MODELING OF ROLLOVER PROTECTIVE STRUCTURE AND FALLING OBJECT PROTECTIVE STRUCTURE TESTS ON A COMPOSITE CAB FOR SKID STEER LOADERS

A Thesis by

Krishna N. Pai

Bachelor of Engineering, Bangalore University, India, 2001

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The following faculty members have examined the final copy of the thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with Major in Mechanical Engineering.

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Dr. Hamid M. Lankarani, Committee Chair

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Dr. Ramazan Asmatulu, Committee Member

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Dr. Krishna K Krishnan, Committee Member

DEDICATION

To my parents and friends

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ABSTRACT

Machines have become indispensable as part of our day today lives. They have made a stand in various fields like agriculture, construction, mining, materials handling, excavating and general use in industries. Skid Steer loader is one such machine which has the ability to fit into all of these categories. Skid steer loaders are known the world over for versatility and maneuverability. These are agile machines which have become a part of most industries. Their ability of having various attachments makes them proficient in handling tasks, which otherwise would be difficult for a human being.

For these skid steer loaders to work to their full potential a skilled operator is required. Among other safety features, these skid steer loaders need to be accountable for the safety of the operator. Hence, the cab mounted on these skid steer loaders need to conform to Roll Over Protective Structure also called as ROPS and Falling Object Protective Structure otherwise known as FOPS standards. There are various standards laid down by the International Organization for Standardization (ISO), Society of Automotive Engineers (SAE) and American National Standards Institute (ANSI) for these ROPS/FOPS cabs on skid steer loaders and other construction and mining equipments world over. This study deals with the composite modeling of ROPS/FOPS cab as per ISO 3471:1994 and ISO 3449:1992 Level I standards for skid steer loaders.

In this research, a skid steer loader model with the operator cab is constructed and tested for the ISO standards. A section of the cab was chosen and its properties are changed to composite properties. Glass fiber/epoxy composite material was chose as part of this study. In addition, a parametric study is carried out on the section to satisfy the current standards in the industry. It is demonstrated that the Glass fiber/epoxy section

with a related orientation\ thickness may present additional energy absorption capabilities than the current steel structure used in the cab. It is also demonstrated that the new designed composite section possibly is more effective than the current steel structure in the cab.

With the advance in computer simulations, a finite element (FE) model of the skid steer loader has been developed and utilized to predict the vehicle behavior in case of roll over. MSC Patran/Hypermesh has been used as the modeler. LS-DYNA has been used as the solver.

TABLE OF CONTENTS

Chapter **Page**

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF TABLES

Table **Page**

CHAPTER 1

INTRODUCTION

1.1 Background

All mobile machinery is at the risk of rolling over, depending on the machine characteristics, working environment and terrain. So the need to protect the operator from the risk of being injured or causing death due to a roll over has been of prime importance in the design and development of all machinery. Although the development of standards has been outpaced by the evolution of the machines, countries world over have set standards addressing the safety of the operators which these machines need to conform to.

Skid steer loader is one such machine which is used across a wide array of industries. The key demands of the operator cab on these machines are that they need to be strong to both withstand the impact forces and absorb the energy which the impact generates without undue deflection. ROPS/FOPS tests are conducted to study the behavior of these structures on impact or simulated impact. Standard test procedures are laid down to determine the pass/fail criteria of these cabs. Currently, in United States, the operators cab need to conform to ISO 3471:1994 and ISO 3449:1992 Level I (Level II optional) standards for Roll over and Falling Object Protective Structures respectively.

1.2 History of ROPS/FOPS

Roll Over Protective Structure, by definition, is a frame or a cab like structure surrounding the seat-belted operator with a hard hat, strong enough to absorb the impact energy in case of roll over of the vehicle. Similarly Falling Object Protective Structure is a structure which protects a seat-belted operator with a hard hat, from falling objects like rocks, tools, tree branches etc.

The need for safety of the operator started with the boom of ride on machinery in 1950's, which gave rise to deaths of operators due to vehicle overturning [10]. Since then research has been going on for developing restraint systems and structures which would rather prevent or minimize the effects of the majority of typical accidents yet also provide protection against the more severe but less frequent accidents. A small change in the working conditions of machines may lead to roll-over be it like change in fuel and oil levels to loose soil on the ground. It was initially decided to train the operator on these factors. But this proved to be too cumbersome for the operators to keep in mind of these factors. Then the idea of restraint system was explored. These not only took time to get deployed but were not effective in case of roll-over. Thus it was decided nationally that fitting ROPS would eliminate both the judgment of the operator and the uncertainty of a safety device operating both quickly and correctly.

Thus the standards for ROPS/FOPS were developed in the field of construction, agriculture, forestry etc. The skid steer loader cabs must be certified by ISO3471:1994 for ROPS and ISO 3449:1992 for FOPS. The FOPS has two different standards, Level I and Level II. All skid steer loader need to conform to Level I and Level II is optional for the buyer.

1.3 Types of ROPS

Two types of ROPS are available based on the number of posts or supporting structures involved.

1.3.1 Two-post ROPS

In case of two post ROPS, there are only two posts supporting the overhead protection structure. These are sometimes called roll bar ROPS and are normally found on small agricultural tractors, lawn movers and other earth moving equipments. A two post ROPS is as shown in figure 1 [1].

Figure 1. Two post ROPS [1].

1.3.2 Four-post ROPS

In case of four post ROPS, there are four posts supporting the overhead protection structure. These are found in majority of the cab structures on all earth moving and other off highway equipments. A four post ROPS is as shown in figure 2 [2].

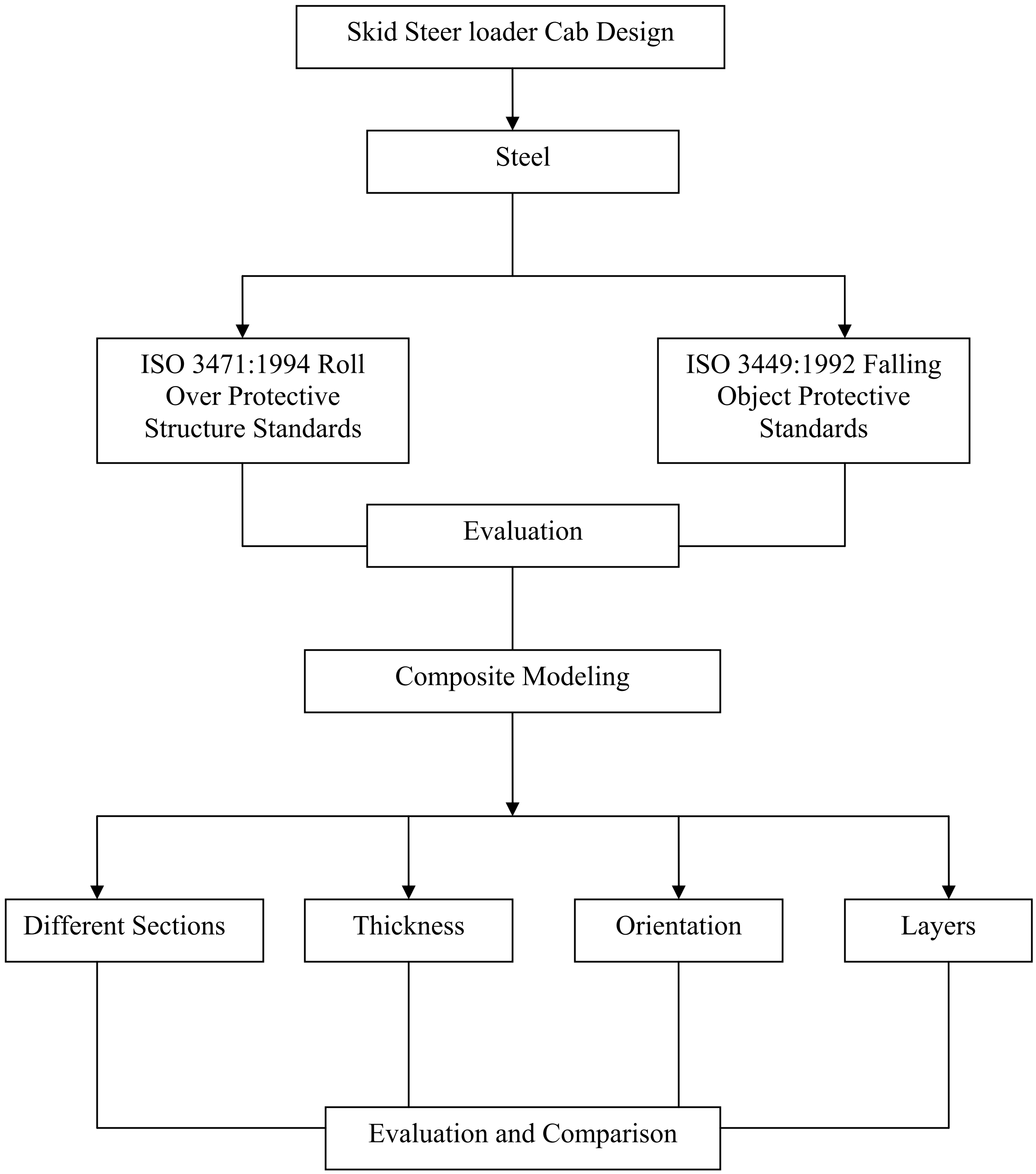
1.4 Statement of Work

Fatalities can be prevented or minimized due to vehicle turnover by the presence of ROPS/FOPS. Skid Steer loaders are one of the best machines to study on as they find application in a spectrum of industries. The current prevailing cabs in the industry are made of steel and conform to the test standards set by ISO for Skid Steer loaders. The main object of this research work is to study the feasibility of using composites in operators cab on mobile equipments. This is done by creating a section of the cab using a composite material and then tests are conducted until they satisfy the current prevailing

Figure 2. Four post ROPS [2].

standards in the industry. Use of composites helps to reduce the total weight of the cab and enhancing the energy absorbing capability of the cab without sacrificing the safety of the operator.

1.5 Methodology



This thesis begins with the construction of a skid steer loader model. This is done using PRO-E. The cab is modeled using PRO-E/Sheet metal. Solid Modeling is used to construct rest of the loader. The cab is then meshed for analysis using Hypermesh. The meshing is done surface by surface and then assembled for analysis. Quad elements are used for meshing most of the surfaces. Some of the edges are meshed using a mixture of quad and trias elements. Equivalence is done for each surface and for the assembly as a whole. The loading fixtures and the drop test objects are mounted on the skid steer cab as per standards using Easi-Crash Dyna. The loading points are then identified. The steel cab is tested for both the Roll Over Protective Structure and Falling Object Protective Structure standards. Various sections of the cab are then chosen and material property of the section is changed from steel to composite. Glass fiber/Epoxy was chose as the composite material. This material chosen is really inexpensive and easily available in the market. The test method is again repeated for a combination of thickness like 1.3mm and 2.6mm, orientation of the fibers like [(±30°)6/0°], [(±45°)6/90°], [(0°/90)6/0°] and the number of layers like 5,7,9,13 until it satisfies the ISO standards.

CHAPTER 2

LITERATURE REVIEW

Skid steer loaders put workers at risk of rollover and run over incidents. Fatalities do happen in work places be it due to operator's negligence or working conditions. The National Institute for Occupational Safety and Health (NIOSH) keeps track of injuries and deaths among workers. It works in close association with Occupational Safety and Health Administration (OSHA) and other agencies to help set up standards in work places to prevent work related casualties. During the period 1980-92, NTOF (the NIOSH National Traumatic Occupational Fatalities) surveillance system used death certificate data to identify 54 work related fatalities involving skid steer loaders [3]. 11 of them were due to roll over [3]. During the period 1992-97, FACE (the NIOSH Fatality Assessment and Control Evaluation) program identified 37 work related fatalities involving skid steer loaders.6 of them were due to roll over [3]. In the agriculture industry, each year, many deaths are caused due to tractor and other farm equipment roll over.

Metals have played an important role in our lives at every stage since long. But the invention of composites is slowly changing the world and has started to influence the usage of metals. Composites are currently being used to a greater extent in the aircraft industry. It is slowly creeping into the automobile industry and will soon be a part of our day to day life. Composites score over metals in many areas such as specific strength (strength to density), specific stiffness (stiffness/density), corrosion resistance, high service temperatures, very high impact load absorbing and damping properties.

2.1 Energy Absorption Capability of Composites

The energy absorption capability [8], [9], [10] of the composite structure mainly depends on the

- Fiber Material – Physical properties of the fiber material directly influences the specific energy absorption of the composite. The brittle nature of the fiber results in more energy absorption rather than the ductile nature of the fiber, which fails by progressive folding.
- Matrix Material – Specific energy absorption linearly increases with the matrix compressive strength.
- Fiber and Matrix Combination – Due to crushing by high energy fragmentation, matrix material with a higher failure strain has high energy absorption than the fiber material.
- Fiber Orientation and Lay-up – High energy absorption composites consist of layers of specified orientation and sequence plies.

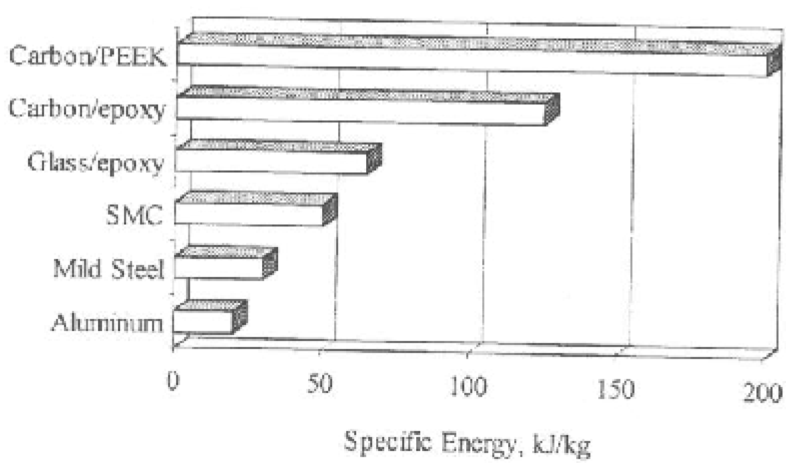


Figure 3. Specific energy of different materials [8].

2.2 Impact Damage Response on Composite Materials

Damage, crashworthiness and behavior of dynamic loading under impact of composite material has been the topic of many researchers in the recent past. Composite materials can fracture along the thickness and \or in-plane. This is called impact damage. Some are visible damages while others are determined using other techniques like optical or electron microscopy, ultrasonic C-scanning, and acoustic imaging.

