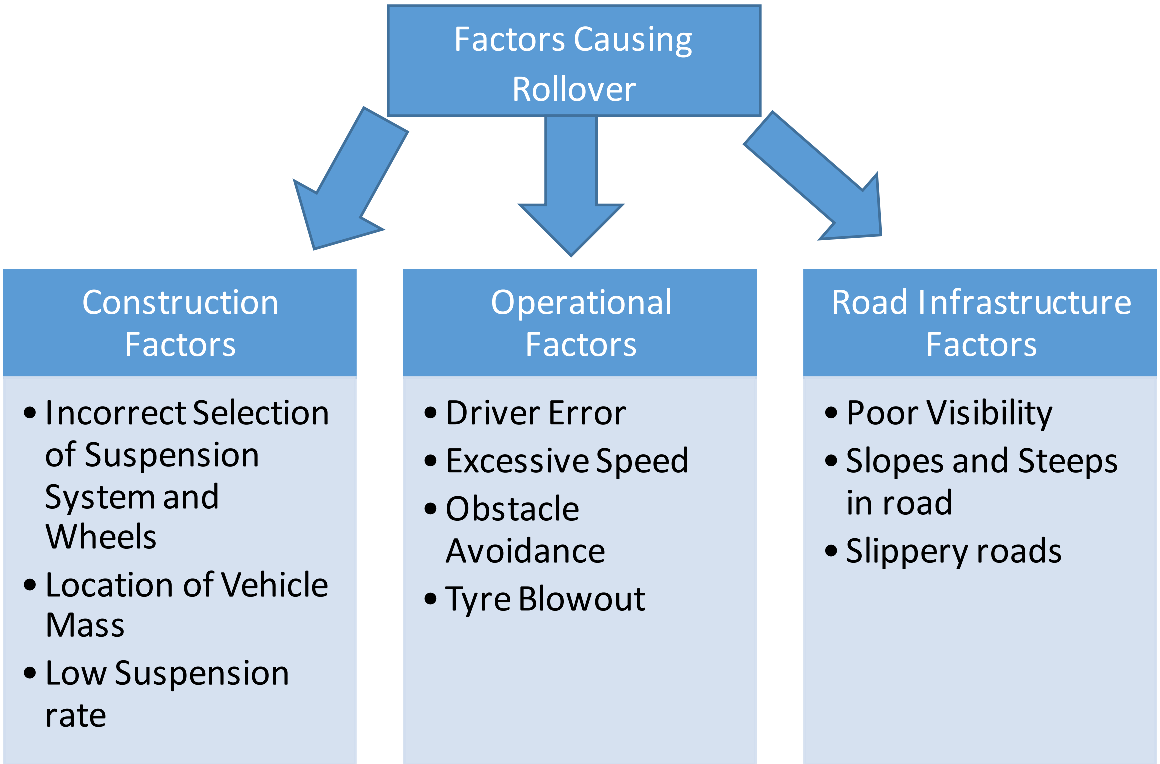


Figure 3.1 Factors Causing Rollover

3.1.1 Construction Factors

Construction factors are due to the errors made by the manufactures during the designing of buses. These errors have a less percentage of impact than the others and occurs less frequently. These factors can be avoided with the help of various regulations that are enforced to avoid the errors made by the manufactures. Main types of constructional factors include:

1. Incorrect Selection of Suspension System and Wheels

Suspension system plays a key role in vehicle dynamics and are used to support ride handling and improve ride qualities. Suspension system containing wheels, shock absorbers and other linkages helps to minimize the chance of rollover if selected correctly. The shock absorbers of the suspension system should be selected based on vehicle mass and its load carrying capabilities and the wheels of the buses should be selected based on its design speed. Any incorrect selection in suspension system can lead to improper ride handling situation which causes rollover of buses.

2. Location of Vehicle Mass

Vehicle mass is a principal factor to consider in terms of vehicle rollover. As the mass of the vehicle is lower the height of centre of gravity of vehicle is higher which can lead to unappropriated handling. The gross weight of the vehicle should be designed to lower height of the centre of gravity of the vehicle. Lowering the height of centre of gravity of vehicle helps in improving the handling of vehicles especially in areas like slopes and corners. A research done by Dr. Matyas M also shows that as the mass of the vehicle is increased the intrusion of the bus superstructure into the residual space is higher [10] which is another key factor to be considered in terms of passenger safety. Therefore, the location mass of vehicle should be chosen in such a way to lower the height of centre of gravity of vehicle as well as lowering the intrusion rate into the residual space.

3. Low Suspension Rate

Suspension rate or spring rate is a critical component that is used to adjust or set the vehicle's ride height or its location in the suspension. This in turn deals with choosing appropriate spring structures for the suspension system. The suspension system of heavy vehicles like buses should have heavier spring to compensate the weight of the vehicle otherwise the suspension system will broke causing a rollover situation. Hence the suspension rate should be higher and low suspension rate of the vehicle especially buses should be avoided.

3.1.2 Operational Factors

These are the factors that occurs during the operation of vehicles. These factors cause a large number of rollover accidents than the other two factors and can be avoided /minimized to prevent the rollover accidents. In simple ways, these are the factors that are caused by human errors during the operation of vehicles.

1. Driver Error

Driver error is a major reason for an enormous number of rollover accidents. In many cases driver's poor riding abilities, improper speed, driver's health conditions cause rollover accidents. Also in case of intercity lines the driver needs to drive a lot of distance without proper rest leads to rollover accidents. These can be avoided by imposing suitable laws on driving conditions and imposing penalties for non-obeying rules.

2. Excessive Speed

Excessive speed is one of the main reason for vehicle rollover. Excessive speed in speed limited roads, country side roads causes improper handling of vehicles especially for larger vehicles like buses which results in rollover. Speed limited roads and speeding cameras are used to reduce the over speeding of buses thereby reducing the possibilities for rollover accident. Excessive speed especially in corners causes a huge amount of rollover because of the vehicle's instability along the corners.

3. Obstacle Avoidance

Avoidance of obstacles like vehicles in front, kerbsides, stones or other items on roads, animals etc., can cause a rollover motion in vehicle. In order to react and avoid the obstacle the driver needs to either apply brakes or change the path of the vehicle, both of them results in a serious rollover accidents. In case of former one the driver applies brakes, which causes a sudden change in the motion of vehicle causing it to slip over. In the later one due to a sudden change in the path of the vehicle the centre of gravity changes suddenly causing a rollover situation which is almost impossible to avoid. Sometimes the driver needs to decelerate due to sudden crossing of animals or other vehicles in middle of the roads causing the bus to take an improper path and results in rollover accidents.

4. Tyre Blowout

This is one of the rare case of rollover accident in which the bus rollovers due to a burst that happened in tyres. A sudden burst in tyre causes an instability in bus motion which makes it impossible to handle and results in a rollover accident. Proper tyres that suits all kind of terrains and climatic conditions can be used to avoid these kinds of accidents.

3.1.3 Road Infrastructure Factors

Roads are designed and maintained in such a way to reduce accidents in all adverse climatic conditions. However sometimes accidents do happen because of the improper maintenance and design of roads. The main factors of rollover accidents due to road infrastructure are:

1. Poor Visibility

Poor road visibilities are sometimes the main reason for accidents not only rollover but also other type of accidents. Poor visibilities in roads during rainy seasons, fogs cause a reduction in reaction time of drivers which ends up in an accident. Visibilities of opposite vehicles, steeps or slopes in roads, corners and obstacles in roads causes a rollover accident. The driver's reaction time during poor visibility condition is much lower than the proper visibility condition which results the drivers to either apply brakes or change the path of the vehicle to avoid collision with obstacles.

2. Slopes and Steeps in Roads

Roads are designed almost as straight roads in many areas however steeps and slopes in roads are primary areas in which rollover occurs frequently. A sudden steep after a slope, corners after slopes and steep causes a large number of rollover accidents. This is because of shift in vehicles centre of gravity when it undergoes a slope or steep and can be avoided by reducing speeds in these areas.

3. Slippery Roads

Slippery roads especially during monsoon seasons in countries like India or slippery roads during winter in other places are one of the important areas where rollover occurs largely. Slippery roads are dangerous in terms that a sudden braking condition in those roads causes the vehicle to lose its friction with the roads. This reduction in friction causes the vehicles to slip or turn on its side causing rollover accidents.

3.2. SEVERITY OF ROLLOVER ACCIDENTS

Rollover is a major type of bus accident which causes severe damage to the bus structure and live hoods of passengers. As per the previous researcher's rollover occurs less frequently then other types of bus accidents like frontal impact collision and rear impact collision. Although it occurs less frequently some common question arises:

'Why rollover should be considered as one of the most severe type of accidents than others?'

'What is the need for researchers to focus more on bus superstructure?'

The answers to these question briefs about the severity of rollover crashes and are explained below:

1. Although rollover accidents occur less frequently then other types of accidents the average fatality rate per Matyas Matolcsy's research [1,10] is about 22 to 25 passengers per accident which is higher than other cases with an average fatality rate of 5 to 10 passengers per accident. However, this fatality rate in case of Indian buses will go higher upto 35 passengers per accidents owing to the fact of larger passenger carrying capacity of these buses.

2. Another important thing to consider in case of rollover accident is that rollover can lead to other type of accidents and damages to bus structures. Since the buses are rotating one or more quarter turns the fuel tanks of the buses gets ruptured and can led to fire accidents which will risk the lives of entire passengers and crew. About 2-5% of rollover accidents results in fire accidents [2] causing it difficult to rescue the passengers. This type of rollover is called as combined rollover accidents.

3. Both ECE R66 and AIS 031 regulations mainly focus on the superstructure of the buses because of the reason that these structures will withstand all kind of impact created during the rollover accidents and protects the residual space without any damage to goods or injuries to the passengers.

4. In case of a severe rollover the passengers body hits many time with the inner compartment of the buses causing severe damage to the passengers. Since the buses are revolving one or more quarters this causes the passengers body to hit the inner compartments many times leading to severe head injuries and other several types of injuries.

From the above answers one can conclude that rollover is a severe type of accidents that needs to be minimized or in better case should be avoided for better and safer bus travel.

