Kaunas University of Technology

Mechanical Engineering and Design Faculty

Investigation of Rollover Protection for Trucks

Master's Final Degree Project

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Kaunas, 2019

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Vehicle Engineering 6211EX021

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Declaration of Academic Integrity

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

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Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Study Programme – Vehicle Engineering 6211EX021

Task Assignment for Final Degree Project of Master Studies

Student Mohankumar Doddaningenahalli Kumara Swamy

1. Title of the Final Project:

Investigation of Rollover Protection For Trucks

Sunkvežimių apsivertimo tyrimas

2. Aim of the Final Project:

To investigate the Rollover Protection For Trucks with the help of AIS 029 and ECE R29 regulations and to propose suitable changes to amend AIS 029 regulations.

3. Tasks of the Final Project:

- To ensure that the truck is designed according to the regulations mentioned by the Automotive Industry Standard AIS 029.
- To ensure that the superstructure of the truck is designed to withstand all kind of impacts created during rollover of the truck.
- To make sure that the residual space of the truck is unharmed before and after rollover accident.
- To optimize the topology of the superstructure of the truck.
- To study the deformation of the superstructure of the truck by using different materials.
- To propose suitable corrections that can be amended to AIS 029 regulations.

4. Structure of the Text Part:

- Literature Survey
- Collection of Accident Data's
- Designing of Trucks Superstructure Model using CAD Software
- Analytical Calculations on Designed Model and FEA Analysis
- Result, Discussions and Conclusion

5. Consultants of the Final Project:

Author of the Final Project _____

(Name, Surname, Signature, date)

Supervisor of the Final Project _____

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Head of Study Programme Janina Jablonskytė _____

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Mohankumar Doddaningenahalli Kumara Swamy. Investigation of Rollover Protection for Trucks. Master's Final Degree Project / supervisor Prof dr. Lukoševičius Vaidas; Mechanical Engineering and Design Faculty, Kaunas University of Technology.

Study field and area (study field group): Transport Engineering (E12), Engineering Science.

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Summary

Since the evolution of wheels till the dicovery of supercars, the transportation have seen a periodic change. Human beings use vehicles in everyday life for travelling, shipping of goods etc. Accidents are one of the unavoidable cause along with the vehicles. When we see news about an accidents we being engineers tend to analyse the reason behind them. There could be many reasons behind accidents. Rollover is one of the common reasons for the accident of the trucks. Instability of the truck in cornering is being main reason for rollover. Rollover is considered as one of the most catastrophic types of accident which causes significant damage to the truck structure and severe injuries to the driver and co-driver.

In this study an Indian truck Ashok Leyland U3118 is taken as an example and designed according to the standards given in AIS 029 in the Solidworks software. The strength of the structure designed in solidworks is analysed in ANSYS Workbench software according to the tests mentioned in regulations. Topology of the designed model is optimized and analysed to compare the strength of structure. Strength of the structure is analysed in dynamic analysis using different materials to show the best material which is safe for structur.

Mohankumar Doddaningenahalli Kumara Swamy. Sunkvežimių apsivertimo tyrimas. Magistro baigiamasis projektas/vadovas Prof dr. Lukoševičius Vaidas; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

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Reikšminiai žodžiai: Sunkvežimių avarijos, Nelaimingi atsitikimai, Apsiversti, AIS 029, ECE R29, Solidworks, ANSYS.

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Santrauka

Transporto priemonės nuolat evoliucionuoja. Žmonės kasdieniniame gyvenime naudojasi transporto priemonėmis gabenti krovinius, prekes ir tt. Transporto priemonių nelaimingi atsitikimai yra neišvengiami. Apsivertimas yra viena iš dažniausių sunkvežimių avarijos priežasčių. Pagrindinė apsivertimo priežastis yra sunkvežimio nestabilumas posūkiuose. Apsivertimas yra laikomas vienu iš katastrofiškiausių nelaimingų atsitikimų tipų, dėl kurių pažeidžiama sunkvežimio konstrukcija ir vairuotojas ar transporto priemonės operatorius patiria sunkius sužalojimus.