Impact damage in composites is broadly classified into major failure modes: Delamination, Matrix Cracking and Fiber Breakage. The inherent properties of the resin dictate the two of these failures: Dealamination and Matrix Cracking. However, Fiber Breakage is depends on the fiber specifications and its characteristics. This is usually caused by higher energy impacts [8].

2.2.1 Matrix cracking

Matrix cracking in an impacted composite occurs due to a combination of two components : tensile stress and stress concentrations at the fiber-matrix interface. Higher tensile stress is usually characterized by denser and longer cracks. The energy absorbed in matrix cracking is easy to calculate. It is the cross product of area of the crack and surface energy. Larger crack areas are generally caused by crack branching. In this case, the cracks run in the direction perpendicular to the direction of fracture. Sometimes, the surface area created by crack branching is much larger compared to the area created by primary cracks. This increases the fracture energy, significantly increasing the toughness and total energy of damage absorbed in impact.

2.2.2 Delamination

Two adjacent plies may easily delaminate if there is a stiffness mismatch at their interface or dissimilar orientation of the plies. Changes in the impact energy has a direct influence on delamination. The cracks, which can initiate Delaminations, can spread through the plies. Crack tips at the fiber–matrix interface in the adjacent plies help to stop delamination. [8]

2.2.3 Fiber breakage

When cracks propagate in the direction perpendicular to the fibers, it might lead to Fiber breakage. If continuous, sometimes, the fiber breakage can eventually grow to completely separate the laminates. Fiber breakage and a higher residual tensile strength is sometimes attributed to the fiber properties. Secondary matrix damage refers to the failure after the initial fiber failure. This is also reduced, allowing residual compressive strength to increase [8].

In general, most composite materials have relatively high specific energy absorption when compared to metals like steel. Their properties of high specific stiffness and high specific strength make them an ideal material for the construction of lightweight vehicle structures. This high energy absorption capability of the composite material is bundled with reduced weight. Thus a right combination of metal and composites can dramatically change the behavior of the structure, providing a proficient design.

CHAPTER 3

COMPUTER AIDED ENGINEERING TOOLS

3.1 PRO-E

PRO-E is geometric modeling software developed by PTC. It is the leading commercial computer program used in product development solutions for wide variety of industries, such as automotive, electrical, electronics etc. which provides greater flexibility in modeling of the irregular contours.

PRO-E is the one of the solution capable of addressing the complete product development process, from product concept specifications through product-in-service, in a fully integrated an associative manner. It facilitates the true collaborative engineering across the multi-disciplinary extended enterprise, including style from design, mechanical design and equipment and systems engineering, managing digital mock-up, machining, analysis, and simulation.

3.2 MSC Patran

MSC Patran is a finite element modeler. It is used to model, mesh and post process common FEM solvers in the market today. It can use shared geometry and provides a platform to conduct many functional design analyses.

MSC Patran can be used as a platform to do multi functional design analysis. With the ability to import geometry from other CAD softwares like Pro-E , CATIA, it is sometimes used to replicate product performance and manufacturing process during early stages in the design-to-manufacture process.

The software comes equipped with a powerful and flexible meshing option. The other advantage the software offers is that the loads and boundary conditions under consideration can be applied to the geometry or to the analysis model. The result visualization tools dissects all information identify decisive information, including minimums', maximums', trends, correlations etc.

3.3 HYPERMESH

Altair HyperMesh is a high-performance finite element pre- and postprocessor compatible with most widely used finite element solvers. Hyper Mesh's user-interface is simple to learn. The tool also supports easy importing of other CAD geometry files \ FEM files. This tool has some advanced operations allowing users to efficiently mesh extremely complex models. It also allows user to define quality criterion and control morphing technology which aids in updating the existing meshes to new design proposals. This also allows automatic mid-surface generation for compound designs with varying wall thicknesses. The meshing time is minimized by using automated tetra-meshing and hexa-meshing. Batch meshing is an option available in Hypermesh which can be used to quickly mesh large models \ parts with minimal cleanup and user interface.

HyperMesh is equipped with a wide array of tools which allows it to seamlessly integrate it self to current engineering processes available in the market today. The Hypermesh menu can be easily customized by every individual user. It has the Tcl/Tk toolkit built within. This makes it advantageous for every user to build custom applications integrated with Hypermesh. Macros can be created for process automation. Export templates and input translators increase the flexibility making Hypermesh compatible with many solvers. Hypermesh has an excellent file export template. This can be used to download formats to other non-supported solvers. The input translators are no different. They support every individual user inputs which is helpful to read various analysis data.

HyperMesh provides an excellent platform to efficiently generate finite element models from top leading CAD data formats in the industry today. It is equipped with robust tools for easy cleaning of imported geometry containing surfaces with gaps, overlaps and misalignments which otherwise prevent auto meshing. The overall meshing speed and quality is improved significantly by using this tool which automatically eliminates misalignments, holes and suppresses the boundaries between adjacent surfaces. This helps the users to mesh across larger and more coherent regions of the model in very short time.

HyperMesh comes equipped with tools which help every user to build and edit the models with ease. Auto meshing is an advantageous option available in Hypermesh. In addition to this, users can opt other mesh creating panels available for use. All these help the user to interactively manipulate mesh parameters such as density of the elements created in the mesh, the algorithm used to create it and more. This gives the user a soaring user control over the meshing process which enables meshing of even extremely complicated surfaces with desired quality.

3.4 LS-DYNA

LS-DYNA is one of the many explicit finite element programs available in the market today. Other FEA codes use implicit methods for solution. LS-DYNA uses explicit time integration without forming a stiffness matrix thus cutting storage requirements and enhancing speed.

The main advantage of using LS-DYNA is that it analyses elements that undergo vast deformations efficiently and flawlessly. Since it operates by using explicit code, it takes less time to compute. This methodology helps to analyze car crashes, air bags in vehicles and metal forming analyses.

LS-DYNA has over one hundred metallic and nonmetallic material models. Many materials can be modeled in LS-DYNA. Some of them are composites, foam, glass etc. This poses a high usage in automotive and aircraft industries. It is also helpful and catching up in other manufacturing industries as a study tool too.

LS-DYNA is also equipped with contact analysis capabilities. Many contact options are available including thermo-mechanical. It uses the constraint and penalty method. This has been used over decades to study complete car crashworthiness and occupant safety in automotive and aircrafts.

LS-DYNA runs on variety of machines. Some of the common ones used are the UNIX workstations, supercomputers and huge MPP's. Problem size dictates the resource requirement. Simulations with more than a million elements have been run using 250 millions words of memory and 4 GB of disk space. On supercomputers, the code takes advantage of multiple processors.

LS-Dyna was used to simulate the loading process for steel as well as a composite cab. It was also used for the impact test requirements and was used to compare the different composite materials in determining the most energy absorbing material [5].

3.5 EASI CRASH DYNA (ECD)

EASI CRASH DYNA is the foremost simulation environment available in the industry. Vehicle and aircraft crash engineering that requires very large manipulation capability. ECD is well adapted to carry on such iterations as it has a fully integrated environment to support this. It can directly read a wide array of file formats. Some of the common input files are from NASTRAN, MADYMO etc. ECD has unique features like:

Pre-Processing Features

- Fully automatic meshing and automatic weld creation
- Rapid graphical assembly of system models
- FE-Dummy and Rigid body dummy structuring, positioning and orientation
- Material database access and manipulation
- Graphical creation, modification and deletion of contacts, materials, constraints and I/O controls
- Automatic detection and correction of initial penetration
- Replacing the component from one model to another model

Post-Processing Features

- Highly optimized loading and animation of DYNA results for design
- Superposition of results for design
- User friendly and complete plotting for processing simulation and test data comparisons
- Quick access to stress energies and displacements without reloading the file
- Dynamic inclusion/exclusion of parts during animation and visualization
- Import and super-imposition of test results with simulation results
- Synchronization between animation and plots, between simulation result file and test result file

EASI-Plot Features

- User friendly complete plotting tool for processing simulation and test data
- Easy access to engineering functions
- Plot file re-generation using template and session file

CHAPTER 4

TEST STANDARDS AND PROCEDURES

ISO 3471: 1994 and ISO 3449: 1992 are the test standards certifying an Operator cab for Roll Over Protective Structure and Falling Object Protective Structure respectively. These standards are set by International Organization for Standardization (ISO), which is a worldwide federation of national standard bodies. Since these standards are not to be reprinted or published, they are briefly explained here below. A majority of the material in this section is referred to reference [6] and [7].

4.1 ISO 3471:1994

This standard certifies a cab for roll over. The strength of the ROPS must be related to the weight of the vehicle (although different conditions apply in different sectors). Also, the ROPS should not enter into the Deflection Limiting Volume (DLV), which is an approximation of a large, seated operator with a hard hat. This procedure of testing not necessarily duplicates structural deformations due to an actual roll. But it ensures crush protection for a seat belted operator.

The ROPS shall be attached to the machine frame as it would be on a operating machine. The complete machine is not required for evaluation. During the test, all normally detachable doors, windows and other non-structural elements shall be removed so that they neither contribute to nor detract from the structural evaluation.

Some of the terms used are as follows:

U = energy absorbed by the structure in Joules (J)

F = Force in Newtons (N)

M = Manufacture’s maximum recommended mass in Kilograms (Kg)

L = Length of the ROPS in millimeters (mm)

W =Width of the ROPS in millimeters (mm)

Δ = Deflection of ROPS in millimeters (mm)

For this work, the mass of the vehicle is taken to be 4800 Kgs.

The loading sequence shall be lateral, vertical and then in the longitudinal directions on the cab, in that order. To ensure that the load is distributed and is not a point load, a load distribution device may be used. The dimensions of the load distribution fixture are different in each case. Once the load distribution fixtures are created, the load application points on the cab are identified and marked. Then the load distribution fixture is mounted on the cab in the way specified in the standard and the tests are conducted. The rate of deflection shall be such that the loading may be considered static.

As mentioned earlier, the loads are calculated on the basis of the operating weight of the vehicle. As per standard, the calculated loads and the energy criteria to be met in this work are as follows:

Lateral Load Force (F): 28800 N

Lateral Load Energy (U): 3976 J

Vertical Load Force (F): 82000 N

Longitudinal Load Force (F): 20000 N

A graph of force v/s displacement is taken in each case. The area under the curve, which gives an account of the energy absorbed, is considered only in the case of lateral loading. The loading in the lateral direction is continued until both the force and the energy requirements are met. Once the force and energy requirements are met, the lateral load is removed and the vertical load is applied. Loading is continued until the ROPS has achieved the force requirement. After the removal of the vertical load, a longitudinal load is applied until the force requirement is achieved.

If all these force and energy criteria are met, then the structure is certified as a ROPS structure.

4.2 ISO 3449:1994

This standard certifies a cab for falling object protective structure. It ensures penetration protection to the operator from objects like rocks, tools etc used in a construction site. The test is conducted by dropping a standard object like a sphere or solid steel of certain mass from a height directly above the DLV. The deflection of this drop test is recorded and then the FOPS is either accepted or rejected. There are two acceptance levels in this standard, Level- I and Level –II.

Level –I is intended for protection from falling bricks, small concrete blocks and hand tools encountered in operations such as highway maintenance, landscaping and other construction site services. A solid steel or sphere of diameter not more than 250 mm dropped from a height sufficient enough to develop energy of 1365 J without penetrating the DLV is the criteria for Level –I FOPS. Level-I FOPS comes standard with the equipment.

Level II acceptance is intended for protection from falling trees or rocks for machines involved in site cleaning, overhead demolition or forestry. A solid steel or sphere of diameter not more than 400 mm dropped from a height sufficient enough to develop energy of 11 600 J without penetrating the DLV is the criteria for Level –II FOPS. If in either case, the drop test object penetrates the DLV, the FOPS is considered rejected. Level-II is optional.

CHAPTER 5

MODELING AND ANALYSIS

5.1 Skid Steer Loader Model

A skid steer loader with an operator cab is modeled using PRO-E. Importance is given to the dimensions of the cab rather than the other parts since we use only the cab for the analysis as explained earlier.

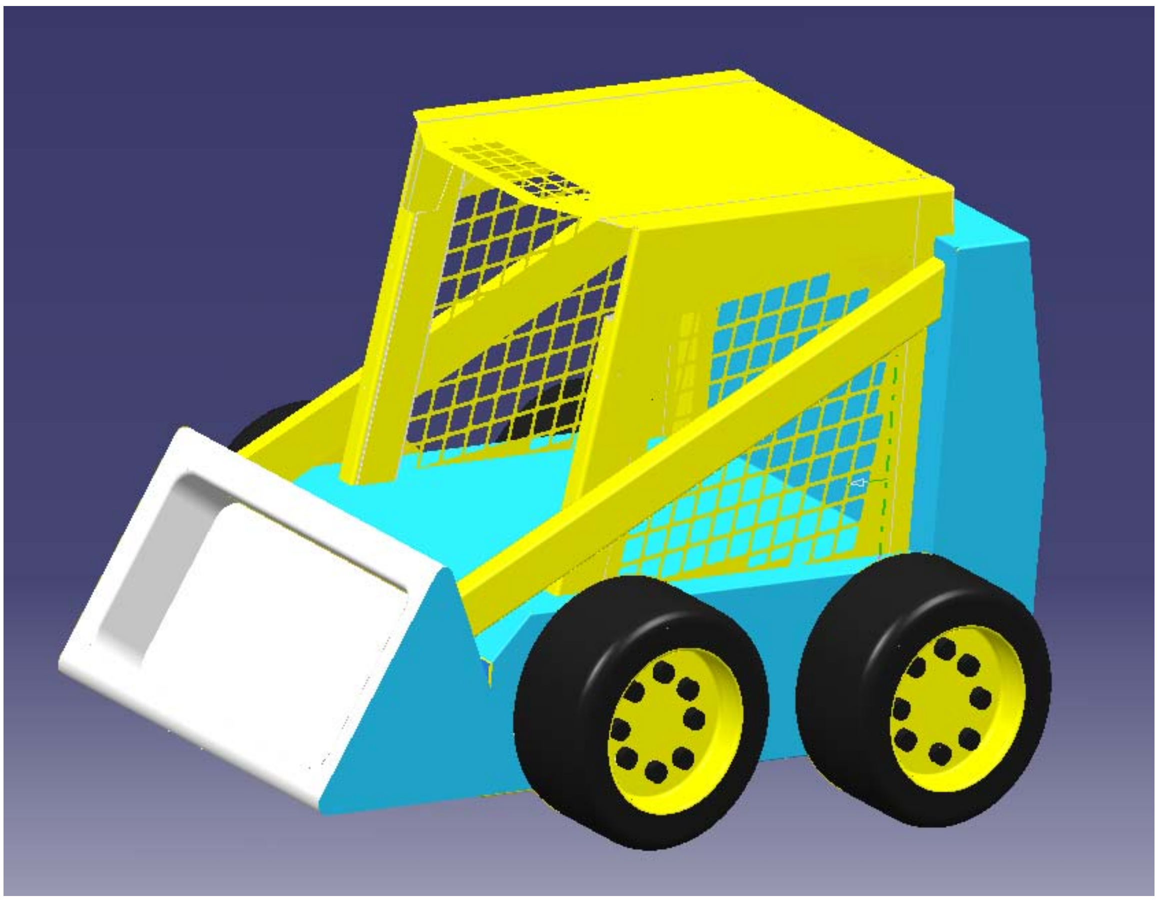


Figure 4. Skid steer loader model.