3.3 INJURY MECHANISMS IN ROLLOVER

In the event of a rollover accident the passengers inside the passenger compartments are subjected to several types of injuries since the passenger's body hits many times with the inner compartments of the super structures. Injuries may occur in the form of small scratches to several severe injuries causing passengers to lose their body parts and even lead to death of the passengers. Passengers are either injured due to the superstructures intrusion into the residual space or due to ejection of passengers from their seats. However, the main injuries are caused due to any one of the following four mechanisms [10]:

1. Intrusion: Intrusion is a type of injury mechanism in which the superstructures of the bus intrude into the residual space of passenger compartments. The intruded elements of the superstructures can contact with the passenger's body causing severe damages to them.

2. Projection: Projection is another type of injury mechanisms in which the passengers themselves hits the superstructures of the bus bodies. This is due to a non-controlled movement of passenger's body inside the passenger compartment. This mainly occurs during the time when bus begins to slip over.

3. Partial Ejection: This injury mechanisms happens in the event of a weak superstructure. Since the buses rolls over on its side the superstructure may broke causing the passengers to eject outside from their seats.

4. Complete Ejection: Complete ejection appears in case of a severe bus rollover and it is one of the worst scenarios that cause death. In case of complete ejection, the passengers are ejected from their seats and thrown outside or under the rolling bus due to broken windows or damaged superstructures. The thrown-out passengers have a risk of being crushed by the superstructures of bus which cause death.

Intrusion and projection are normal injury mechanisms that results in all cases of rollover accidents. These accident mechanisms can be avoided and minimized with the help of occupant restraint systems such as the usage of seatbelts. In these mechanisms, the risk factor is low as it causes only a little damage to the passengers. Whereas projection on the other hand is a severe factor that causes a large number of fatalities in rollover accidents. While seatbelts are used to minimize the risk caused by intrusion and projection mechanisms, ejection either complete or partial can be minimized only with the help of a strong and unbreakable superstructures.

4. RESEARCH METHODOLOGY

Investigation of rollover protection in Indian buses is a research study in which an intercity bus which is designed and modelled for Indian roads is selected and investigated to ensure its safety in the event of a rollover accident. The main objectives of this thesis study include:

- To ensure that the bus is designed according to the regulations mentioned by the Automotive Industry Standard AIS 031.
- To ensure that the superstructure of the bus is designed to withstand all kind of impacts created during rollover of bus.
- To make sure that the residual space of the bus is unharmed before and after rollover accident and
- To propose suitable corrections that can be amended to AIS 031 regulations.

4.1. RESEARCH METHODS

This research study is an investigation based on the testing procedures as mentioned in AIS 031 and ECE R66 regulations for rollover of buses. A well-defined research method as proposed by these regulations is used in this work for successful validation of results. The thesis is organized into five different types of methods which are listed below figure:

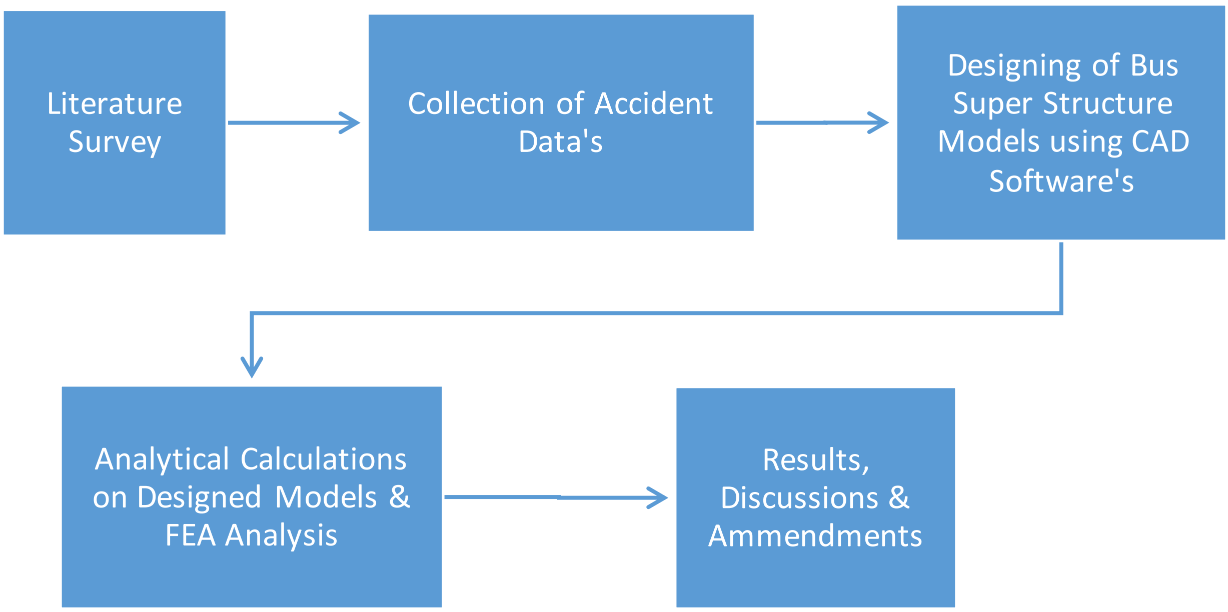


Figure 4.1 Research Methodology

In the above-mentioned research methodology, the first step or process is the literature review which is based on the previous research work done by various researchers in the field of bus rollover. This section is used to determine the severity of rollover accidents and main problems that are related with the rollover analysis is identified. The second process is the collection of rollover accident data's that happened during the last few years. This data is used in understanding the severity of rollover accidents and the reasons and fatality rates in those accidents.

The next process is choosing a valid model for the research to carry forward. A suitable model that is designed for Indian roads is chosen and the model is designed using CAD software's. In this work CATIA is used as a CAD software for the designing of model. The fourth process is the important process in which the designed model is analysed with the help of an analysis software. The testing procedures mentioned in AIS 031 and ECE R66 regulations are used to calculate the theoretical values which are then compared with the analytical solutions. The last step is the discussions section in which the results are discussed and some suitable correction to amend AIS 031 and ECE R66 regulations are discussed.

4.2. PROBLEM IDENTIFICATION

A literature review is done based on the research works done by the previous authors regarding rollover of buses and some of the main problems are identified. This includes:

- Rollover should be considered as one of the most important type of accidents although it occurs less frequently. The severity of rollover accidents and the average fatality rate makes it as one of the dangerous type of accidents compared to other types.
- The superstructure of the bus should be designed and tested according to the specifications mentioned in ECE R66 and AIS 031 regulations. The residual space must be unharmed before and after the testing which is the only means to identify whether the superstructure is strong enough or not to withstand all kind of impacts.
- Also, from the literature studies, it is noted that a computer simulation on rollover protection is preferred than the physical rollover testing, because the later includes a lot of time, money and human power.
- A major drawback of AIS 031 regulation is the lack of a computer simulation for rollover testing which could be an easier and faster way to perform rollover analysis than physical rollover tests. This problem should be given prior importance and can be solved by proposing possible amendments to AIS031 regulations.

4.3 ACCIDENT STATISTICS

Accidents occurs at anytime, anywhere and are unpredictable in nature. Accident data are reported and stored in all countries which are then used for many purposes. However, sometimes accidents are not reported to the police due to several factors. Accident data, in particular accidents that involves rollover of buses are collected all over India and in Europe. These accident data show about the severity of rollover accidents in those regions.

4.3.1 Accident Statistics of India

India is one of the countries in the world in which a huge number of peoples are killed in road accidents every year. The amount of fatalities is higher in Indian than the entire European Union. Because of its populous nature, a larger number of accidents are happening in India. Bus transport is considered as one of the largest mode of transportation in India and a huge population uses buses for their daily uses. In terms of city or Intercity travels buses are widely used than other means making bus travel a widely used one.

Buses in India and other developing countries are designed keeping in mind the population of such countries. Theses buses where designed to carry a huge number of passengers when compared to buses in Europe and other places. According to Volvo's product specifications data the B7R coaches built for Europe has a passenger capacity of 37+D whereas the same variant for Indian market has a passenger capacity of 49+D which is 12 passengers more than the European market. Hence in case of an accident the number of passengers and the fatality rate is higher in Indian variants than the European one.

In recent years India is having one of the highest motorization growth in the world. A rapid growth in the urbanization, population causes a huge motorization growth which although considered as the positive face of development has some serious drawbacks in case of accidents. Due to high traffic growth and large road population it is facing several consequences in terms of road safety. Several initiatives have been made by the Government of India to minimize the accidents and fatalities in Indian roads. The government of India is pledged to reduce fifty percentage of road accidents and its fatalities by the year 2020.

Ministry of Road Transport and Highways (MRTH) is a special ministry of Indian government that is responsible for the development of road transports in India. MRTH aims to reduce the road accidents in India and it along with the association from ARAI published the AIS standards for manufactures and operators. AIS 031 is one such regulation which is mainly focused with the rollover of buses. The Transport Research Wing (TRW) is a nodal agency of

MRTH which provides the accident data in the form of a report that is released every year in the name ‘Road Accidents in India’.

