UNIVERSITY OF NAIROBI

DEPARTMENT OF MECHANICAL AND MANUFACTURING ENGINEERING

FINAL YEAR PROJECT

STATIC CRASHWORTHINESS OF BUS FRAMES IN KENYA

PROJECT CODE: HJ 01/2015

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Submitted in partial fulfillment for the award of degree in Mechanical and Manufacturing Engineering

DECLARATIONS

We declare that this work submitted as our final year project is our original efforts and to the best of our knowledge has never been presented anywhere before for academic purposes.

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Above all, glory to God Almighty.

SYMBOLS AND ABBREVIATIONS

CAD	Computer Aided Design
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Method
FMVSS	Federal Motor Vehicle Safety Standards
FTA	Federal Transport Administration
GVM	Gross Vehicle Mass
KS	Kenya Standard
KEBS	Kenya Bureau of Standards
NTSB	National Transport and Safety Board
NTSA	National Transport and Safety Authority
RHS	Rectangular Hollow Section
SHS	Square Hollow Section
σ_y	Yield stress
σ_a	Allowable stress
σ_{max}	Maximum stress
ε	Strain
n	Safety factor
y	Displacement
E	Young's Modulus
I	Moment of inertia

ABSTRACT

Transit buses are a fundamental aspect of travelling in Kenya with most intercity traveling depending mostly on buses. Together with matatus, they are easily the cheapest means of transport. Although buses are one of the safest means of transport, occupant injuries and fatalities in bus crashes do occur hence rollover strength is an important aspect for the industry partakers. Various regulations involving rollover tests have been put into place, mostly in European and American States to prevent catastrophic accidents by the National Transport and Safety Board (NTSB) and Federal Motor Vehicle Safety Standards (FMVSS) from the United States and similar institutions in Europe.

This project is tasked with determining the static crashworthiness of the bus' superstructure here in our country. The standards laid out by Kenya Bureau of Standards (KEBS) do not have provisions for testing bus frames, only specifying the materials and workmanship to be used in fabrication. After doing a field survey of the bus fabrication industry where the designs and methods for fabrication were studied, a computer aided design (CAD) model of a bus' superstructure representing the designs used locally was developed.

The project employs the use of Finite Element Analysis (FEA), through Autodesk's Inventor Professional to carry out a static analysis of the bus' CAD model. To achieve this, several processes were undertaken, starting with a material characterization on a frame obtained from one of the fabricators, where the yield stress and ultimate tensile strength were determined. The yield stress was 252.67 Mpa, and the ultimate tensile strength 423.33 Mpa. A theoretical and simulation analysis was done on this specimen to ascertain the results given by the FE simulation. This process is termed model validation.

After the validation, the next step was to simulate the bus' structure, subjecting it to similar static loading under NTSB's and FMVSS' tests. They are the structure being able to withstand its own weight (1X) and also being able to withstand one and a half times (1.5X) its own weight. However this was not possible given the computational power of the available resources. Hence it was decided to do the analysis on half the model of the bus.

A sectional frame of the bus was modeled and used to determine the mesh size to be applied in the simulation. This was done by means of a mesh convergence plot. The minimum mesh size selected from the plot was 0.03125, which as per the program is a fraction of the longest parameter of a particular object. Upon determination of a mesh size to work with, the simulations for the half model were done. The quantities of interest at the end of the simulation are the maximum stress imposed on the frame and the deformation. The deformation is investigated to check whether there is any intrusion in the passenger survival space (residual space) along the entire vehicle and the stress checking for yielding or fracture of the material. Further load of two times and two and a half times the weight of the bus were included and its simulations included in this research.

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CHAPTER 1

1.1 INTRODUCTION

Road accidents in Kenya have been a national tragedy and as highlighted by statistics from NTSA, passengers account for second place in deaths related to motor accidents with pedestrians taking the first spot. The main causes of accidents in our country arise from poor road networks as well as dangerous roads with numerous black spots, careless driving and flouting of laid down regulations by drivers and pedestrians such as over speeding, pedestrian carelessness, incompetent drivers on roads and drunk driving.

Measures have been put into place to control the accidents such as improving our road networks, enforcing traffic rules such as fitting PSVs with speed limiters but human errors, as nature dictates are bound to happen. As much as there are regulations put into place to curb the problem, it still remains a big challenge to the nation as some measures are hard to implement. Measures such as reducing black spots which call for a complete redesign of many roads making it expensive and time consuming. It is also almost impossible to attain a 100% accident free rate on our roads as human errors can't be eliminated hence something needs to be done for situations where an accident occurs so as to reduce the number of fatalities.

Of all the vehicle types, high capacity buses operating from city to city contribute to the highest number of occupant injuries and fatalities. One of the major factors that has generally been overlooked in our country and doesn't feature in accident reports is why the structure or the frame of the bus fails after an accident. It being a purely engineering aspect of the problem it is very critical that it is studied and understood in order to set a safe and effective system which abides to the related engineering rules meanwhile observing the monetary implications of such systems.

From the wreckages of the accidents, it is clear that something is wrong with the existing standards put into place in the fabrication of our local buses. In most cases than not, the bus' structure is deformed extensively and fails thus sparing no life on board in the event of an accident. This raises questions as to whether the structure is designed to withstand impact loads or if certain standards are not being adhered to or are not up to date to address the existing problems.

The project will address the issues above including but not limited to existing standards, fabrication methods, material selections and static load analysis of the bus structure. Critical examination of current designs and methods of fabrication and simulating static loading will give a clear answer to whether the frames used are up to standard. This is imperative to the goal of making our public transportation safe as we focus on achieving vision 2030 since loss of lives and disability arising from the accidents have a direct implication to the economically active and productive population.

1.2 STATEMENT OF THE PROBLEM

Complete failure of bus frames is one of the major factors that has greatly been overlooked and which causes a high number of fatalities during accidents. A clear and precise analysis of this type of failure is important so as to improve performance of the frame structure during accidents and in the process reduce the number of casualties.

This project aims to show the direct relations between the bus frame design and failure associated with it in accidents in order to improve future designs which will more than eliminate total failure of the structure.

1.3 OBJECTIVES OF THE PROJECT

1.3.1 Overall objective

To study the crashworthiness of bus frames under static conditions

1.3.2 Specific objectives

i. To look/study at various designs used in fabrication of local buses
ii. To carry out material characterization of the structural members of the frames
iii. To validate the material characterization using FEM
iv. To carry out a static simulation of the bus frame

1.4 SCOPE OF THE PROJECT

The main area of concern is the failure of the bus' structure under static loads as per Kenyan standards or any other standards that can be adopted as a replica of the same and how the structure's stability can be improved in order to reduce the number of casualties after an accident. This will be done through material characterization of the frames, studying designs used by the fabrication companies, static simulation of the bus frame and trying to relate the failure or damage imposed on the frame to its design.

1.5 LIMITATIONS OF THE PROJECT

A major part of the project requires cooperation between the project partakers (students) and the local bus fabricating companies who may hold on to some important data or information sighting market fears or data landing into the wrong hands. Also access to high performance computers to carry out the intended simulations may pose as a challenge hence relying on 'normal' computers for the work.

1.6 REQUIREMENTS FOR THE PROJECT

1. Data and designs from bus fabricating companies
2. Kenya Bureau of Standards act on bus fabrication
3. Statistics from NTSA and other regulatory bodies
4. Design software: a) Autodesk Inventor Professional (Student Version)

   b) 3DS Solidworks

CHAPTER 2

2.1 LITERATURE REVIEW

According to the world health organization (WHO) road fatalities account for about 1.24 million deaths and between 20-50 million injuries worldwide. The majority of those affected are young individuals ranging from 15-29 years of age which is unfortunate since these young people represent the majority of the working force. To compound this matter further, 91% of these accidents occurs in the low to middle income countries of Africa and Asia. This alarming statistic is predicted to increase to 1.9 million fatalities by 2020 and to these poor countries, not only do they lose a vibrant workforce but the cost of taking care of the injuries caused by these accidents is a burden since they lack critical systems like universal health coverage.

Figure 2.1-1: *A police officer walks passed the mangle wreck of the Ntulele crash at a police station (Courtesy: Daily Nation online edition)*

This begs the question why are the majority of this accidents occurring in poor countries which only account for 52% of worldwide registered vehicles and 72% of world population yet 80% of world fatalities are recorded to occur in these countries. This figure might even be higher due to the difficulty of gathering data since most of these accidents occur in remote areas. Average fatalities rates for low income countries in 2012 (WHO study) stood at about 20.1 per 100,000 people with that of high income countries being 8.7 per 100,000. The study also showed the risk of dying in a road related accident was high in the African region with 24.1 per 100,000 and lowest in the European region with 10.3 per 100,000.

Kenya has one of the highest rates of road fatalities in the world with the WHO giving it a rating of 34.4 per 100,000 persons which translates to roughly 3000 deaths per year. This figure is high with road accidents being the ninth leading cause of death in Kenya. This is due to several factors from dilapidated roads and poorly designed motorways to inadequate sensitization of the public towards road safety practices. With the inherent corruption in the agencies that are mandated to oversee the transport system to make it safe and reliable, the situation is further deteriorated.

Figure 2.1-2*: Scene of a roll-over accident in Vihiga County (Courtesy: Standard online)*

Kenyans have come to identify numerous places as black spots but this has not had any effect on the outcome of the situation since many accidents do occur at those same spots. Poor road designs and reckless driving has mostly been blamed for these accidents and in most cases this is evidently true. However road fatalities are usually a consequence of many varying factors ranging from state of the road to judgments made by the driver.

Changing factors such as the road design or the way traffic rules are enforced is difficult and in the Kenyan context a long term solution that in the end will save lives. However small measures can be taken that are more effective and very practical given the price Kenyans are currently paying.

Fatalities caused by buses account for less deaths and injuries compared to accident involving pedestrians and personal cars but leave behind a big “mark” showing how road safety must be improved.

2.2 WORST ROAD ACCIDENTS RECORDED IN KENYA

Period	Description
April 7, 1963	A bus carrying passengers returning from a church meeting plunges into the Tiva River, Machakos, killing at least 72 people
November 14, 1989	55 people are killed in an accident after a bus plunges into the Thwake River in Machakos
January 6, 1991	A bus slams into a tree on a railroad crossing on the outskirts of Murang'a after the speeding driver lost control, killing 47 people. Another 40 are injured.
October 3, 1993	A multiple road accident involving a passenger bus, truck and numerous other vehicles on Nakuru—Eldoret road kills 35 people and injures 41.
January 7, 1998	A bus on Meru-Nairobi route plunges into Nithi River, killing 58 people, and injuring 42.
March 29, 2000	74 people die in a collision between two buses in Kericho.
November 7, 2000	A bus with 80 passengers on board flew over a bridge at the outskirts of Meru, killing 45.
August 15, 2001	A minibus veers off the road and plunges into the Mwania River in Machakos, killing 23.
14 April, 2007	A matatu overturns and bursts into flames in Garissa, killing 15 and injuring 61.
February 4, 2012	Twenty—six people are killed in a road accident involving two mini buses along the Kisumu-Kakamega highway.
August 29, 2013	Forty two people perish and 44 other are injured at the notorious Ntulele black spot on the Maai Mahiu – Narok road.

Table 2.2-1: *Worst accidents in Kenya's history (Courtesy: www.softkenya.com)*

Majority of these fatal road accident occur in Kenyan highway linking cities and towns. The large swaths of uninhabited and poorly enforced areas tend to give the drivers a leeway to breaking traffic rules by either over speeding, overloading or blatantly driving recklessly.

Most of the vehicles used in intercity commuting are buses and to an extent make the number of fatalities higher whenever an accident occurs. Taking a similar approach to air safety since the number of lives at stake is roughly the same, a critical and thorough understanding of how the whole process leading up to the accidents takes place is invaluable.

In Kenya, one of the factors that is generally overlooked and doesn't even feature in reports is how the body or the structure of the bus fails. As it is purely an engineering aspect of the problem, it is very critical that it is studied and understood in order to set a safe and effective system that conforms to the related engineering rules and at the same time observing the monetary implications of such systems.

Critical examination of current designs and methods of fabrication and simulating the outcome of a rollover accident will give a clear answer to weather the frames used are safe to be used in Kenyan roads.

2.3 COMPARISON WITH OTHER COUNTRIES

If we compare the aftermath of rollover accidents between locally fabricated buses and those in the developed world, a clear and profound difference is noted. In the case of local buses there is a total disintegration of the superstructure while in crushes in the developed world, the structure remains intact.

Figure 2.3-1 *(Courtesy: Daily Nation)*

Figure 2.3-2 *(Courtesy: www.mirror.co.uk)*

Fig 2.3-1 shows the aftermath of the city to city bus crash along the Mwingi-Garissa highway. Fig 2.3-2 shows a school bus wreckage in Hereford, England.

A simple visual observation of the images above and below draws a clear conclusion that the damage after the rollover is significant in the local buses than in the developed world, which shows minimal deformation.

Figure 2.3-3 *(Courtesy: Daily Nation)*

Figure 2.3-4 *(Courtesy: www.dalje.com)*

Fig 2.3-3 shows the aftermath of the Ntulele bus crash along the Nairobi-Narok highway. Fig 2.3-4 shows a Hong Kong bus accident. Although 18 people were killed and 44 injured, the bus' structure is still intact.

2.4 STANDARDS AND REGULATIONS

Standards provide a common reference point for the assessment of the quality of goods and services. They ensure that products and services are safe, reliable and of good quality. In Kenya, standards are drafted and implemented by the Kenya Bureau of Standards (KEBS) and one of their main responsibility is to ensure that local manufacturers import and use quality raw materials and other inputs. Manufacturing of bus coaches is mostly done by local manufactures. Hence they have the task of ensuring that the design and fabrication of these buses conforms to the given standards to ensure safety of passengers.

System have in the years been put in place in order to curtail on road users who break the law and endanger the population. One famous set of laws were the "Michuki laws" which introduced speed governors, safety belts, public display of the operator's photo and wearing of uniforms. In addition, crews of buses and matatus had to be vetted by police and receive a Certificate of Good Conduct before employment. These laws were put in place in order to make the industry safe.

The laws reduced the number of fatalities initially but this can be attributed to decreasing the number of vehicles on the road since a majority could not incur the cost of all the equipment needed. This in turn led to fewer vehicles on the road, the situation leading to hiking of commuter fares making people travel less hence the number of accidents reducing at face value. However the percentage of fatalities remained the same

The problem of corrupt law enforcement agents is going to take long to solve but in the meantime other factors that contribute to the road carnage must also be addressed. Apart from these human related factors one major issue that has largely not been emphasized is the engineering aspect. This is a crucial yet ignored aspect, the question that should first arise is "does Kenya have standards pertaining to the design, analysis and fabrication/production of these buses."

Kenya bureau of standard has KS 372 which gives information and guidelines on design, materials, assembling and fabrication of buses to local fabricators. However most of the provisions of this standard have been adopted from other countries or regions. These provisions include the materials to be used in the making of those bus frames.

One major factor to note is that apart from the standard providing the material to be used and the overall limits to the design, it is insufficient in explaining important parameters concerning testing and validation of the design and workmanship that goes into the fabrication.

Fabricators rarely carry out tests like static loading and roll over tests which are crucial in any manufacturing that concerns automobiles, yet these are among the core pillars of safety in any automobile production. An example of this is the crash tests that are done to determine how safe the occupant will be in an event of a crash, the data collected is then used to change design or to add safety features like airbags and antiroll bars.

The lack of these tests is mainly due to budgetary constraints of the fabricator, lack of capacity to do so both in the technical aspect and monetary aspect. On the monetary aspect it puts a doubt in what other cost effective measures the fabricators might be employing.

Another core responsibility of the Kenya Bureau of Standard is to ensure that the proper specified material is used. However this is very hard to inspect and the inherent corruption doesn't help in the situation. Majority, especially small scale fabricators use steel meant for other applications such as gates fabrication as they are cheaper and easily available.

2.5 BACKGROUND ON KENYAN MANUFACTURING

As of 2013 Kenya has officially been elevated to a middle income country even with the continued widening of the income gap between the rich and poor making it one of the most unequal countries in the world. This has Kenya ranked 121 out of 175.

Throughout the years numerous policies have been enacted with the latest one being the vision 2030 whose main objective is to make Kenya a developed country by 2030. To achieve this, Kenya is targeting an annual GDP growth of 8.2 percent between 2013 and 2017 and getting this rate to double digit from 2017 onwards.

Kenya's highest GDP earner is agriculture with current estimated growth rate of 6.5 percent. However manufacturing is one sector that can increase gross national saving by greatly reducing import expenses and providing employment to thousands of Kenyans. The industrial sector manufacturing accounts for 70% of the GDP contributions with other sectors such as construction, mining and quarrying cumulatively contributing the remaining 30%.

Kenya's vision 2030 identifies the manufacturing sector as a key driver for increasing the GDP growth rate with the manufacturing sector identified as having a huge potential to provide employment and to facilitate local products getting into the market both in Kenya and beyond. While agriculture has its limitation in the availability and cost of land, manufacturing has all the right ingredients in abundance, one of them being a highly skilled workforce that can be a game changer towards making Kenya a developed country.

Country	2007	2008	2009	2010	2011
Kenya	0.016	0.018	0.019	0.017	0.018
Singapore	2.391	2.271	2.37	2.542	2.429
China	11.964	12.766	13.458	14.763	15.393
Malaysia	1.314	1.245	1.309	1.332	1.223
Tanzania	0.005	0.007	0.006	0.008	0.007
Uganda	0.004	0.006	0.006	0.005	0.006
South Africa	0.342	0.365	0.302	0.328	0.321

Table 2.5-1: *Industrial growth indices of emerging markets in Asia and Africa (Courtesy: www.mfa.go.ke)*

2.6 BUS FABRICATION IN KENYA

Majority of the buses in Kenya are manufactured locally. Some of the well-known fabricators in Kenya are:

- Banbros Ltd.
- Choda Fabricators Ltd
- Kenya Coach Industries
- Master Fabricators Ltd.
- Kenya Vehicle Manufacturers Ltd
- Labh Singh Harnam Singh Ltd

This information is also validated by a field survey taken and the results given in Tables in the appendix.

Nearly all fabricators are signatories to the KS 372 standard from which gives out the specifications for the fabrication and the materials to be used. However there are some “underground “fabricators that fabricate buses illegally.

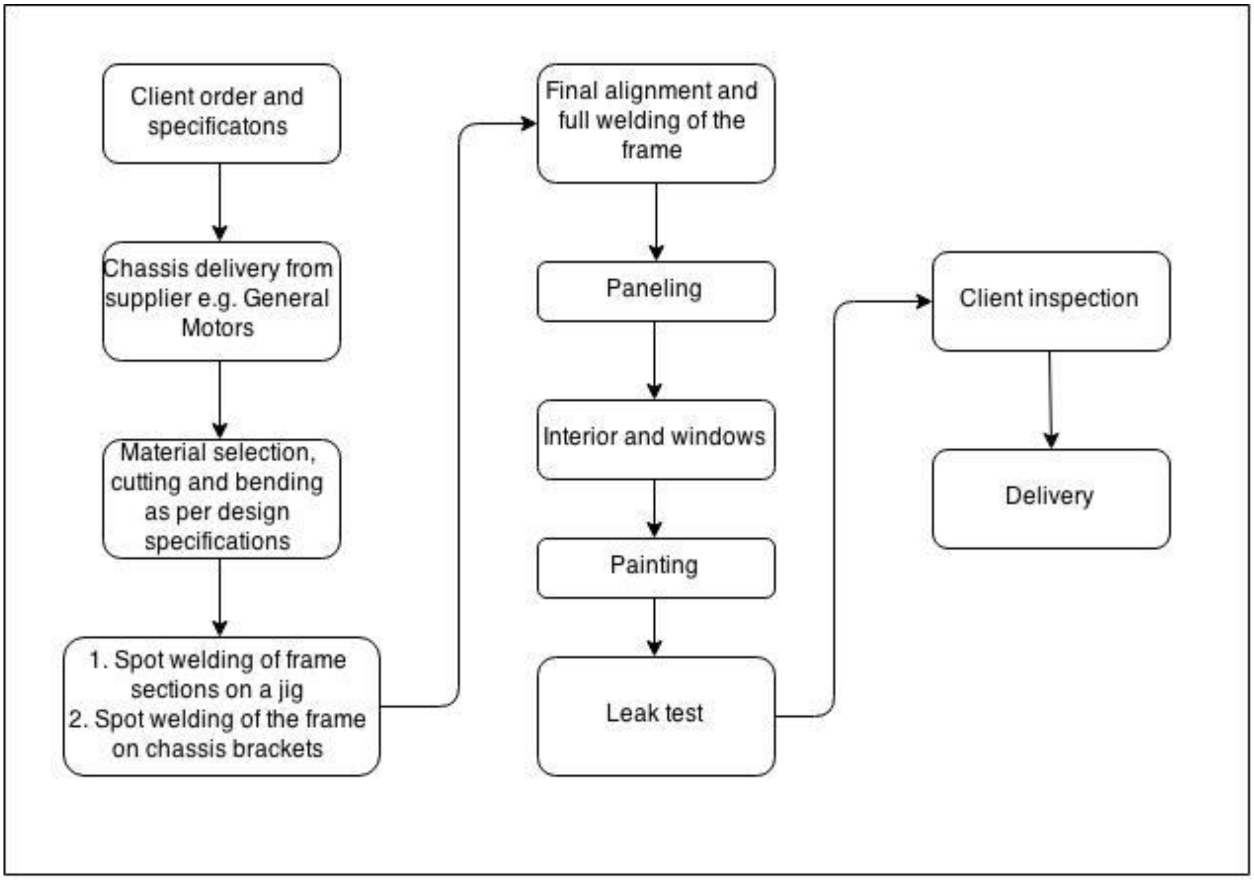


Figure 2.6-1: *A simplified bus fabrication process in Kenya*

The bus fabrication process employed by a number of fabricators takes the following form and order

2.6.1 Client Order and Specifications

The chassis is received from different suppliers e.g. General Motors, Hino Kenya, Simba Colt Motors etc. as per client order and specifications. An order number is then assigned to the chassis together with the design specifications and a worksheet attached to the chassis detailing all the clients' specifications.

Then some components are removed from the chassis e.g. battery, fuel tank, electronics, etc. as they may get damaged during the fabrication process. Others such as the fuel tank are hazardous.

2.6.2 Material Selection and Preparation

Material is received from steel suppliers e.g. Tononoka Steel, Tuff Steel etc. in various profiles such as I sections, angle lines, C channels, rectangular and square hollow sections as well as flat plates/sheets of various gauges. They are then checked for any defects and sorted out.

The materials are treated in red oxide both externally and internally to prevent external as well as interior corrosion which is a weakening factor in the metal. Finally the materials are cut and bent depending on the particular part of the bus they are going to build e.g. roof section. This process is done by several machines including power saws and roller benders.

2.6.3 Material Joining

The cut materials are fitted in jigs i.e. side, front, roof and back jigs for alignment and then spot welded to secure them in position. The chassis is fitted with front and rear antiroll bars and cross members which are spot welded onto the chassis mounting brackets. The brackets vary in form depending on the fabricator's choice with the most common being L plates and channel sections.

The side verticals are then welded onto the cross members and the front, back and roof frames spot welded together with the members. Angle lines acting as trusses are then spot welded to the side panels below the window for strengthening purposes and also to aid in fixing the panels. Final alignment is carried out before full frame welding (MIG) is done.