Darbe išnagrinėtas Indijoje plačiai naudojamas sunkvežimis „Ashok Leyland U3118“. Sunkvežimio konstrukcijos stiprumas analizuojamas ANSYS Workbench programinėje įrangoje pagal reglamentuotus nurodytus bandymus. Sukurto modelio topologija optimizuojama ir analizuojama, kad būtų galima palyginti skaičiuojąmąjį modelį. Konstrukcijos stiprumas analizuojamas ir palyginamas veikiant dinaminėms apkrovoms, naudojant įvairias medžiagas.

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Introduction

Rollover is the type of truck accident that is most widely recognized and overwhelming. In a washing machine, finding a rollover resembles being inside. The result is subject to the road for the inhabitants and includes the geology, speed and genuine vitality consumed by the cabin structure. Regardless of whether the absolute vitality, for the most part, is high, the consumed vitality by cabin exist extensively regularly low enough, for example super structure impact, aspiring in the range in which possible counter measures by for example an appropriate BIW configuration is conceivable. Clearly, regardless of whether the 3-point safety belt contains defects in rollover mishaps, despite everything, it computes enormously for the fruitful result[1].

High winds are the most obvious weather is linked to roll-over of a vehicle. In the circumstances at the point of large center of gravity chance of rolling over of vehicle increases in heavy winds. In addition, the high winds, road surfaces during different weather (snow, rain, ice) can all add up for roll-over of vehicle by constraining contacts among tyres and surface of the road. Some trailers on the high side are more expected to roll over[2].

- Avoidance of Vehicle Roll-over

This kind of incident happens when driver attempts to stay away from the hurdles in their path, by turning the vehicle suddenly results in eventual overturn situation. The situation of overturn is usually happening by the correction of the initial prevention maneuver which results in action of cumulative pendulum that would boost up or reduces as vehicle progesses to move straightly. The pendulum movement is been improved by the vehicles with the high centre of gravity, like car transporters and double deck trailer units, powder or liquid tankers and many more[2].

- Braking system

For keeping more command on a vehicle for a driver the braking system is more important for the vehicle working in correct order. Electronic Braking Systems (EBS), Anti-lock Braking Systems (ABS) and Electronic Stability Programs (ESP) these all help prevent vehicles from rolling over as they can modify braking arrangement for each and every wheel, probably gives more control to the driver. ABS, EBS and ESP united effects ,sensors like yaw rate and steering angle may take remedial action to believe the control of a driver and decrease the chances of rollover[2].

- Cornering

By checking, a bigger portion of the vehicle roll-overs happens during the cornering. Because of the more center of gravity and lower threshold of roll-over, coming in corner at the extreme speed boosts the leaning and the roll-over of the vehicle[2].

- Driver Error

Driver error or inadequate training can be attributed to a number of factors. Failure to judge the magnitude of a corner may cause vehicle to enter the corner very fast. Even lack of the attention may add up to the vehicle's roll-over. By the disturbance and even drowsiness or by simply not evaluating the path infront can lead to a immediate alertness of the danger for which immediate action should be taken incase to avoid the danger. The action taken can lead to the driver's sharp turn, promoting roll-

over. Some situations are there where either the driver runs on soft shoulder and is pulled over through the runoff or kerb and the load shift is affected by a roll-over[2].

- Excessive speed

Current studies shows that enormous speeds boost the possibilityof a vehicle rollovers [2].

- Jack Knifing

Jack-knifing is mainly due to failure of the equipment, locking of the wheels because braking and weak grip due to unfavourable conditions of driving. Relying on the speed the vehicle is traveling, jack-knifing may results in a vehicle roll-over[2].