The dimensions of the cab are as follows:

Width : 900 mm

Length : 850 mm

Height : 1000 mm

5.2 FEM Modeling of the Cab

During conducting the tests, all the detachable members like panels, doors and other non-structural elements need to be removed so that they don't neither contribute to nor detract from the structural evaluation. So only the cab without the wheel or the base is used for analysis. The cab is then imported into Hypermesh and meshed for analysis and is as shown in figure 5. Meshing is an important step and care should be taken to see that all the parts are meshed.

Figure 5. FEM model of the cab.

5.3 Load Distribution Fixture

The load distribution fixture is modeled using MSC Patran. Shell elements are used to model it. A load distribution fixture looks like as shown in figure 6. Three such load distribution fixtures are designed, one each for Lateral, Longitudinal and Vertical Loading.

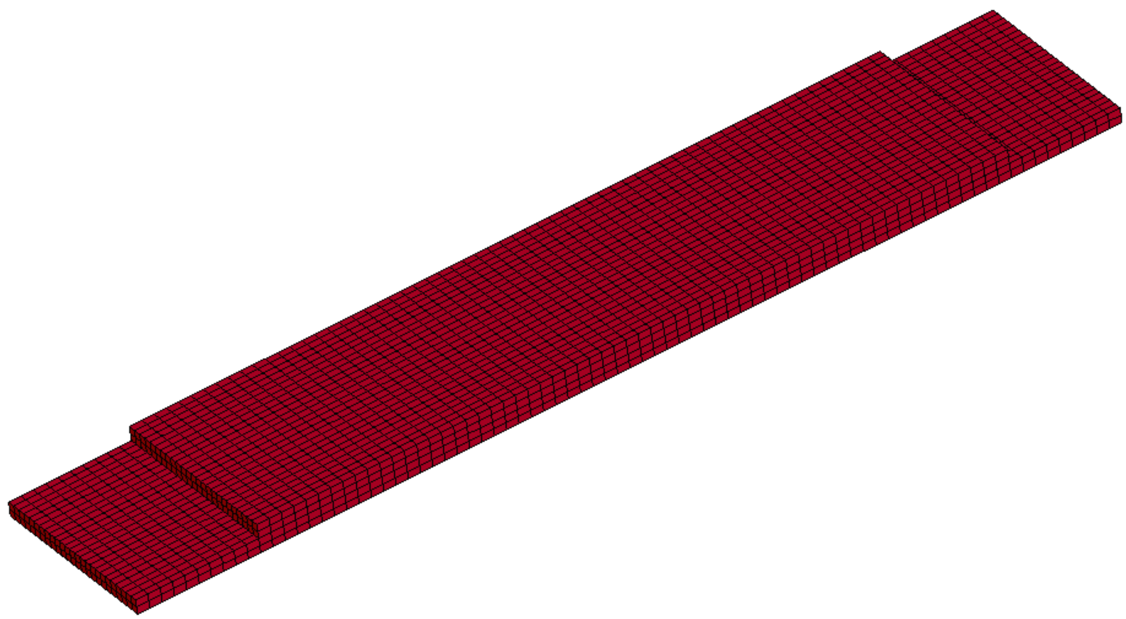


Figure 6. Loading distribution fixture.

Lateral Load Distribution Fixture Dimensions:	712 mm X 130 mm
Vertical Load Distribution Fixture Dimensions:	860 mm X 130 mm
Longitudinal Load Distribution Fixture Dimensions:	688 mm X 130 mm
Thickness of Load Distribution Fixture:	20 mm

5.4 Load Application Points

The loading application points for lateral, vertical and longitudinal directions are first marked on the cab. The loading fixture is then mounting on the cab as per standards described in ISO standards.

5.4.1 Lateral loading

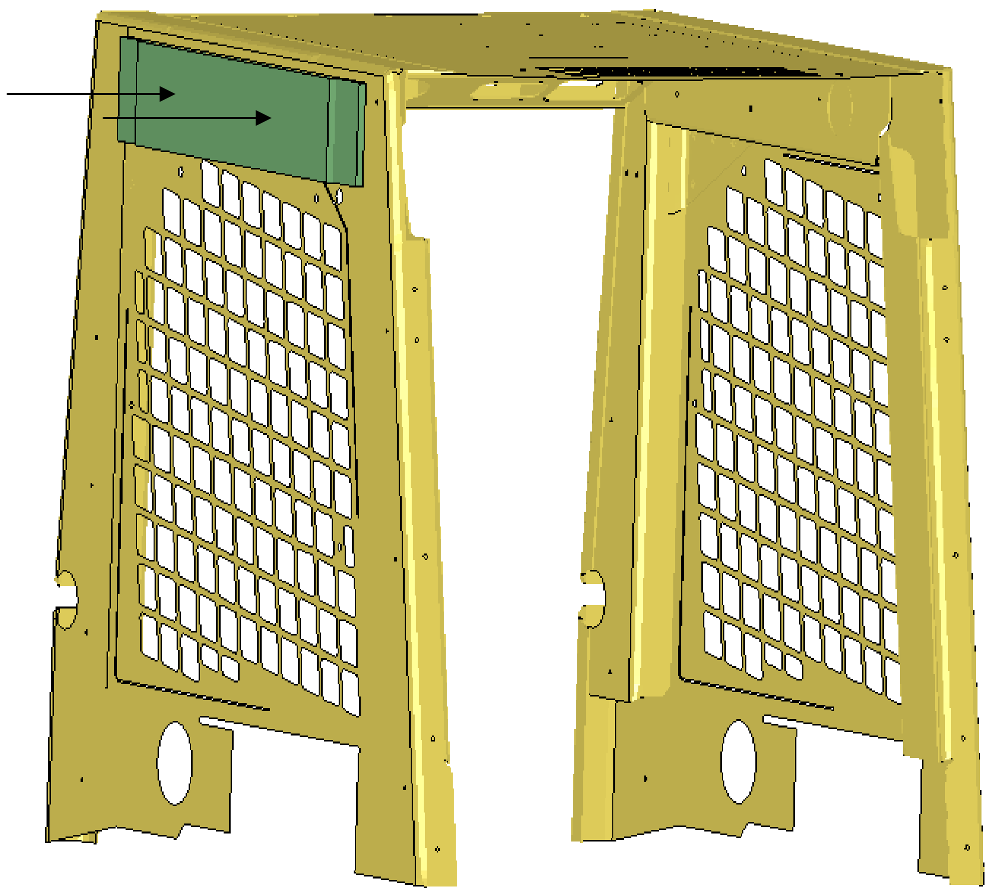


Figure 7. Lateral load application point.

The load distribution device in the case of lateral loading must not distribute load over 80 % of the total length of the cab. The load application points may not be within L/3 of the ROPS structure. These rule the design of the load application device and the dimensions of the same are given in the section 5.3.

5.4.2 Vertical loading

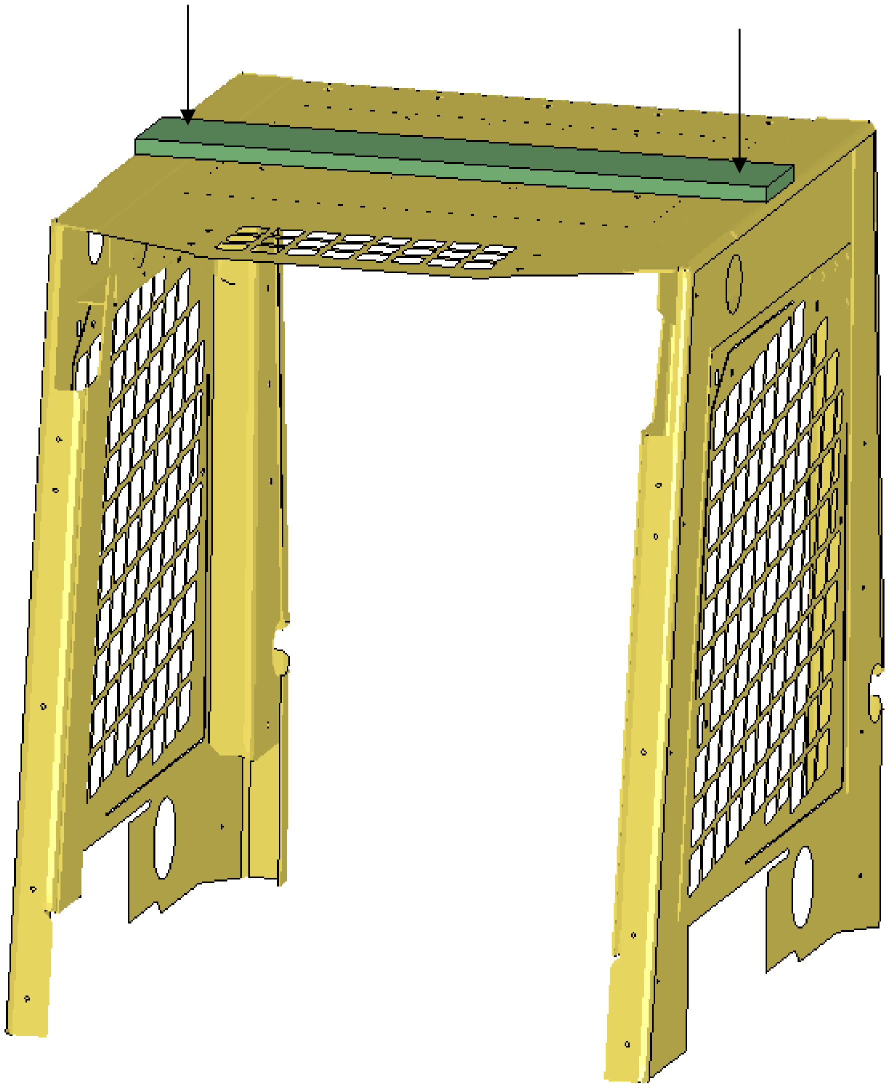


Figure 8. Vertical load application point.

After removal of lateral load, the vertical load is applied. The load distribution device in the case of vertical loading must be at the center of the ROPS cab and the DLV. The load application points are at the ends. These rule the design of the load application device and the dimensions of the same are given in the section 5.3.

5.4.3 Longitudinal loading

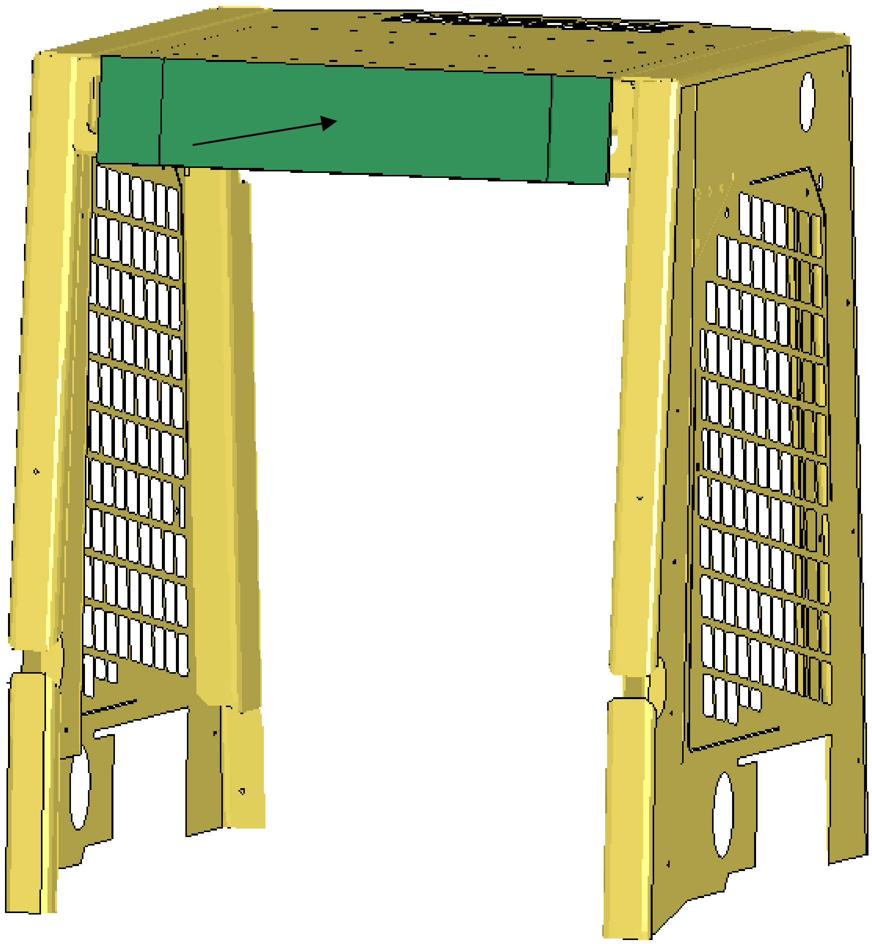


Figure 9. Longitudinal load application point.

After removal of vertical load, the longitudinal load is applied. The load distribution device in the case of longitudinal loading must be at the center of the width of the ROPS cab. The load application point needs to be parallel to the longitudinal center line of the machine. These rule the design of the load application device and the dimensions of the same are given in the section 5.3.

5.5 ISO 3449:1992 Falling Object Protective Structure Test

As explained earlier, this test is conducted by dropping a standard object like a sphere or solid steel of certain mass from a height directly above the DLV. In this research, the drop test object used is a sphere. This is modeled using PATRAN and is as shown in figure10.