2.6.4 Paneling

The side, roof, front and rear panels are fitted and spot welded. Full welding may be done or sika glue used to join the panel to the frame. The body is then scrubbed with body filler and if the welding was done properly, as minimum body filler as possible will be used.

2.6.5 Painting and Interiors

The bus is then painted, the interiors done including seats, windows, floor and any other aesthetic components to enhance the interior's décor e.g. fiber glass roof covers, LED lighting etc.

2.6.6 Inspection

A leakage test is then done on the completed bus where it is subjected to water and inspection done on the interior to check for any leaks. Other inspections done on the bus performed include:

- Quality inspection- To ensure that the proper workmanship has been performed to the quality standards of the fabricator
- Chassis supplier inspection- To ensure no alterations have been done to the chassis so as to not compromise its integrity
- Government inspection- To check if government standards have been followed as stipulated by KS 372 and the regulation stipulated by the Motor Vehicle Inspection Unit followed.
- Client inspection – To determine if the client specifications have been meet

After all the inspections have been done and certified the bus is delivered to the client.

KS 372 provides all the specifications required to fabricate the bus. However from an engineering perspective one very clear "absentee" in the process is the guidelines concerning testing of the superstructure. Given the fact that a bus carries a large amount of people, safety should be paramount. According to the USA's National Transport and Safety Board (NTSB), the vast majority of fatalities in rollover crashes involve occupant ejections. While a large percentage of fatalities in rollover crashes are due to the occupants being ejected, some fatalities can be attributed to the collapse of the structure during the rollover event.

2.7 TESTING OF A BUS' SUPERSTRUCTURE

Bus frames around the world are generally tested in two ways; a quasi-static test and a dynamic rollover test to establish the structural integrity of the bus.

2.7.1 Quasi-Static Test

This is probably one of the most common tests performed. It entails loading the bus in a stationary position and observing how much weight the bus frame can support. In other cases, it is used to test the roof crush resistance of the bus. FMVSS No. 220 is an example of a quasi-static test in which a bus roof has a uniformly distributed vertical force pushing directly downward on the top of the bus via a plate. A factor of the bus weight is then applied to the plate and the subsequent deformation observed.

According to the National Highway Traffic Safety Administration (NHTSA), the FMVSS No. 220 is used to test school buses where the applied load is 1.5X the unloaded weight of the bus. The standard required roof deformation observed should not exceed 130mm.

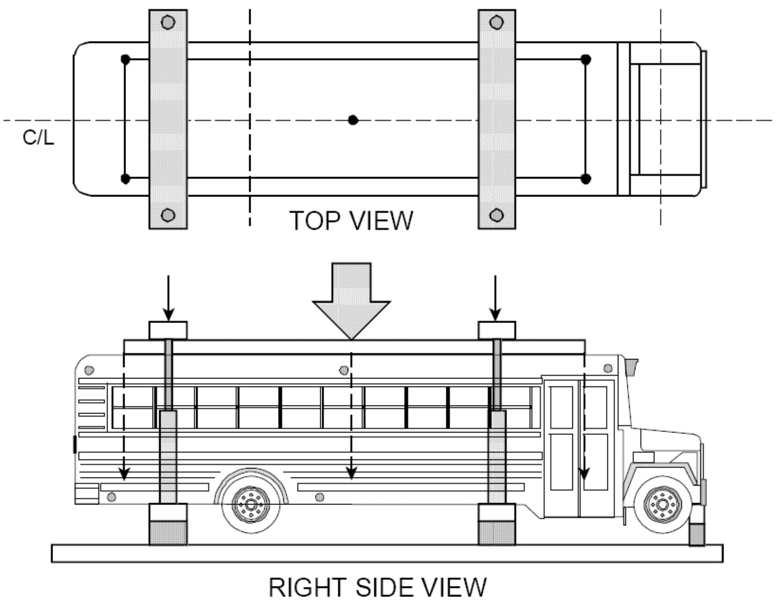


Figure 2.7-1: *NHTSA FMVSS No. 220 static roof crush test setup*

2.7.2 Dynamic Rollover Test

This is a destructive test intended to determine the strength of the vehicle body. In this test the bus is tilted until it topples over onto a hard surface from a specified height. The deformations are then observed and analyzed with regards to penetration into the passenger compartment, hereby determining the practical strength of the frame.

This tilt test can be performed on a complete bus or on a section of the frame and is done on a complete bus when the total effects of a rollover are to be observed and analyzed. However in the case of studying a specific effect on the structure or when testing improvements on the materials and design, a sectional tilt test is preferred.

Figure 2.7-2: *A tilt test set up (Courtesy: www.eobus.com)*

2.7.3 Occupant Survival Space

This is defined as a set of designated boundaries of the three-dimensional space in the bus' superstructure where there can be no material intrusion in the event of a crush. It is primarily designed to ensure the safety of the occupants from either crushing or deformation of the roof or the intrusion of the side structure or from any foreign surface impact in the case of a collision.

In Kenya it is a requirement by law that all passengers put on safety belts making it imperative that the occupant be protected from these intrusions since it is highly likely that his/her movement will be restricted by the seat belt.

This survival space should be designed in such a manner that all the occupants of the bus including the driver are within the boundaries of the survival space to ensure their survival in the event of a rollover or a collision accident. This survival space sets up the parameter for testing of the bus' structural integrity by determining the intrusion limits of the superstructure.

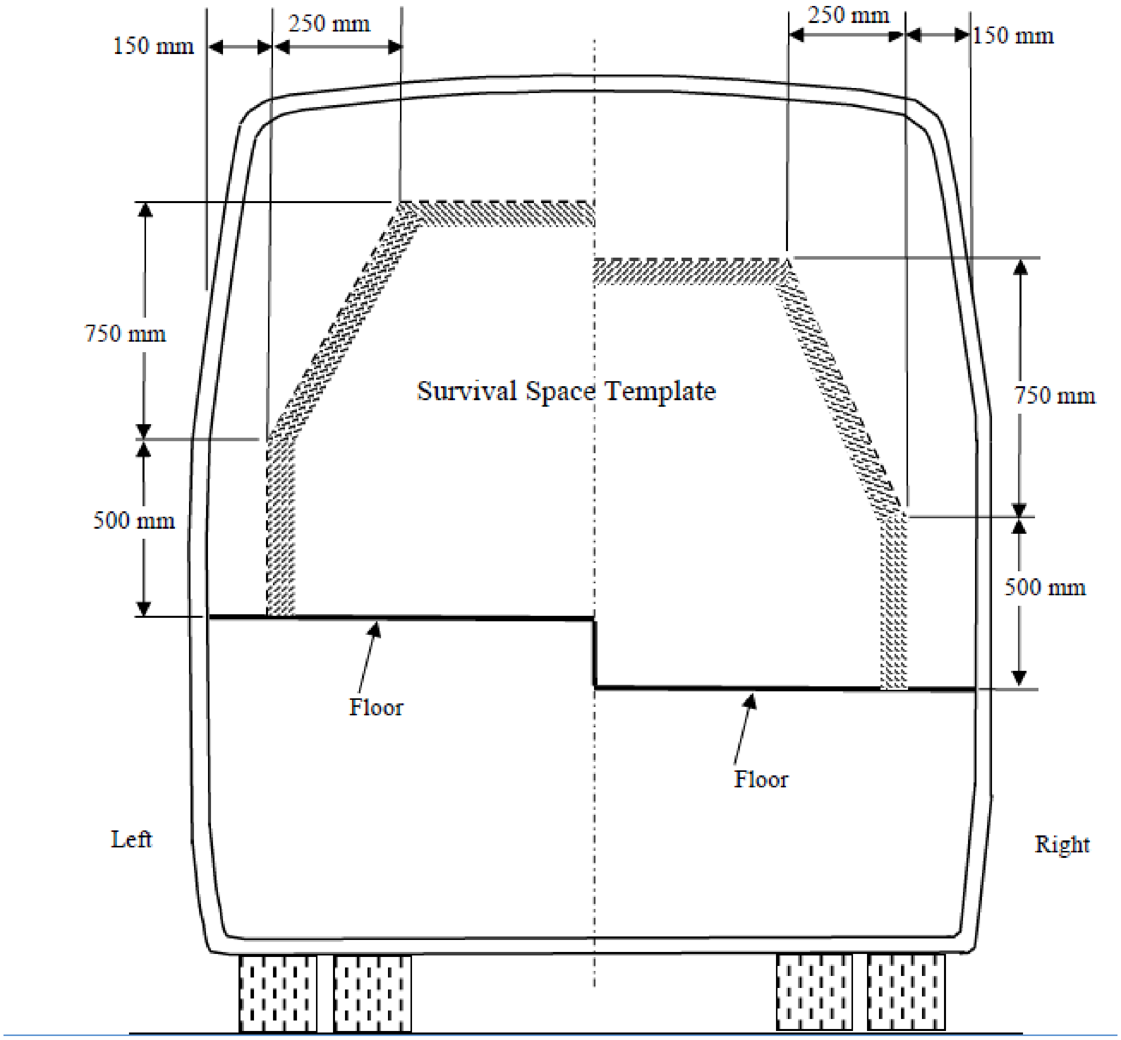


Figure 2.7-3: *Survival space of a bus' structure (Courtesy: NTSB)*

2.7.4 Comparison of NTSB's Regulations with Kenya

In Kenya, the KS372 does not provide the tests stipulated previously by the NTSB. This brings out a clear doubt on how stable the bus frames manufactured in Kenya are as the standards only address the fabrication process and the type of material used but no tests specified e.g. to ensure the structural strength required in the event of an accident.

The KS372 adopts many bus fabrication standard from different regions around the world. Some of these are India's IS 2062 GR.A and IS 2062 GR.B, Europe's EN10025 S235, Germany's ST37.2 and USA standards. Therefore there is a clear need to have a similar test as the one used by the NTSB taking into account Kenya's unique characteristics regarding infrastructure and the manner in which the buses are loaded (passengers and luggage) and maintained.

From a general observation, the buses manufactured in western countries appear to have a nearly similar internal structure which might imply that they are all designed and manufactured with similar standards. This means for any two buses of the same capacity they must pass the same static and dynamic test, therefore the design will be identical. However in our country, it can be observed that majority of the buses of almost a similar capacity often differ in their structural design.

Figure 2.7-4: *(Courtesy: www.japantoday.com)*

Figure 2.7-5: *(Courtesy: ecopedia.com)*

Figures 2-10 and 2-11 show two buses with similar designs from Japan and Germany respectively

Figure 2.7-6: *(Courtesy: nairobiwire.com)*

Figure 2.7-7: *(Courtesy: www.afroautos.com)*

Figures 2-12 and 2-13 show two buses with different designs from Kenya

The figures illustrate the similarity in the design of buses which are fabricated in different regions against the difference in the structural design of locally fabricated buses.

CHAPTER 3

3.1 STRUCTURAL ANALYSIS USING FINITE ELEMENT METHOD

This chapter introduces the background, concepts and procedures used in the Finite Element Method (FEM) for structural mechanics analysis.

3.2 CLASSIFICATION OF MECHANICS

Mechanics is an area of science concerned with the behavior of physical bodies when subjected to forces or displacement and the subsequent effects of the bodies on their environment. It is the practical application of that science to the design, construction or operation of material systems or devices such as machines, vehicles or structures. It can be distinguished into four categories namely:

1. Theoretical
2. Applied
3. Computational
4. Experimental

Theoretical mechanics is concerned with fundamental laws and principles studied for their scientific value. Applied mechanics transfers this theoretical knowledge to scientific and engineering applications, especially as regards the construction of mathematical models of physical phenomena. Computational mechanics solves specific problems by model-based simulation through numerical methods implemented and integrated into computer programs. Experimental mechanics subjects the knowledge derived from theory, application and simulation to the ultimate test of observation. Here we will dwell on computational mechanics.

3.2.1 Computational Mechanics

Computational mechanics represents the integration of several disciplines as listed below

1. Nano mechanics
2. Micromechanics
3. Continuum mechanics
4. Systems

Nano mechanics is a branch of nanoscience which deals with the study and application of fundamental mechanical properties of physical systems at the nanoscale like elastic, thermal and kinetic properties. It deals with phenomena at the molecular and atomic levels

Micromechanics is the analysis of composite or heterogeneous materials on the level of the individual constituents that make up the material. It finds its application in the design and fabrication of materials and micro devices.

Continuum mechanics studies bodies at the macroscopic level, using continuum models in which the microstructure is homogenizes is phenomenological averaging. The two traditional areas of application are solid and fluid mechanics. Computational structural mechanics emphasizes technological applications to the analysis and design of structures.

Systems identifies mechanical objects, whether natural or artificial, that perform a distinguishable function. Examples of systems are air-planes, buildings, bridges, engines, cars, microchips, radio telescopes and robots.

Of interest here is continuum mechanics which may be further subdivided into either static or dynamic analyses. Under static analysis, inertial forces are ignored or neglected. In dynamic analysis, the time dependence is explicitly considered because the calculation inertial and/or damping forces requires derivatives with respect to actual time to be taken.

For the problem at hand and the scope of the project, static analysis is particularly relevant. It deals with static problems in which the response is linear in the cause and effect sense e.g. if the applied forces are doubled, the displacements and internal stresses also double. Problems outside this domain are classified as non-linear.

A final classification of computational solid and structural mechanics for static analysis is based on the method of discretization employed by which the continuum mathematical model is discretized in space i.e. converted to a discrete model of finite number if degrees of freedom. Some of the discretization techniques in structural mechanics are

1. Finite Element Method (FEM)
2. Boundary Element Method (BEM)
3. Finite Difference Method (FDM)
4. Finite Volume Method (FVM)
5. Spectral Method

For linear problems, FEM is by far the most widely used discretization technique followed closely by BEM. For nonlinear problems, FEM technique is also the dominant method.

FDM method in solid and structural mechanics have virtually disappeared from practical use, however in fluid mechanics they are still applicable. FVM methods are favored in nonlinear problems of fluid mechanics. They focus highly on the direct discretization of conservation laws. Spectral methods take on a global approach that map the physical computational domain to transform spaces where the problem can be efficiently solved.

In non-structural application areas such as fluid mechanics and electromagnetics, FEM is gradually making up ground but faces stiff competition from both the classical and energy based FDM. FDM and FVM methods are particularly well entrenched in computational; fluid dynamics spanning moderate to high Reynolds numbers.

3.3 FINITE ELEMENT METHOD AND ANALYSIS

Finite element analysis (FEA) is a computerized method for predicting how a product reacts to real world forces, vibration, heat, fluid flow, and other physical effects. It is a way of implementing a mathematical theory of physical behavior and was developed by engineers using physical insight than by mathematicians using abstract methods. It was first applied to problems of stress analysis and has since been applied to other problems such as vibration, heat and fluid flow analysis. In all applications the analyst seeks to calculate a field quantity: in stress analysis it is the displacement filed or the stress field; in thermal analysis it is the heat flux or the temperature field; in fluid flow it may be the stream function or the velocity potential etc.

A simple description of the FE method is that it involves breaking a structure into several elements (pieces of the structure), describing the behavior of each element in a simple way then reconnecting element at nodes which simply can be viewed as pins holding the elements together

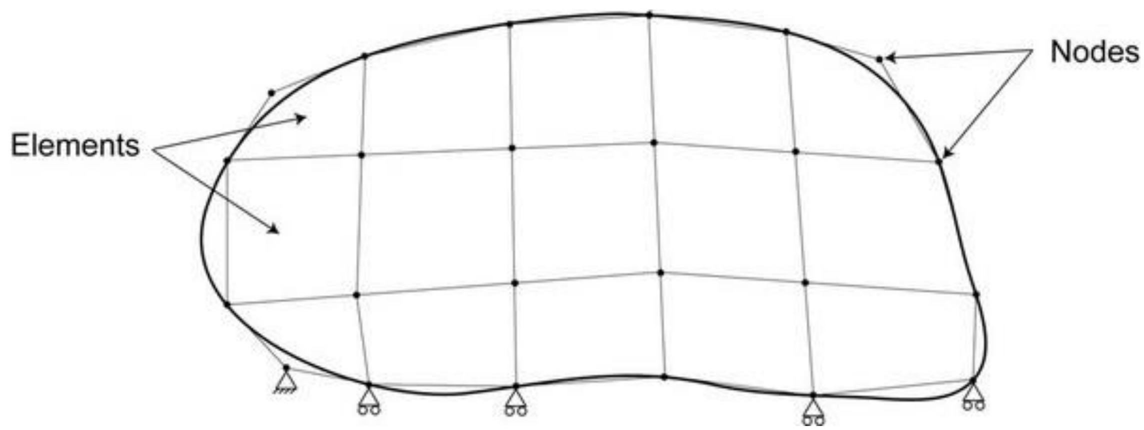


Figure 3.3-1: *Elements and nodes (courtesy www.nature.com)*

Nodes are discussed further in *section 3.5*. This process results in a set of algebraic equations. In stress analysis these equations are equilibrium equations of the nodes. There may be several hundred or several thousands of these equations hence computer implementation is mandatory.

The power of FEM is its versatility. The structure analyzed may have arbitrary shape, supports, and arbitrary loads. Such generality does not exist in classical analytical methods. For example, temperature induced stresses are usually difficult to analyze with classical methods, even when the geometry and temperature field are both simple. The FEM teats thermal stresses as easily as stresses induced by mechanical load, and the temperature distribution itself can be calculated by FEM.

3.3.1 How It Works

The theory of FEM includes matrix manipulations, numerical integrations, equation solving, and other procedures carried out automatically by commercial software. FEA works by breaking down a real object into a large number (thousands to hundreds of thousands) of finite elements, such as little cubes. Analogous to the idea that connecting many tiny straight lines can approximate a larger circle, FEM encompasses methods for connecting many simple element equations over many small subdomains, named finite elements, to approximate a more complex equation over a larger domain. Mathematical equations help predict the behavior of each element. A computer then adds up all the individual behaviors to predict the behavior of the actual object.

The user may only see hints of these procedures as the software process the data. The user doesn't interact with the background mathematical and computational part but mainly deals with what is referred to as preprocessing and post processing bits.

3.3.2 Preprocessing and Post processing

Preprocessing is concerned with describing loads, supports, boundary conditions, materials and generation of the FEM mesh. Post processing deals with sorting output, listing, plotting and refinement of results. Specific procedures of pre and post processing are different in different programs. Selection of the program is mainly a matter of user preference while learning to use them is often a matter of trial, assisted by introductory notes, manuals and online documentations and videos. Also the vendors of the programs offer training courses on the same such as Autodesk through the Autodesk Extension University program.

3.3.3 FEM Application

In any design process, an engineer or a user may ask himself some key questions of the design such as: Does design meet strength criteria? Is it strong enough? Does it meet the minimum safety threshold? How far can it be pushed before it fails? What materials should be used? Is it overdesigned or under designed? Can design objective be reached by using a different material or different geometry?

These questions can get their answers from first principles but some, such as optimizing the design may be too cumbersome from first principles as it'll involve changing many parameters as well as properties repeatedly. This is where the FEM comes into play. It helps predict the behavior of products affected by many physical affects including but not limited to:

- Mechanical stress
- Mechanical vibration
- Fatigue
- Motion
- Heat transfer
- Fluid flow
- Electrostatics
- Plastic injection molding

For the FEM to be used, there are some key concepts that the user should be familiar with. These are broken into three main parts i.e.

1. Elements
2. Nodes
3. Meshes

But before getting into the above, there are further questions that a user may ask himself before starting the FEM application such as: What kind of elements should be used, and how many of them? Where should the mesh be fine and where should it be coarse? Can the model be simplified? How mush physical detail must be represented? Is the important behavior static, dynamic, nonlinear, or what? How accurate will the results be, and how can they be refined?

Though one doesn't need to know the mathematics and the computations behind the results (*Robert D. Cook-Finite Element Modelling for Stress Analysis*), a competent user must understand how elements behave in order to choose suitable kinds, sizes, and shapes of elements and to guard against misinterpretations and unrealistically high expectations. A user should also learn that the FEM is a way of implementing a mathematical theory of physical behavior. Accordingly, assumptions and limitations of theory must not be violated by what we ask the software to do. In some dynamic and nonlinear analyses, algorithms by which theory is implemented must be understood to avoid choosing an inappropriate algorithm, and to avoid interpreting results produced by limitations as actual physical behavior. Despite all this understanding it is still easy to make mistakes in describing a problem to the computer program. Therefore it is also essential that a competent user have a good physical grasp of the problem i.e. engineering background so that errors in computed results can be detected and a decision made as to whether the results are to be trusted or not.

Questions such as the strength criteria can be answered from the design calculations but when it comes to optimizing, the manual way may become too tedious due to the iterative process. The Finite Element Analysis method comes in here as some key areas of the design may be altered and the results generated immediately for quick decision making. It shows whether a product will break, wear out, or work the way it was designed. It is called analysis, but in the product development process, it is used to predict what is going to happen when the product is used.

3.4 DISCRETIZATION AND OTHER APPROXIMATIONS

Whatever the analysis method, we do not analyze the actual physical problem; rather, we analyze a mathematical model of it. Mathematical modeling is a simplifying step but models of physical systems are not necessarily simple to solve. They often involve coupled differential equations in space and time subject to boundary conditions.

The spatial configuration of any such system is described by its degrees of freedom abbreviated as DOF. These are also called generalizes coordinates. If the number of degrees of freedom is finite, the model is called discrete and continuous if otherwise. Since FEM is a discretization method, the number of DOFs in a model is necessarily finite. They are collected in a column vector called **D** and this vector is called the DOF vector or state vector.

In analytical mechanics, each degree freedom has a corresponding "conjugate" or "dual" term, which represents a generalized force. In non-mechanical applications, there is a similar set of conjugate quantities, which for lack of a better term are called forces or forcing terms. They are the agents of change. These forces are collected in a column vector called **R**. The inner product

$\mathbf{R}^T\mathbf{D}$ has the meaning of external energy or work. The physical significance of the vectors **D** and **R** varies according to the applications being modeled as illustrated in *Table 3.4-1*

Application Problem	**DOF vector D represents**	**Conjugate vector R represents**
Solid and structural mechanics	Displacement	Mechanical force
Heat conduction	Temperature	Heat flux
Acoustic fluid	Displacement potential	Particle velocity
Potential flows	Pressure	Particle velocity
General flows	Velocity	Fluxes
Electrostatics	Electric potential	Charge density
Magnetostatics	Magnetic potential	Magnetic intensity

Table 3.4-1: *Significance of **D** and **R** in FEM applications (Courtesy: University of Colorado Boulder-An Introduction to Finite Element Modelling)*

The relationship between **D** and **R** is assumed to be of linear and homogeneous nature. This implies that if **D** vanishes so does **R**. The relation is then expressed by the master stiffness equation

$$\mathbf{KD=R} \tag{3.3-1}$$

Where **K** is a square matrix of known constants, **R** is a column vector of known constants and **D** is a column vector of unknowns. Solution for **D** may be symbolized as

$$\mathbf{D=K^{-1}R} \tag{3.3-2}$$

In finite element work**, K** is universally called the stiffness matrix that is usually large and sparse. It would be wasteful of storage and time to invert it. Thus $\mathbf{D=K^{-1}R}$ usually means "solve for the unknowns", probably by some efficient form of Gauss elimination or perhaps by an iterative method. Solving for Eq. 3.3-1 for **D** is a major part of FE calculations, but usually the user need not know how the software goes about it.