In this section, the reports published by the TRW and MRTH is used to determine the severity of rollover accidents in India. According to this report [18] the total number or road accidents that happened in India during the year 2007-2015 is 5,01,423 in which 1,46,133 fatalities were reported. Motorized vehicles account for the enormous number of accidents in roads and out of these 8.3 percentage of accidents are involving accident of buses. In case of bus accidents in these years the number of person killed is 12,133 and 55,083 are injured. Out of these bus accidents a large of accidents are happened due to rollover of buses, rollover accounts for about 32 percentage of bus accidents causing a death of 3890 passengers. Other type of bus accidents includes 40 percentage of frontal/ head on collision, 20 percentage of side impact collision, about 3 percentage of rear impact collision and 5 percentage accidents are resulted due to other factors like fire etc., The following pie chart shows about the type of bus rollover accidents that happened during the year 2007-2015:

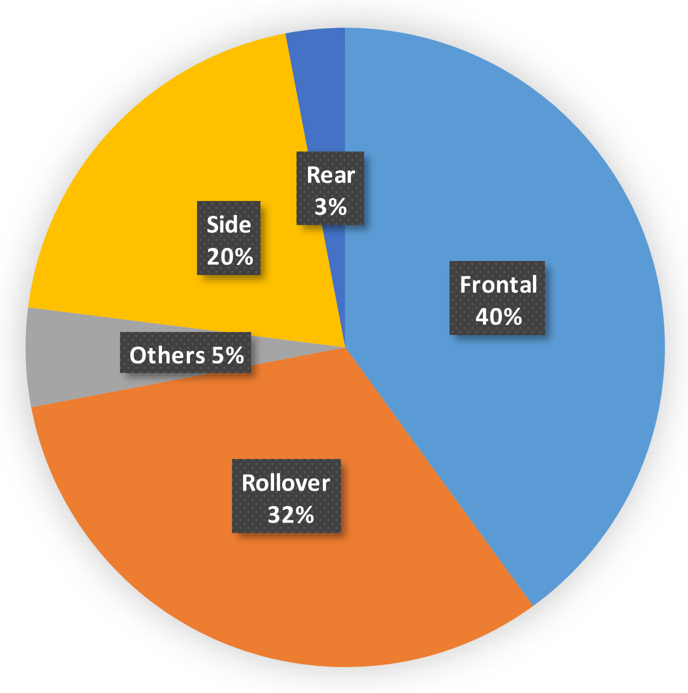


Figure 4.2 Type of Bus Accidents

Bus rollover accidents in India accounts for about 3890 deaths and injury to 17,626 passengers. Although frontal or head on collision accounts for a large number of accidents then rollover, rollover should be considered as a catastrophic type of accident because of its huge fatality rate. Frontal collision occurs frequently and hence it tops the table whereas rollover on the other hand occurs less frequently but accounts for a vast number of deaths. The following table shows the occurrence percentage of bus rollover accidents in different road conditions.

Table 4.1 Rollover Accidents on different types of Roads

Single Lane Roads	50
2 lane w/o shoulder	7
2 lanes with paved shoulder	10
4 lanes divided	4
6 lanes divided	2
2 lanes hill road	27

From the above table, it is noted that Single lane roads and hilly roads accounts for an enormous number or rollover accidents [19].

4.3.2 Accident Statistics of Europe

Europe is one of the areas in the world where safety of passengers is given a key role. The Economic Commission for Europe as well as the statutory bodies of each European countries have enforced several regulations that focus on the safety of passengers travelling in bus. The ECE is one of such bodies which enforced the safety regulations for buses prior to other countries. The ECE R66 is one such regulation that comes to force from 1987 itself. During that time safety is not given a key factor role in developing countries like India. Also, the ECE R66 regulations is a basic model for deriving the AIS 031 regulations.

The European Commission aims to reduce its fatality rate to zero in the year 2020. In 2011, about 30,000 peoples died in road accidents in Europe [7]. Various European researchers have done research on the bus rollover protection much prior before the world was aware of rollover. Bus rollover statistics were researched by some of the researchers which shows that rollover is one of the most severe type of bus accidents in Europe. In the year between 2000 to 2011 about 338 bus rollover accidents occurred in Europe which causes a fatality of about 4054 passengers [10]. The following table shows about this data's in detail.

Table 4.2 Accident Statistics of Europe 2000-2011 [1]

Number of Bus Rollover Accidents	338
Fatalities	4054
Serious Injuries	1029
Light Injuries	977
Injuries Without Classification	2594

The accident data collected from both India and Europe shows that rollover is a catastrophic type of accident that must be minimized and in better case should be avoided to ensure safer bus transport.

4.4 MODEL DESCRIPTION

For investigating rollover protection in Indian buses a better bus model needs to be chosen which is an important part to be considered. For this purpose, 'Ashok Leyland Luxura' is chosen to be the model in which a rollover investigation is done with the help of AIS 031 and ECE R66 regulations.

Ashok Leyland is the second largest commercial vehicle manufacture in India and fourth largest in the world. The company was founded in the year 1948 and is headquartered in Chennai, India. Ashok Leyland is the Indian market leader in buses producing a wide range of buses from 18 seaters to 80 seaters for school, sub urban, City, mofussil, Intercity and Special applications. With more than about 69 years of service in Indian market Ashok Leyland carries about 70 million passengers a day in its buses [20]. This number is higher than the total number of passengers travelling in Indian rail network. Ashok Leyland also has its bus manufacturing facilities in Great Britain and United Arab Emirates.

The model chosen for investigation is Ashok Leyland Luxura which falls under its Intercity application. Luxura is one of the two intercity bus models manufactured by Ashok Leyland the other being 12M model. Ashok Leyland Luxura begins to operation from the year 2012 and is ruling the intercity markets of India.

Figure 4.3 Ashok Leyland Luxura [20]

The Luxura model comes with a seating option of three variants as:

- 36 + D with calf support
- 40+D with Driver Berth
- 45+D

For our analysis purpose the variant with maximum seating capacity i.e., 45+D is chosen. Some of the important dimensions that are used to draw the model in CATIA software is listed below in below table 4.3 and a brief description of other specification parameters are mentioned in Appendix B.

Table 4. 3 Luxura Specifications [20]

Overall Length	12000 mm
Overall Width	2550
Overall Height	3545
Wheelbase	6200 mm
Front Over Hang	2400
Rear Over Hang	3600
Front Track	2054
Rear Track	1816

4.5 CATIA MODEL

CATIA V5 is used as a design software to model the chosen bus. CATIA is a designing software developed by the French company Dassault Systems. CATIA is the acronym for Computer Aided Three-Dimensional Interface Application. It is one of the widely-used software in aerospace and automotive industries. Only the superstructure of the bus is designed as per the manufacture's specifications. A luggage bay section with luggage space of 7 m^3 is designed. The designed CAD model of bus superstructures is shown below:

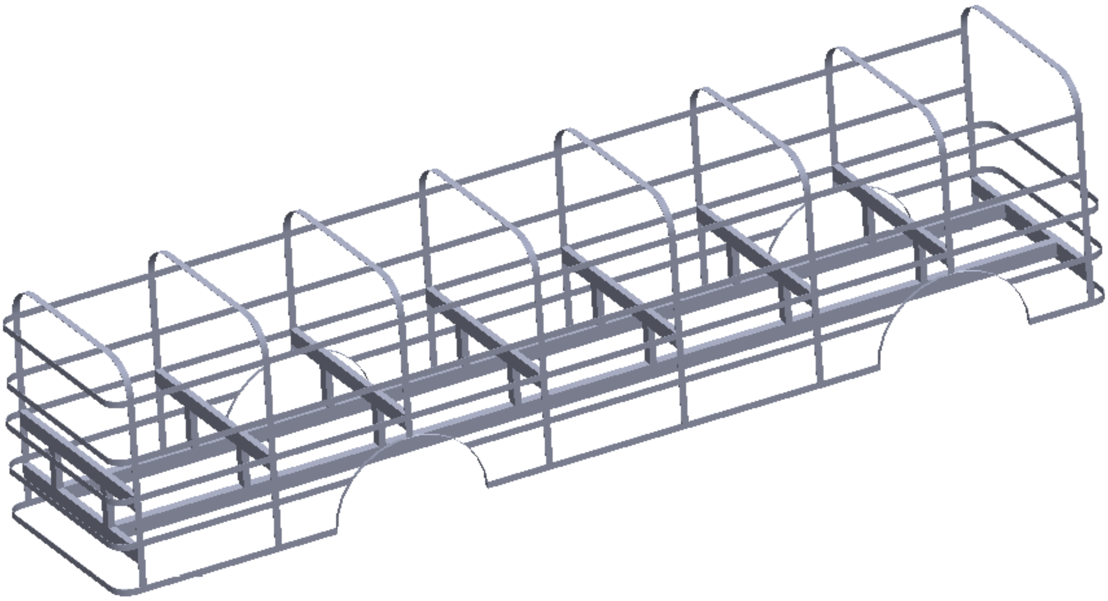


Figure 4.4 Designed Structures of Bus Model

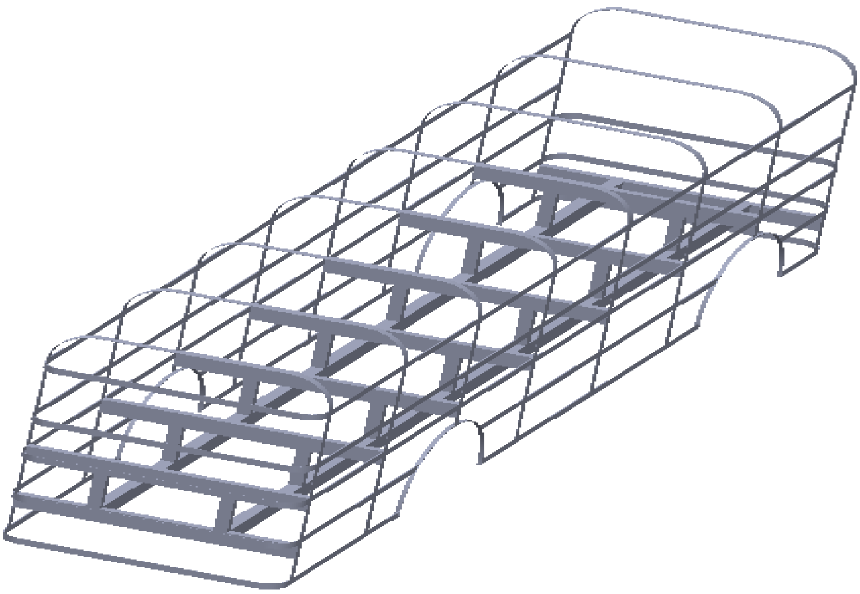


Figure 4.5 Structures of Designed Model

5. CALCULATIONS

The superstructure of the buses needs to be strong enough to protect the passengers in case of rollover accidents. To determine the strength of the superstructures of bus certain parameters needs to be calculated. This includes the theoretical calculation of total reference energy, unladen kerb mass of the vehicle and the calculation of centre of gravity of vehicle as per the formulas mentioned in AIS 031/ECE R66 regulations. These three factors are inter related to one another and a change in one of these factors causes the other factor to change considerably. One these factors are calculated the load that needs to be applied to determine the strength of superstructure is calculated and this load is applied to the superstructure in computer simulations and thereby the strength of the structure is determined.

5.1 CALCULATION OF UNLADEN KERB MASS

According to ECE R66/AIS 031 regulations the unladen kerb mass M is the mass of the vehicle unloaded and unoccupied. This mass is the initial mass of the bus superstructures without the addition of any other components and passenger weights. Unladen kerb mass includes the mass of driver alone without considering the passengers mass, mass of the fuel with 90 percentage of fuel tank capacity mentioned by the manufacturer and the mass of coolants, lubricants and other tools [3,4].