- Load

Due to the load-related factors, most vehicle roll-overs occur. This can be due to insufficient loading or incorrect loading. The elevation of the center of gravity of load will directly influence the vehicle's center of gravity–thereby changing Rollover Threshold. The double-deck trailers are at higher opportunities for roll-over when it is loading, specificslly if the higher load percentage or heavier load is inaccurately fixed on top deck of the trailer[2].

- Oversteering

Oversteering can occur for a variety of reasons. Previously mentioned points are arriving to corner at high speeds or an immediate attention of danger, which could lead to oversteering. However, oversteer can also occur as a result of excessively abrupt or over-correcting lanes–where the turn made by driver is too much and later tries to correct the steering that surpass the balance of vehicle which shows a pendulum effect as explained in avoidance od vehicle rollover[2].

- Road design

Road design can make a significant contribution to the roll-over of vehicles. Roundabouts, adverse cambers, slip roads, double track contra-flow lane changes and double bends can all constitute to roll-over, as they are not everytime designed with LGVs and PCVs keeping in mind and are usually not signed properly[2].

- Suspension settings

The proper suspension settings must be aligned with distinct situations. Incorrect setting of ride height, faulty condition and air suspension unit pressures, and breakdown to restart the ride. The height control valve after loading / unloading may all boost the possibility of vehicle roll-over[2].

- Tyres

Under-inflated tyres were attributed to a number of vehicle roll-over cases. Considering the under-inflated tyres means that a vehicle leans too much if the tyres were inflated correctly. There's problem even with with worn tyres. It is because the vehicle's cornering ability is adversely affected by a worn tyre's limited grip on low friction surfaces[2].

Conclusions on driver injuries and cab deformations: It is important to keep driver in the position during the whole sequence that is applying seat belt, in order to protect the occupants. The robust cab

structure gives space for survival, and the' friendly' interiors safegaurds driver from internal impact injuries. The person is usually injured because the seatbelt is not put up. If seat belt is removed, he is been thrown out of the cab and sometimes, in whole or in part, out of the cab[3].

Average seat belt usage in the sample is lesser than 10 percent over the years. (However, it is been improving the seat belt use currently is almost 35 percent in Sweden.) The ART seatbelt effect analysis is accurate in at least 60 percent of accidents, the seatbelt wearing effect has an injury-reducing effect[3].

Even if the seatbelt is put up, in a nearside rollover there is a risk of injury. The upper part of the body could affect the hard ground or be partially ejected by the opening of the side window. An active curtain covering the side window that keeps the driver tighter to the seat may reduce the risk of head, chest and upper extremities being injured. ~40% of all accidents in the sample are deformed by the upper A-pillar. This is primarily due to impact after a rollover on the ground, earthen bank, guardrail, rock, tree, etc[3].

Studies show that the most common cause is the driver's inability to assess the combination of speed, heavy loads, and cornering for many trucks rolling over. It also plays an important role to secure the load. The dangers posed by these combined factors may seem obvious, but the problem is that the driver needs to learn how to evaluate them from behind the wheel. Doing so requires good judgment, vehicle knowledge, and practical training if possible. There are a number of factors causing a vehicle rollover. Road incidents can result in injury, death, property damage, and environmental damage[3].

As mentioned earlier, the most common cause for many trucks rolling over is the driver’s inability to assess the combination of speed, heavy loads, and cornering. Securing the load is also an essential factor in vehicle stability[1].

The following list highlights the main risk factors for rollover:

- Load-displacement.
- Bad road conditions.
- Driver behaviour, aggressive driving and distraction are vital issues to address.
- Secondary fault, such as collision with another vehicle, or skidding towards the edge of the road.
- High centre of gravity
- High speed[1]

What happens to the vehicle?

- Wheels on driving axles are most often the first to lift up.
- For semitrailers, the trailer wheels are the first to lift up.
- For vehicles with trailers, the trailers are usually better balanced than the vehicle[1].