A square matrix is called singular if its determinant is zero. If **K** in Eq. 3.3-1 is singular, there is no unique solution vector **D**, and standard equation-solving subroutines will fail. As examples, the following matrices are singular.

$$\begin{bmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} \end{bmatrix} \qquad \begin{bmatrix} \mathbf{1} & \mathbf{-1} \\ \mathbf{-1} & \mathbf{1} \end{bmatrix} \qquad \begin{bmatrix} \mathbf{2} & \mathbf{4} \\ \mathbf{4} & \mathbf{8} \end{bmatrix} \tag{3.3-3}$$

Let **K** be an n by n matrix and **D** an n by 1 column vector. Also let $\mathbf{D} \neq \mathbf{0}$, which means that at least one coefficient $\mathbf{D_i}$ is non zero. Then, for all **D**, if $\mathbf{D^T K D} > 0$, $\mathbf{K}$ is called positive definite **(3.3-4)**

if $\mathbf{D^T K D} \geq 0$, $\mathbf{K}$ is called positive semi definite **(3.3-5)**

A positive definite matrix is nonsingular. In stress analysis, as stiffness matrix **K** is positive semidefinite and singular if supports of the FE structure do not prevent all possible rigid-body motions.

3.4.1.1 Analytical or Numerical

Analytical solutions, also called “closed form solutions”, are more intellectually satisfying, particularly if they apply to a wide class of problems, so that particular instances may be obtained by substituting the values of free parameters. Unfortunately they tend to be restricted to regular geometries and simple boundary conditions. Moreover some closed-form solutions, expressed as inverses of integral transforms may have to be anyway numerically integrated to be useful.

Most problems faced by engineers either do not yield to analytical treatment or doing so would require a disproportionate amount of effort and time. The practical and effective way out is numerical simulation where the FEM enters the scene. To make numerical simulations practical it is necessary to reduce the number of DOFs to a finite number. The reduction is called discretization and the product of the process is the discrete model. Discretization can proceed in space dimension as well as time dimension. But due to the statics problem at hand and also the complication of time dimension, focus would be put on spatial discretization.

3.4.1.2 Error Sources and Approximations

In engineering practice, modelling errors are by far the most common and thus important. But they are also difficult and expensive to evaluate, because model validation requires access to and comparison with experimental results. These may be either scarce, or unavailable in the case of a new product in the design stage. Also of importance is the discretization error. Even if solution errors are ignored, and in most cases they are, the computed solution of the discrete mode; is in general only an approximation in some sense to the exact solution of the mathematical model.

A quantitative measurement of this discrepancy is called discretization error. The characterization and study of this error is addressed by a branch of numerical mathematics called approximation theory. Intuitively one might suspect that the accuracy of the discrete model solution would improve as the number of DOFs is increased, and that the discretization error goes to zero as that number goes to infinity. This statement describes the convergence requirement of discrete approximations. One of the key goals of approximation theory is to make the statement as precise as it can be expected from a branch of mathematics.

3.5 ELEMENTS, NODES AND MESHES

The basic concept in the physical FEM is the subdivision of the mathematical model into disjoint (non-overlapping) components of simple geometry called elements. An element is the basic building block of finite element analysis. It is a mathematical relation that defines how the degrees of freedom of a node relate to the next. Elements can have intrinsic dimensionality of one, two or three space dimensions. There are also spatial elements with zero dimensionality such as lumped springs or point masses. The intrinsic dimensionality can be expanded as necessary by use of kinematic transformations. For example a 1D element such as a bar, spar or beam may be used to build a model in 2D such as a shell or 3D e.g. solid elements space. By using beams and shells instead of solid elements, a representative model can be created using fewer *nodes* without compromising accuracy. Each modeling scheme requires a different range of properties to be defined, such as:

- Section areas
- Moments of inertia
- Torsional constant
- Plate thickness
- Bending stiffness
- Transverse shear

The response of each element is expressed in terms of a finite number of degrees of freedom characterized as the value of an unknown function, or function at a set of *nodal points*. The response of the mathematical method is then considered to be approximated by that of the discrete model obtained by connecting or assembling the collection of all elements.

A finite element model comprises a system of points, called “nodes”, which form the shape of the design. A node is a coordinate location in space where the degrees of freedom are defined. The DOFs for this point represent the possible movement of this point due to the loading of the structure. The DOFs also represent which forces and moments are transferred from one element to the next. The results of FEA i.e. deflection and stresses are usually given at the nodes. Nodes appear on element boundaries and serve as connectors that fasten the elements together. They serve a dual purpose: definition of element geometry and home for degrees of freedom. When a distinction is necessary, the former is referred to as geometric nodes and the latter connection nodes. For most elements, geometric and connector nodes coalesce. Nodes are usually located at the corners or end points of elements.

In the real world, a point can move in 6different directions, translation in X, Y and Z, and rotation about X, Y and Z. In FEA, a node may be limited in the calculated motions for a variety of reasons e.g. there is no need to calculate the out of plane translation on a 2D element; it would not be a 2D element if its nodes were allowed to move out of the plane. The DOF for the generic element types are given in *Table 3.5-1*

Element Type	Translation			Rotation		
	X	**Y**	**Z**	**X**	**Y**	**Z**
Truss, spring, gap	Yes	Yes	Yes			
Beam	Yes	Yes	Yes	Yes	Yes	Yes
2-D		Yes	Yes			
Membrane	Yes	Yes	Yes			
Plate, shell	Yes	Yes	Yes	Yes*	Yes*	*
Brick, tetrahedral	Yes	Yes	Yes			

Table 3.5-1: *Degrees of freedom for element types (Courtesy: Autodesk.com)*

Yes indicates the deflections are calculated. Transmission of forces or moments is supported

** Rotational DOF for plate elements are based on local direction 1, 2. 3 instead of global direction X, Y and Z. rotations about the local axes 1 and 2 (axes in the plane of the element) are calculated. Rotation about the local axis 3 (axis perpendicular to the element) is not calculated.*

The DOF of a node which is based on the element type also relates what type of forces and restraints are transmitted through the node to the element. A force (axial or shear) is equivalent to a translation DOF. A moment is equivalent to a rotational DOF. Thus, to transfer a moment about a certain axis, the node must have a rotational DOF about the axis. If a node does not have the rotational DOF, then applying a moment to the node will have no effect on the analysis. This fact may also place requirements on how two parts are connected together. Additional modeling may be required to insure that the connection between the parts does not produce a hinge.

Likewise restraining the node with a rotational boundary condition will have no effect if the node does not have the ability to transmit the moment. So, placing a boundary condition of Tx Ty Tz Rx Ry Rz on a node of a brick element is the same as applying a Tx Ty Tz boundary condition; the brick element does not calculate rotations.

The finite elements themselves form the finite element mesh and contain the material and structural properties of the model; defining how it will react and behave to certain conditions. The density of the element mesh may vary throughout the material, depending on the anticipated change in stress levels of a particular area. Regions that experience high changes in stress usually require a higher mesh density than those that experience little or no stress variation. Points of interest may include fracture points of previously tested material, fillets, corners, complex detail, and high-stress areas.

3.6 MODELING THE PROBLEM AND CHECKING RESULTS

Modeling is the simulation of a physical structure or physical process by means of a substitute analytical or numerical construct. It is not simply preparing a mesh of nodes and elements. Modeling requires that the physical action of the problem be understood well enough to choose suitable kinds of elements, and enough of them, to represent the physical action adequately. Badly shaped elements and elements too large to represent important variations of the field quantity. On the other hand, it is also important to avoid long analysis time and computer resources associated with over-refinement i.e. using many more elements than needed to adequately represent the field and its gradients. After the computer is done with the calculations, we must check the results to see if they are reasonable. This is important as it is easy to make mistakes in describing the problem to the software.

3.6.1 Implicit versus Explicit Modeling

In implicit modeling, one has a general purpose finite element program which offers a catalog of element types, for example bars, beams, plates, shells and 3D solids. This means that once you choose a particular element, you automatically accept the mathematical model on which the elements are based.

Explicit modeling on the other hand involves shopping around for a finite element program that implements the model at hand, or writing the program yourself. It requires far more technical expertise, resources and experience than implicit modeling.

In practice a combination of implicit and explicit modelling is common. The physical problem to be simulated is broken down into sub problems. These sub problems that are conventional and fit available programs may be treated with implicit modeling, whereas those that require special handling may also submit to explicit modeling.

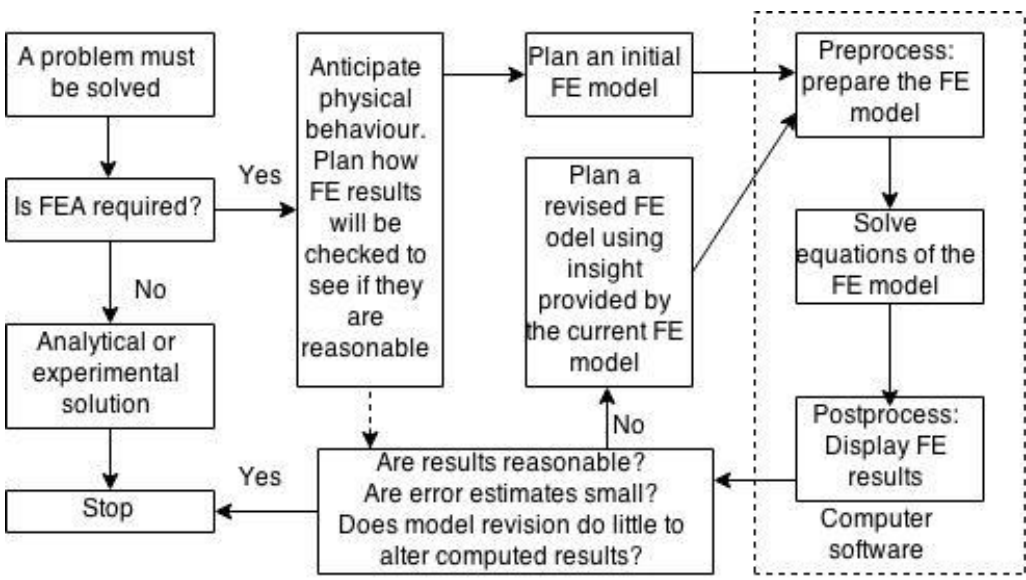


Figure 3.6-1: *Outline of a Finite Element Project (Courtesy: Finite Element Modelling for Stress Analysis-Robert D. Cook)*

3.6.2 User Responsibility

It must be admitted that the software almost certainly contains error. Commercial software packages are large, versatile, and under continual revision. It is practically impossible to get everything right. Many errors either make the software feature inoperable or cause the program to crash, but some can lead to erroneous results. It is tempting to blame all strange results on software, but it is far more often the case that we have made errors in modelling or in describing the problem to the software. Strange results are obtained so often that it is vital that the analyst be able to recognize that the results are strange.

FEM and FEA computer programs have become widely available, easier to user, and can display results with good graphics. Even an inept user can produce some kind of answer. It is hard to disbelieve FE results because of the effort needed to get them and the polish of their presentation. But smooth and colorful stress contours can be produces in any model, good or bad. It is possible that most FE analyses are so flawed that they cannot be trusted. Even a poor mesh, inappropriate element types, incorrect loads, or improper supports may produce results that appears reasonable on casual inspection. A poor model may have defects that are not removed by refinement of the mesh.

Hence it is critical that a responsible user must understand the physical nature of the problem and the behavior of finite elements well enough to prepare a suitable model and evaluate the quality of the results. Competence in using FE for stress analysis does not imply competence in using FE for (say) magnetic field problems. Responsibility for results produced is taken by the engineer who uses the software, not the software vendor, even if the results are affected by errors in the software.

CHAPTER 4

4.1 MODEL CREATION AND VALIDATION

Computational vehicle models need to capture the deformation and interaction of structural parts and subsystems under loading. The accuracy with which the crash behavior of a vehicle is simulated depend on the quality of the computer aided design (CAD) data and its meshing. CAD geometry should be accurate in shape and size to resemble the actual vehicle. The FEM mesh should be dense enough to ensure computational; convergence and to keep the computational time reasonably low.

The general steps taken in model creation and analysis are as shown below

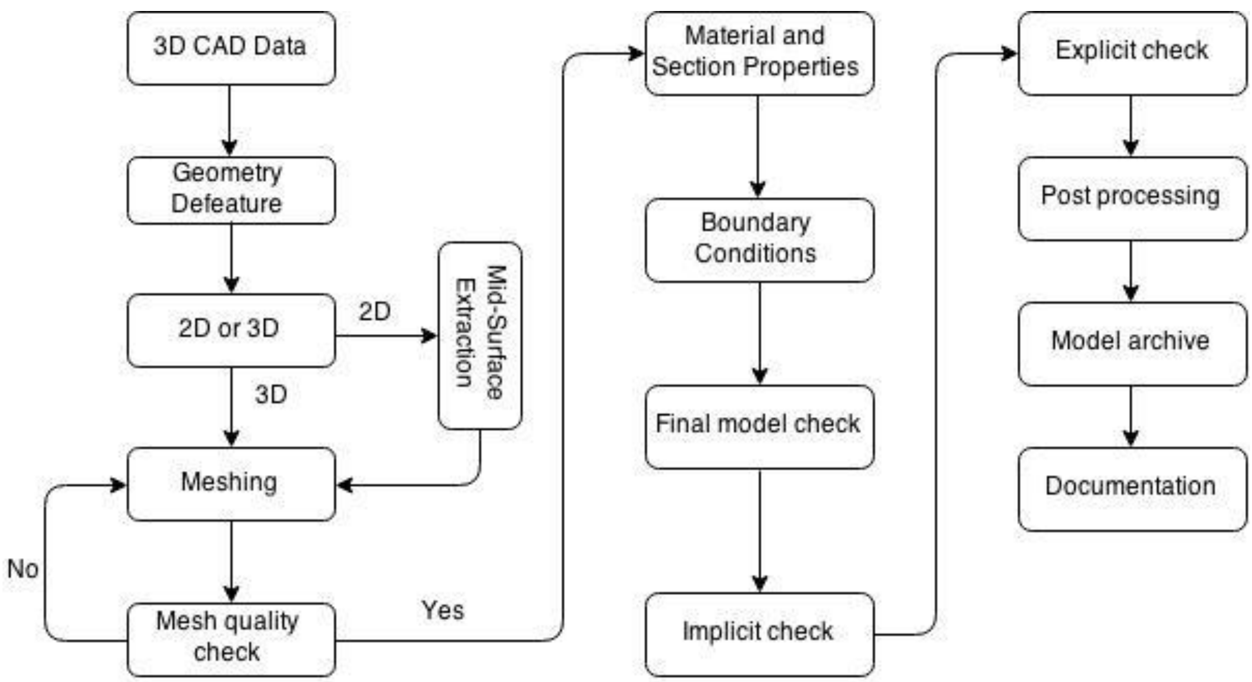


Figure 4.1-1: *Modeling and simulation process*

But before modeling, we need to ascertain that the FEA program we are using will give the correct results. The process by which this is done is known as ***model validation*** where the computer simulation is compared to theoretical and experimental data and results. In engineering practice, model validation requires access to and comparison with experimental results as well as theoretical calculations. These may be either scarce, costly or unavailable in the case of a new product in the design stage.

However experimental results in our project in the form of tensile test data are readily accessible and cost effective.

4.2 MODEL VALIDATION

4.2.1 Tensile Test

The purpose of the test is to determine the yield stress and ultimate tensile stress of the sample specimen obtained from one of the fabricators.

A tensile is one of the most fundamental mechanical test performed on materials. The test specimen consists of a standardized sample cross-section with two shoulders and a gauge length in between. The shoulders are used to grip onto the specimen while the gauge length has a smaller cross-section making the deformation and failure occur in that area. The aim of a tensile test is to determine the amount of load a specimen can take before it yields and fails and this is achieved by plotting a graph of stress against strain.

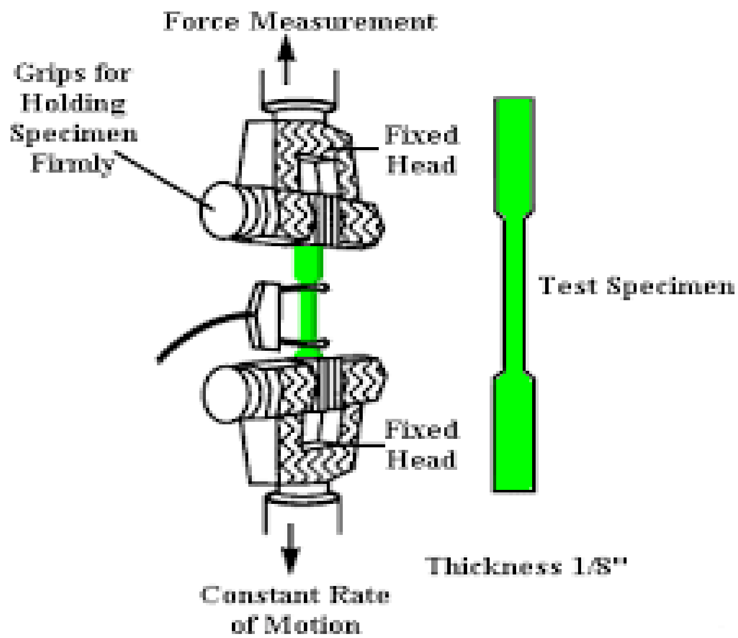


Figure 4.2-1: *Tensile test representation on an extensometer (Courtesy: www.aboutcivil.org)*

4.2.1.1 Apparatus

Torsee universal tensile testing machine and three steel specimens.

4.2.1.2 Procedure

A sample steel frame was taken from one of the local fabricators in the form of a square hollow section (SHS) measuring 40x40x2 mm. The steel section was cut longitudinally along the corners of the tube to give four rectangular pieces. One of the pieces was left out of the preparation because of the weld seam that joins the tube. The profile of the tensile specimen (B.S.I Long Standard) as shown in *Fig 4.2-3,* was traced onto the rectangular sheet of metal using a scriber. An outline was then cut out using a hacksaw with great care being taken to leave allowance for finishing. After the cutting, a light finish was done on the specimen using a grinder and later fine finish done using files. The specimen was then secured on the extensometer and loading done. Readings of applied load and extensions were noted and recorded.

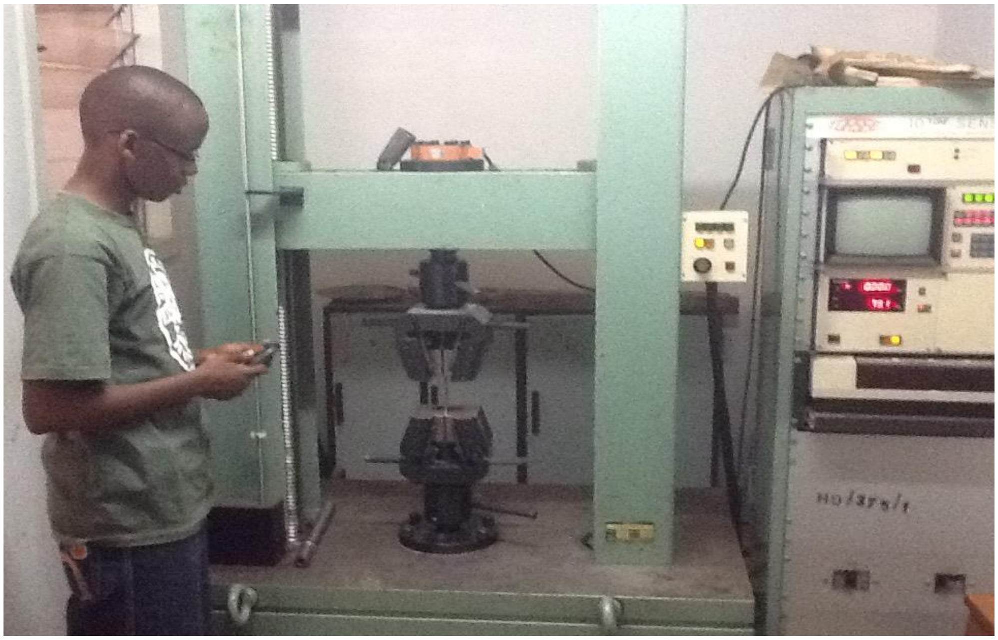


Figure 4.2-2 *Torsee Extensometer*

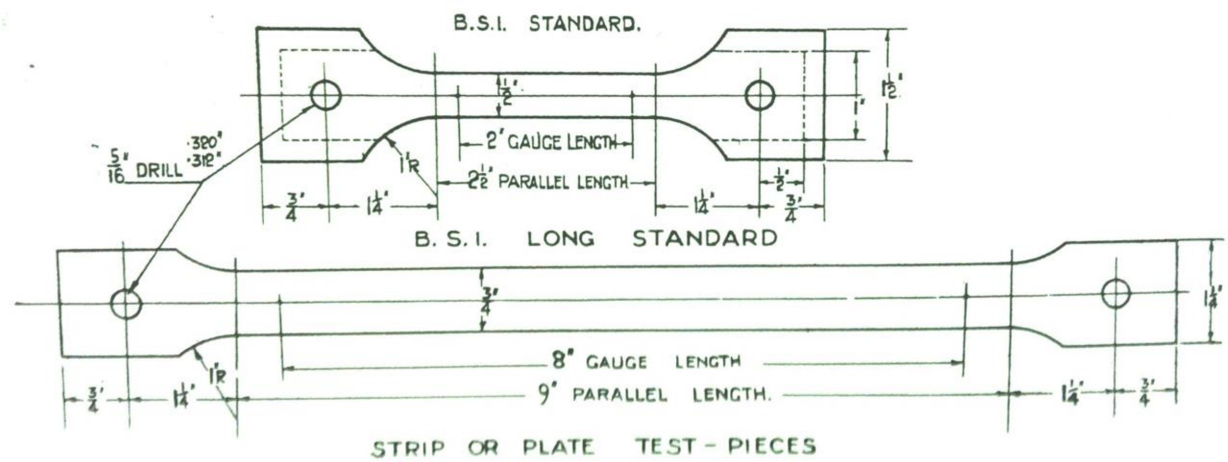
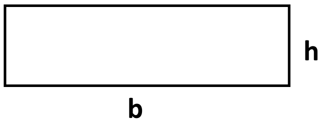


Figure 4.2-3: *BSI standards for tensile test specimen preparation*

4.2.1.3 Tensile Test Results and Analysis

The results for this test are as given in *Tables 8.2-1 through to 8.2-3 in Appendix B*

Analysis



b=0.5inches=12.7mm

h=2mm

The cross sectional area is given as

A=bh

A=12.7x2

∴A=25.4mm^2

Original length, $L_o = 2inches$ = 50.8mm

Sample calculations

Stress

$$\sigma = \frac{P}{A}$$

For test 1 under a load of 1508.6N, the stress is therefore

$$\boldsymbol{\sigma = \frac{1508.6}{25.4}} = \textbf{59.3937 Mpa}$$

Strain

Strain is given by

$\varepsilon = \frac{\Delta L}{L_o}$ Where ΔL is the change in length and L_o is the original length

Under the same test and under a load of 1508.6N, $\Delta L = 0.178mm$

$$\therefore \boldsymbol{\varepsilon = \frac{0.178}{50.8} = 0.0035}$$

Percentage Elongation

$\%\ \text{Elongation} = \frac{L_f - L_o}{L_o}$ Where Lf is the final length and Lo the original length of the gauge

$L_f - L_o$ is the final change in length which for test 1 is 6.798mm

Hence,

$$\%\ \text{Elongation} = \frac{6.798}{50.8} \text{X } 100 = 13.38\%$$

The yield stress is given by 0.2% proof strain

For the stress-strain curve for test 1, this is equivalent to *252 Mpa as shown in Fig 8.2-1, Appendix B*

The results summary is as follows

	Yield stress, σ_y (Mpa)	Ultimate Tensile Strength (Mpa)	% Elongation
Specimen 1	252	425	13.38
Specimen 2	255	425	13.35
Specimen 3	251	420	13.39
Average	252.67	423.33	13.37

Table 4.2-1: *Summarized results for the tensile test carried out on the sample specimen*

4.2.2 Theoretical Calculations

Here two types of calculations were done, one using the tensile test specimen guide and another using beam deflection theory on a single section representing the sections that make up the bus.