The gross vehicle mass (GVM) of Luxura as mentioned by the manufacturer is 16200 Kg. [20]

The total seating capacity of these bus for this investigating purpose is chosen as 45. According to ECE R66 regulation the mass of individual occupant i.e., the mass of a passenger is 68kg. This means that the total mass of passengers is 45*68 =3060Kg. The mass of the driver is about 75Kg. [4]

The fuel tank capacity of Luxura is 350 litres. In the calculation of unladen kerb mass 90 percentage mass of the total fuel tank capacity needs to be considered which is about 315 litres. To convert the fuel capacity from litres to Kg the density of the fuel is multiplied (i.e., Weight= Density * Volume). The density of diesel is found to be 0.85 Kg/L. Therefore, the mass of the fuel is calculated as 268Kg.

Luxura has a luggage space of about approximately 7m^3 in which upto 1000Kg maximum goods and luggage's can be carried.

The weight of lubricants, coolants and other tools are found to be 92Kg as per the manufacture.

Therefore, the unladen kerb mass of the vehicle is calculated as follows:

Unladen Kerb Mass M = {GVM – (Mass of Passengers+ Mass of Goods) + (Mass of Driver + Mass of Fuel+ Mass of Lubricants and other tools).

= {16200 – (3060+1000) + (75+268+92)}

Unladen Kerb Mass M = 12575Kg.

5.2 CALCULATION OF HEIGHT OF CENTRE OF GRAVITY

Centre of gravity is a crucial factor to be calculated in case of rollover accidents. The height of centre of gravity h_o plays a vital role in testing because of the fact that it varies upon the addition of mass of the vehicle. Centre of gravity of the vehicle can be determined either in its unladen mass or with its total effective mass. As per the AIS 031/ ECE R66 regulations the centre of gravity for the vehicle with unladen kerb mass can be determined by measurements [3,4]. The following diagram shows the measurement method that is used to calculate the centre of gravity of the bus.

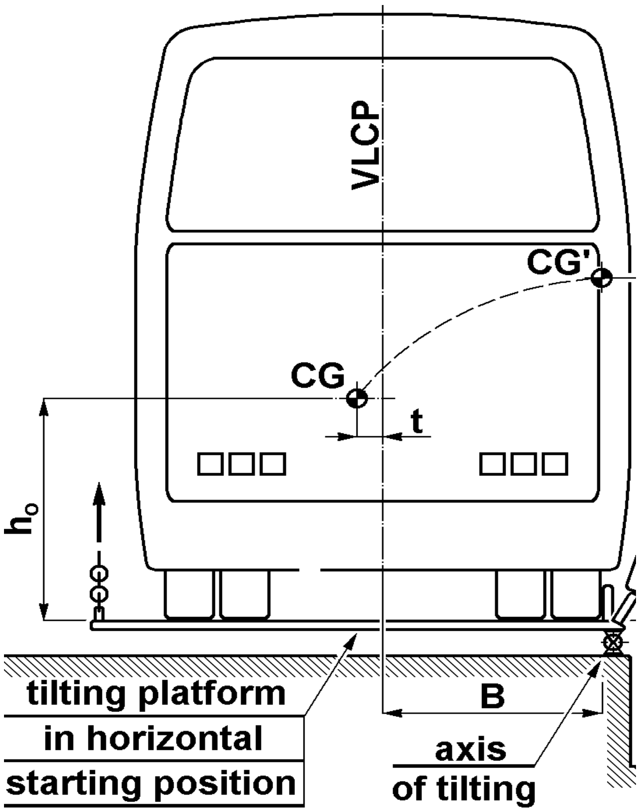


Figure 5. 1 Height of Centre of Gravity [4]

Where h_o is the height of centre of gravity of the vehicle for the choosen mass. Since in our case the unladen kerb mass is chosen the value of h_o is measured as per manufacture's instruction as 1.81 meters. This value of h_o is used for further calculations.

5.3 CALCULATION OF TOTAL ENERGY

The total energy E^* is the energy that needs to be absorbed by the superstructure. This is nothing but the potential energy of the superstructure that is absorbed during the case of an rollover accident. The bus is found to be safe only if the superstructures absorbs an energy which is greater than or equal to the total energy. If it absorbs the energy lesser than this the superstructure is said to be not strong enough to withstand the impacts and in this case it is certified as fail. The formula for calculation of total energy and the diagram showing the parameters is given below:

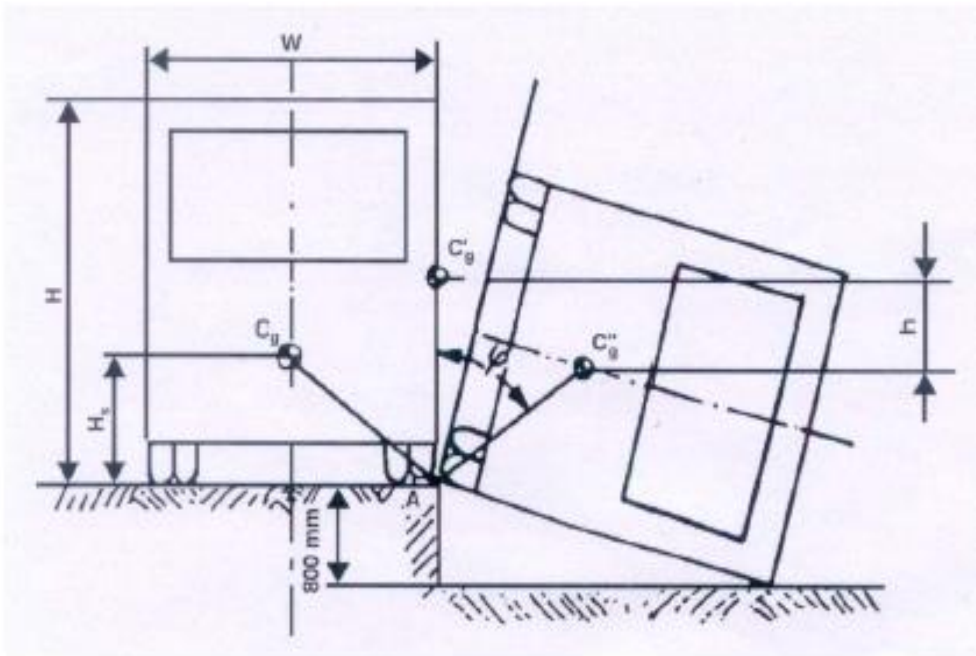


Figure 5. 2 Total Energy Calculation [3]

Total Energy $E^* = 0.75 *M.g. [\sqrt{((\frac{W}{2})^2 + H_s^2)} - \frac{W}{2H} \sqrt{(H^2 - 0.8^2)} + 0.8 \frac{Hs}{H}]$ (5.3.1)

Where, M is the unladen Kerb mass of the vehicle =12575 Kg

g is the gravity constant = 9.81 m/s^2

W is the overall width of the vehicle

H is the overall height of the vehicle

$H_s = h_o = 1.81$ m is the height of centre of gravity of the unladen vehicle

Substituting the known values in equation 5.3.1 we get the total energy as,

$$E^* = 1276.8762 \text{ mJ}$$

The superstructure of the bus is said to be safe if the value of total energy absorbed by the structure should be equal to or greater than the value of E^*.

5.4 FINITE ELEMENT CALCULATIONS USING ANSYS

The next step in calculation and the final step in this thesis is finite element calculation of the chosen bus model. A computer simulation is used to determine the strength of the superstructure due to the fact that it is faster, cheaper and less time consuming than the physical rollover test. A major drawback of AIS 031 regulation is the lack of a computer simulation for rollover testing which could be an easier and faster way to perform rollover analysis than physical rollover tests. This problem should be given prior importance and can be solved by proposing possible amendments to AIS031 regulations. For this purpose, a computer simulation rollover testing method as proposed in ECE R66 regulations is chosen and the analysis is done to determine the strength of superstructure and the results of these analysis is compared with the analytical calculations done in the previous sections. The detailed description of the computer simulation, the method proposed by ECE R66 regulations is described in Appendix A.

For finite element analysis ANSYS Workbench software is used. ANSYS is a computer aided engineering software which is used to determine finite element, structural analysis, Computational Fluid Dynamics analyis, Explicit and Implicit methods. For our case finite element static structural analyis is chosen and used. The finite element calculation is done to determine the deformation of the structure and other parameters such as the stress and energy absorbed by the structures. These calculations are then checked with the theoretical calculations to determine the strength of the superstructures. In finite element analysis the entire bus superstructure is discretized into smaller elements called as finite elements and the analysis is done on all these finite elements. The accuracy of the elements depends on the accuracy of the meshing. ANSYS software is used as an simulation program as it satisfies the requirments as mentioned by the ECE R66 regulation (See section 3 of Appendix A).

In our case a new method of computer simulation is proposed in which ANSYS is used to determine the strength of the superstructure. Statis Structural Analysis is chosen from the different types of analysis and the superstructure model designed in CATIA is imported into

ANSYS workbench. The steps included in ANSYS workbench is explained in below sections and are also mentioned in below diagram:

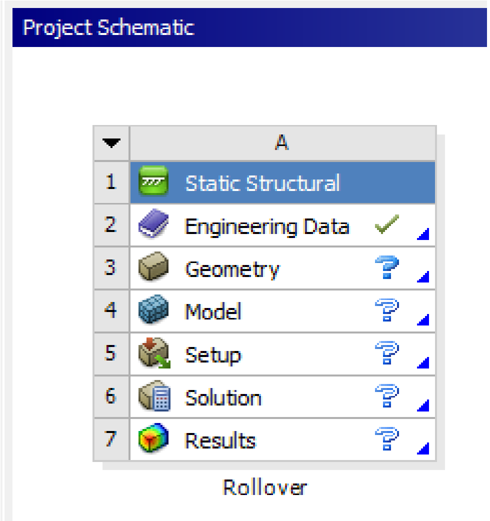


Figure 5. 3 ANSYS Workbench Analysis Steps

5.4.1 Calculation of Load

As mentioned earlier our case is a new one inwhich the computer simulation is done with the help of own steps which also satisifies the requriments as mentioned in section 3 of Appendix A. The initial point of contact as mentioned in section 3.2 is identified. This is nothing but the side structure of the superstructure which is considered as weak side or the side in which the bus starts rolls over. As mentioned in the steps for physical rollover method this can be identified as the right side of the bus structure.