5.5.1 Modeling of the drop test object in PATRAN

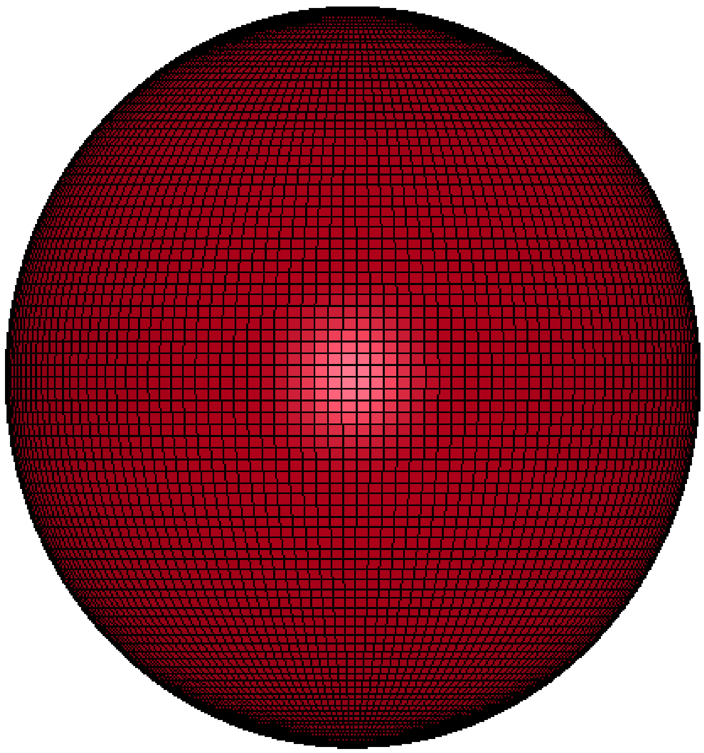


Figure 10. Drop test object.

Diameter of the Sphere:	250 mm
Mass of the Sphere:	45 KG
Energy to be Absorbed:	1365 J

CHAPTER 6

COMPOSITE MODELING

A section of the cab is chosen and its properties are changed from steel to composites. This cab with the modified section is then tested again as per ISO standards to full satisfy the ROPS/FOPS criteria. In this work, the section chosen are the main load bearing members of the whole parent structure. This section acts as both roll over and falling object protective structure. This is shown in the figure 11 and figure 12.

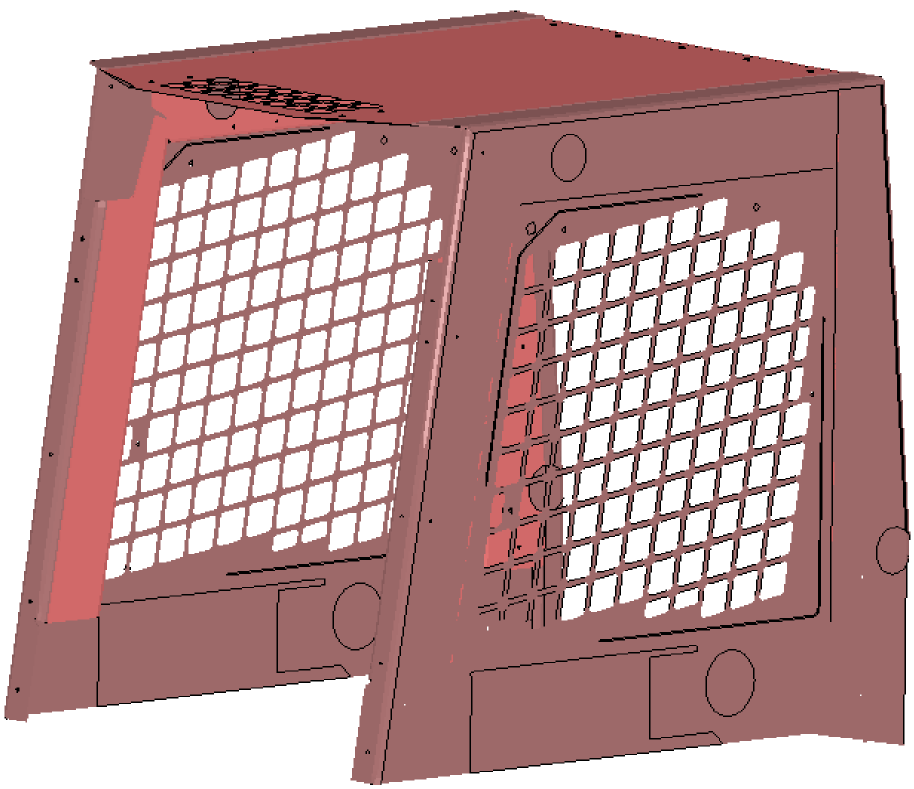


Figure 11. Composite section of cab.

6.1 Material Description

Glass-Fiber/Epoxy is the material used here. The glass fiber composites are light weight material because of its low density. The mechanical properties of the glass fiber are very much suitable as they have high impact energy absorption before fail and also they have high strength requirements. The mechanical properties of the glass fiber composites can be changed according to the requirement by changing orientation of the fiber in the loading direction, layer stacking and by changing the volume fraction of the fiber and the matrix.

Glass fiber composite can sustain the same load as of steel even with the 40 percent of the steel weight [8]. The glass fiber composites have very high specific strength and specific stiffness when compared to steel.

Table 6.1.1 Material Property for Glass- Fiber/Epoxy

Property	**Value**	**Units**
Density	2.076E-06	Kg/mm^3
Ply longtitudinal modulus	45.00	Gpa
Ply transverse modulus	12.00	Gpa
Ply poisson's ratio	0.19	-
Ply shear modulus in plane	5.5	Gpa
Ply transverse modulus parallel to fiber direction	6.574	Gpa
Ply transverse modulus perpendicular to fiber direction	5.5	Gpa
Ply longitudinal tensile strength	1.02	Gpa
Ply longitudinal compressive strength	0.62	Gpa
Ply transverse tensile strength	0.04	Gpa
Ply transverse compression strength	0.14	Gpa
Ply shear strength	0.06	Gpa

Table 6.1.2 Material Property for Steel

Mass Density	7.8 g/cc
Young's Modulus	200 Gpa
Poison's Ratio	0.3
Yield Stress	0.215 Gpa

6.2 Optimization of the Composite Section

MAT_ENHANCED_COMPOSITE_DAMAGE is the LS-DYNA material card used to define the composite material property of the composite material. This material is based on the lamination shell theory. This is material 54 in LS DYNA, which deals with the failure of composite structures under compression by additional procedures. In this card arbitrary orthotropic material e.g. unidirectional layers in composite shell structure can be defined. This material card has special measures to failure under compression. Belytschko tsay element formulation was used for the shell elements in consideration

Total energy absorption is one of the main factors considered in selecting the composite material orientation and thickness. There are a number of factors involved when composites need to be used for a section of the operator cab. The different parameters considered in the optimization of the composite section are:

1) Thickness of the Shell Element.
2) Number of layers
3) Orientation

Various combinations of these factors were analyzed and each of these is discussed below in the following sections.

Figure 12. Four post composite section.

6.2.1 Thickness of the shell element

In energy absorption of a material, thickness is major factor. The structure can withstand more loads and absorb more energy by increasing the thickness. However, with this comes an increase in volume. The mass of the structure increases with the thickness and weight is a vital component of the system which is a constraint. The analysis was carried out for two shell thicknesses of 1.3 and 2.6**.** It was found that there was no difference when the thickness was altered. The graph is as shown in figure13.

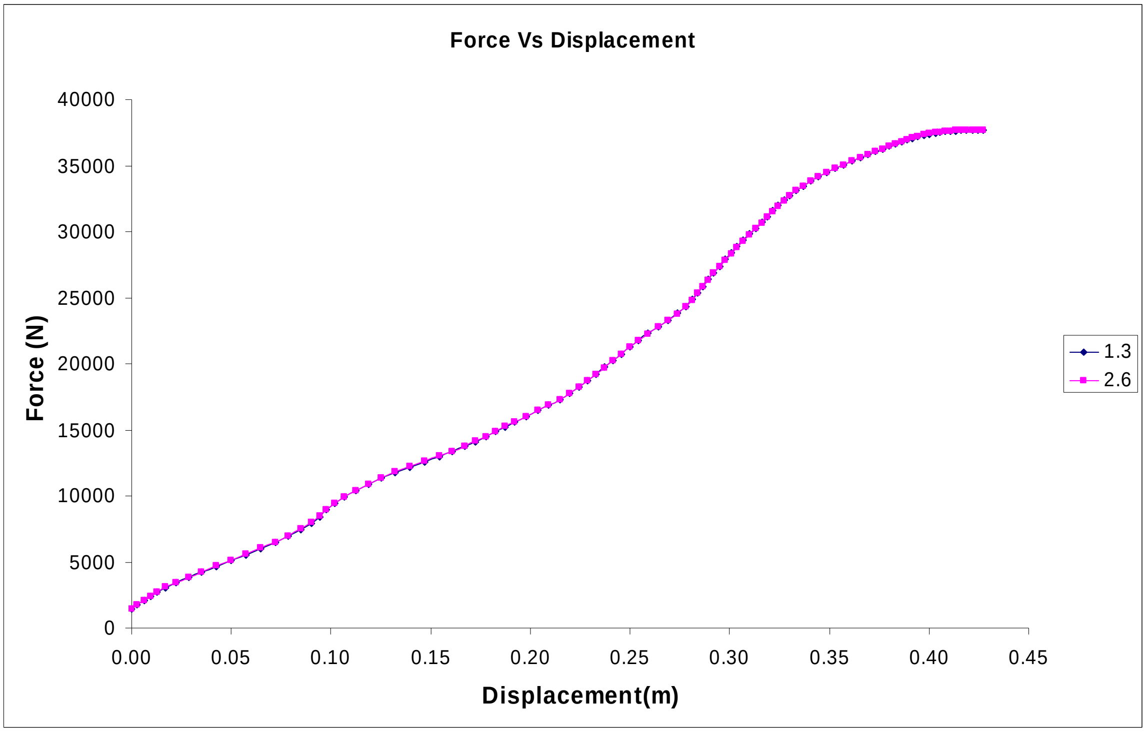


Figure 13. Force Vs displacement for different thickness.

6.2.2 Number of layers

Keeping the thickness constant as 2.6, the analysis was carried out for different number of layers. It was analyzed for 5, 7, 9 and 13 layers. Large scale diminishing of mesh elements were found in the case of 5 and 9 layers. The graph in figure 14 shows the comparison between 7 and 13 layers. From the graph we observe that the energy absorbed is more for 7 layers. But the deflection is more in this case. Since human safety factor is involved here, the one with the least displacement is chosen and hence the ideal number of layers was taken to be 13.

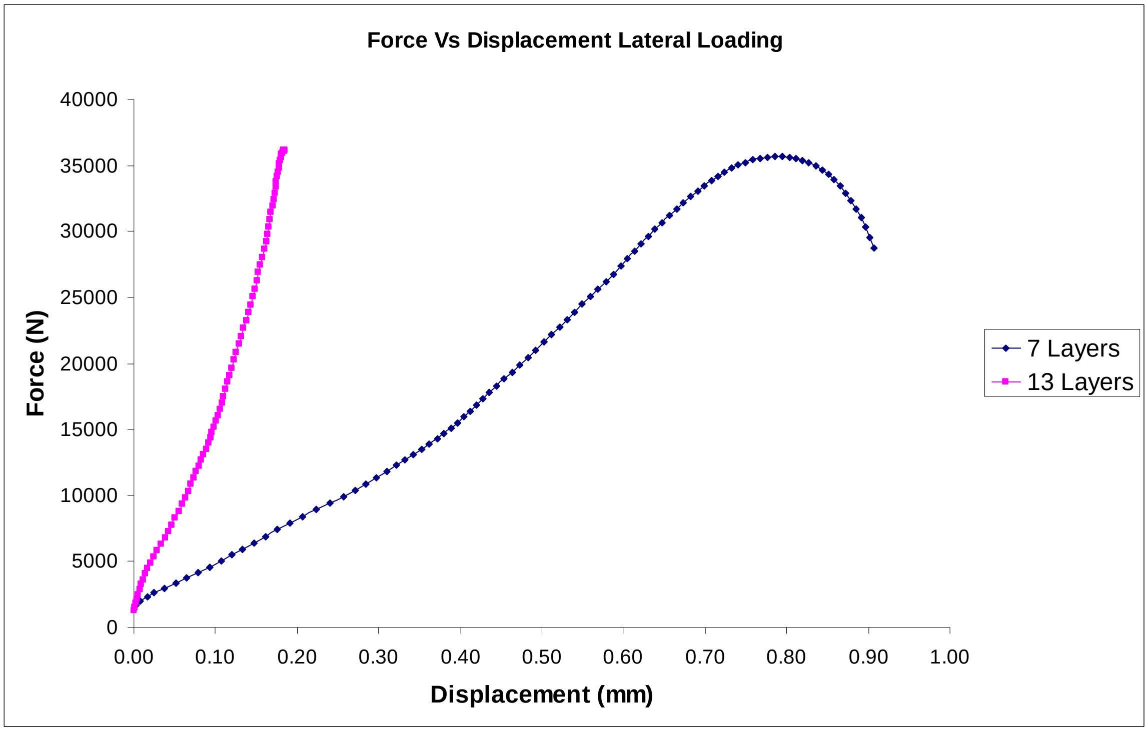


Figure 14. Force Vs displacement for different layers.

6.2.3 Orientation

It takes numerous iterations to find out the best orientation which gives maximum energy absorption. It started with some of the common orientations. These were compared using the Force v/s Displacement curve and the energy dissipated in each specimen. The energy absorbed in every iteration was recorded and compared. Finally, an orientation with the highest energy absorption capability was chosen for further study in this research. Now keeping the thickness constant at 2.6 and the number of layers to be 13, the analysis was carried for different orientations as below:

a) 30,-30,30,-30,30,-30,0,-30,30,-30,30,-30,30

b) 45,-45,45,-45,45,-45,90,-45,45,-45,45,-45,45

c) 0,90,0,90,0,90,0,90,0,90,0,90,0

The results are shown in the graph in figure 15.