4.2.2.1 Tensile test

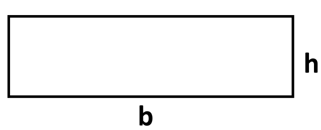
From structural mechanics, stress σ is expressed by

$$\sigma = \frac{P}{A} \qquad (4.2\text{-}1)$$

Where P is load in Newtons (N) and A is cross-sectional area (N/mm^2)

From Fig, the cross sectional dimensions are

b=0.5 inches=12.7mm



h=2mm

A=bh

$\therefore A=25.4mm^2$

For a load of 1000N, the stress would therefore be

$$\sigma = \frac{1000}{25.4} = 39.37 \text{ Mpa}$$

Similarly, the other stresses for the other loads would be as shown in Table 4.1-1

Load (N)	Stress (Mpa)
1000	39.37
4000	157.48
6350	250
10160	400

Table 4.2-2: Stresses and Load

From equation 4.1-1, load P can be expressed as

$$P=\sigma A \quad (4.2\text{-}2)$$

∴For the material to yield, a load of 6350 N is required i.e.

$$25.4 \text{ mm}^2 \text{ x } 250 \text{ Mpa} = 6350 \text{ N}$$

6350N is the theoretical load required to cause yielding at 250 Mpa. Similarly 10160 N is the theoretical stress required for a UTS of 400 Mpa.

4.2.2.2 Beam deflection

4.2.2.2.1 Theory

The equation for giving the deflection of a beam with a uniformly distributed load is calculated by the equation below;

$$\frac{d^2y}{dx^2} = \frac{M}{EI} \quad (4.2\text{-}3)$$

$$EI\frac{d^2y}{dx^2} = M \quad (4.2\text{-}4)$$

But M about a section for a uniformly distributed load on a simply supported beam is given by

$$M = \frac{\omega lx}{2} - \frac{\omega x^2}{2} \quad (4.2\text{-}5)$$

The first integral of *Eq. 4.1-5* with respect to x gives the slope of the beam i.e.

$$\mathrm{EI}\int \frac{d^2y}{dx^2} = \int M = \int (\frac{\omega lx}{2} - \frac{\omega x^2}{2})$$

$$\mathrm{EI}\frac{dy}{dx} = \frac{\omega lx^2}{4} - \frac{\omega x^2}{6} + C_1 \quad (4.2\text{-}6)$$

A second integration with respect to x gives the deflection of the beam

$$\text{EIy}=\frac{\omega l x^3}{12}-\frac{\omega x^4}{24}+C_1x+C_2 \qquad (4.2\text{-}7)$$

Putting in boundary conditions at x=0 y=0 in Eq. 4.1-7 we get $C_2 = 0$

At x=L, the deflection y=0

$$\text{EI (0)} =\frac{\omega l^4}{12}-\frac{\omega l^4}{24}+C_1L \qquad (4.2\text{-}8)$$

Making C_1 the subject

$$C_1 = \frac{\omega l^3}{24}$$

Substituting the value of C_1 in Eq. 4.1-7

This makes the equation for deflection of a simply supported beam to be

$$EIy = \frac{\omega l x^3}{12}-\frac{\omega x^4}{24}-\frac{\omega l^3 x}{24} \qquad (4.2\text{-}9)$$

4.2.2.2.2 Calculations

The frame has the following dimensions

- RHS frame of 0.06m by 0.04m by 0.002m
- Height of 2.3m
- Width of 2.36m

Calculating the value of second moment of inertia

$$\text{I}=\frac{bh^3}{12} \qquad (4.2\text{-}10)$$

$$\text{I}=\frac{0.06*0.04^3}{12}-\frac{0.056*0.036^3}{12}$$

$$\therefore \text{I}=1.228*10^{-7}m^4$$

For ASTM A36, E= 200GPa

The value of the applied load is taken as 11990 N, which is calculated from the total loading capacity of the bus divided by the nine segments.

For a simply supported beam with a uniformly distributed load, the maximum deflection occurs at the center i.e. at x=0.5L. Putting in L=2.36m x=1.18m in Eq.4.1-9

$$EIy = \frac{\omega l x^3}{12} - \frac{\omega x^4}{24} - \frac{\omega l^3 x}{24}$$

$$\{(200x10^9)(1.228x10^{-7})y = \left(\frac{11990x2.36x1.18^3}{12}\right) - \left(\frac{11990x1.18^4}{24}\right) - \left(\frac{11990x2.36^3x1.18}{24}\right)$$

$$28600y = 3874.324 - 968.58 - 7748.648$$

$$y = \frac{-4842.904}{228600}$$

$$\boldsymbol{y = 0.021185m\ or\ 21.185mm}$$

Reaction forces at either end are given by $R = \frac{\omega L}{2}$ (4.2-11)

∴ Reaction force, R in the y direction is **5995N**

4.2.3 Simulation Results and Analysis

4.2.3.1 Tensile test specimen

Here, an exact replica of the tensile test specimen was modeled in the program (Autodesk Inventor Professional). Since the longitudinal dimensions are far much greater than the thickness, the model was treated as a thin section in the analysis, in which the program creates shell elements out of it. The boundary conditions for this model were fixing one edge as shown by the blue line in *Fig 4.2-4* and then applying a force on the other edge at the extreme side as shown in *Fig 4.2-5*

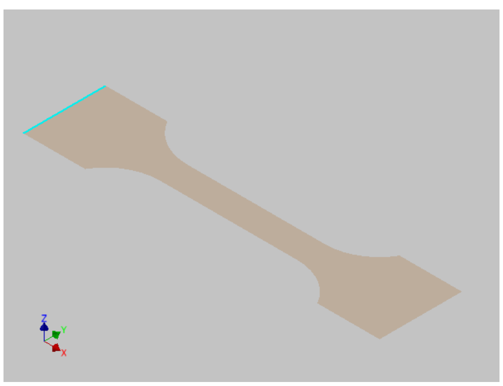


Figure 4.2-4: *Fixed edge*

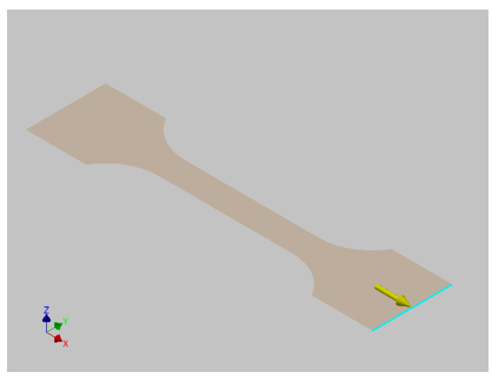


Figure 4.2-5: *Edge where load is applied*

Then material properties were applied to the model by selecting a material of known properties. For the model, we settled on ASTM A36 with a yield strength of 250 MPa and an ultimate tensile strength (UTS) of 399.9 MPA. This selection is as per India's IS 2062 GR.A, IS 2062 GR.B, Europe's EN10025 S235, Germany's ST37.2 and USA standards as specified under KS372. Since Kenya has adopted this standards as our own, ASTM A36 is the closest in terms of properties to the specified standards.

The loading was done as per the loads pre-determined in the theoretical part above i.e. 1000N, 4000N, 6350N and 10.16kN. Finally the simulations were done and the results are shown in *Fig 4.2-6* through to *Fig 4.2-10* and summarized in *Table 4.2-3 and 4.2-4*

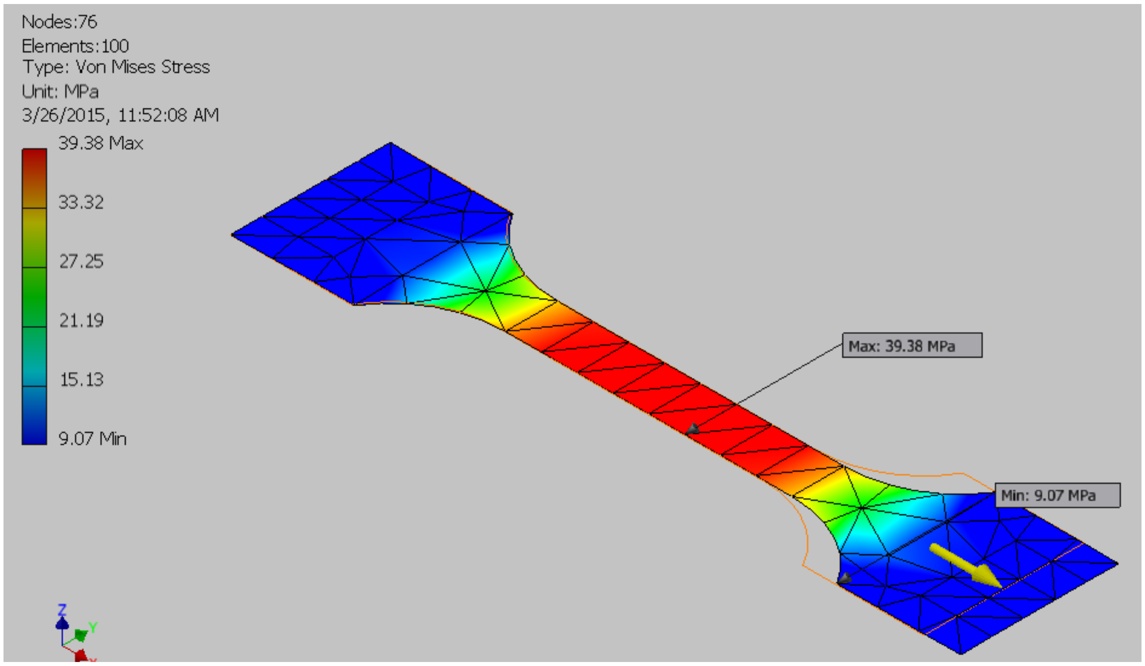


Figure 4.2-6: *Maximum stressed (39.38 Mpa) area under a load of 1000N*

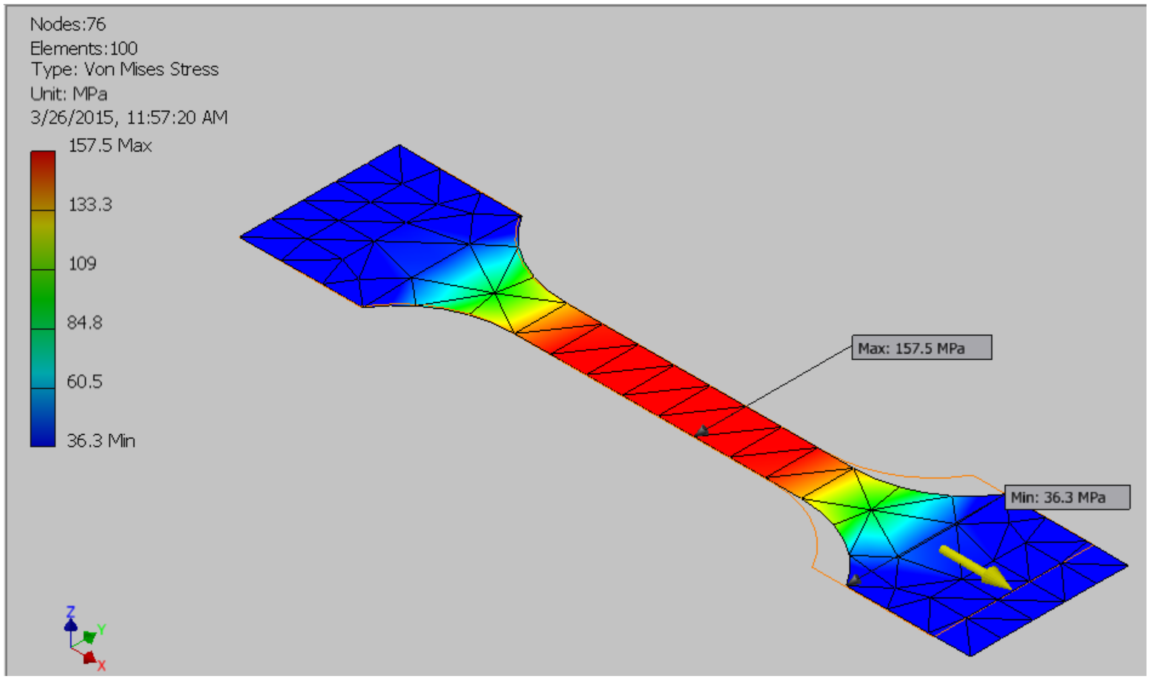


Figure 4.2-7: *Maximum stressed area (157.5 Mpa) under a load of 4000N*

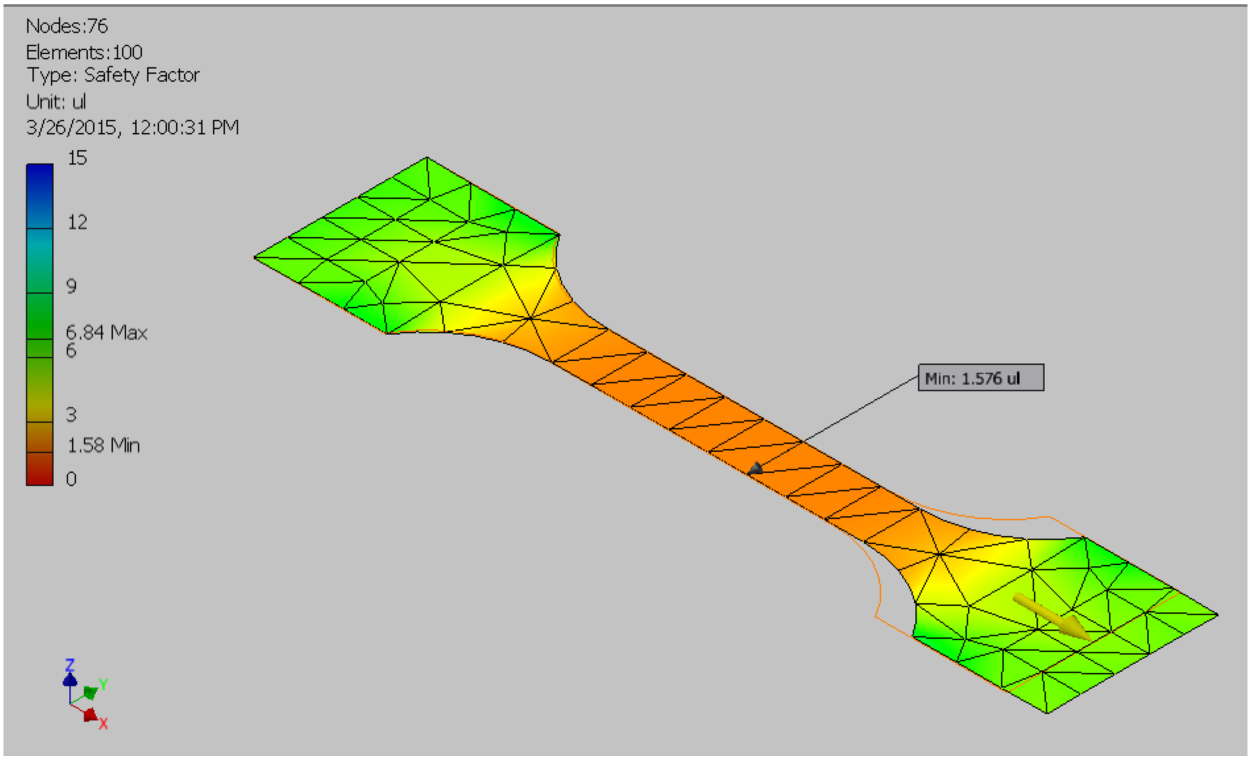


Figure 4.2-8: *Minimum safety factor (1.576) at the maximum stressed area under a load of 4000N*

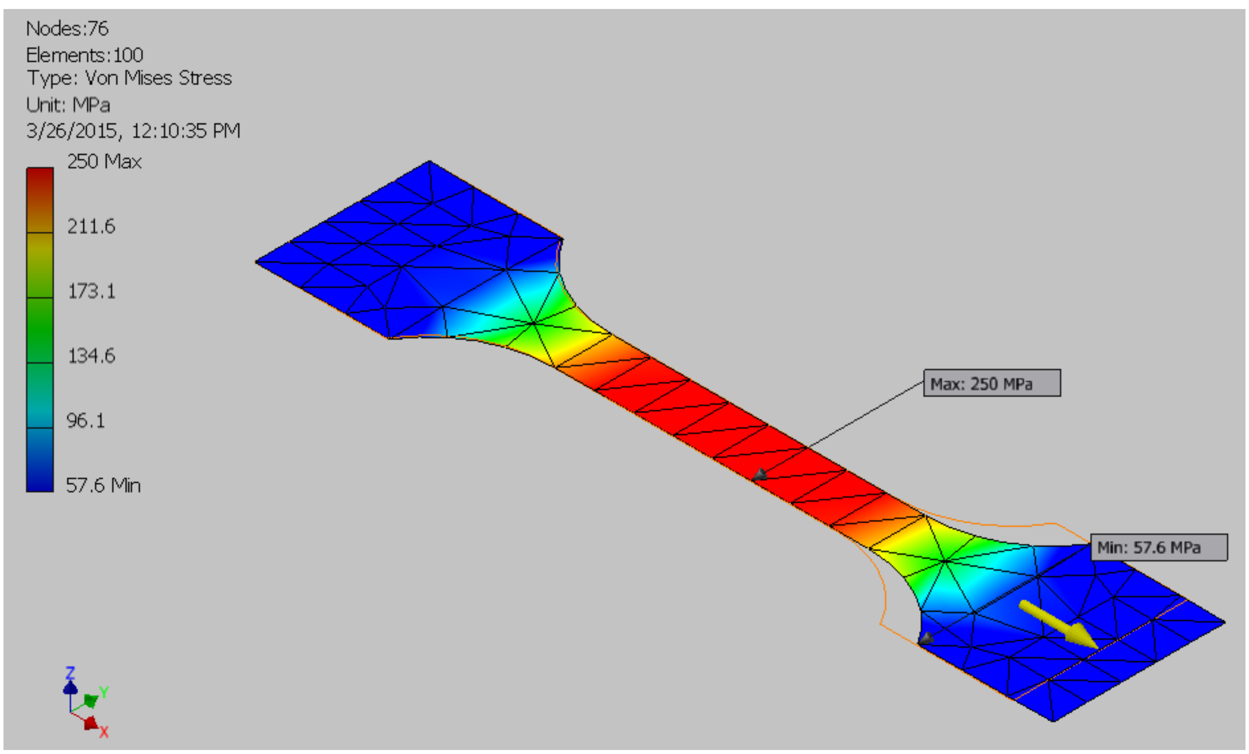


Figure 4.2-9: Maximum stressed area (250 Mpa) under a load of 6350N

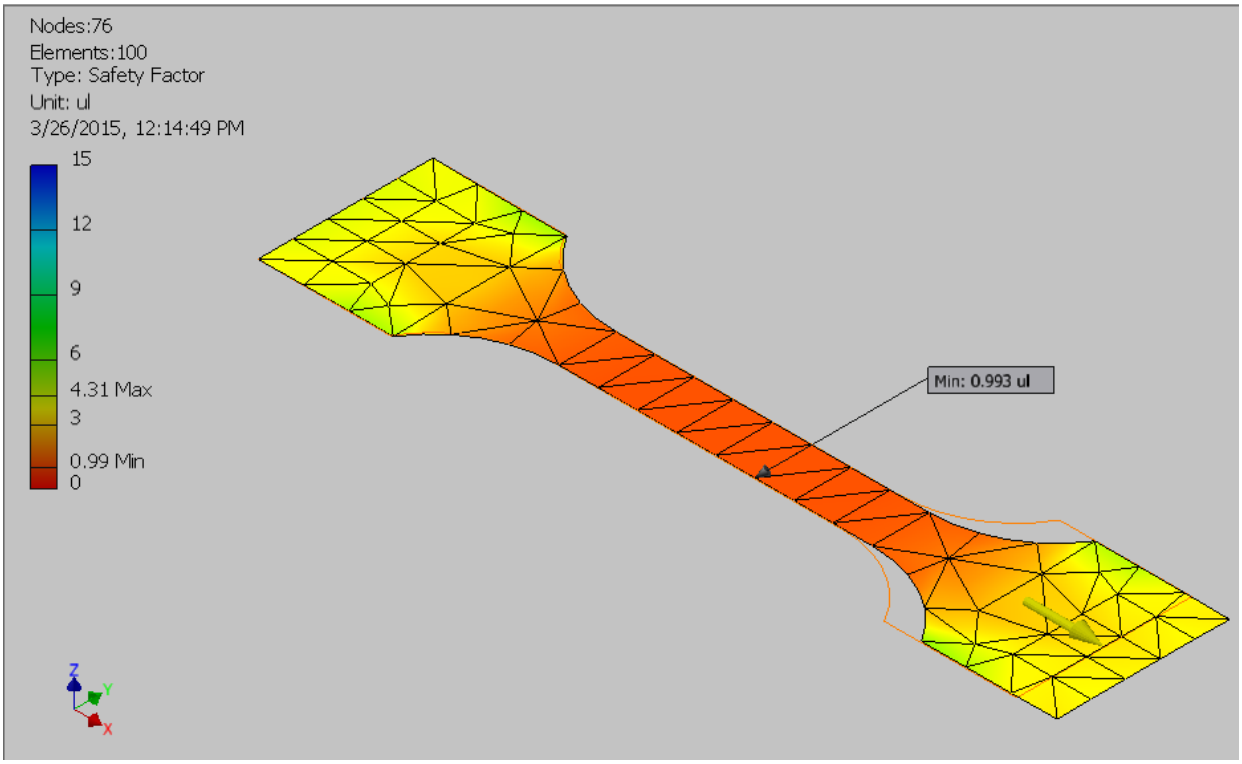


Figure 4.2-10: *Minimum safety factor (0.993) under a load of 6350N*

Load (N)	Stress (Mpa)
1000	39.38
4000	157.5
6350	250
10160	400.1

Table 4.2-3: *Stress results for tensile test simulation*

	Experiment	Theoretical	Simulation
Load (N) Stress (Mpa)	- -	1000 39.37	1000 39.38
Load (N) Stress (Mpa)	- -	4000 157.48	4000 157.5
Load (N) Stress (Mpa)	- 252.67	6350 250	6350 250
Load (N) Stress (Mpa)	- 423.33	10160 400	10160 400.1