The regulations mentioned by ECE R66 and AIS 031 states that the bus superstructure needs to withstand a load which is 1.5 time greater than the unladen mass of the vehicle [3,4]. A much similar method is used by some of the previous researchers in their studies. One such study is done by Pankaj S.Deshmukh in which the author applies a load which is 1.5 times greater than the mass of the bus [11]. Hence a similiar method is used here in which a load which is 1.5 times greater then the mass of the vehicle is applied to the chosen side structure of the bus.

Unladen Mass of the bus =12575 Kg

Load to be applied = 12575 *1.5*9.81 = 1.85 e5 N

5.4.2. Imported Model

The designed model of bus superstructure is now imported into the ANSYS for analysis purpose. Once the model is imported the engineering data for the model is given. This includes the material data in which the material used for structures and its properties are chosen. For the bus superstructure the material specified by the manufacture is Galvanized Iron Steel or GI Steel. The imported model is shown in the below figure:

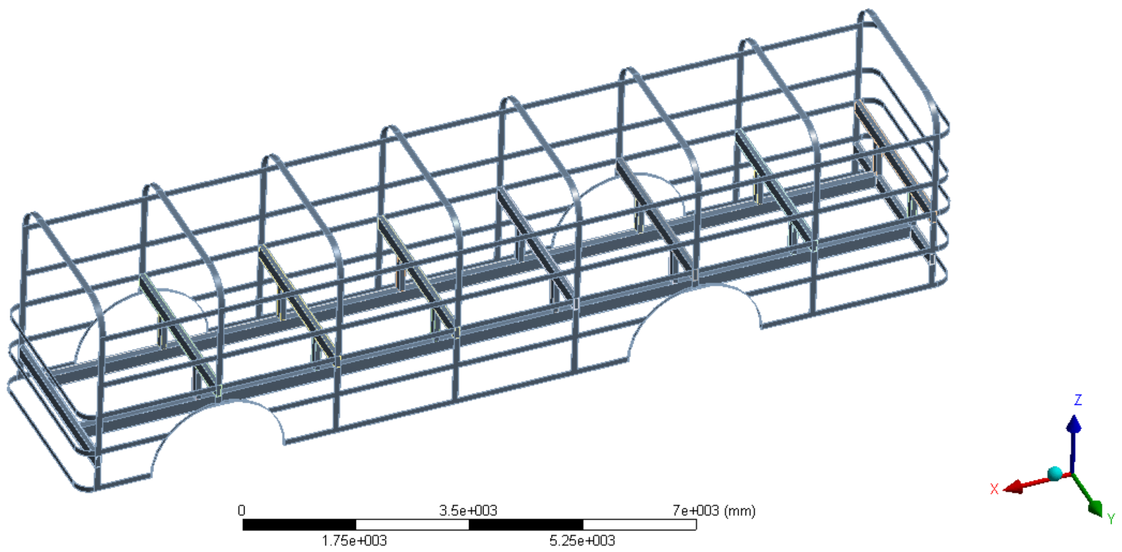


Figure 5. 4 Imported Model in ANSYS

5.4.3 Boundary Conditions

The next step in ANSYS workbench analysis is the model setup in which the imported model is given some boundary conditions for the analysis purpose. This is the step in which the datas related to static structural analysis is given. The model datas such as fixtures, loads and other datas that are needed for static structural analysis is setup in this step.

Fixtures: The bus superstructure is fixed in order to carry out the analysis process. The superstructure is fixed at four places below the chassis (shown inside the red circle). These are the places where the suspension systems of the buses are placed. The below diagram shows the fixtures in detail:

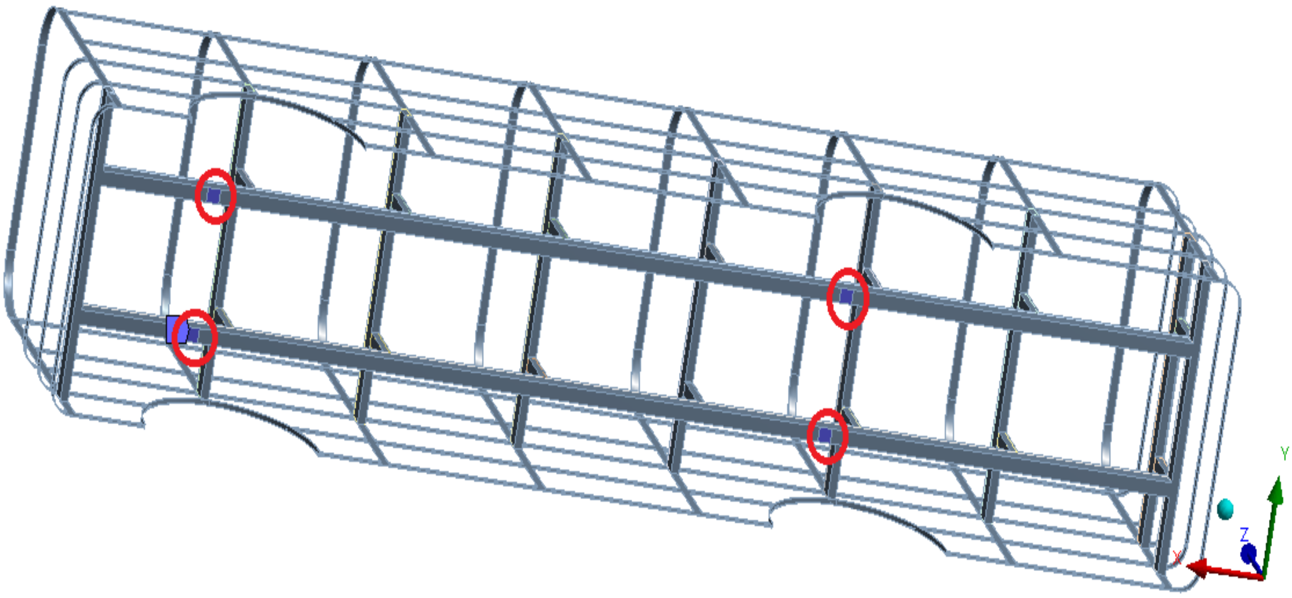


Figure 5. 5 Boundary Conditions Fixtures

Loads: As mentioned in section 5.4.1 of this thesis the loads are calculated and are appiled on the right side of the bus. A load of 1.85e5 N is applied to the structure.

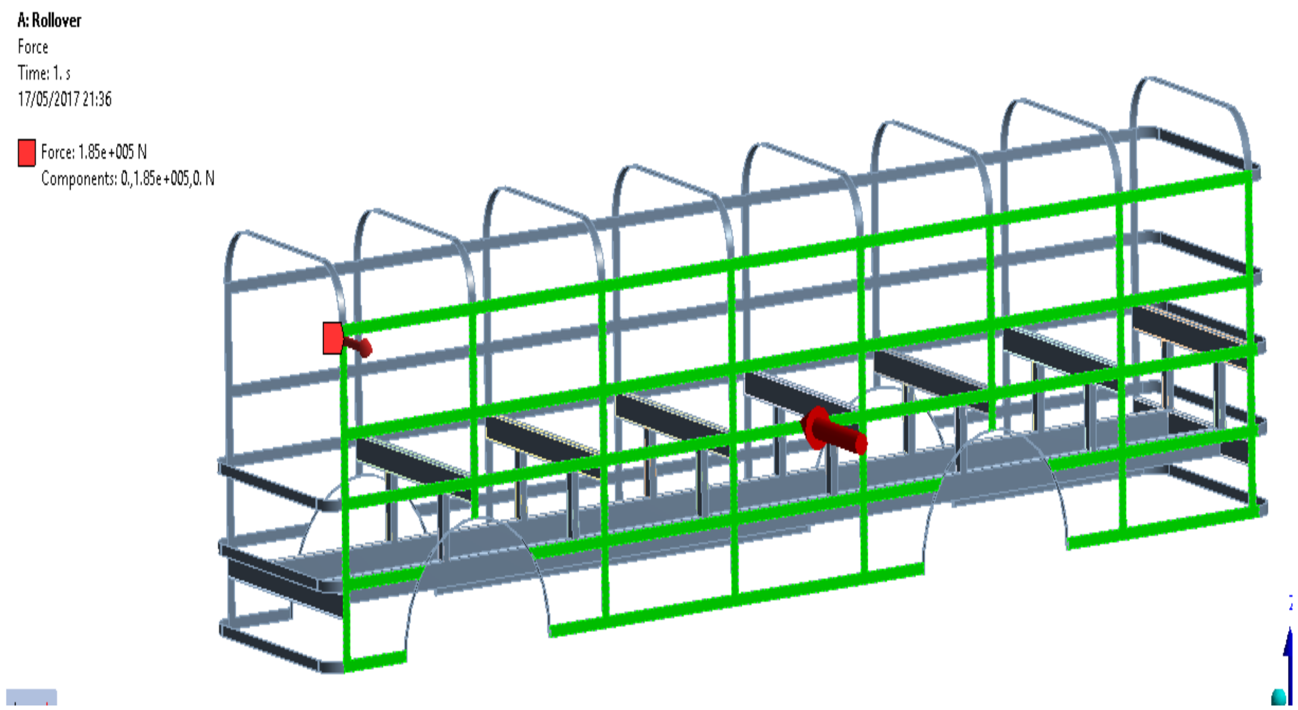


Figure 5. 6 Boundary Conditions Load

5.4.4. Mesh

The accuracy of the finite element analysis depends upon the accuracy of meshing. A coarse mesh is chosen and the entire structure is meshed. The following table shows about the mesh datas in detail:

Table 5. 1 Mesh Quality Details

Number of Nodes	31667
Number of Elements	10217
Size Function	Adaptive
Relevent Centre	Coarse
Minimum Edge Length	1e-001 mm
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2

The following diagram shows the meshed structure of bus:

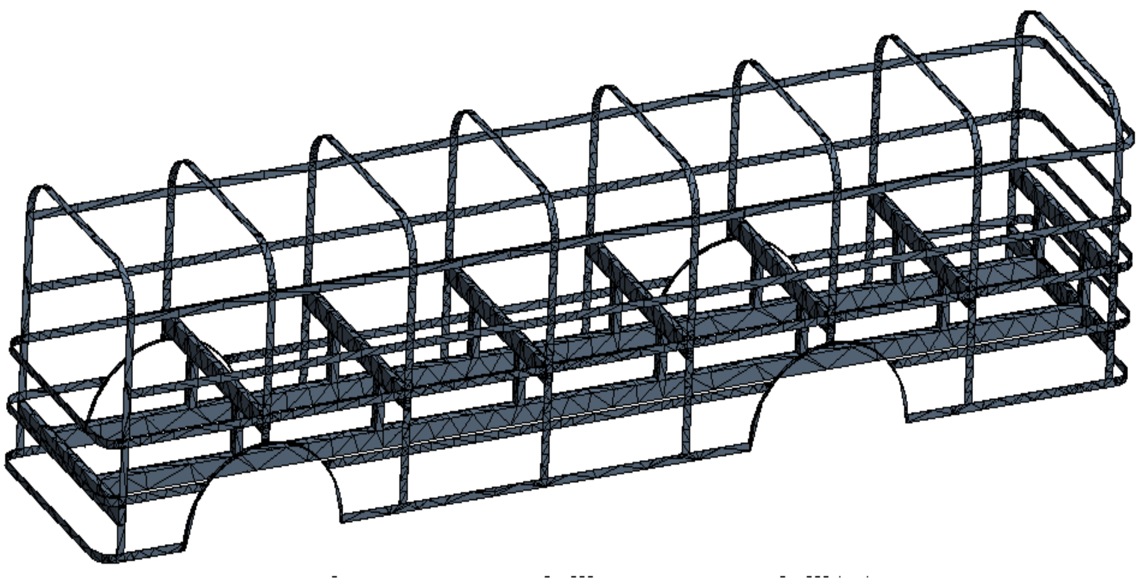


Figure 5. 7 Meshed Structure of Bus

6. RESULTS AND DISCUSSIONS

After the calculations are done and the model is imported into ANSYS workbench, analysis is done to determine the strength of superstructure and results are obtained. This section discusses about those results and its impact on rollover analysis.

6.1 FINITE ELEMENT ANALYSIS RESULTS

The superstructure of the bus is analysed in ANSYS with a given load as calculated in section 5.4.1. Two solutions which are required for rollover of buses are obtained from the finite element analysis and are shown below:

- Total Deformation
- Strain Energy or Total Energy

6.1.1 Total Deformation

Deformation is one of the important analysis results that shows whether the bus superstructure intrudes into the residual space or not. The bus superstructure is found to be safe if it withstands the impacts created during a rollover accident and deforms in a lesser amount. The total deformation value is shown in the below diagram:

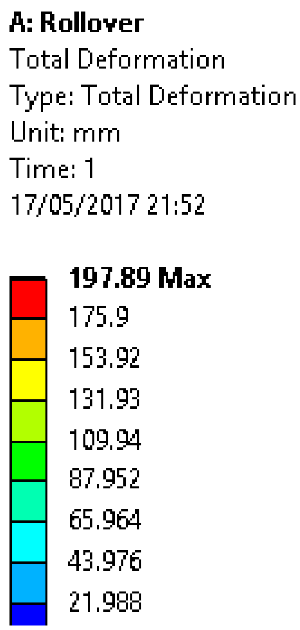


Figure 6. 1 Total Deformation Values

The below diagram shows about deformation of superstructure. The maximum deformation occurs at the middle section which is coloured in red. This deformation occurs between the pillars 4 and 5.

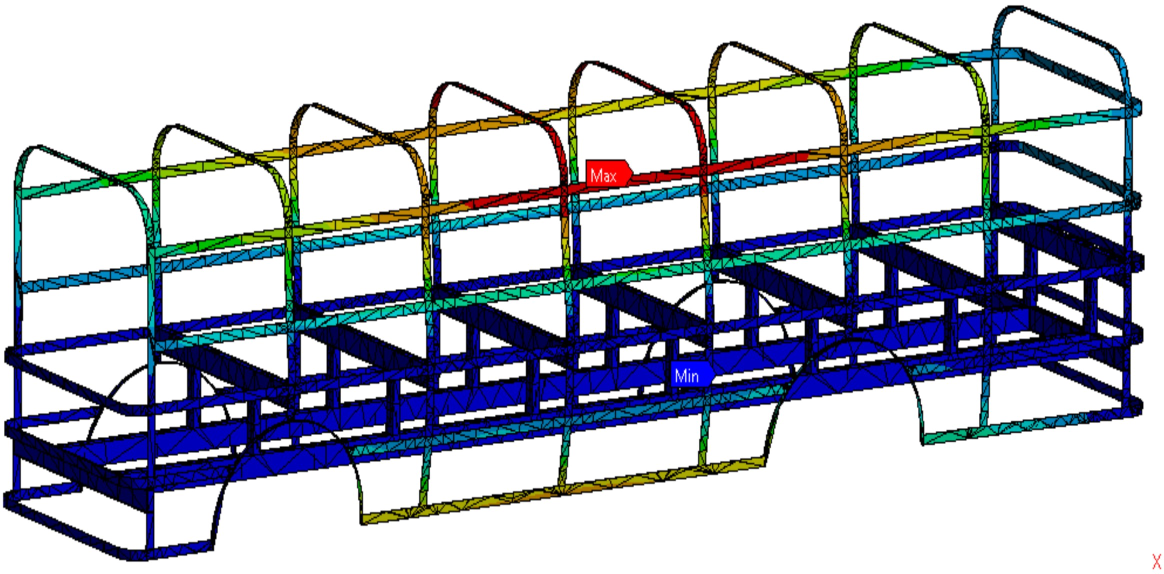


Figure 6. 2 Deformed Structures of Bus

6.1.2 Strain Energy

The Strain energy or the total energy is the energy absorbed by the superstructure of the bus for the applied load. In real case, it is the energy absorbed by the superstructures of the bus superstructure when it undergoes a rollover accident. This is nothing but the potential energy of the superstructure that is absorbed during the case of an rollover accident. The superstructure of the bus should be strong enough to absorb a higher energy to prevent the intrusion into residual space. This value is compared with the total energy value calculated in section 5.3. The bus is found to be safe only if the superstructures absorbs an energy which is greater than or equal to the total energy as calculated from section 5.3. The below diagram shows the values of energy absorbed for the given load values:

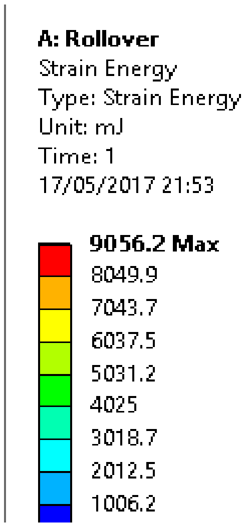


Figure 6. 3 Stress Energy Values

The following diagram shows strain energy value of different parts of the superstructure. It is to be noted that the superstructure absorbs the energy that is larger than the one obtained from the theoretical value. All parts of the superstructure absorb more energy whereas the maximum energy is absorbed near the bay section.

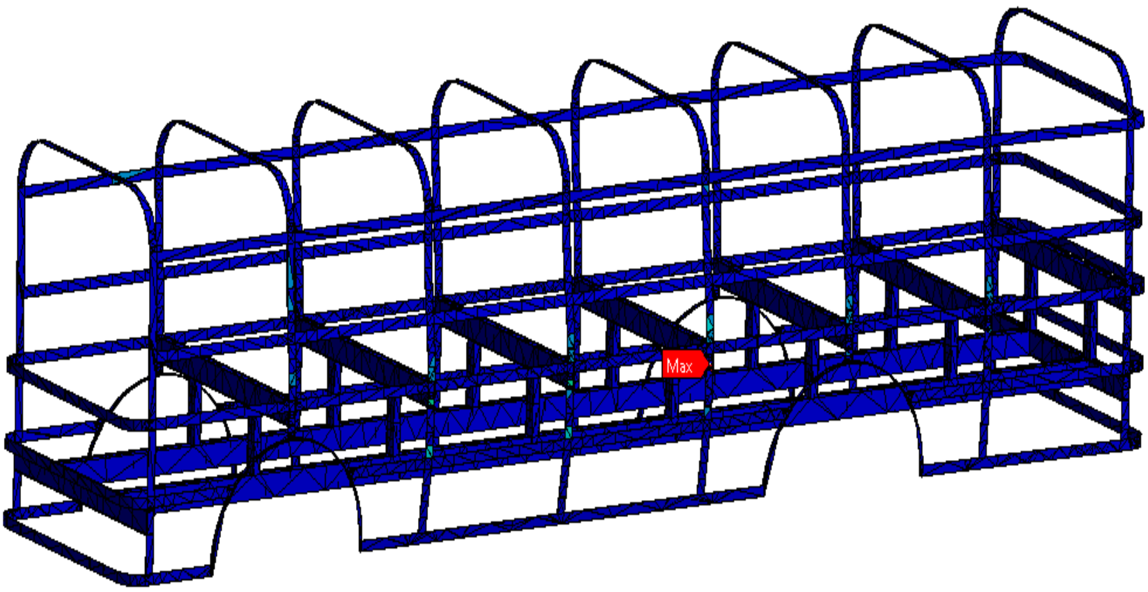


Figure 6. 4 Bus Structure showing Absorbed Energy

6.2 DISCUSSIONS

According to ECE R66 and AIS 031 regulations the superstructure is certified to be safe only on the satisfaction of following conditions:

1. No part of the vehicle which is outside the residual space during the start of the test (e.g. pillars, safety rings, luggage racks) shall intrude into the residual space during the test and
2. No parts of the residual space shall project outside the contour of the deformed space. The contour of the deformed structure shall be determined sequentially between every adjacent window and/or door pillars.