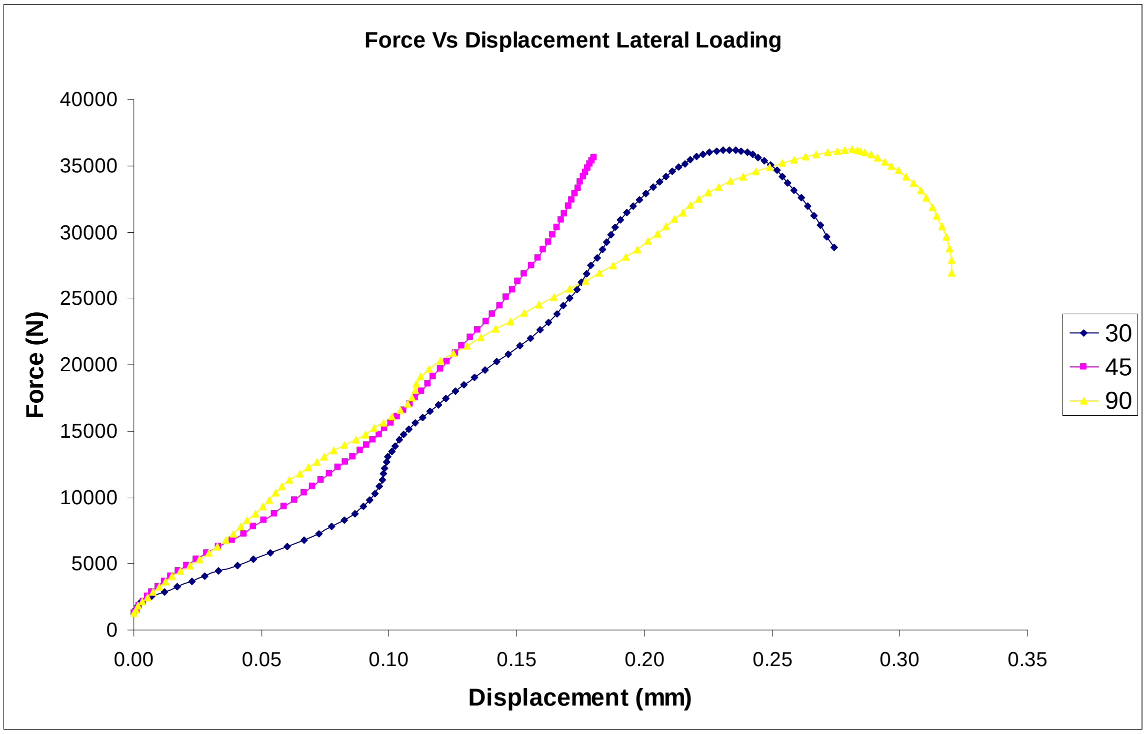


Figure 15. Force Vs displacement for different orientation.

Lateral Load Energy:

a) 30 degree orientation: 3280 J

b) 45 degree orientation: 5499 J

c) 90 degree orientation: 7310 J

The 30 degree orientation is ruled out of using as it is not satisfying the lateral load energy requirements. Since the 45 degree orientation is satisfying the requirements as well as has the least displacement, this is selected for further studies. This was applied for vertical as well as longitudinal loading and the results are discussed in the following chapters.

CHAPTER 7

RESULTS AND DISCUSSION

7.1 ISO 3471:1994

Simulation Results with current Steel Roll Over Protective Structure

The ROPS test is carried out as per the ISO test standards explained earlier. The results are first discussed for the steel cab and then for the composite cab.

7.1.1 Lateral loading

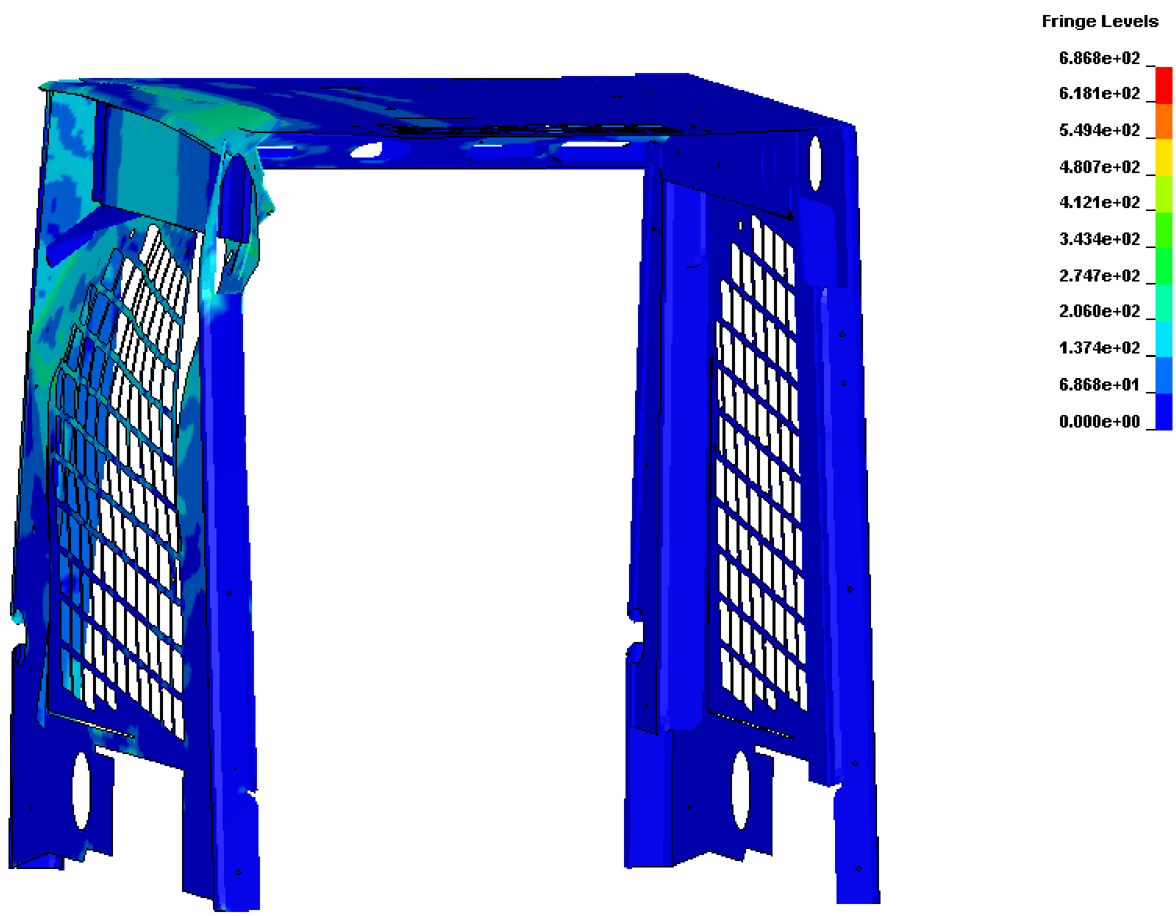


Figure 16. Lateral loading of the steel cab.

Load Applied: 28800 N

Lateral Load Energy: As Per Calculations: 3976 J

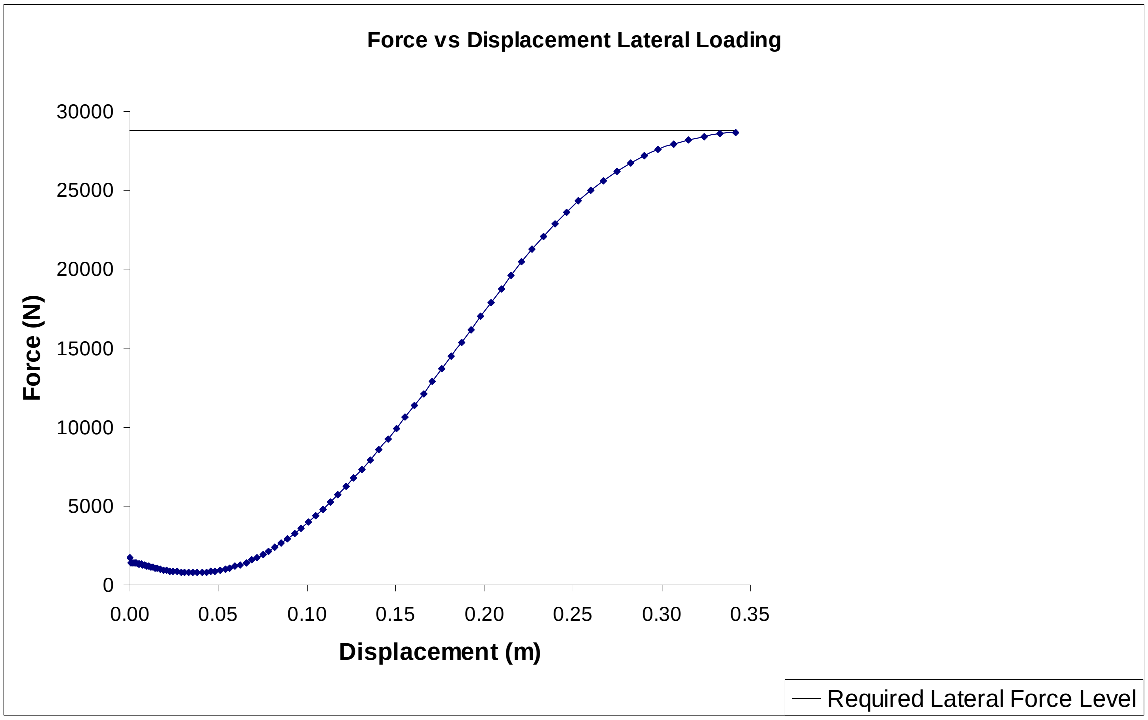


Figure 17. Force Vs displacement for lateral loading of steel cab.

LS- DYNA was used to do the analysis. The results are as shown in figure 16. The lateral load force and the lateral load energy are calculated using the formulae given in the standards. Considering the mass of the vehicle, the cab should withstand a lateral load force of 28800N and lateral load energy of 3976 J. The lateral load energy is calculated from the Force V/s Displacement graph for lateral loading as shown in figure 17. The area under the curve of force v/s displacement is calculated using MATLAB and is found to satisfy the requirements as per standards. Hence the steel cab is validated for lateral loading.

7.1.2 Vertical loading

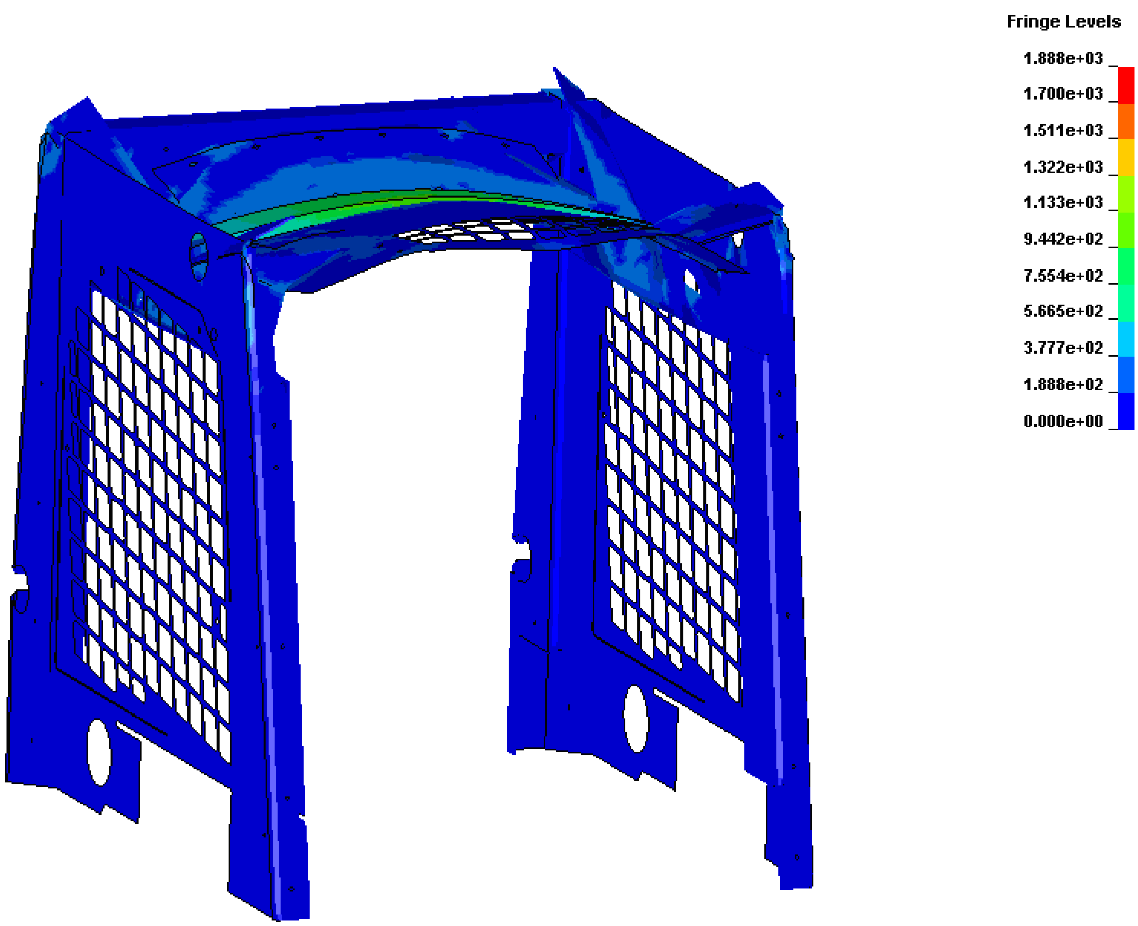


Figure 18. Vertical loading of the steel cab.

Load Applied: 82000 N

LS- DYNA was used to do the analysis. The results are as shown in figure 18. The vertical load force is calculated using the formula given in the standards. Considering the mass of the vehicle, the cab should withstand a vertical load force of 82000N. The graph of Force V/s Displacement for vertical loading is as shown in figure 19.