Table 4.2-4: *Results summary for experiment, theoretical and simulation*

4.2.3.2 Beam deflection

The portal frame below was modeled in the program as shown in *Fig 4.2-11*

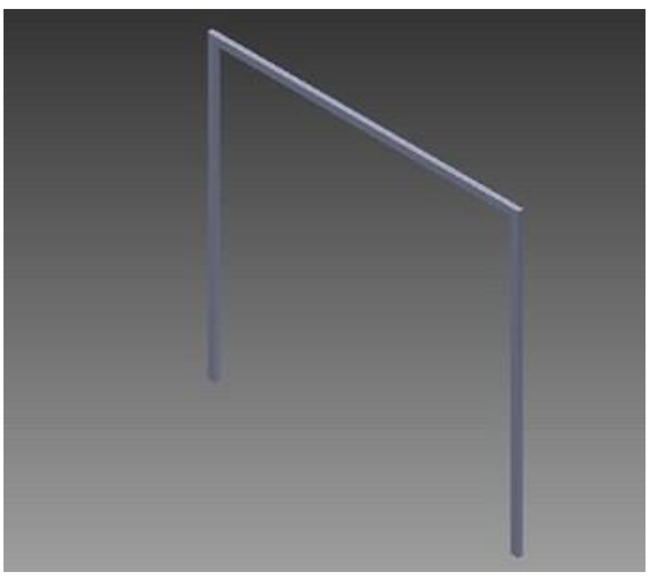


Figure 4.2-11: *Frame section*

Since the longitudinal dimensions are far much greater than the thickness, the program automatically identifies it as a thin body. It generates mid surfaces which are treated as shell elements in the simulation. The boundary conditions applied for this model are fixing the edges at the end as shown by the blue lines in *Fig 4.2-12*

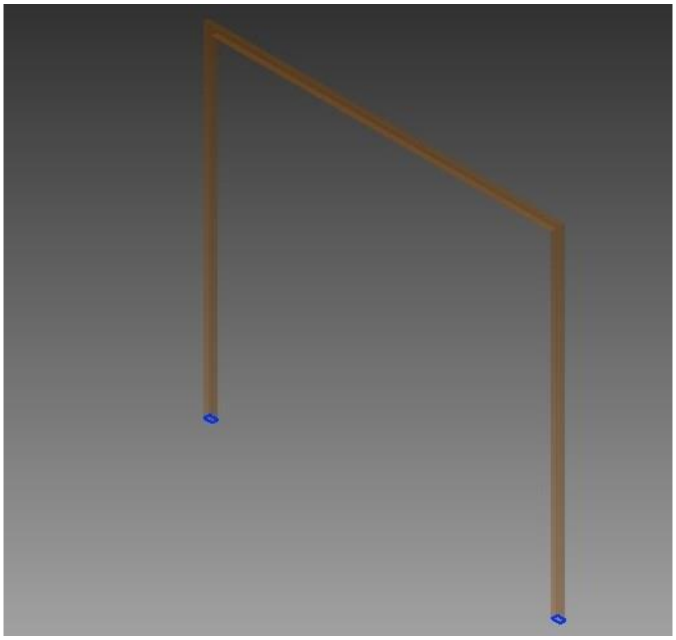


Figure 4.2-12: *Fixed boundary conditions*

The material properties applied are as given previously in section 4.2.3.1

A load of 11990N was applied at the center of the frame and simulation carried. The max deflection occurred at the center and was 20.27mm as shown below

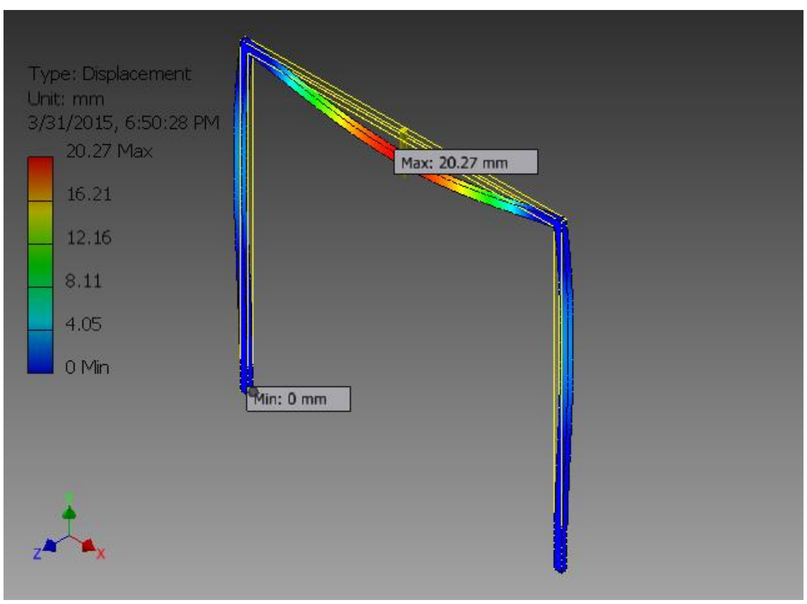


Figure 4.2-13: *Simulation result under a load of 11.99kN*

The other results are as shown next in *Table 4.2-5*

Constraint Name	Reaction Force		Reaction Moment	
	Magnitude	**Component (X,Y,Z)**	**Magnitude**	**Component (X,Y,Z)**
Fixed Constraint:1	6075.06 N	-983.025 N	744.496 N m	-1.55764 N m
		5995 N		-0.742807 N m
		0 N		744.494 N m
Fixed Constraint:2	6075.06 N	983.025 N	744.5 N m	1.55753 N m
		5995 N		-0.678833 N m
		0 N		-744.498 N m

Table 4.2-5: *Detailed results for the frame simulation*

The simulation images are given in the *Appendix C*

4.2.4 Analysis

In the tensile test simulation results and under a load of 6350N which is the load required for yielding at 250 Mpa, the safety factor at the maximum stressed region was 0.993. Theoretically the safety factor cannot be below 1, otherwise the material would either yield or fracture depending on the amount of load applied on it. For a safety factor of 1, the allowable stress would be equal to the yield stress which is evident from *Eq. 4.1-12*

Factor of safety, n

$$n = \frac{\sigma_y}{\sigma_a} \tag{4.2-12}$$

Where σ_a is the allowable stress and σ_y the yield stress.

∴ for a safety factor of 1, $\sigma_a = \sigma_y$ implying that a yield strength of 250 Mpa, under a 6350N load should result to a safety factor of 1. But in the simulation, this load gives a safety factor of 0.993

The percentage error obtained in the simulation safety factor is therefore

$$\%\ error = \frac{n_{theoretical} - n_{simulation}}{n_{theoretical}} \tag{4.2-13}$$

∴ error =0.7%

For the beam deflection theory, the maximum displacement was found to be 21.185mm. The simulation gave a maximum displacement of 20.27mm. The percentage error obtained in the two values is

$$\%\ error = \frac{y_{theoretical} - y_{simulation}}{y_{theoretical}} \tag{4.2-14}$$

∴ Error =4.32%

The theoretical reaction force at either end from *Eq. 4.1-11* is 5995N. The simulation results given in *Table 4.2-5* show the reaction forces of either end in the y direction as 5995N which is identical with the theoretical values.

The above results yield a tolerable percentage error, we can hence place confidence in the software simulations.

4.3 MODEL CREATION

Using chassis data provided by General Motors, the chassis i.e. Isuzu LT 133P with a recommended gross vehicle mass (GVM) of 13500Kg was modelled. The structural frame was modelled by guidance of Kenya's bus body building specifications under KS372 and observations made from the industrial visits. The chassis and the structural frame were later assembled. One of the assumptions made in the model is that all joint that are to be welded are taken as rigid joints. Otherwise this would bring about a new study of finite element analysis of the welds, coupled together with the heat affected zones around the welds which is beyond the scope of the project.

For accuracy in the results obtained, it is important to have a quick grasp of how the program computes the problem and the various settings used to adjust the results for an improvement in accuracy.

4.3.1 Autodesk Inventor Professional

Autodesk's Inventor professional is a high performance design, visualization and simulation product. It offers an easy-to-use set of tools for 3D mechanical design, documentation and product simulation. Digital prototyping with Inventor Professional helps one design and validate products before they are built to deliver better products, reduce development costs and get to market faster. In its FEM applications, there are some settings regarding meshes that the user need to be conversant with and they have been included below

4.3.1.1 Average Element Size

This specifies the average distance between mesh element nodes. The value is a fraction of longest model dimension in X, Y or Z direction. Specifying a smaller value results in smaller mesh elements and an increase in mesh nodes. Generally, the number of elements is inversely proportional to:

- The cube of this parameter for bulky models
- The square of this parameter for thin bodies

The average element size is given by the following illustration

If the Average Element Size input is 0.2, mesh size is computed as

Size of mesh element = Longest parameter of object x Average element size.

Consider the figure below

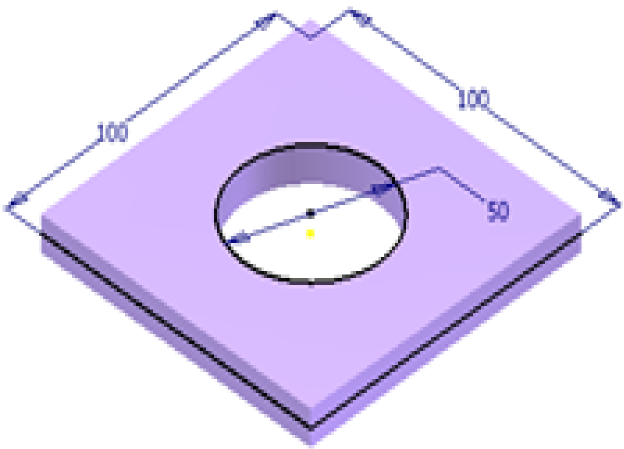
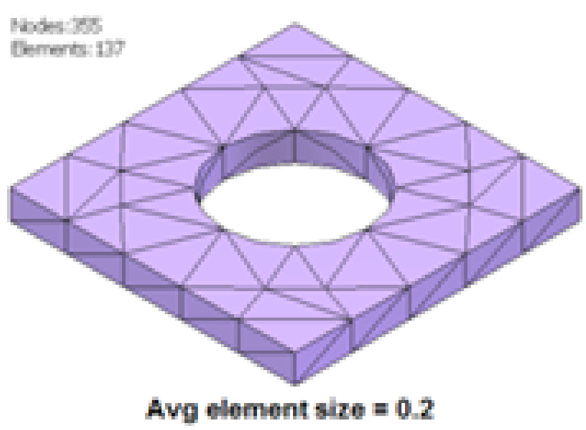


Figure 4.3-1 *(Courtesy: vrblog.info)*

The longest parameter of the object is 100mm. For an average Element Size of 0.1, the mesh size would be approximately equal to 10mm i.e.

Size of mesh element = 100 x 0.2 = 10

This is illustrated below

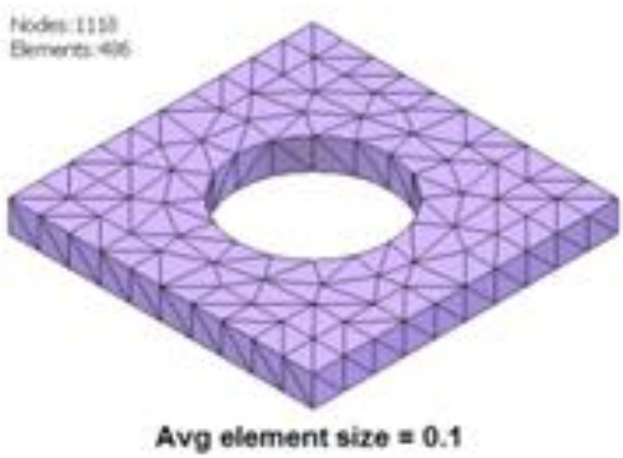


Nodes: 355

Elements: 137

Figure 4.3-2 *(Courtesy: vrblog.info)*

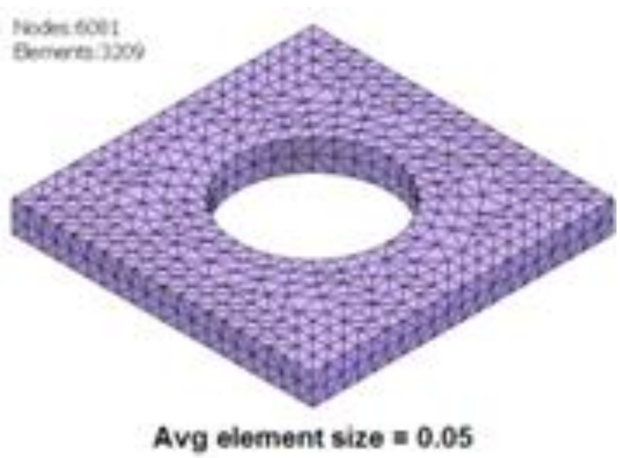
And with different average element sizes, we obtain the below



Nodes: 1118

Elements: 436

Figure 4.3-3 *(Courtesy: vrblog.info)*



Nodes: 6081

Elements: 3209

Figure 4.3-4 *(Courtesy: vrblog.info)*

An average element size of 0.05 will create an element size of 5mm, as per the illustration hence will create two element across the thickness of the plate. It is normally good practice to create at least two more elements across the thickness to get a better stress distribution.

4.3.1.2 Minimum Element Size

This specified the minimum distance between mesh nodes. The value is a fraction of the mesh Average Size value. It is a highly sensitive parameter. If increased, the mesh nodal density will decrease, but the mesh quality may suffer as a result. If decreased, the mesh quality will improve, but the elements may increase significantly and hence more accuracy of results.

Of importance is also the intended analysis and the computational power required for the analysis. Regions that experience high changes in stress usually require a higher mesh density than those that experience little or no stress variation. Points of interest may include fracture points of previously tested material, fillets, corners, complex detail, and high-stress areas. For this areas, a very fine mesh density would be required to improve on the accuracy of the results at the expense of time as it will take longer to analyze.

Common practice usually involves only refining the mesh density at this points of interest rather than for the whole model which would be unnecessary and time consuming. In Autodesk Inventor, this is done by reducing the "Minimum Element Size" in the mesh settings.

4.3.1.3 Maximum Turn Angle

This specifies the maximum angle for arcs, from 1 through to 90 degrees. This can increase the number of elements on curved area. A smaller angle produces smaller mesh elements hence more accurate results.

4.4 BUS MODEL

The model was done as per Isuzu's LT 133P. Its overall length is 10.2m and as per KS 372, it falls under high capacity buses with 52≤N≤ 62 where N is the number of passengers.

KS 372 specifies that the body structures shall not be welded to the chassis. Instead brackets should be bolted to the chassis and the body structures welded on top of it. The brackets as used in the local industry are L plates or channel iron sections and the choice between the two is a matter of the fabricators preference.

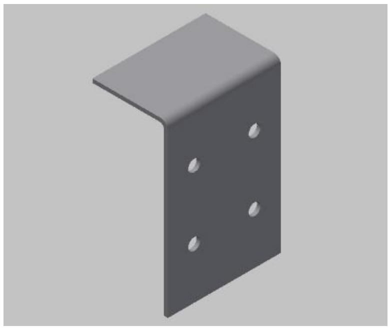


Figure 4.4-1: CAD model for a channel iron section

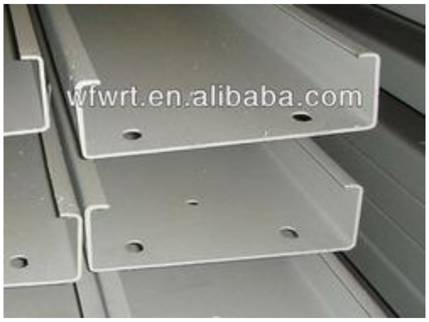


Figure 4.4-2: Channel iron section

(Courtesy: Alibaba.com)

For our model, we settled on L plates and the CAD model is as shown in *Fig 4.4-1* above

The body structures welded onto the chassis mounting brackets are referred to as cross members. They run horizontally and their top most level marks the floor level. Under KS 372 specifications for the chassis model length, RHS frames measuring 100x50x6 should be used. Their form together with their joining to the chassis mounting bracket is as shown in *Fig 4.4-3*

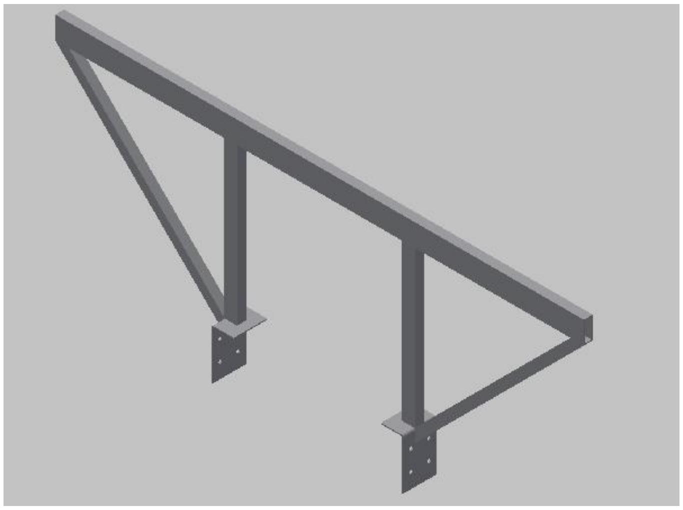


Figure 4.4-3: *CAD model for a body cross member joined on the chassis mounting bracket*

The rest of the body structures together with their dimensions under KS 372 are summarized in *Table 4.4-1*

	Chassis Length	>10.5m
	Approx. number of passengers	±53
	Proposed classification	Large
BODY SECTIONS	Body cross members	Channel section -100x50x6 or I section – 100x50x6
	Side verticals (Anti-roll bars)	RHS 60x40x3 Spacing between the pillars should be placed in a way that they come in line with the cross members placed on the chassis and with a maximum spacing of 1.55m
	Side horizontals	Above cross member level- SHS 40x40x2 and below cross member level-SHS 40x40x2
	Window spacing and height	No window shall exceed the aspect ratio of 2. This means one dimension can only be a maximum of twice the other dimension
	Roof sticks	SHS 40x40x2 and spaced according to the vertical pillars
	Roof longitudinals	Shall be of the same material as used in the roof sticks and spaced equally so as to form a nest structure
	Front and rear sections	Shall have strong supporting with a minimum of SHS 40x40x2 reinforced with angle iron 40x40x3 at front frame. At rear frame a minimum of SHS 30x30x2 and where needed angle iron 40x40x3, for either metal sheeting or fiber glass

Table 4.4-1: *Steel structures descriptions (Extracted from KS372)*

The completed full modeled structure under the guidance of data given in *Table 4.4-1* is shown in *Fig 4.4-4*

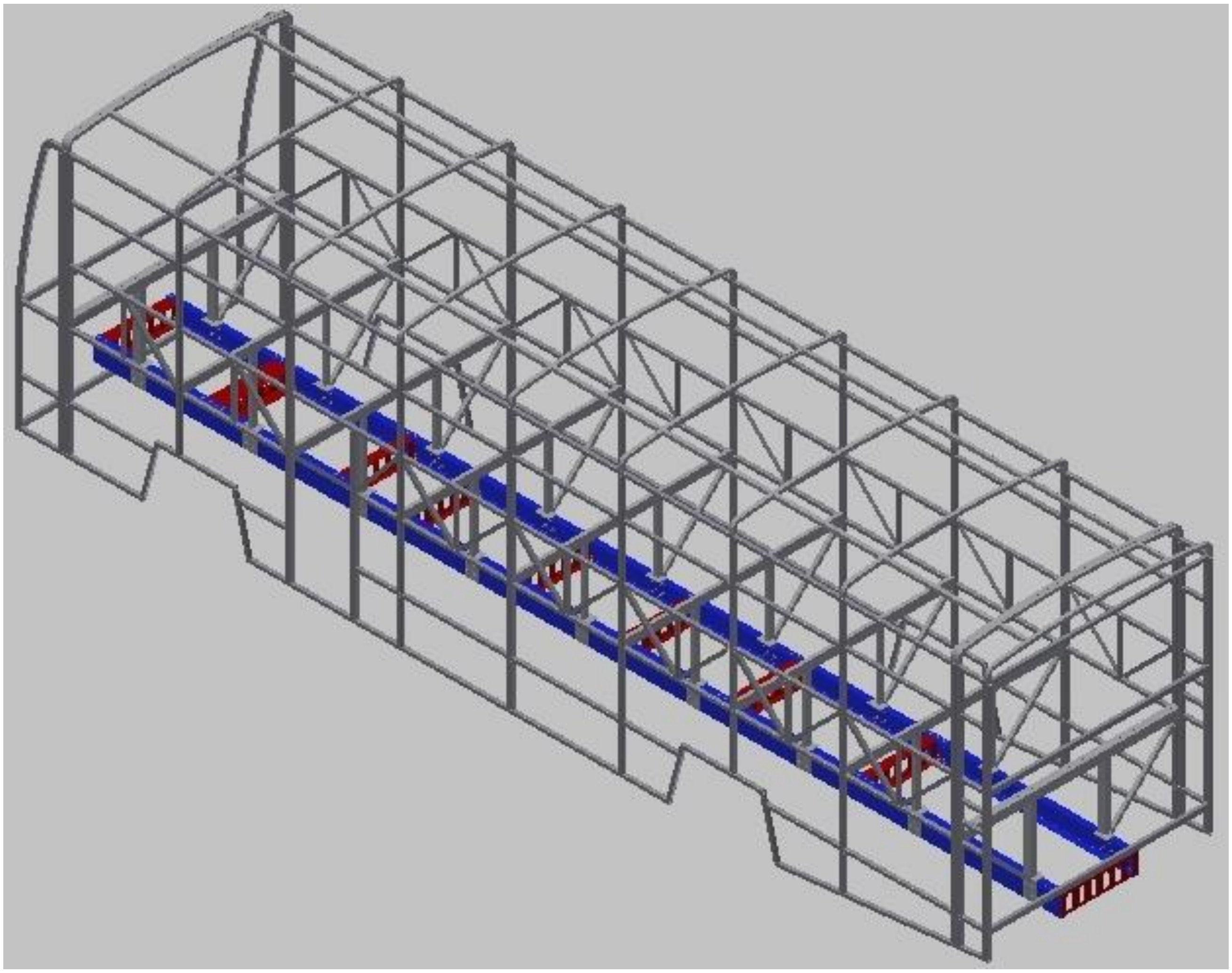


Figure 4.4-4: *CAD model for a bus structure*

CHAPTER 5

5.1 STRUCTURAL ANALYSIS

The mass of this chassis model is 11 tones. The recommended passenger capacity is ±53. Locally, many of such chassis length (10.915m) have a passenger capacity of 62. It is assumed that the average mass of a single passenger is 68kg each with a luggage of 32kg hence a single passenger together with his/her luggage has a total mass of 100kg. Summing this with 62passengers and the dead mass of the bus, this results to a gross vehicle mass (GVM) of 11 tones.

5.2 FINITE ELEMENT MODEL OF THE BUS

The program automatically detects any thin structures and creates mid surfaces which are analyzed as shell elements. The bus' structures have a large longitudinal length compared to the thickness for example a side horizontal with a length of 1200mm and a thickness of 2mm. the ration between the two dimensions is 600 which is greater than 10 i.e. $R \geq 10$ therefore is a thin member.