From the finite element analysis, it is found that the above two mentioned conditions are satisfied. This can also be explained clearly in following statements. The maximum value of deformation in the structure is found to be 197.89 mm which is observed in upper section between the pillars 4 and 5. Now let's recall the residual space dimensions as mentioned by the ECE R66 and AIS 031 regulations. The following figure shows the dimensions of the residual space:

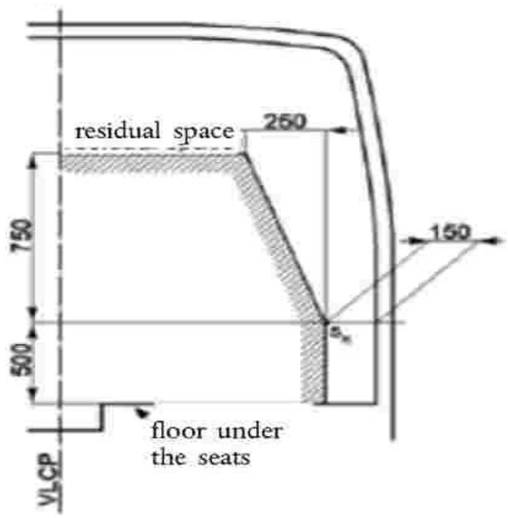


Figure 6. 5 Residual Space Dimensions [3,4]

From the above diagram, it is clear that the space between the residual space and the superstructure of the bus is about 250mm in the upper section near the roof whereas in the lower section near the floor the space is about 150 mm. From figure 6.2 it is noted that the maximum deformation occurs between pillars 4 and 5 in their upper part and the value of this maximum deformation is 197.87 mm in the upper section and 87.95 mm in the lower section near the floor. Therefore it is clear that the maximum deformation that occurred in superstructure doesn't intrude inside the residual space and the residual space if found to be unharmed after the application of loads. The below diagram shows about this discussion in brief. In this diagram, the original dimensions of the residual space is compared with the deformed structure of bus. The residual space is unharmed after a deformation in the structure.

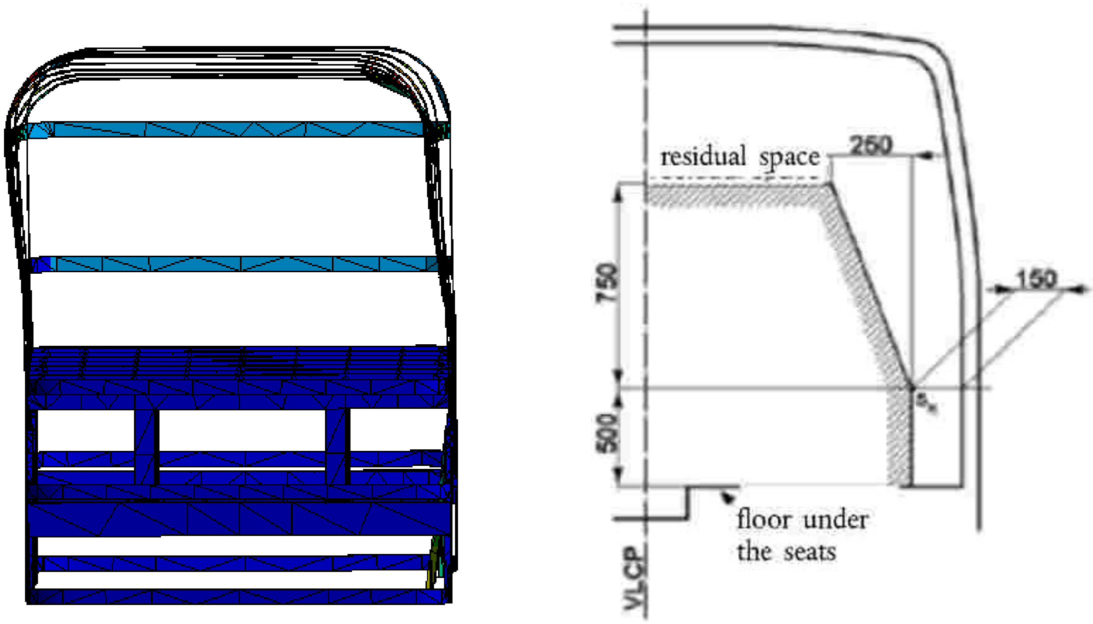


Figure 6. 6 Comparison between Residual Space and Deformed Structure

The next important thing to be discussed is the 'Total Energy or Strain energy'. The total energy is nothing but the potential energy of the superstructure that is absorbed during the case of a rollover accident. The bus is found to be safe only if the superstructures absorbs an energy which is greater than or equal to the total energy. If it absorbs the energy lesser than this the superstructure is said to be not strong enough to withstand the impacts and in this case it is certified as fail.

The strain energy value obtained from the theoretical calculation done in section 5.3 is about 1276.8762 mJ. From the finite element analysis the strain energy value observed in a large quantity among the superstructure is 2012.5 mJ which is much larger than the theoretical caluclation. Thus it is noted that the superstructure is strong enough to withstand a huge amount of imapct during a rollover accident which is much more than the calculated values. Maximum energy is absorbed in some parts of the bay sections which is of values 9056.2 mJ.

A detailed description of the theoretical and finite element values is given in the below table:

Table 6. 1 Comparison Between Analytical and Theoretical Values

	Theoretical	Analytical
Deformation	250 mm	197.87 mm
Total Energy	1276.876 mJ	2012.5 mJ

Thus, the above analysis shows that the chosen model for investigating rollover protection 'Ashok Leyland Luxura' is found to be safest model for transportation and it can withstand all kind of impacts created during the rollover accident.

6.3 PROPOSED CHANGES TO AMEND AIS 031 REGULATIONS

The AIS 031 regulation is now widely used among the Indian bus manufactures for rollover testing of superstructure. However, the current regulations can be modified in some of the below mentioned ways to make it a more effective one. Some of the drawbacks and the ways to overcome it are discussed below.

Change 1 A major drawback of AIS 031 regulation is the lack of a computer simulation for rollover testing. A computer simulation as mentioned in ECE R66 regulation is an easier way to perform rollover testing than the physical rollover testing method. A computer simulation is easier, faster and are less time consuming than the physical testing. It also eliminates the need of many equipment's that are used during rollover physical tests. In terms of cost required to perform the rollover analysis the computer simulation is less than the other three methods proposed by AIS 031 regulations. This problem should be given prior importance and can be solved by proposing possible amendments to AIS031 regulations.

Change 2 While calculating the total energy, it is found that only the unladen kerb mass of the vehicle is considered. This leads to a limitation that is much different from the actual rollover condition. In case of a real-time accident rollover occurs with fully loaded bus with passengers and luggage's. The height of centre of gravity of the vehicle differs with the weight of the vehicle. When the vehicle is operated at its full operating mass the height of centre of gravity will either lower or higher and thus a shift in centre of gravity occurs. This also needs to be included in the calculation to ensure a safer calculation methods. This change can be proposed for both ECE R66 and AIS 031 regulations.

6.4 CONCLUSIONS

The theoretical calculations done with the help of formulas mentioned by the AIS 031 and ECE R66 regulations are used along with the numerical values from Ansys to determine whether the four main objectives of this thesis study are satisfied and are stated below:

1. 'To ensure that the bus is designed as per the safety regulations mentioned by the Automotive Industry Standard AIS 031' and this objective of the thesis is satisfied and the chosen bus model 'Ashok Leyland Luxura' is found to be safer for transportation.
2. 'To ensure that the superstructure of the bus is designed to withstand all kind of impacts created during rollover of bus.' The energy values obtained from the Ansys calculations satisfy this condition as the energy absorbed by the structures of the bus is 2012.5 mJ which is found to be much larger than the calculated value of 1276.876 mJ. This means that the structure is strong enough to withstand all kind of impacts occurring during the rollover accident.
3. 'To make sure that the residual space of the bus is unharmed before and after rollover accident.' Consider the values of deformation obtained from Ansys and the maximum value of deformation obtained from the test is 197.87mm which is found to be much safer than the maximum allowable value of 250mm and thus the residual space is said to be unharmed before and after the test.
4. 'To propose suitable corrections that can be amended to AIS 031 regulations.' Suitable corrections are proposed to make some changes in AIS 031 regulations which could make it one of the best effective methods to analyse the strength of superstructure for rollover accidents.

Regulations are always made by the government to ensure the safety of passengers and a sound knowledge about safety regulations should reach every normal passenger by that way even normal passengers can know about the safety norms of the vehicles which they are using. This would be so much important in developing countries like India where still safety is a main concern for both passengers and operators. While discussing about the safety of superstructures considerable importance should be given for the evacuation of passengers in case if an accident happens. Accidents which are unpredictable and unavoidable in nature needs to be minimized. As the saying 'Prevention is better than cure' accidents must be prevented with the help of as much as safety norms instead of curing. Preventing an accident in public transportation system made the passengers feel secure and increases the reliability of transport system.

REFERENCES

[1] Matyas Matolcsy, "The Severity of Bus Roll Over Accidents", Scientific Society of Mechanical Engineers, Hungary.

[2] Vishwajeet Belsare, Milind Kulkarni, Prof. Charudatta Pathak, "Rollover Analysis of Passenger Bus as per ASI031", International Journal of Engineering Research and Development, October 2012.

[3] Automotive Industry Standard AIS 031 Regulation, Ministry of Road Transport and Highways, Government of India, September 2008.

[4] Economic Commission for Europe ECE R66 Regulation, Economic Commission for Europe, February 2006

[5] TEMSA A.S. Turkey, "An Investigation of Roll Over Crashworthiness of an Inter-City Coach, Influence of Seat Structures and Passenger Weight".

[6] C. C. Liang & L. G. Nam, "Comparative Analysis of Bus Rollover Protection Under Existing Standards", Department of Mechanical and Automation Engineering, Da-Yeh University, Taiwan, ROC.

[7] Erich Mayrhofer, "Enhanced Coach and Bus Occupant Safety", Graz University of Technology, Vehicle Safety Institute-Austria.

[8] Rahul Mahajan & Rishi Shah, "Automated Process Tool for Pre- and Post-Processing of Bus Rollover Analysis in Compliance with AIS031/ECE R66", The Automotive Research Association of India.

[9] Ajinkiya Patil, Prof. S.R. Pawar, "Roll Over Analysis of Sleeper Coach Bus by Virtual Simulations in LS-DYNA", BVUCOE Pune.

[10] Dr. Matolcsy Matyas, "Passenger's Ejection in Bus Rollover Accident", Informal Document GRSG 103-2, 2012.

[11] Pankaj S. Deshmukh "Rollover and Roof Crush Analysis of Low Floor Mass Transit Bus" Wichita State University, December 2006.