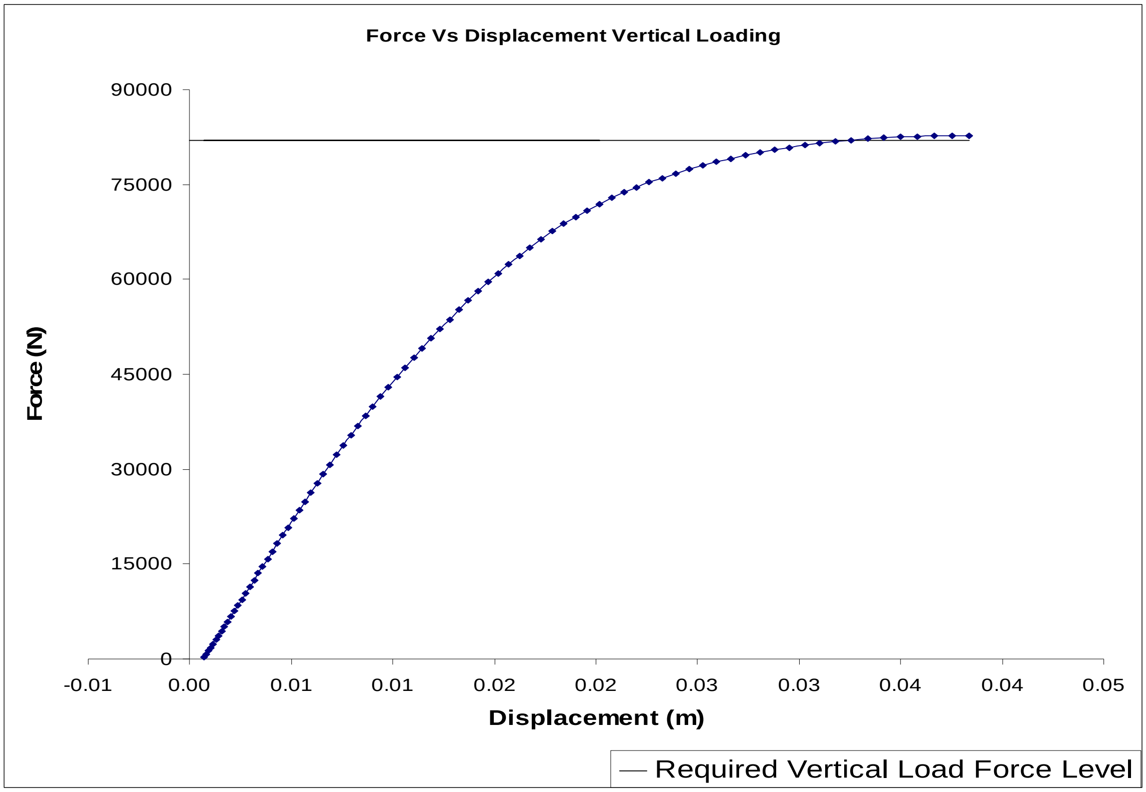


Figure 19. Force Vs displacement for vertical loading of steel cab.

From the graph we see that the force in excess of the required minimum as per standards is achieved. Since it satisfies the requirements as per standards, the steel cab is said to be validated for vertical loading.

7.1.3 Longitudinal loading

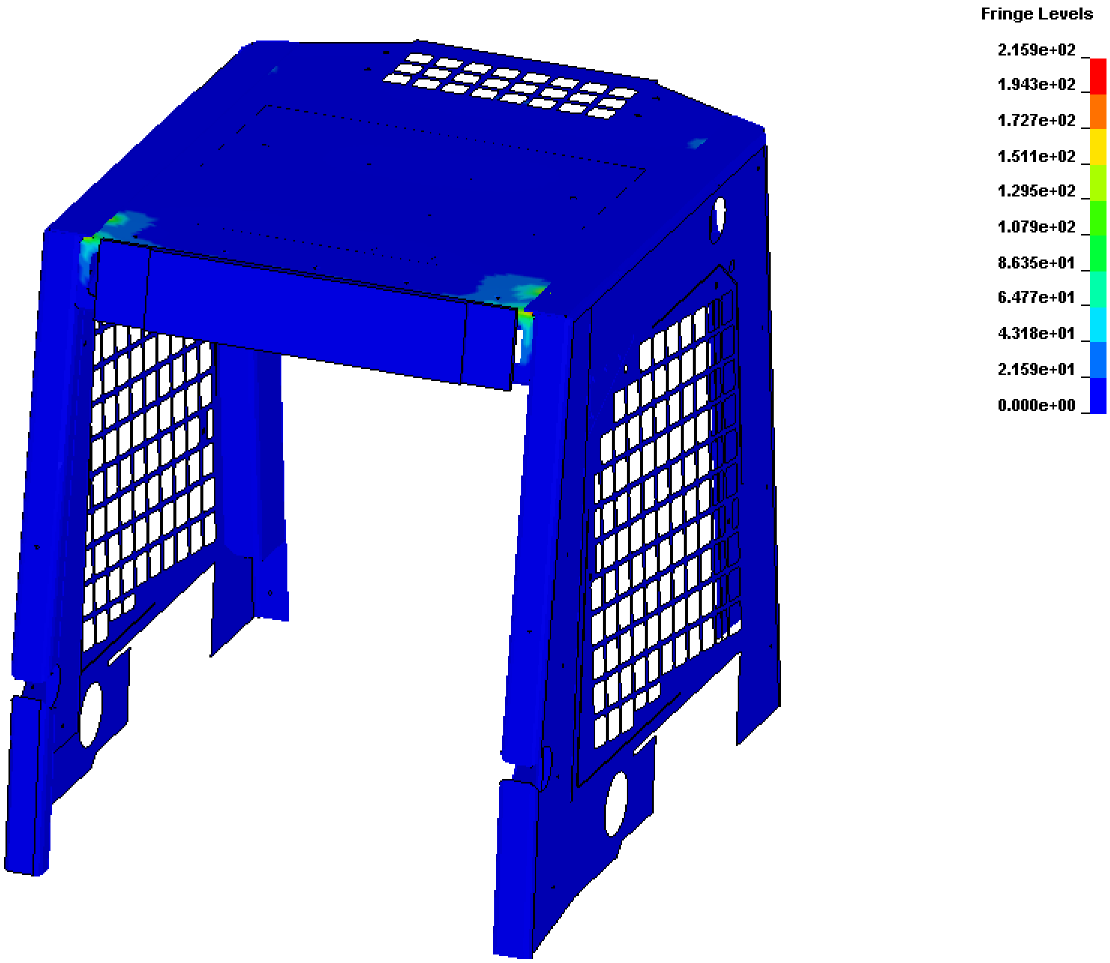


Figure 20. Longitudinal loading of the steel cab.

Load Applied: 20000 N

LS- DYNA was used to do the analysis. The results are as shown in figure 20. The longitudinal load force is calculated using the formula given in the standards. Considering the mass of the vehicle, the cab should withstand a longitudinal load force of 20000 N. The graph of Force V/s Displacement for longitudinal loading is as shown in figure 21.

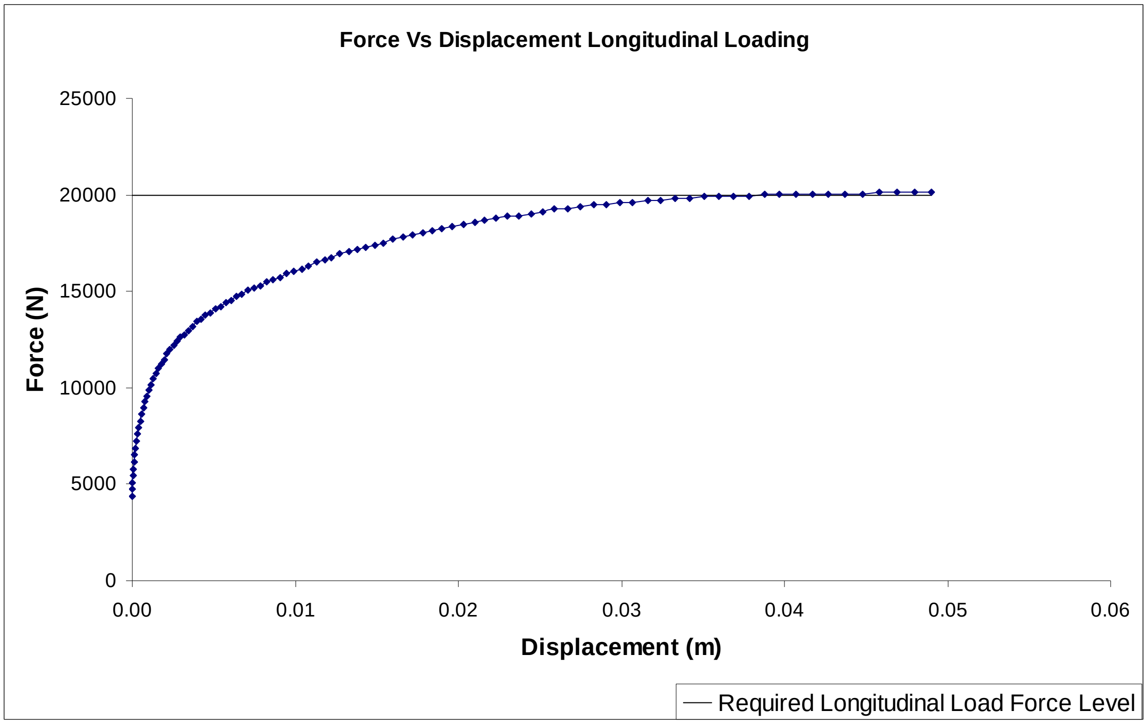


Figure 21. Force Vs displacement for longitudinal loading of steel cab.

From the graph we see that the force is about the required minimum as per standards. Since it satisfies the requirements as per standards, the steel cab is said to be validated for longitudinal loading.

Once the steel cab is fully validated for the ROPS standards, a section is chosen and then the properties are changed from steel to composites. The analysis and validation of the composite section cab is discussed in the next section.

7.2 ISO 3471:1994

Simulation Results with composite section Roll Over Protective Structure

7.2.1 Lateral loading

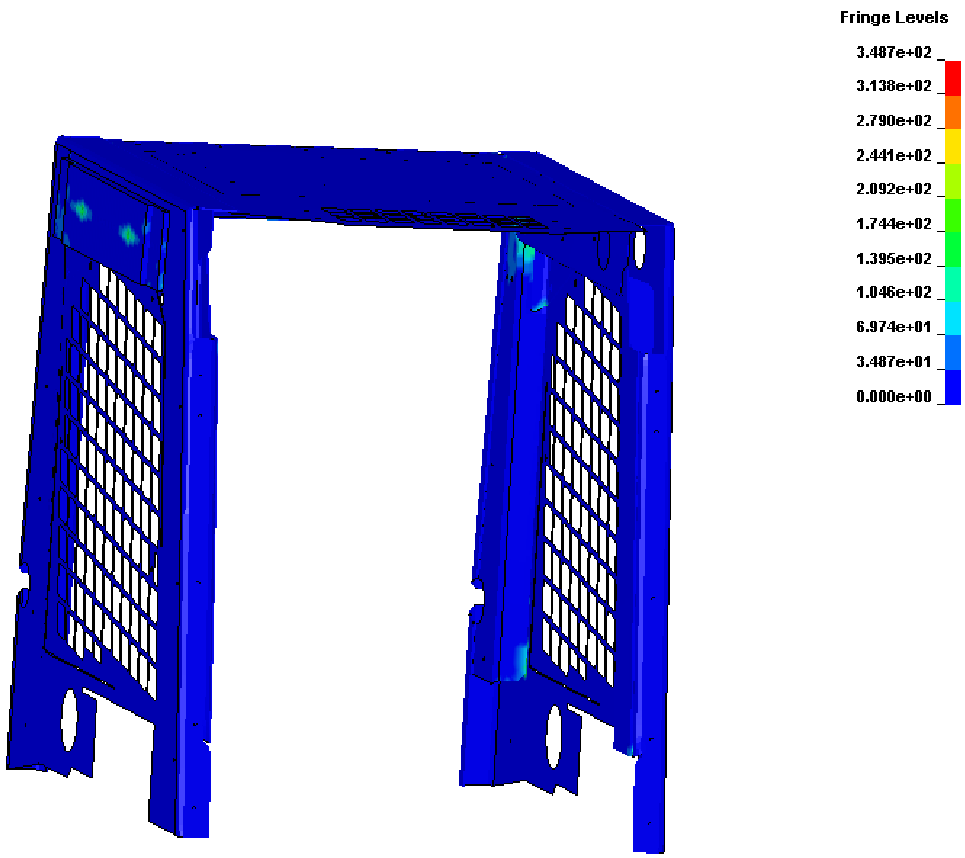


Figure 22. Lateral loading of the composite cab.

Load Applied: 28800 N

Lateral Load Energy: As Per Calculations : 3976 J

As Per Analysis : 5801 J

LS- DYNA was used to do the analysis. The results are as shown in figure 22. The lateral load force and the lateral load energy were calculated using the formulae given in the standards as explained earlier.

The Force V/s Displacement graph for lateral loading of the composite section cab is as shown in figure 23. Here we can observe that the composite section duly complies with the minimum lateral load force requirement of 28800N. Also in comparison to steel, the displacement is also less.

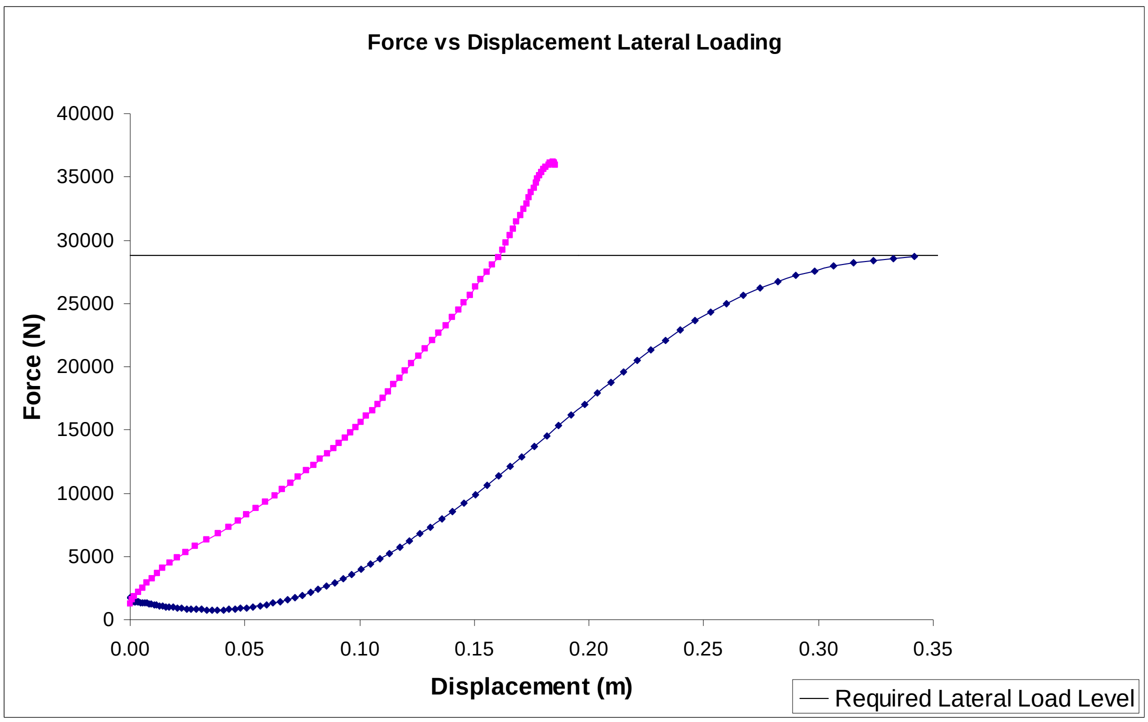


Figure 23. Force Vs displacement for lateral loading of composite cab.