Hence mid surfaces were created out of them. The small vertical members found on the lower side of the bus did not meet this criteria. However since they are not load bearing structures, they were treated as thin members. Meshing was done onto the model using a mesh size of 0.03125. This mesh size selection is explained later in *section 5.3* under convergence. The finite element model summary of the bus frame is shown in below

No. of nodes	351840
No. of elements	616476

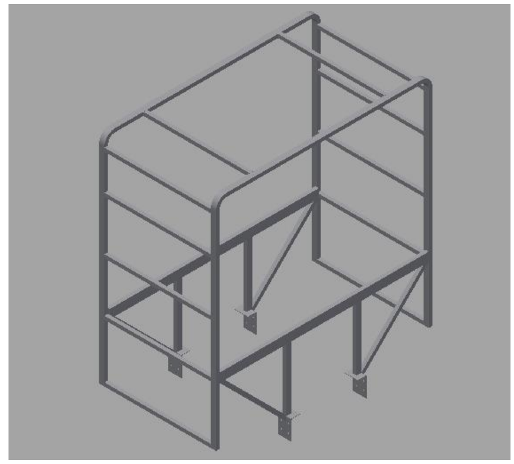
Table 5.2-1: *Number of meshes and nodes for the bus model*

The nodes and elements number is too large for the computational power of the available computers hence it was decided to analyze the bus in sections. First a single section, which is a combination of the side verticals and the roof sticks joined to the cross member welded onto the L plate was done. Then half the bus was analyzed, whose results can be taken to represent the full model of the bus.

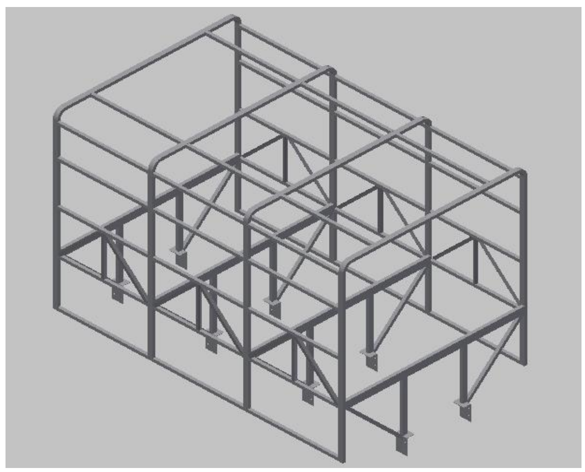
The chassis is only a base where the body frame is fixed to, hence where the structure is joined to the chassis is a fixed support. Hence the chassis can be removed from the analysis to save on the computational power required and instead its mass used in the analysis loads. The boundary conditions applied are:

- Fixed supports at the edges of the L plate
- Fixed joint where the side verticals are welded onto the cross members
- Fixed joints everywhere else where welding need to be done as per the assumptions stated prior

The extracted models from the main bus are shown below



(a) (b)



(c)

Figure 5.2-1 (*a) Single section (b) Two sections with bracing and (c) Half model consisting of four sections*

According to NTSB tests, the bus frame should be able to withstand its own gross weight. This is equivalent to applying the weight of the bus from the top. For the analysis, the gross weight of the bus is divided by the number of U sections and multiplied by 4 to represent half the bus. Hence

Gross weight = GVM x 9.81

$$11000\text{Kg} \times 9.81\text{m/s}^2 = 107910\text{N}$$

Dividing this value by the number of sections that make up the bus which is 9, we get the load for a single section i.e.

$$\frac{107910}{9} = 11990\text{N}$$

For half the bus, this is multiplied by 4 to give

11990N x 4 =47960N.

Hence a load of 47960N should be applied uniformly at the top and it is expected that the frame should be able to withstand that load. The maximum stress should not exceed the yield stress of (250 Mpa for ASTM A36) and the maximum deflection should be below 150mm so as not to intrude on the survival pace (NTSB)

5.3 RESULTS

5.3.1 Single Section

The load that a single U section from the previous section is 11.99kN. This load was applied to the finite element model of the section with an initial average mesh size of 0.5. After simulation, the results are as summarized in *Table 5.3-1* below

Name	Minimum	Maximum
Volume	9428530 mm^3	
Mass	74.0049 kg	
Displacement	0 mm	7.40407 mm
Von Mises Stress	0.0329201 MPa	321.973 MPa
Rotation	0 deg	0.62421 deg
1st Principal Stress	-5.57612 MPa	235.703 MPa
3rd Principal Stress	-159.365 MPa	2.27977 MPa
Safety Factor	0.770947	15

Table 5.3-1: *Results summary for 0.5mesh size under a load of 11.99kN*

A mesh refinement was done reducing the average element size 0.25 and the results are as summarized in *Table 5.3-2*

Name	Minimum	Maximum
Volume	9428530 mm^3	
Mass	74.0049 kg	
Displacement	0 mm	7.57696 mm
Von Mises Stress	0.0330877 MPa	327.746 MPa
Rotation	0 deg	0.635732 deg
1st Principal Stress	-7.84339 MPa	228.247 MPa
3rd Principal Stress	-152.024 MPa	3.15489 MPa
Safety Factor	0.757369	15

Table 5.3-2: *Results summary for 0.25mesh size under a load of 11.99kN*

Further mesh refinement was done reducing the average element size 0.125 and the results are summarized in *Table 5.3-3*

Name	Minimum	Maximum
Volume	9428530 mm^3	
Mass	74.0049 kg	
Displacement	0 mm	8.20549 mm
Von Mises Stress	0.0212388 MPa	313.493 MPa
Rotation	0 deg	0.727562 deg
1st Principal Stress	-16.9024 MPa	232.751 MPa
3rd Principal Stress	-155.804 MPa	3.3869 MPa
Safety Factor	0.791803	15

Table 5.3-3: *Results summary for 0.125mesh size under a load of 11.99kN*

Further mesh refinement was done reducing the average element size 0.0625. The results are summarized in *Table 5.3-4*

Name	Minimum	Maximum
Volume	9428530 mm^3	
Mass	74.0049 kg	
Displacement	0 mm	8.20549 mm
Von Mises Stress	0.0212388 MPa	313.493 MPa
Rotation	0 deg	0.727562 deg
1st Principal Stress	-16.9024 MPa	232.751 MPa
3rd Principal Stress	-155.804 MPa	3.3869 MPa
Safety Factor	0.791803	15

Table 5.3-4: *Results summary for 0.0625mesh size under a load of 11.99kN*

Further reduction of the mesh size was done now reducing the size to 0.03125. The results are summarized in *Table 5.3-5*

Name	Minimum	Maximum
Volume	9428530 mm^3	
Mass	74.0049 kg	
Displacement	0 mm	8.20549 mm
Von Mises Stress	0.0212388 MPa	313.493 MPa
Rotation	0 deg	0.727562 deg
1st Principal Stress	-16.9024 MPa	232.751 MPa
3rd Principal Stress	-155.804 MPa	3.3869 MPa
Safety Factor	0.791803	15

Table 5.3-5: *Results summary for 0.05mesh size under a load of 11.99kN*

From these results, it can be observed that the max stress is converging to 313.5Mpa as summarized in *Table 5.3-6*

Mesh size	0.5	0.25	0.125	0.0625	0.03125
Maximum Stress (Mpa)	321.993	327.496	313.493	313.493	313.493

Table 5.3-6: *Results summary for the mesh sizes used*

A convergence plot of this stress results is shown below

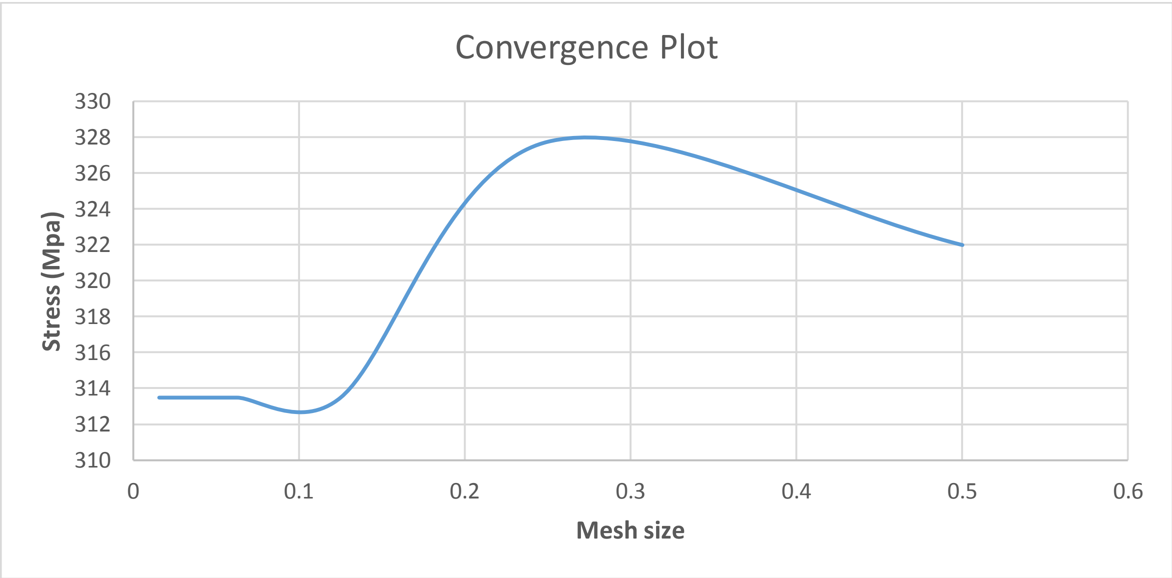


Table 5.3-7: *Convergence plot for stress under the different mesh sizes*

Percentage errors between two successive mesh sizes can be calculated and is as shown in *Table 5.3-8*

Mesh range	0.5-0.25	0.25-0.125	0.125-0.0625	0.0625-0.03125
Stress change (Mpa)	70.46	17.948	7.602	2.903
Percentage stress change (%)	1.709	4.467	0	0

Table 5.3-8: *Percentage error between two consecutive mesh sizes*

From *Table 5.2-8* above, we observe no change between the last two mesh refinements which implies the results will not deviate from 313.493 Mpa even if the mesh size is further reduced. Hence for subsequent simulations, a mesh size of 0.03125 will be used.

5.3.2 Half model frame

After doing a meshing with a mesh size of 0.03125, the following results were obtained

Number of nodes	58640
Number of elements	102746

Table 5.3-9: *Nodes and elements number for the half model of the bus*

From *section 5.1*, the half model of the frame should be able to withstand a load of 47.96kN. The simulation results for this model are shown below

Name	**Minimum**	**Maximum**
Volume	56491400 mm^3	
Mass	443.403 kg	
Displacement	0 mm	7.92032 mm
Von Mises Stress	0.00796922 MPa	158.745 MPa
Rotation	0 deg	0.749919 deg
1st Principal Stress	-25.3367 MPa	166.443 MPa
3rd Principal Stress	-160.751 MPa	15.4286 MPa
Safety Factor	1.56366	15

Table 5.3-10: *Results for half model of the bus under its own weight*

According to NTSB, the bus should also be able to withstand 1.5times its gross weight. This factor represents an upper limit that the bus should be able to take and in many instances used to portray dynamic conditions e.g. when the vehicle tips

Gross weight = 11000 x 1.5 x 9.81 = 1618650N

A single section should therefore take

$$\frac{1618650}{9} = 179850\text{N}$$

∴ For 1.5x the load, the half the model of the bus should take a load of 719400N

For this load, the simulations results are as below

Name	Minimum	Maximum
Volume	56491400 mm^3	
Mass	443.403 kg	
Displacement	0 mm	11.8805 mm
Von Mises Stress	0.0119539 MPa	238.118 MPa
Rotation	0 deg	1.1248 deg
1st Principal Stress	-38.005 MPa	249.665 MPa
3rd Principal Stress	-241.126 MPa	23.1429 Mpa
Safety Factor	1.04244	15

Table 5.3-11: *Results for half model of the bus under 1.5X its own weight*

Given local conditions, we cannot settle on the above and further a load that is 2 times the gross weight of the bus should be used. This can be an equivalent of an overload condition which is a similar occurrence locally. Further a load 2.5 times the gross weight of the bus was. This load factor is also recommended by the Federal Transit Administration (FTA) that provides financial and technical assistance to local public transportation systems in the United States of America. Adopting this factor is a major recommendation as it can be used to portray extreme conditions of overload which are a common occurrence locally. The loads hence will be

2 times the load

Gross weight = 11000 x 9.81 x 2 = 215820N

Single frame load

$$\frac{215820}{9} = 23980\text{N}$$

Total load for half model 23980N x 4 = 95920N

2.5 times the load

Gross weight = 11000 x 9.81 x 2.5 = 269775N

Single frame load

$$\frac{269775}{9} = 29975\text{N}$$

Total load for half model 29975 x 4 = 119900N

These results are summarized below

Volume 56491400 mm^3 Mass 443.403 kg								
Load	47960N (1X)		71940N (1.5X)		95920N (2X)		119900N (2.5X)	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Displacement (mm)	0	7.92032	0	11.8805	0	15.8406	0	19.8008
Von Mises Stress (Mpa)	0.0079692	158.745	0.0119539	238.118	0.0159384	317.491	0.0199233	396.864
Rotation (Degrees)	0	0.749919	0	1.1248	0	1.49958	0	1.87424
1st Principal Stress (Mpa)	-25.3367	166.443	-38.005	249.665	-50.6734	332.886	-63.3417	416.108
3rd Principal Stress (Mpa)	-160.751	15.4286	-241.126	23.1429	-321.502	30.8572	-401.877	38.5715
Safety Factor	1.56366	15	1.04244	15	0.781832	15	0.625466	15

Table 5.3-12: *Simulation results for half model of the bus under loads of 1X, 1.5X, 2X, 2.5X the weight of the bus*

CHAPTER 6

6.1 DISCUSSIONS

The analysis of the frame in the simulations was done at different loadings which is a representative of NTSBs standards and our local conditions here e.g. Apart from the frame being able to withstand its own weight, NTSB recommends that the structure should be structurally sound under a load of one and a half times (1.5X) the weight of the bus which would represent a moderately overloaded bus. But considering the cases of overloading of buses here in Kenya, a further two times (2X), representing a heavy overload, and two and a half times (2.5X), representing extreme overload should be applicable. Of important interest in the analysis

- Maximum stress
- Maximum deflection

6.1.1 Maximum Stress

The main aim of observing this is to determine where it occurs, and the value compared to the yield stress (σ_y) and the ultimate tensile stress ($\sigma_{UTS)}$ to determine whether the structure has yielded or is about to break. In the event that the maximum stress is greater than σ_{UTS}, failure of the material will have occurred.

6.1.2 Maximum Deflection

The maximum deflection was taken into account in order to observe by how much the frame structure intrudes into the survival space. The threshold of this intrusion as set by the NTSB is 150mm. However in the event of the structure failing i.e. $\sigma_{max} > \sigma_{UTS}$, the deflection becomes null and void as failure has already occurred.

6.1.3 Simulation Results

The ideal case for the simulation was to do it on the whole bus structure as shown in *Fig 4.4-4*. However due to limitations of computing power of the available resources, the simulation was done progressively starting with a single section, then two sections and finally four frames which is a representative of half the bus as shown in *Fig 5.2-1 (c)*. A full bus frame was attempted several times with no success as the program would crush after almost four and a half hours of generating mid-surfaces from the model even before getting to meshing of the model.

Before simulation, different mesh sizes were applied on a single section of the bus so as to find out a mesh size to give the best results. This is done via a convergence plot of the respective mesh sizes together with the stresses observed under them. The plot as given in *Fig 5.3-7* shows the stress converging to 314.493 Mpa with minimum mesh sizes of 0.0625 and 0.03125. Hence for more accurate results, we settled on a minimum element size of 0.03125 with an average mesh size of 0.5. A point to note is that the minimum mesh size is concerned with regions of stress concentrations while the average, just as the name suggests is the average size of the mesh in the model.

From the simulation results, it can be observed that when a single section was loaded at 11.99 kN, which is a representative of the total bus weight divided by the nine sections that make up the bus, the maximum stress observed was 321.993 Mpa. On adding a second section braced together with the first using horizontal members, the max stress observed was 200.299 Mpa. From statics, this is expected as the braces should relieve some of the stresses from the main section. Hence with further bracing, a further drop in the maximum stress observed is expected, which for our case was 158.745 Mpa from 200.299 Mpa.

With the final mesh size determined, the simulation was hence conducted on the half model of the bus under different load factors of its own weight and the results are as given previously in *section 5.3.2*. These results are on the basis of whether the frame would yield and/or fail and whether the displacement would pass the threshold of 150mm set by the NTSB. In the event of the structure failing i.e. fracture, the displacement would also be a fail. A YES hence will indicate a pass and a NO indicates a fail. These results are as summarized in *Table 6.1-1*

Load Factor	1X	1.5X	2X	2.5X
Displacement	YES	YES	YES	YES
Von Misses (Max)	YES	YES	NO	NO

Table 6.1-1: *Results summary for yielding and fracture*

From the above table, the frame structure passes at both 1X and 2X loading in the displacement and maximum stress observed. It yields at 2X and 2.5X i.e. $\sigma_{max} > \sigma_y$ and at the same time indicating a pass on the displacement. However at the condition of 2.5X, the maximum stresses observed of 396.864 Mpa was almost the ultimate tensile stress of 399.9 Mpa. This indicates the possibility of the material failing at the slightest of load increase as the difference between the two is only 3.036 Mpa.

6.2 CONCLUSION

A study of the different bus frame designs was done albeit with the cooperation limitation between us and the local fabricators. The information gathered from the industrial visits coupled together with specifications from KS372 was used to model the bus structure. Autodesk's Inventor Professional was used for modeling and simulation, primarily because it's a dedicated program for 3D design and simulation and also due to its availability as a free student's version.

Material characterization involves determining specific material properties such as yield stress, ultimate tensile strength, ductility etc. through tests. A sample of the frame used for fabrication of the buses was obtained from one of the local companies, from which 3 tensile test specimens were prepared and a tensile test carried out in order to determine the yield stress and ultimate tensile tress of the samples. The results from the test were compared to the given properties of the material from KS372. The material did indeed meet the standards with a yield stress of approximately

252.67 Mpa and a UTS of 423.33 Mpa. It is important to state that the sample was not selected at random but was supplied by the fabricator.

Model validation is done as a proof of what is done virtually thorough the program is what actually takes place in physical tests. After modeling the specimen in the program, assigning the respective material properties and simulating the test, the simulation results values obtained matched both the theoretical and experimental values. Hence the model was validated.

A model comprising of four section representing half the bus was simulated for static conditions by applying a uniformly distributed load at the top of the frame. This load was gradually increased by factors of 1.5,2 and 2.5 as recommended by NTSB, FMVSS and our local conditions. The stresses on the frame and the corresponding displacements were observed and analyzed, of interest being maximum stresses and displacements. These were observed to be the corners and joint, which theoretically are the expected regions of stress concentrations.

6.3 RECOMMENDATIONS

In terms of the existing designs there are several alternative solutions that can improve the crashworthiness of the bus structure and they include

1. Increasing the thickness of the side vertical members
2. Altering the designs to include cross braces connecting the roof to the side frames
3. Decrease the weight of the bus by using engineered light but strong materials e.g. Aluminium

6.3.1 Increasing Thickness of Side Verticals

From the used RHS of 60x40x3mm, the next available size for this member is 60x40x4mm. This was done on our simulation giving the following results

Under a load of two times (2X) and two and a half times (2.5X), the maximum stresses observed are still above the yield point, though they have dropped compared to the values of 3mm thickness of the RHS as shown in *Table 6.3-1*. This suggests a further increase in the thickness of the frame to see how it will behave. However, the 60x40x4mm RHS size is the maximum that is available in the market hence not possible to do this trial.

To note is also the increase of the GVM of the half model of the bus from 443.403Kg to 505.974Kg. In terms of percentage increase of the GVM, it is an equivalent of 14.11%. Hence increasing the size of the RHS thickness from 3mm to 4mm would result to an increase on the GVM of the whole bus by 14.11%.

Increase of mass in a vehicle has a corresponding increase in the cost of fabricating a unit and also on the fuel consumption.

Volume 64463200 mm^3 Mass 505.974Kg								
Load	47960N (1X)		71940N (1.5X)		95920N (2X)		119900N (2.5X)	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Displacement (mm)	0	6.17505	0	9.26258	0	12.3501	0	15.4376
Von Mises Stress (Mpa)	0.003003	148.204	0.004505	222.306	0.006007	296.408	0.007509	370.51
Rotation (Degrees)	0	0.583727	0	0.875552	0	1.16733	0	1.45905
1st Principal Stress (Mpa)	-25.2876	150.809	-37.9314	226.214	-50.5753	301.618	-63.2191	377.023
3rd Principal Stress (Mpa)	-162.392	17.2585	-243.588	25.8878	-324.784	34.5171	-405.98	43.1464
Safety Factor	1.67488	15	1.11659	15	0.837441	15	0.669953	15

Table 6.3-1: *Results summary for an increase in thickness of the vertical members from 3mm to 4mm*

A summary of these results is as given below

Load Factor		1X	1.5X	2X	2.5X
Maximum stress (Mpa)	60x40x3mm	158.745	238.118	317.491	396.864
	60x40x4mm	148.204	222.306	296.408	370.51
Difference (%)		6.64	6.64	6.64	6.64

Table 6.3-2: *Result summary for maximum stresses observed between 3mm and 4mm thick vertical members respectively*

These being all economic factors, they are vital in the decision making if the above was to be applied. Correlating the percentage increase to the fabrication cost, it would increase by approximately 14%. The effect of fuel consumption will call for experiments on a bus to determine its fuel consumption per kilometer under different loads and hence getting the fuel consumption per mass per kilometer covered.

6.3.2 Including Cross Braces

Cross braces can be welded between the roof frames and side frames. A schematic of this is as shown below. This would have the effect of relieving some of the stresses from the stress concentrations resulting from the corners.

6.3.3 Using Engineered Materials

Engineered materials are simply materials designed with a specific purpose in mind. Examples in use in the market are reinforced carbon fiber shafts used in formula one cars that are strong and light which exhibit a high strength-to-weight ratio.

In our case, special alloys of aluminium which exhibit good strength properties can be used. Aluminium has a density of 2700Kgm^{-3} and comparing this with steel's density of approximately 7800Kgm^{-3}, it is evident that the GVM of the bus would more than half.

6.3.4 Possible Challenges

Given the logical suggestions on the improvements, there still lies a big challenge in statistics between passenger and pedestrian deaths in Kenya.

CLASS OF VICTIMS	2013	2014	VARIANCE	% VARIANCE
DEAD	2,684	2,375	-309	-11.5
SERIOUSLY INJURED	5,444	4,322	-1122	-20.6
SLIGHTLY INJURED	4,190	3,239	-951	-22.7
TOTAL	**12,318**	**9,936**	-2382	-19.3

Table 6.3-3: *Summary of victims*

	2014	2013	% VARIANCE
PEDESTRIANS	1109	1227	-9.616951915
DRIVERS	212	237	-10.54852321
PASSENGERS	510	696	-26.72413793
PILLION PASSENGERS	130	131	-0.763358779
PEDAL CYCLISTS	89	118	-24.57627119
MOTORCYCLISTS	325	275	18.18181818
TOTAL	**2,375**	**2,684**	**-11.51266766**

Table 6.3-4: *Summary of the dead*

Tables 6.3-3 and 6.3-4 are statistics for 2013 and 2014 as at 1st November 2014 (Courtesy: NTSA). Refer to Appendix C, Table 8.3-1

It is clear from the above statistics that pedestrians account for more deaths resulting from road accidents compared to passengers. Hence as much as solutions to improve the structural integrity of the bus structures in our country have been given, the bodies mandated to do so (NTSA and KEBS) may place priority in first reducing pedestrian related fatalities. In as much as this is a good measure, the value of life should not be prioritized depending on the circumstance but should come first at all times. Hence a way to implement the two should be developed.