[12] Hee-Young Yo, Kwang-Bok Shin, Kwang Woo Jeon and Seo-Hyun Cho "A Study on the Cross Worthiness and rollover characteristics of Low Floor Bus made of Sandwich Composites", Journal of Mechanical Science and Technology 2006.

[13] MD. Liaka Tali "Impact of Bus Superstructure due to Rollover" Universiti Teknologi Malaysia, November 2008.

[14] A. Subic and J. He, S. Preston "Modal Analysis of Bus Roll Cage Structure for Optimum Rollover Design", Victoria University of Technology Australia.

[15] Srinivasalu T "Bus Rollover Simulation using Body Sections in RADIOSS", Ashok Leyland Technical Centre, Chennai India, HTC 2012.

[16] D. Senthil Kumar, "Rollover Analysis of Bus Body Structure as per ECER66/ASI031", Volvo Groups Truck Technology India, HTC 2012.

[17] Leon Prochowski, Karol Zielonka, Andrzej Muszynski, "Analysis of the Process of Double Decker Bus Rollover at the Avoidance of an Obstacle Having Suddenly Sprung Up", Journal of KONES Powertrain and Transport, Volume 19, 2012.

[18] Ministry of Road Transport and Highways, "Road Accidents in India", Government of India, 2015.

[19] Dinesh Mohan, Geetam Tiwari, Kavi Bhalla, "Road Safety in India Status Report", Indian Institute of Technology Delhi, 2015.

[20] Ashok Leyland Model Description, Online available at http://www.ashokleyland.com/

APPENDICES

APPENDIX A

Computer Simulation of Rollover Test on Complete Vehicle as an Equivalent Approval Method

1. Additional data and information

The superstructure may be shown to meet the requirements specified in the Regulation by a computer simulation method approved by the technical service.

If the manufacturer chooses this testing method, the following information shall be supplied to the technical service in addition to the data, and drawings listed in Regulation;

1.1. A description of the applied simulation and calculation method which has been utilised, and clear precise identification of the analysis software, including at least, its producer, its commercial name, the version used and contact details of the developer.

1.2. The material models and the input data utilized.

1.3. The values for defined masses, centre of gravity and the moments of inertia used in the mathematical model.

2. The mathematical model

The model shall be capable of describing the real physical behavior of the rollover process. The mathematical model shall be constructed, and assumptions prescribed, in such a way that the calculation gives conservative results. The model shall be built up with the following considerations:

2.1. The technical service may require tests to be carried out on the actual vehicle structure to prove the validity of the mathematical model and to verify the assumptions made in the model.

2.2. The total mass and the centre of gravity position used in the mathematical model shall be identical to those of the vehicle to be approved.

2.3. The mass distribution in the mathematical model shall correspond to the vehicle to be approved. Moments of inertia used in the mathematical model shall be calculated on the basis of this mass distribution.

3. Requirements for the algorithm and simulation program, and for computing equipment

3.1. The position of the vehicle in unstable equilibrium at point of rollover, and the position at first contact with the ground shall be specified. The simulation program may start at the unstable equilibrium position, but shall start, at the latest, at the point of first contact with the ground.

3.2. The initial conditions at the point of first contact with the ground shall be defined using the change of potential energy from the unstable equilibrium position.

3.3. The simulation program shall run, at least, until the maximum deformation is reached.

3.4. The simulation program shall produce a stable solution, in which the result is independent of the incremental time step.

3.5. The simulation program shall be able to calculate the energy components for the energy balance at every incremental time step.

3.6. Non-physical energy components introduced by the process of mathematical modelling (for example, "hourglass" and internal damping) shall not exceed 5 per cent of the total energy at any time.

3.7. The friction coefficient used at the ground contact shall be validated with physical test results, or the calculation shall prove that the friction coefficient chosen produces conservative results.

3.8. All the possible physical contacts between parts of the vehicle shall be taken into account in the mathematical model.

4. Evaluation of the simulation

4.1. When the stated requirements for the simulation program are met, the simulation of the changes in geometry of the interior structure and comparison with the geometrical shape of the residual space can be evaluated as defined in the Regulation.

4.2. If the residual space is not infringed during the rollover simulation, the approval shall be granted.

4.3. If the residual space is infringed during the rollover simulation, the approval shall be refused,

5. Documentation

5.1. The report on the simulation shall contain the following information:

5.1.1. all the data and information stated in regulation,

5.1.2. a drawing showing the mathematical model of the superstructure,

5.1.3. a statement of the values of angle, velocity, and angular velocity at the unstable equilibrium position of the vehicle and at the position of first contact with the ground,

5.1.4. a table of the value of the total energy and the values of all its components (kinetic energy, internal energy, hourglass energy), at time increments of 1 ms covering, at least, the period from first contact with the ground until the maximum deformation is reached

5.1.5. The assumed ground friction coefficient,

5.1.6. plots or data which show in an appropriate way that the requirements specified in Regulation are met. This requirement can be satisfied by the provision of a plot, against time, of the distance between the inside contour of the deformed structure and the periphery of the residual space(s),

5.1.7. a statement of whether, or not, the requirements specified in paragraphs 5.1.1. and 5.1.2. of this Regulation, have been met,

5.1.8. all the data and information necessary for the clear identification of the vehicle type, its superstructure, the mathematical model of the superstructure, and the calculation itself.

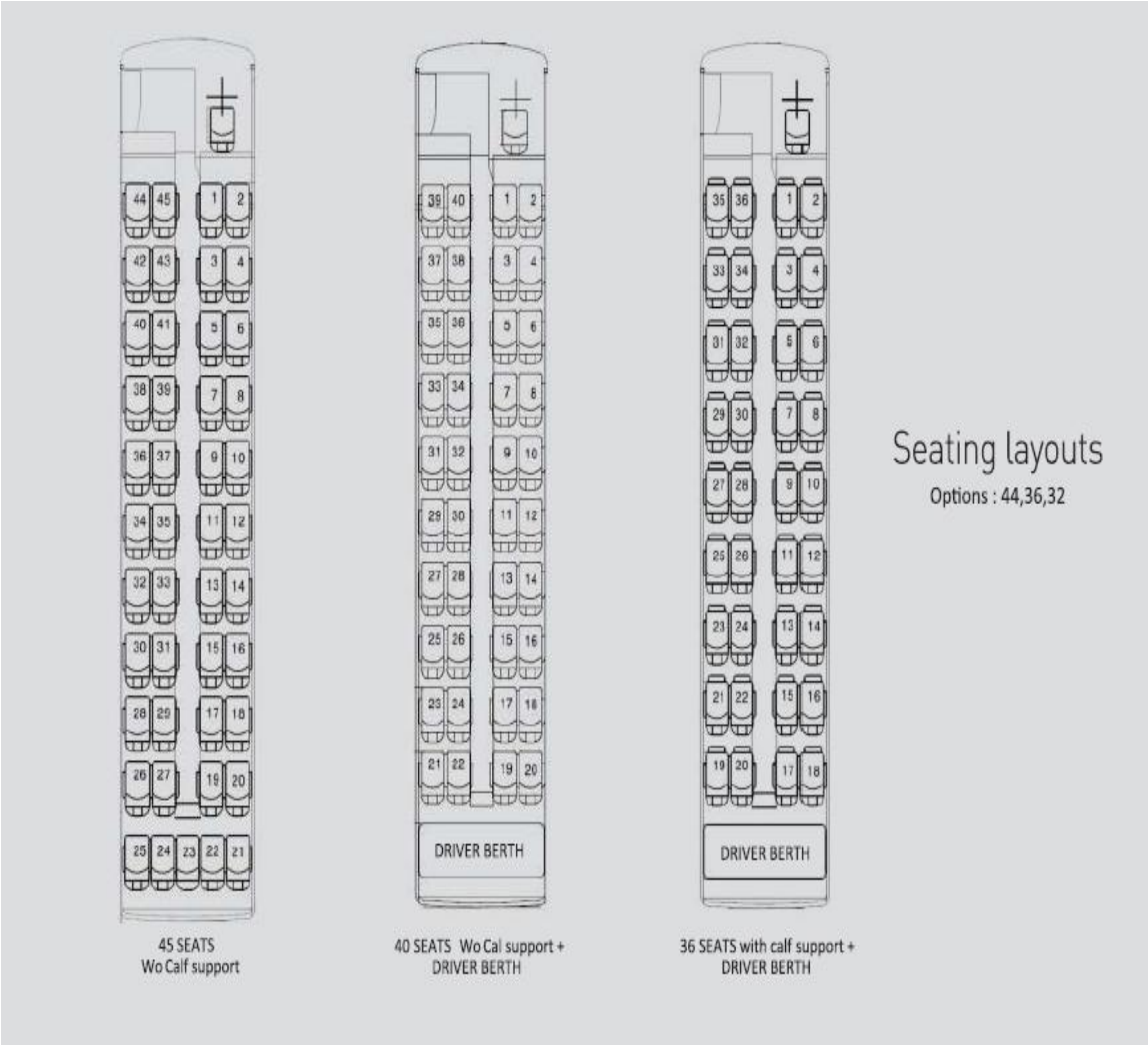
5.2. It is recommended that the report also contains plots of the deformed structure at the moment when maximum deformation occurs, giving an overview of the superstructure and regions of large plastic deformation.

5.3. At the request of the technical service, further information shall be provided and included in the report.

APPENDIX B

Ashok Leyland Luxura Specifications

Dimensions (in mm)	
Wheel Base	6200
Front over hang	2400
Rear over hang	3600
Front track	2054
Rear track	1816
Min ground clearance	270
Turning cycle	11500
Overall width	2550
Overall height	3545
Overall length	12000
Saloon height	2050
Gang way width	560
Door width	840
Body structure	All steel GI Tubular structure with anti-rust coating
Luggage space	Approx.7m^3
Engine	'H' Series CRS BSIII Electrically controlled
Suspension	Air suspension with shock absorber and anti-roll bar at rear and front
Frame	All Steel ladder type 275*85*6.15 (mm)
Fuel Tank Litres	350
Gross Vehicle Weight	16200 Kg
Engine Location	Rear


Seating layouts
Options : 44,36,32
DRIVER BERTH
DRIVER BERTH
45 SEATS
Wo Calf support
40 SEATS Wo Cal support +
DRIVER BERTH
36 SEATS with calf support +
DRIVER BERTH