MATLAB was used to calculate the lateral load energy. The area under the Force V/s Displacement curve was used as the input. It is found that the cab with the composite section not only complies with the minimum requirement but also exceeds it by about 46% more than that of the steel. Once validated for lateral loading, the test proceeds to check with the vertical and the longitudinal loading. These are discussed in the next two sections.

7.2.2 Vertical loading

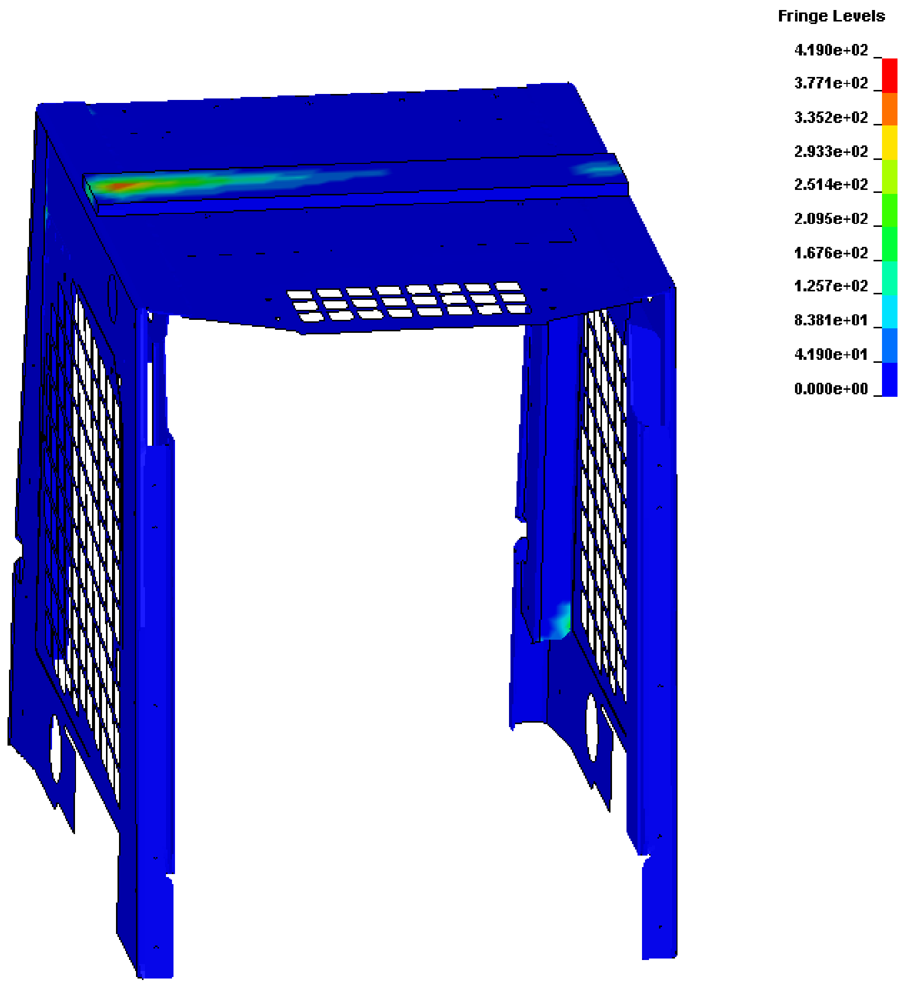


Figure 24. Vertical loading of the composite cab.

Load Applied: 82000 N

LS- DYNA was used to do the analysis. The results are as shown in figure 24. The vertical load force is calculated using the formulae given in the standards as explained earlier.

The Force V/s Displacement graph for vertical loading of the composite section cab is as shown in figure 25. Here we can observe that the composite section duly complies with the minimum lateral load force requirement of 82000 N. Also in comparison to steel, the displacement is also less.

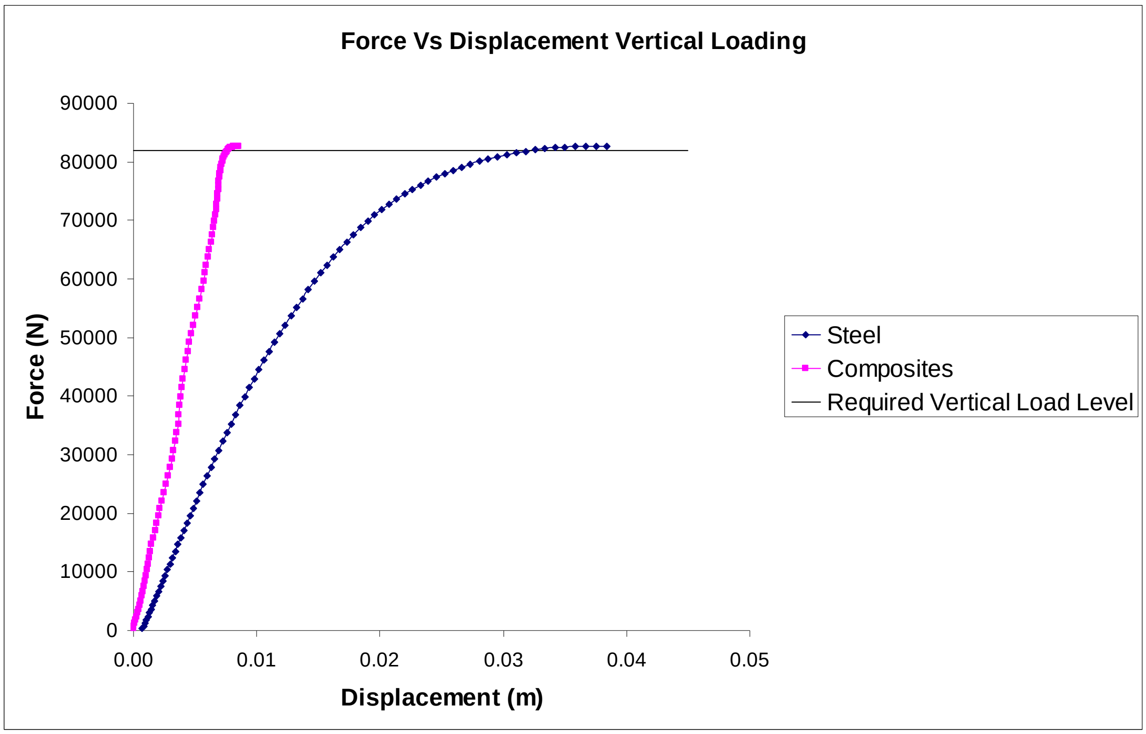


Figure 25. Force Vs displacement for vertical loading of composite cab.

The cab with the composite section is now validated for lateral and vertical loading conditions. The test proceeds to check with the longitudinal loading which is discussed in the next section.

7.2.3 Longitudinal loading

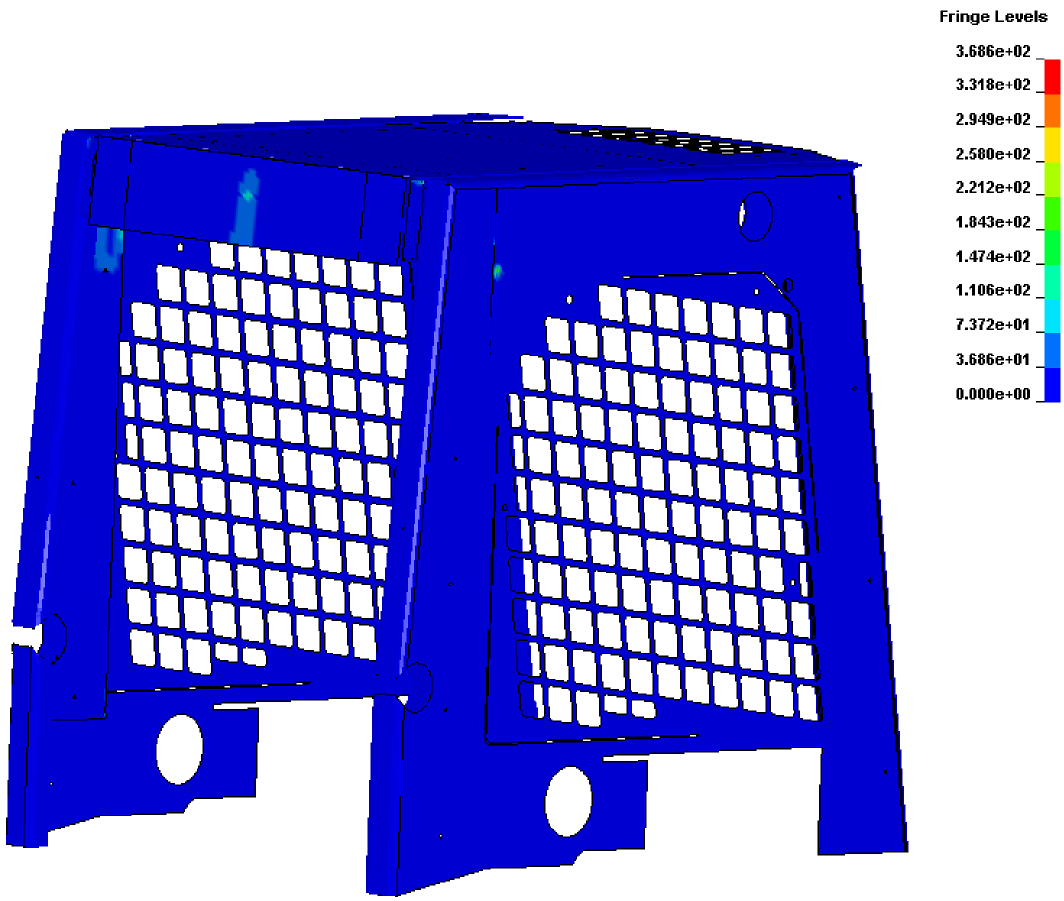


Figure 26. Longitudinal loading of the composite cab.

Load Applied: 20000 N

LS- DYNA was used to do the analysis. The results are as shown in figure 26. The longitudinal load force is calculated using the formulae given in the standards as explained earlier.

The Force V/s Displacement graph for longitudinal loading of the composite section cab is as shown in figure 27. Here we can observe that the composite section duly complies with the minimum longitudinal load force requirement of 20000 N. Also in comparison to steel, the displacement is also less.

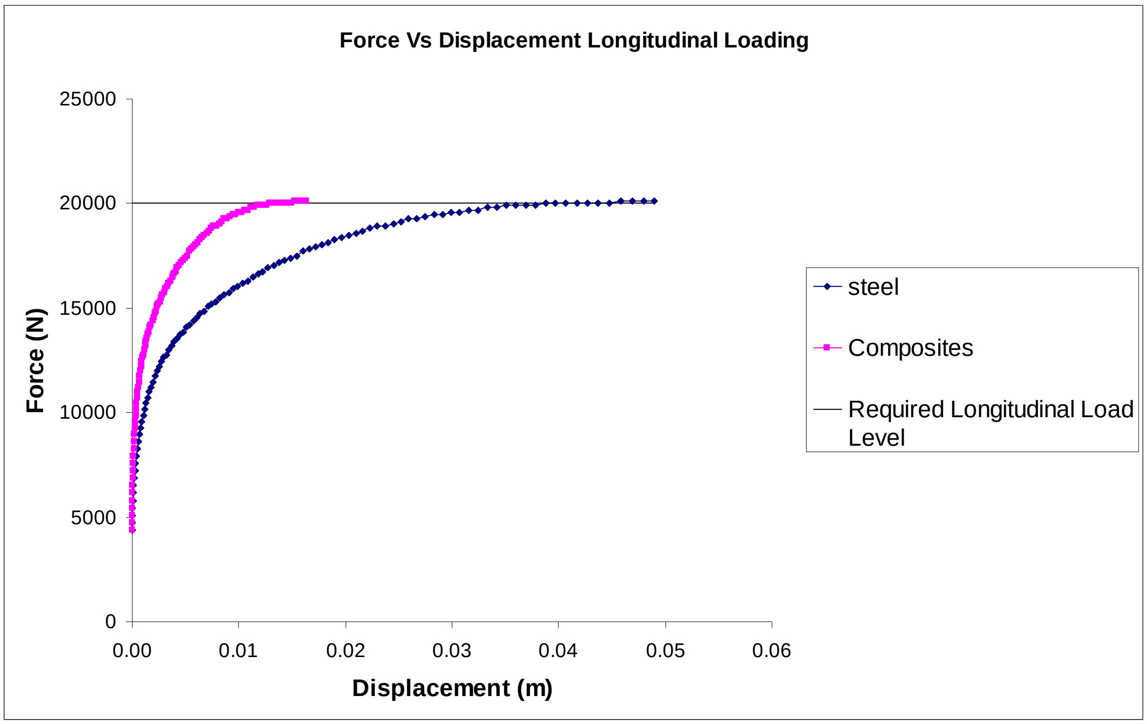


Figure 27. Force Vs displacement for longitudinal loading of composite cab.

The cab with the composite section is now fully validated for lateral, vertical and longitudinal loading conditions as per ISO 3471:1994 standards for ROPS. Now the cab needs to conform to the basic FOPS standards as well, which comes standard with the equipment. This is discussed in the next few sections.

7.3 ISO 3449:1992

The FOPS test is carried out as per the ISO test standards explained earlier. The results are first discussed for the steel cab and then for the composite cab.