6.3.5 Future work

The recommendations given leaves a gap for future work given the time and resources. Other scholars with a similar interest can pursue and continue with the work. A strong recommendation is given to use of engineered materials

CHAPTER 7

REFERENCES

1. Autodesk.com, 2015. *Finite Element Analysis.* [Online]
   Available at: http://usa.autodesk.com/adsk/servlet/item?siteID=123112&id=17670721

2. Autodesk.com, 2015. *Nodes and Elements.* [Online]
   Available at: http://knowledge.autodesk.com/support/simulation-mechanical/learn-explore/caas/CloudHelp/cloudhelp/2015/ENU/SimMech/files/GUID-16EF4987-F5D2-4301-B73E-75F56E2A7A03-htm.html

3. Cook, R. D., 1995. *Finite Element Method for Stress Analysis.* s.l.:JOHN WILEY & SONS.

4. Engineer, D. S. K. C., 2009. *Rollover Analysis of Bus Body Structure as Per AIS 031/ECE R66-Simulation Driven Innovation,* Bangalore, India: Volvo Group Trucks Technology.

5. Expectancy, W. L., 2011. *Kenya: Road Traffic Accidents.* [Online]
   Available at: www.worldlifeexpectancy.com/kenya-road-traffic-accidents

6. Geo-informatics, C. G. M. A. P. o., 2013. *Combating Road Traffic Accidents in Kenya: A Challange For an Emerging Economy,* s.l.: Radford University, Radford, VA.

7. International Monetary Fund-Country Report, 2015. *POVERTY REDUCTION STRATEGY PAPER—JOINT STAFF.* [Online]
   Available at: http://www.imf.org/external/pubs/ft/scr/2014/cr1474.pdf

8. Ministry of Foreign Affairs, 2012. *Kenya Facts and Figures.* [Online]
   Available at: http://www.mfa.go.ke/downloads/9-Kenya-facts-and-figures-2012.pdf

9. Muchene, L. K., 2012. *Road Accidents in Kenya: a Case of Poor Road Network,* Diepenbeek: Universityof Hasselt, Diepenbeek, Belgium.

10. MUKABANAH, E. M., 2013. *Road Reforms ,* Nairobi: Road Transport ACT 2013.

11. National Highway Traffic Safety Administration- USA, 2007. *Bus Rollover Structural Integrity,* Washington, DC: Department of Transportation-USA.

12. NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION, 1991. *FMVSS 220 School Bus Rollover Protection,* s.l.: s.n.

13. National Transport and Saftery Authority Kenya, 2013/2014. *Accident Statistics.* [Online]
    Available at:
    http://www.ntsa.go.ke/index.php?option=com_content&view=article&id=213&Itemid=706

14. Owen, B. D. a. G. W., n.d. *STEEL DESIGNER'S MANUAL.* 6th Edition ed. s.l.:Blackwell Publishing.

15. Region, T. D.-T. G. o. t. H. K. S. A., 2014. *Vehicle Registration and Eexamination.* [Online]
    Available at:
    http://www.td.gov.hk/en/publications_and_press_releases/publications/free_publications/annual_transport_digest_2000__/vehicle_examination_/index.html

16. Rotter, A. S. &. J., 2013. *Solid or shell finite elements to model thick cylindrical tubes and shells under global bending,* London, UK: International Journal of Mechanical Sciences.

17. sen, n.d. *POVERTY REDUCTION STRATEGY PAPER—JOINT STAFF.* [Online].

18. Sharad, D. P., December 2006. *ROLLOVER AND ROOF CRUSH ANALYSIS OF LOW FLOOR MASS TRANSIT BUS,* s.l.: Marathwada University.

19. Standard Media, 2015. *NTSA Reports Decline in Number of Road Accidents.* [Online] Available at: http://www.standardmedia.co.ke/article/2000140286/ntsa-reports-decline-in-number-of-road-accidents/

20. University of Colorado Boulder, n.d. *Introduction to Finite Element Analysis.* [Online] Available at: http://www.colorado.edu/engineering/cas/courses.d/IFEM.d/IFEM.Ch06.d/IFEM.Ch06.pdf

21. University of Colorado Boulder, n.d. *Introduction to Finite Element Methods.* [Online] Available at: http://www.colorado.edu/engineering/cas/courses.d/IFEM.d/IFEM.Ch01.d/IFEM.Ch01.pdf

22. Wilson Odero, M. K. P. H., 2003. *Road Traffic Injuries In Kenya : Magnitude,Causes and Status of Intervention,* Nairobi : Swets & Zeithlinger .

23. World Health Ranking, 2015. *Kenya: Road Traffic Accidents.* [Online] Available at: http://www.worldlifeexpectancy.com/kenya-road-traffic-accidents

APPENDICES

8.1 APPENDIX A

Type	29/33 Seater		51 and above	
Destination	From Town	Into Town	From Town	Into Town
Total Passenger Vehicles	116	50	23	8
Respective Fabricators				
KVM	2	0	1	1
Harveer	2	0	0	0
TMD	4	2	0	1
CFG	22	5	0	0
KCI	32	17	0	0
LSHS	17	5	6	2
Master Fabricators	1	0	1	0
Dodi Autotech	9	9	0	1
AM	1	1	0	0
Banbros	4	0	2	0
2M Autotech	0	0	2	0
Matam Fabricators	0	0	0	0
Choda Fabricators	1	0	3	0
Astrabell	0	4	0	1
Highlands	0	1	0	0
Truckworld	0	0	0	0
Unknowns	21	6	8	2
Total	**116**	**50**	**23**	**8**

Table 8.1-1: *Data showing bus fabricators taken at Haile Selassie Avenue between Railways roundabout Junction and Uhuru Highway/Haile Selassie roundabouts from 9:50am-10:30am*

Type	29/33 Seater		51 and above	
Destination	From Town	Into Town	From Town	Into Town
Total Passenger Vehicles	38	87	44	58
Respective Fabricators				
KVM	0	0	0	1
Harveer	0	0	0	2
TMD	0	2	1	0
CFG	0	27	0	0
KCI	2	9	2	5
LSHS	4	13	4	6
Master Fabricators	0	0	0	1
Dodi Autotech	0	9	0	0
AM	0	5	1	3
Banbros	5	9	8	7
2M Autotech	6	4	10	7
Matam Fabricators	0	0	0	0
Choda Fabricators	0	0	0	1
Astrabell	0	0	0	0
Highlands	0	0	0	0
Truckworld	0	0	1	0
Unknowns	21	9	17	25
Total	**38**	**87**	**44**	**58**

Table 8.1-2: *Data showing bus fabricators taken at Kenyatta Avenue between Sarova Stanley Junction and Uhuru Highway/Kenyatta Avenue roundabouts from 11:00am-11:40am*

Type	**29/33 Seater**		**51 and above**	
Destination	From Town	Into Town	From Town	Into Town
Total Passenger Vehicles	69	47	14	2
Respective Fabricators				
KVM	0	0	0	0
Harveer	0	0	3	0
TMD	0	0	2	0
CFG	13	14	0	0
KCI	31	15	0	0
LSHS	3	1	2	0
Master Fabricators	0	0	3	0
Dodi Autotech	15	6	0	0
AM	1	1	0	0
Banbros	2	0	2	0
2M Autotech	0	0	0	0
Matam Fabricators	1	0	0	0
Choda Fabricators	0	0	0	0
Astrabell	0	0	0	0
Highlands	0	0	0	0
Truckworld	0	0	0	0
Unknowns	3	10	2	2
Total	**69**	**47**	**14**	**2**

Table 8.1-3: *Data showing bus fabricators taken on Waiyaki Way between Westlands roundabout and Museum Hill from 12:35am-1:20pm*

8.2 APPENDIX B

LOAD (N)	Original Length (mm)	Final Length (mm)	Extension (mm)	Stress (Nmm^{-2})	Strain
0	50.8	50.8	0.000	0	0
1508.6	50.8	50.978	0.178	59.3937	0.003504
2239	50.8	51.096	0.296	88.14961	0.005827
2956.6	50.8	51.223	0.423	116.4016	0.008327
3809	50.8	51.358	0.558	149.9606	0.010984
4772.5	50.8	51.488	0.688	187.8937	0.013543
5770.8	50.8	51.603	0.803	227.1969	0.015807
6759.1	50.8	51.725	0.925	266.1063	0.018209
7461.6	50.8	51.823	1.023	293.7638	0.020138
8412.5	50.8	51.978	1.178	331.2008	0.023189
9145	50.8	52.108	1.308	360.0394	0.025748
9733.3	50.8	52.227	1.427	383.2008	0.028091
10140	50.8	52.357	1.557	399.2126	0.03065
10306.6	50.8	52.476	1.676	405.7717	0.032992
10400.8	50.8	52.604	1.804	409.4803	0.035512
10465.8	50.8	52.727	1.927	412.0394	0.037933
10506.6	50.8	52.850	2.050	413.6457	0.040354
10523.3	50.8	52.981	2.181	414.3031	0.042933
10544.1	50.8	53.105	2.305	415.122	0.045374
10546.1	50.8	53.231	2.431	415.2008	0.047854
10538.3	50.8	53.355	2.555	414.8937	0.050295
10531.6	50.8	53.479	2.679	414.6299	0.052736
10520	50.8	53.602	2.802	414.1732	0.055157
10509	50.8	53.730	2.930	413.7402	0.057677
10480	50.8	53.852	3.052	412.5984	0.060079
10453.3	50.8	53.975	3.175	411.5472	0.0625
10433.3	50.8	54.107	3.307	410.7598	0.065098
10414.1	50.8	54.228	3.428	410.0039	0.06748
10388.3	50.8	54.351	3.551	408.9882	0.069902
10360.8	50.8	54.474	3.674	407.9055	0.072323
10333.3	50.8	54.596	3.796	406.8228	0.074724
10309.1	50.8	54.732	3.932	405.8701	0.077402
10293.3	50.8	54.855	4.055	405.248	0.079823
10258.3	50.8	54.976	4.176	403.8701	0.082205
10232.5	50.8	55.102	4.302	402.8543	0.084685

10200	50.8	55.224	4.424	401.5748	0.087087
10171.6	50.8	55.353	4.553	400.4567	0.089626
10133.3	50.8	55.479	4.679	398.9488	0.092106
10098.3	50.8	55.597	4.797	397.5709	0.094429
10053.3	50.8	55.723	4.923	395.7992	0.096909
10013.3	50.8	55.852	5.052	394.2244	0.099449
9971.6	50.8	55.976	5.176	392.5827	0.10189
9907.5	50.8	56.105	5.305	390.0591	0.104429
9840	50.8	56.213	5.413	387.4016	0.106555
9772.9	50.8	56.360	5.560	384.7598	0.109449
9683.3	50.8	56.477	5.677	381.2323	0.111752
9586.6	50.8	56.603	5.803	377.4252	0.114232
9469.1	50.8	56.729	5.929	372.7992	0.116713
9333.3	50.8	56.854	6.054	367.4528	0.119173
9165	50.8	56.988	6.188	360.8268	0.121811
8942.5	50.8	57.110	6.310	352.0669	0.124213
8668.3	50.8	57.229	6.429	341.2717	0.126555
8330	50.8	57.348	6.548	327.9528	0.128898
7838.3	50.8	57.477	6.677	308.5945	0.131437
4157.5	50.8	57.598	6.798	163.6811	0.133819

Table 8.2-1: *Tensile test results for specimen 1*

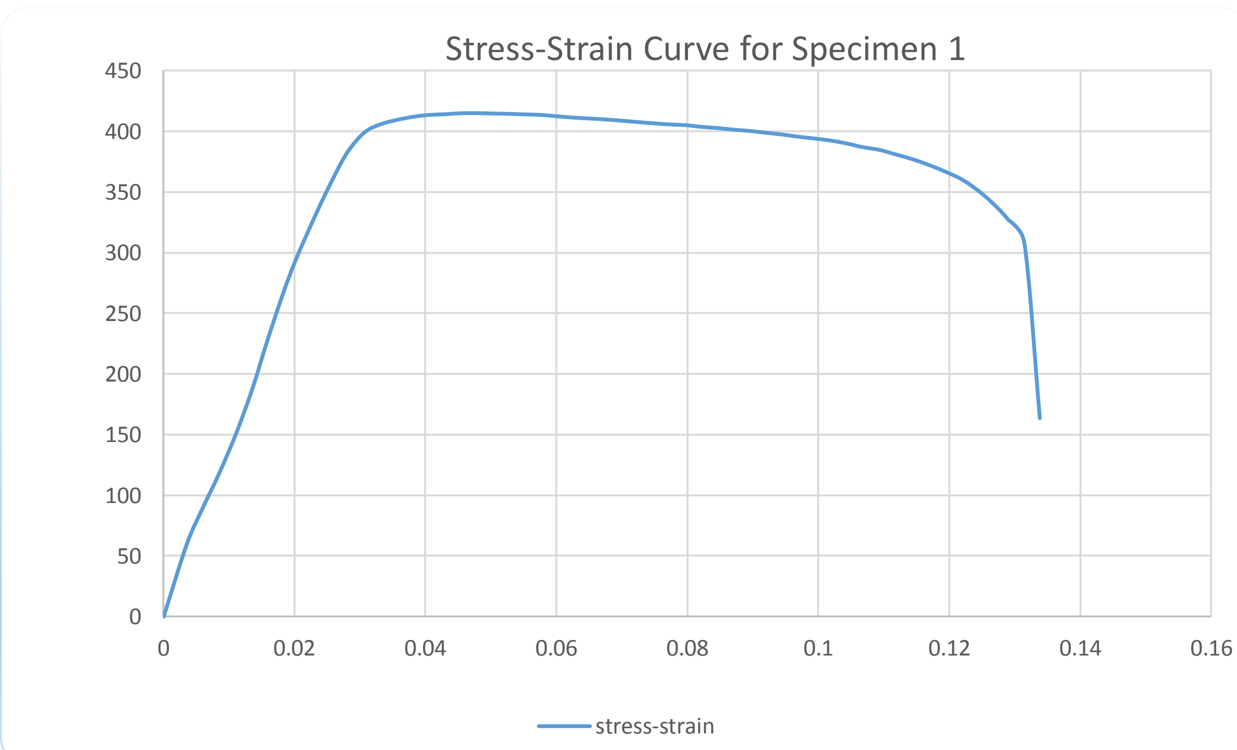


Figure 8.2-1: *Stress-strain curve for specimen 1*

Load (N)	Original Length (mm)	Final Length (mm)	Extension (mm)	Stress (Nmm^{-2})	Strain
0	50.8	50.8	0	0.000	0
1995.8	50.8	50.962	0.162	78.575	0.003188976
2125	50.8	51.076	0.276	83.661	0.005433071
2840	50.8	51.205	0.405	111.811	0.007972441
3668.3	50.8	51.334	0.534	144.421	0.010511811
4545	50.8	51.452	0.652	178.937	0.012834646
5645.8	50.8	51.585	0.785	222.276	0.015452756
6594.1	50.8	51.703	0.903	259.610	0.017775591
7478.3	50.8	51.826	1.026	294.421	0.02019685
8291.6	50.8	51.958	1.158	326.441	0.022795276
8995.8	50.8	52.082	1.282	354.165	0.02523622
9628.3	50.8	52.203	1.403	379.067	0.02761811
10075	50.8	52.329	1.529	396.654	0.030098425
10293.3	50.8	52.459	1.659	405.248	0.03265748
10399.1	50.8	52.589	1.789	409.413	0.035216535
10453.3	50.8	52.689	1.889	411.547	0.037185039
10506.6	50.8	52.833	2.033	413.646	0.040019685
10523.3	50.8	52.958	2.158	414.303	0.042480315
10543.3	50.8	53.081	2.281	415.091	0.044901575
10545	50.8	53.207	2.407	415.157	0.04738189
10545.8	50.8	53.329	2.529	415.189	0.049783465
10533.3	50.8	53.457	2.657	414.697	0.05230315
10520	50.8	53.581	2.781	414.173	0.054744094
10500	50.8	53.709	2.909	413.386	0.05726378
10480.8	50.8	53.83	3.03	412.630	0.059645669
10457.5	50.8	53.962	3.162	411.713	0.062244094
10439.1	50.8	54.079	3.279	410.988	0.064547244
10413.3	50.8	54.203	3.403	409.972	0.066988189
10400	50.8	54.331	3.531	409.449	0.069507874
10371.6	50.8	54.458	3.658	408.331	0.072007874
10346.6	50.8	54.579	3.779	407.346	0.074389764
10320.8	50.8	54.709	3.909	406.331	0.076948819
10293.3	50.8	54.836	4.036	405.248	0.079448819
10266.6	50.8	54.955	4.155	404.197	0.081791339
10240	50.8	55.078	4.278	403.150	0.084212598
10207.5	50.8	55.209	4.409	401.870	0.086791339
10179.8	50.8	55.333	4.533	400.780	0.089232283
10144.1	50.8	55.455	4.655	399.374	0.091633858
10106.6	50.8	55.579	4.779	397.898	0.094074803

10065.8	50.8	55.706	4.906	396.291	0.096574803
10025.8	50.8	55.832	5.032	394.717	0.099055118
9974.1	50.8	55.958	5.158	392.681	0.101535433
9919.1	50.8	56.083	5.283	390.516	0.103996063
9857.5	50.8	56.205	5.405	388.091	0.106397638
9785	50.8	56.332	5.532	385.236	0.108897638
9706.6	50.8	56.45	5.65	382.150	0.111220472
9603.3	50.8	56.586	5.786	378.083	0.113897638
9494.1	50.8	56.707	5.907	373.783	0.116279528
9373.3	50.8	56.824	6.024	369.028	0.118582677
9191.6	50.8	56.958	6.158	361.874	0.121220472
8998.3	50.8	57.088	6.288	354.264	0.123779528
8721.6	50.8	57.208	6.408	343.370	0.126141732
8398.3	50.8	57.331	6.531	330.642	0.128562992
7919.9	50.8	57.457	6.657	311.807	0.131043307
4338.3	50.8	57.583	6.783	170.799	0.133523622

Table 8.2-2: *Tensile test results for specimen 2*

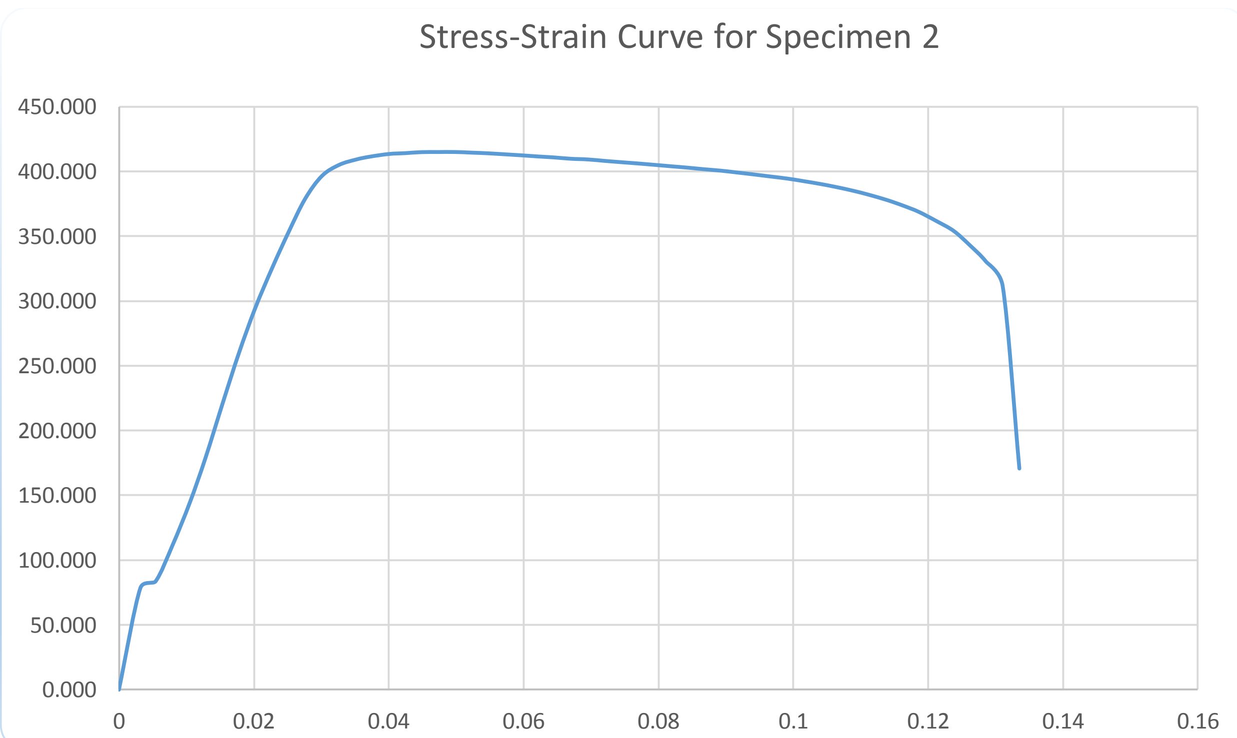


Figure 8.2-2: *Stress-strain curve for specimen 2*

Load (N)	**Original Length** (mm)	**Final Length** (mm)	**Extension** (mm)	**Stress** (Nmm^{-2})	**Strain**
0	50.8	0	0.000	0	0
1518.6	50.8	50.976	0.176	59.7874	0.003465
2249	50.8	51.093	0.293	88.54331	0.005768
2966.6	50.8	51.233	0.433	116.7953	0.008524
3809	50.8	51.355	0.555	149.9606	0.010925
4782.5	50.8	51.485	0.685	188.2874	0.013484
5780.8	50.8	51.609	0.809	227.5906	0.015925
6769.1	50.8	51.730	0.930	266.5	0.018307
7471.6	50.8	51.826	1.026	294.1575	0.020197
8422.5	50.8	51.977	1.177	331.5945	0.023169
9155	50.8	52.106	1.306	360.4331	0.025709
9743.3	50.8	52.226	1.426	383.5945	0.028071
10150	50.8	52.359	1.559	399.6063	0.030689
10326.6	50.8	52.473	1.673	406.5591	0.032933
10410.8	50.8	52.607	1.807	409.874	0.035571
10455.8	50.8	52.725	1.925	411.6457	0.037894
10526.6	50.8	52.830	2.030	414.4331	0.039961
10533.3	50.8	52.983	2.183	414.6969	0.042972
10554.1	50.8	53.107	2.307	415.5157	0.045413
10556.1	50.8	53.233	2.433	415.5945	0.047894
10548.3	50.8	53.358	2.558	415.2874	0.050354
10551.6	50.8	53.478	2.678	415.4173	0.052717
10530	50.8	53.605	2.805	414.5669	0.055217
10519	50.8	53.760	2.960	414.1339	0.058268
10490	50.8	53.854	3.054	412.9921	0.060118
10463.3	50.8	53.976	3.176	411.9409	0.06252
10443.3	50.8	54.109	3.309	411.1535	0.065138
10424.1	50.8	54.231	3.431	410.3976	0.067539
10398.3	50.8	54.356	3.556	409.3819	0.07
10370.8	50.8	54.473	3.673	408.2992	0.072303
10353.3	50.8	54.595	3.795	407.6102	0.074705
10319.1	50.8	54.736	3.936	406.2638	0.07748
10283.3	50.8	54.857	4.057	404.8543	0.079862
10268.3	50.8	54.979	4.179	404.2638	0.082264
10242.5	50.8	55.101	4.301	403.248	0.084665
10210	50.8	55.226	4.426	401.9685	0.087126
10181.6	50.8	55.356	4.556	400.8504	0.089685
10143.3	50.8	55.475	4.675	399.3425	0.092028
10088.3	50.8	55.593	4.793	397.1772	0.09435