7.3.1 Test set up

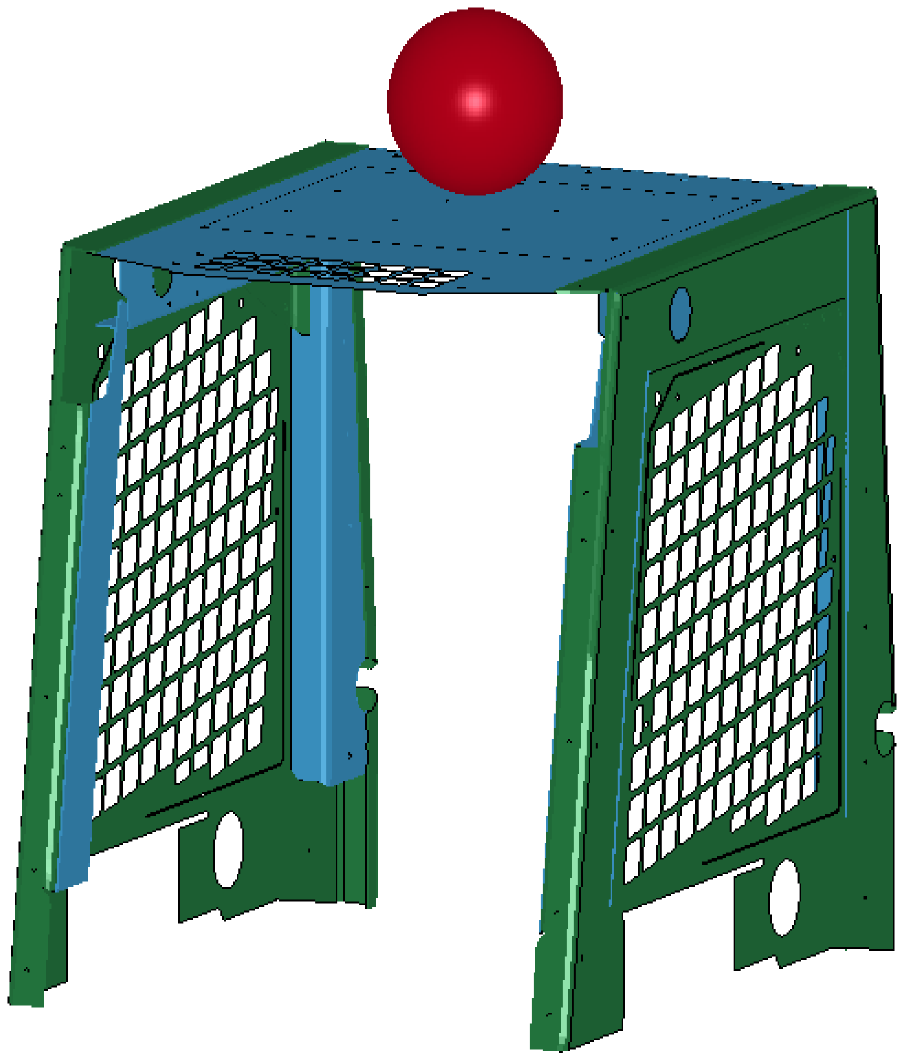


Figure 28. Test set up for FOPS.

The sphere of weight and dimensions as discussed in section 5.5 is set above the DLV of the cab using ECD. The test set up is shown in figure 28.

7.4 Simulation Results with Current Steel Falling Object Protective Structure

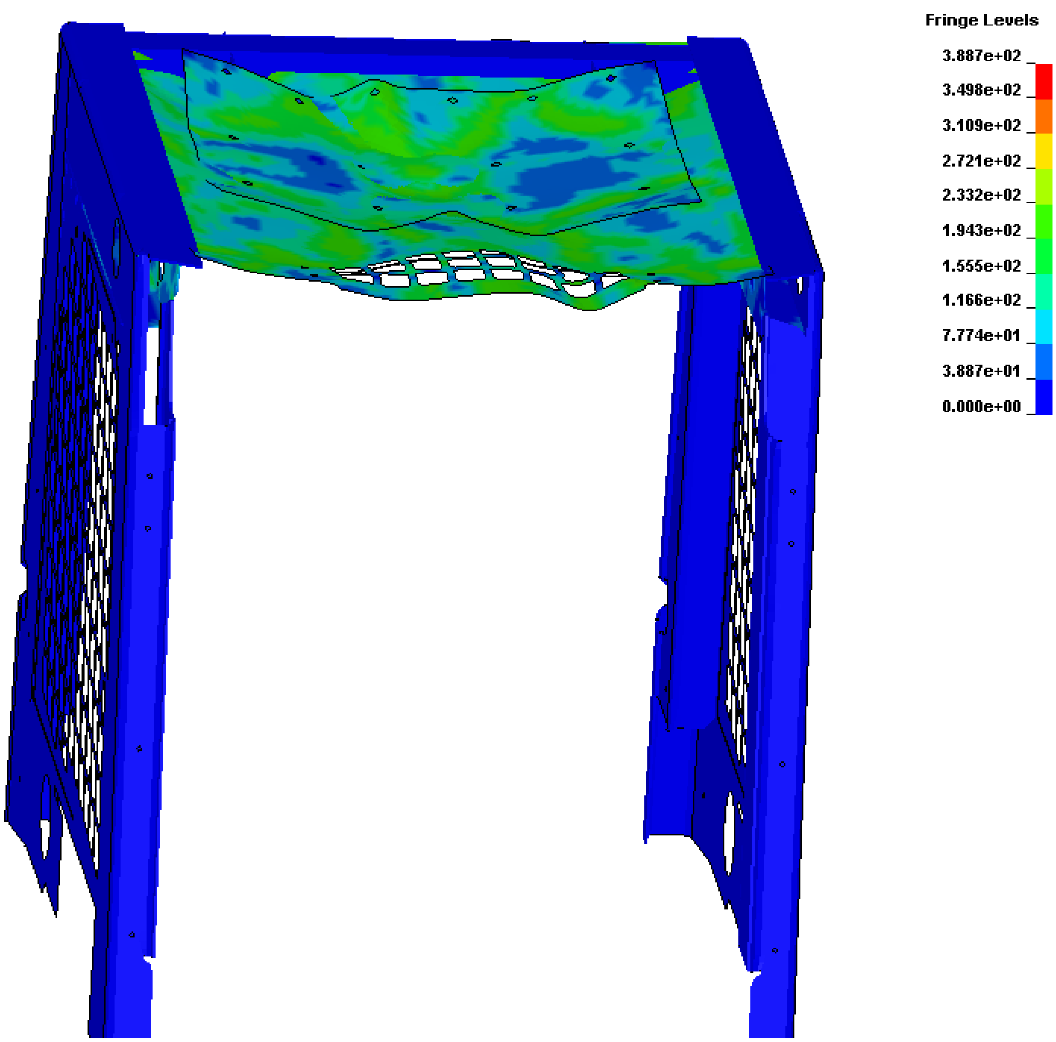


Figure 29. Drop test simulation of the steel cab.

LS- DYNA was used to do the analysis. The results are as shown in figure 29. Since the drop test object (a sphere in this case) is not entering the DLV, the FOPS cab designed passes the test criteria as per ISO standards. The deflection is calculated from the force v/s displacement graph as shown in figure 31. The steel cab is now validated for the FOPS test and the test proceeds to check the same with the composite section.

7.5 Simulation Results of Composite Section Falling Object Protective Structure

LS- DYNA was used to do the analysis. The results are as shown below in figure 30. Here the cab with the composites section is used and the since the drop test object (a sphere in this case) is not entering the DLV, the FOPS cab designed passes the test criteria as per ISO standards. The deflection is calculated from the force v/s displacement graph as shown in figure 31.

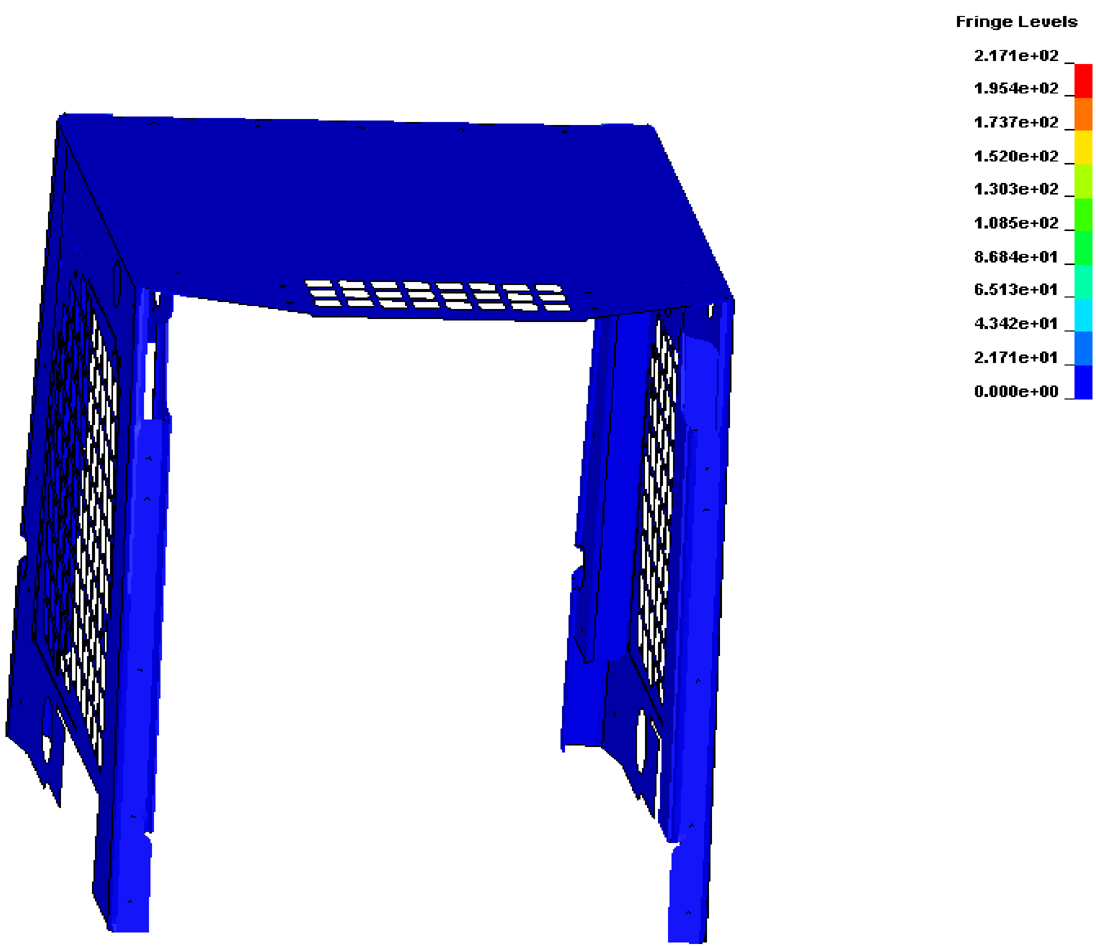


Figure 30. Drop test simulation of the composite cab.

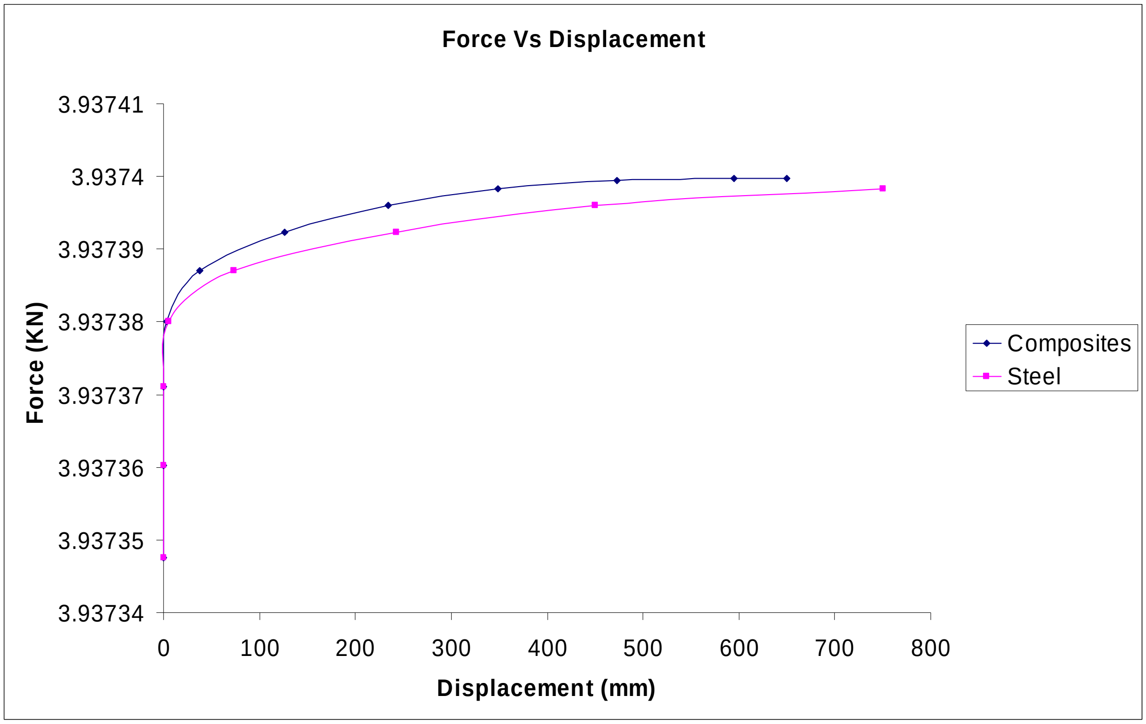


Figure 31. Force Vs displacement comparison of steel and composite section cab during FOPS test.

The force v/s displacement graph for the FOPS test for both steel and composites is compared in the figure 31. From the graph we can see that the displacement for composite section of said material, orientation and thickness has less deflection than the steel. Therefore it can be concluded that the cab with the composite section is now fully validated as per ISO 3449:1992 standards for FOPS.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to investigate the use of composites as an alternative in the operator cab of skid steer loaders. A skid steer loader model was constructed using PRO-E and then meshed for analysis using HYPERMESH. Then ECD was used to place the load distribution devices on the cab. The load application points are determined and the skid steer loader cab is tested for ROPS/FOPS standards as per ISO standards. First the cab is tested and evaluated for steel. Then different sections of the cab are selected and the properties are changed to composites. Once the section was chosen, different material \ orientations were applied to achieve high energy absorption option. This study suggests that composite sections in the cab can be used and effectively reduce the impact energy and intrusion into the DLV to a greater extent than steel.

8.1 CONCLUSIONS

By comparing the computational results of steel cab with the composite cab, it can be concluded that:

- Composite sections in a steel cab are more effective for both ISO 3471:1994 and ISO 3449:1992 ROPS/FOPS standards.
- Using the composite section would reduce the weight of the cab by about 30 %
- User can optimize the mechanical properties of the composite material by changing the fiber orientation and fiber matrix volume ratio.
- Composite materials are replaceable where high strength and high stiffness are required.

- DOE can be used to optimize the composite section to find out the right orientation, precise material and the correct thickness that absorbs most energy.

8.2 RECOMMENDATIONS

The following are the future recommendations which can be addressed by using composite material with new design:

- The FOPS standards can also be modeled and tested for Level-II ISO standards.
- Environmental parameters like the moisture content, temperatures and service life of the composite section can be explored.
- Experimental validation can be conducted to verify the results obtained.
- Glass fiber was used in the analysis here. A different material or a combination of composite materials can be used to reinforce the section and analysed.
- Experimental validation needs to be done before practically implementing on the skid steers in industry.
- This methodology can be extended to different operators cab for other earthmoving equipments.
- Manufacturing, at present, is expensive. Alternatives to reduce the manufacturability cost can be explored.

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