10063.3	50.8	55.726	4.926	396.1929	0.096969
10023.3	50.8	55.855	5.055	394.6181	0.099508
9981.6	50.8	55.979	5.179	392.9764	0.101949
9917.5	50.8	56.107	5.307	390.4528	0.104469
9850	50.8	56.215	5.415	387.7953	0.106594
9782.9	50.8	56.370	5.570	385.1535	0.109646
9693.3	50.8	56.479	5.679	381.626	0.111791
9596.6	50.8	56.605	5.805	377.8189	0.114272
9469.1	50.8	56.728	5.928	372.7992	0.116693
9343.3	50.8	56.853	6.053	367.8465	0.119154
9185	50.8	56.989	6.189	361.6142	0.121831
8952.5	50.8	57.130	6.330	352.4606	0.124606
8678.3	50.8	57.225	6.425	341.6654	0.126476
8340	50.8	57.345	6.545	328.3465	0.128839
7848.3	50.8	57.476	6.676	308.9882	0.131417
4167.5	50.8	57.601	6.801	164.0748	0.133878

Table 8.2-3: *Tensile test results for specimen 3*

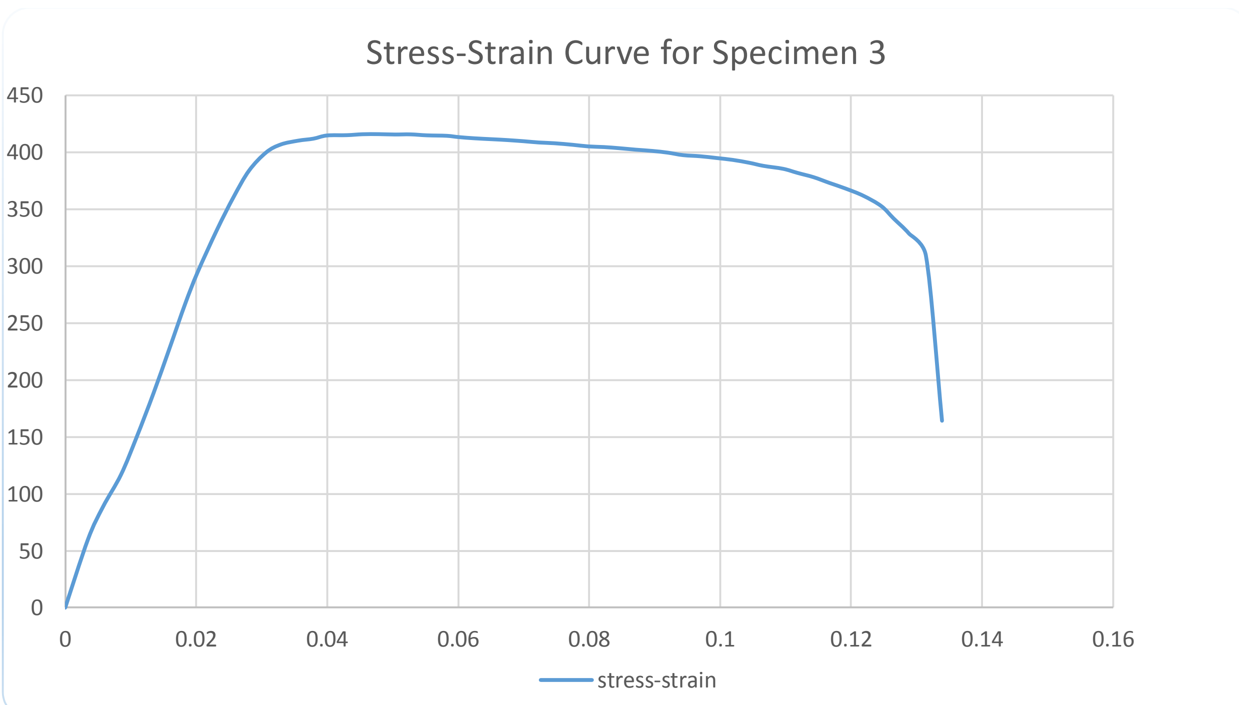
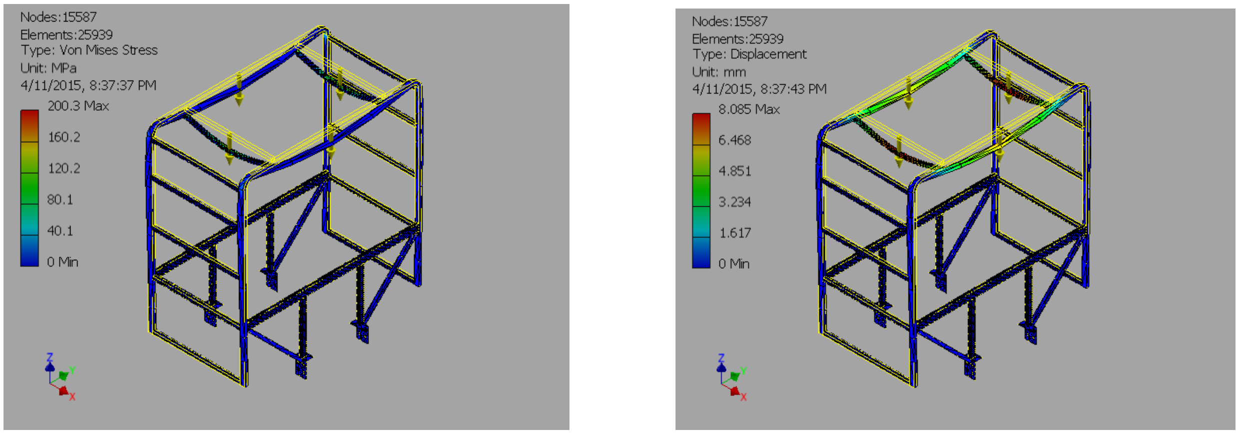


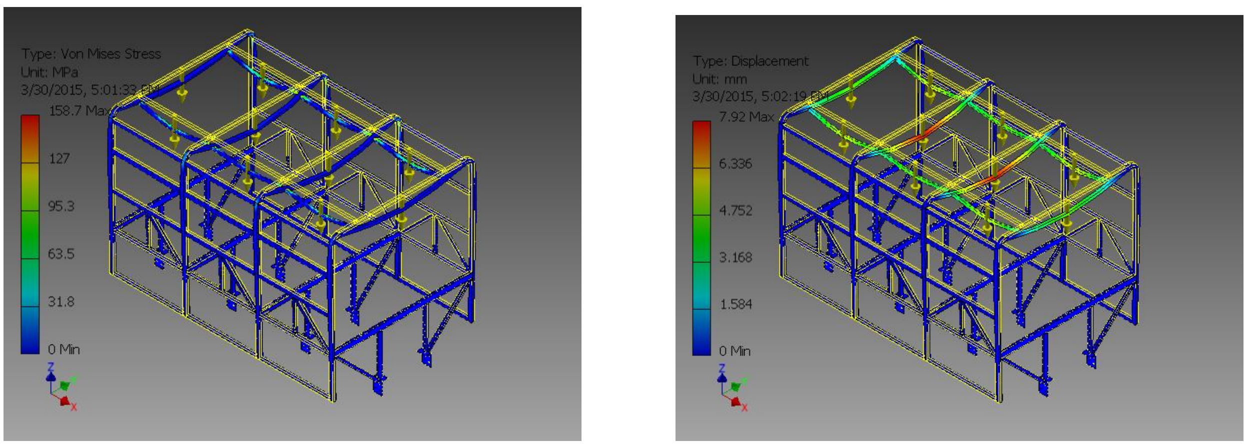
Figure 8.2-3: *Stress-strain curve for specimen 3*

8.3 APPENDIX C



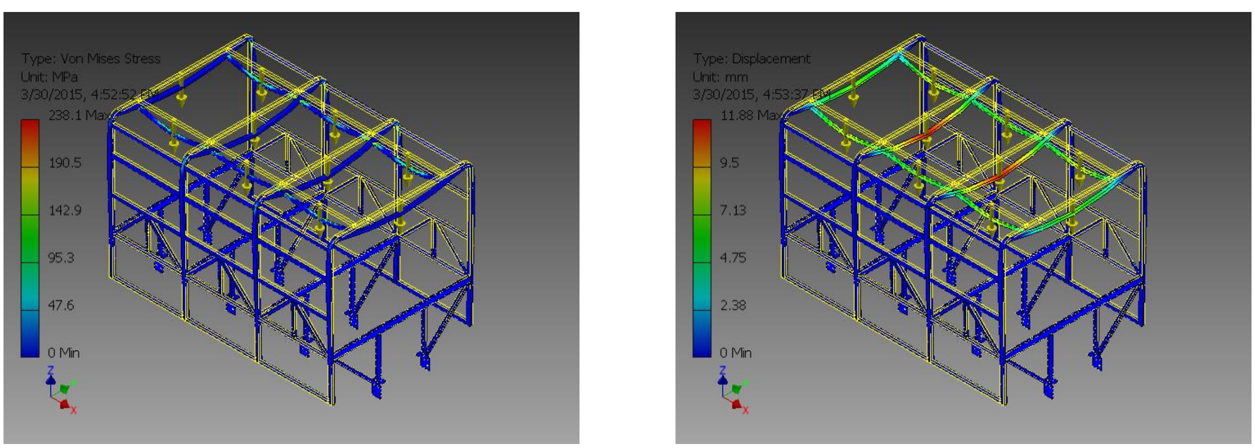
(a) (b)

Figure 8.3-1 (a) Stress and (b) displacement for the braced double frame of the bus under a load of 23980N



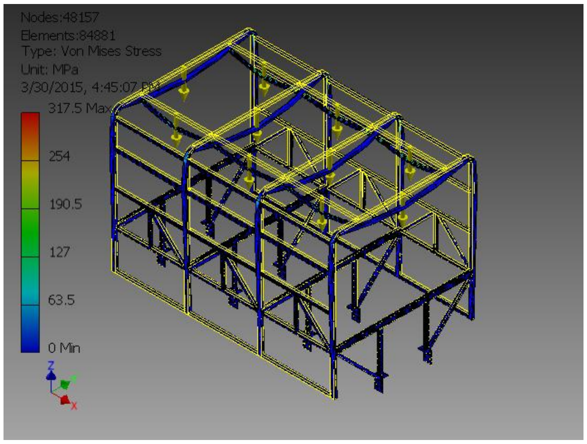
(a) (b)

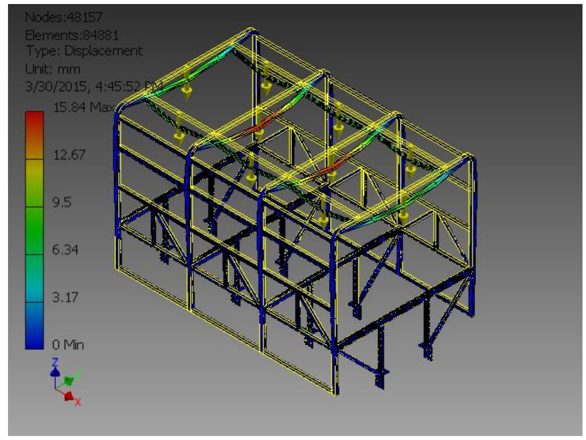
Figure 8.3-2 (a) Stress and (b) displacement for the half model of the bus under a load of 47960N



(a) (b)

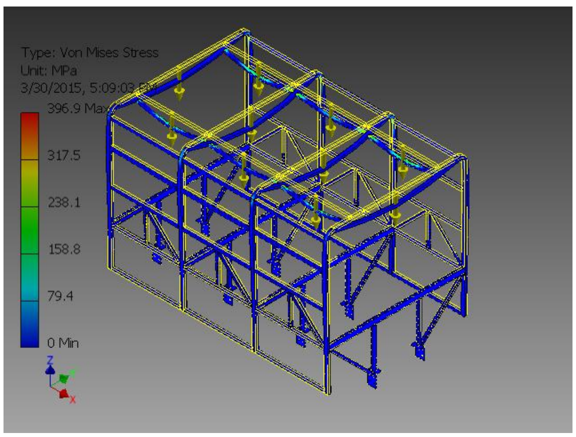
Figure 8.3-3 (a) Stress and (b) displacement for the half model of the bus under a load of 71940N

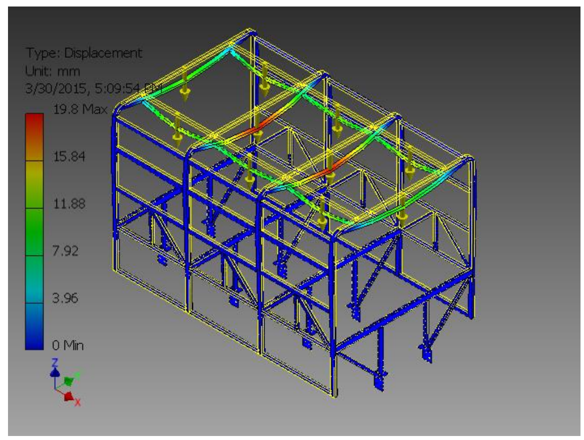




(a) (b)

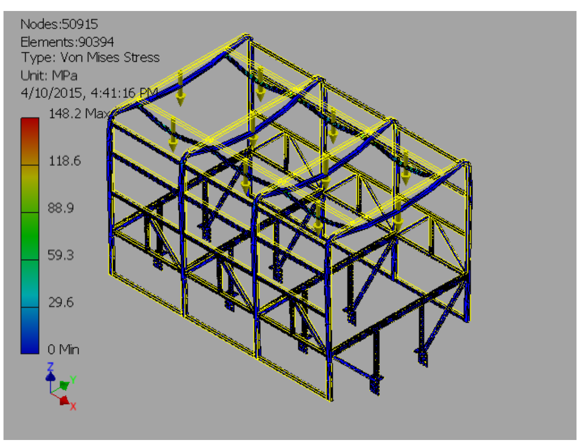
Figure 8.3-4 (a) Stress and (b) displacement for the half model of the bus under a load of 95920N

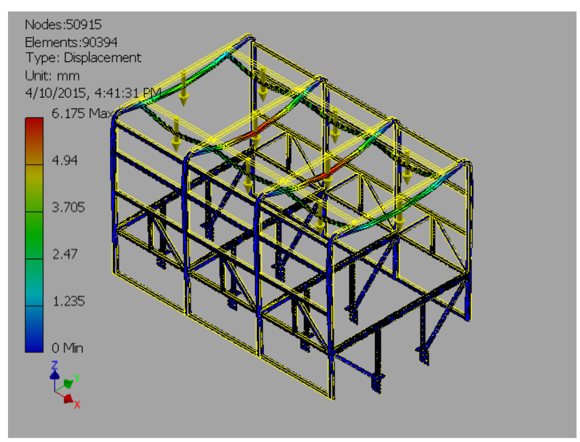




(a) (b)

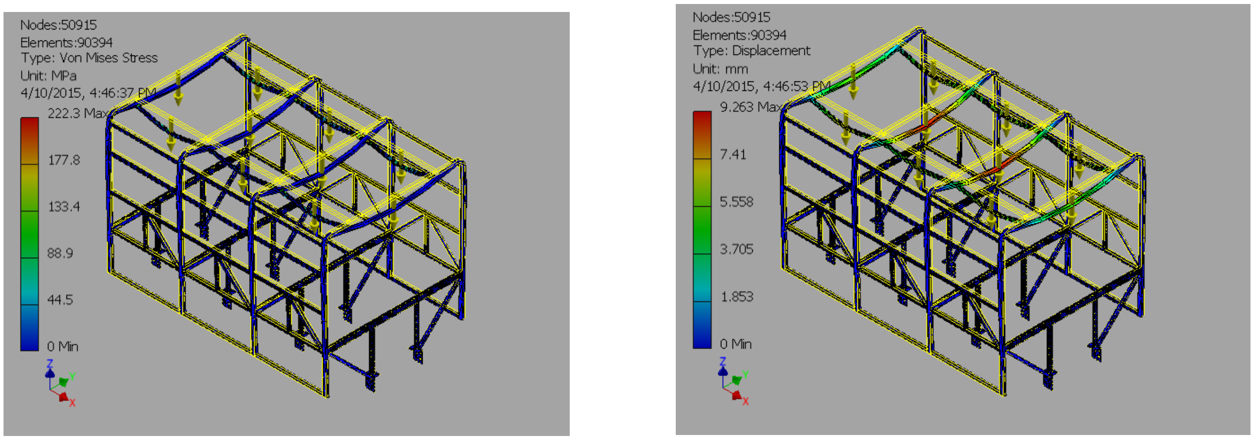
Figure 8.3-5 (a) Stress and (b) displacement for the half model of the bus under a load of 119900N





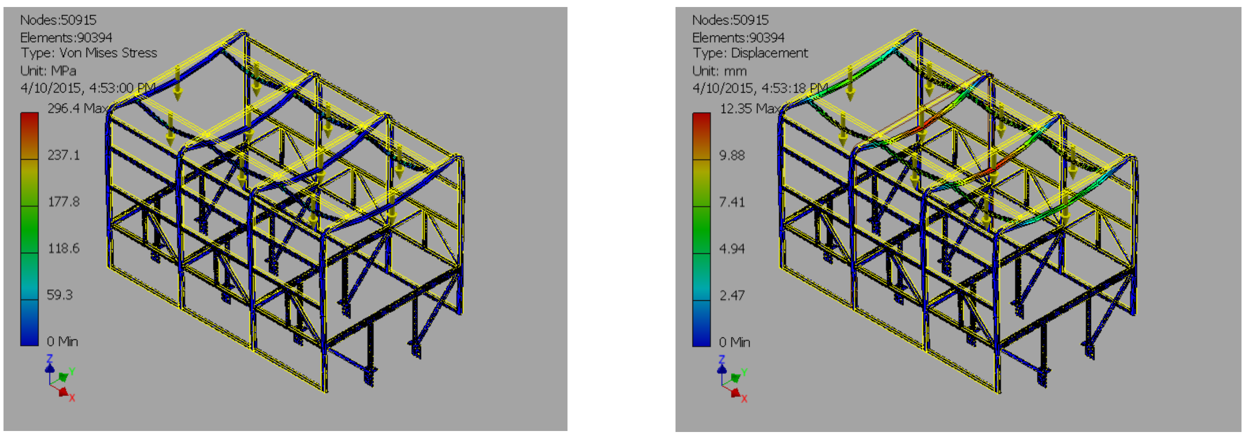
A b

Figure 8.3-6 (a) Stress and (b) displacement for the half model of the bus under a load of 47960N for the 4mm thick RHS



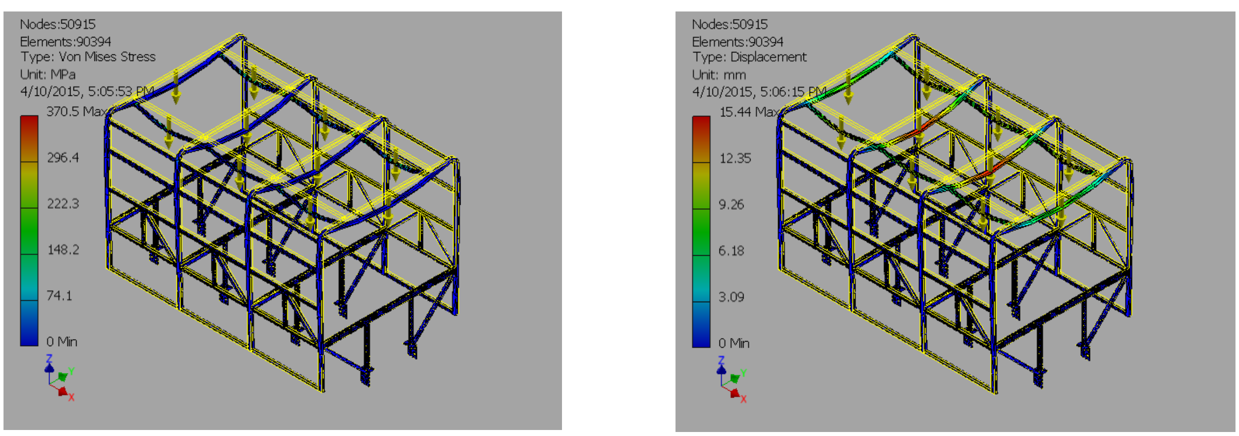
(a) (b)

Figure 8.3-7 (a) Stress and (b) displacement for the half model of the bus under a load of 71940N for the 4mm thick RHS



(a) (b)

Figure 8.3-8 (a) Stress and (b) displacement for the half model of the bus under a load of 95920N for the 4mm thick RHS



(a) (b)

Figure 8.3-9 (a) Stress and (b) displacement for the half model of the bus under a load of 119900N for the 4mm thick RHS

PERIOD	CLASSES OF VICTIMS																		
	PEDESTRIANS			DRIVERS			PASSENGERS			PILLION PASS			PEDAL CYC			M/CYCLISTS			TOTAL
	Dead	Seriously Injured	Slightly Injured	Dead	Seriously Injured	Slightly Injured	Dead	Seriously Injured	Slightly Injured	Dead	Seriously Injured	Slightly Injured	Dead	Seriously Injured	Slightly Injured	Dead	Seriously Injured	Slightly Injured	
1 Jan-1 November 2013	**1227**	1312	363	**237**	425	257	**696**	2544	3279	**131**	396	115	**118**	143	40	**275**	624	136	**12,318**
1 Jan-1 November 2014	**1109**	1137	245	**212**	445	264	**510**	1676	2405	**130**	380	151	**89**	103	30	**325**	583	142	**9,936**
Variance	***-118***	***-175***	***-118***	***-25***	***20***	***7***	***-186***	***-868***	***-874***	***-1***	***-16***	***36***	***-29***	***-40***	***-10***	***50***	***-41***	***6***	***-2,382***
%Variance	*-9.6*	*-13.3*	*-32.5*	*-11*	*4.71*	*2.7237*	*-27*	*-34.1*	*-26.7*	*-1*	*-4.04*	*31.3*	*-25*	*-28*	*-25*	*18*	*-6.57*	*4.41*	*-19.3*

(a)

	2014	2013	% VARIANCE
PEDESTRIANS	1109	1227	-9.616951915
DRIVERS	212	237	-10.54852321
PASSENGERS	510	696	-26.72413793
PILLION PASSENGERS	130	131	-0.763358779
PEDAL CYCLISTS	89	118	-24.57627119
MOTORCYCLISTS	325	275	18.18181818
TOTAL	**2,375**	**2,684**	**-11.51266766**

(b)

CLASS OF VICTIMS	2013	2014	VARIANCE	% VARIANCE
DEAD	2,684	2,375	-309	-11.5
SERIOUSLY INJURED	5,444	4,322	-1122	-20.6
SLIGHTLY INJURED	4,190	3,239	-951	-22.7
TOTAL	**12,318**	**9,936**	-2382	-19.3

(c)

Variance from target **2013/2014:** -12%+11.5%=0.5%

FY (13/14)/ (14/15): -12%+7%=5%

Table 8.3-1: (a) *Comparative statistics trends for 2013 and 2014 as at 1st November 2014, (b) Summary of the dead, (c) Summary of victims (Courtesy: NTSA)*