A rollover of a heavy truck may take a severe toll on both health of a person and financialy. Literally, by the survey of the National Highway Traffic and Safety Administration, almost like around 1000 trucks accidents of rollover results in death or injuries of the people each year [11].

Rollovers of the truck are explained by the truck turning on the sides/top of vehicle. Its usually seen when two vehicles like a car and a truck are in situation to hit each other and both of them turn aside

quickly to escape from an accident. Rather the truck is pushed aside and rolls many times before it stops. By analysis, it is possible to understand the force delivered is excellent and still there is a significant amount of accidents occurred for the drivers. Furthermore, with this incident there is a chance of injuring the other passengers in the other vehicles as well [11].

In the recent study, 15000 trucks (commercial) that experience the rollover for every year averaging, 1 rollover for truck travelling for million miles. Because of the size and weight of the trucks it is common that this type of accidents are usually with the catastrophic injuries. The fact is only 4% of accidents include rollover where as more than 12% of all fatal accidents of truck are resulted from it [11].

Introduction to AIS 029

Automotive Research Association of India (ARAI) in association with the Automotive Industry Standards Committee (AISC) published the Automotive Industry Standard 'AIS 029' regulations named as "Survival Space for the Protection of the Occupants of the Cab of a Commercial Vehicle" to make sure the safety of occupant of the truck. While doing this standard, they have considered the regulations mentioned in ECE R29[4].

The cab of the vehicle should be drafted and joined to the vehicle to eradicate the tremendous effect of risk of injury to the driver in the act of a fatal accident. This standard specifies the requirement of survival space for the protection of driver of the cab of a commercial vehicle of category N. This standard forms a part of the Track Body Code[4].

Automotive Industry Standard AIS 029 is applied for trucks which are carrying 6 to 60 tons of goods. It is mentioned about cab structure, load body, technical requirements, truck construction material etc. The main scope of this regulation, as mentioned by the Automotive Industry Standard Committee, is[4]:

The structure of the truck should be so drafted and built as to eradicate the tremendous possible extent of risk of fatal incidents to the driver in the act of an accident[4].

There are several testing methods involved to protect occupants from severe accidents. To do this test the following conditions should be fulfilled:

- Prior to the test, the cab doors shouldn't be locked but they should just be closed.
- The engine or a model equivalent to the mass and dimension of the engine should be mounted to the vehicle[4].

The following tests are mentioned in AIS 029 to know the strength of the cab and to know it will protect the occupants of the cab:

FRONT IMPACT TEST (TEST A)

Swing Bob test: The swing bob should be composed of steel and its mass should be 1500 Kg and it is evenly distributed. So, it can be made of rectangular and flat of dimension 2500 mm wide and 800 mm height[4].

The swing bob assembly should be of rigid construction. The swing bob should be freely suspended by two beams rigidly attached to it and spaced more than 1000 mm apart. The beam should be of "I" section with a web height of more than 100 mm should be of a section comprising at least an equivalent moment of inertia. The beam should not be less than 3500 mm long from the axis of the attachment of the beam[4].

The swing bob should strike the cab at the front of the cab. The direction of the impact should be horizontal and should be parallel to the median of longitudinal plane of the vehicle. The impact energy should be 3000 mkgf for vehicles of maximum tolerable mass up to 7000 kg and 4500 mkgf for vehicles of maximum tolerable mass exceeds this value[4].

ROOF STRENGTH (TEST B)

The roof of the cab should bear a static load correspondent to the utmost mass accredited for the frontal axles of the vehicle, subject to a maximum of 10000 kgf. This load should be uniformly distributed over the members of the roof structure of the cab[4].

REAR WALL SRENGTH (TEST C)

The rear wall of the cab should withstand a static load of 200 kgf per tonne of bearable suitable load. This load should be enforced by the mode of a rigid wall perpendicular to the longitudinal median axis of the vehicle, covering at least the whole of the cab rear wall placed above the chassis frame, and moving parallel to that axis[4].

1. Literature Review

1.The research study was done by Bill Rehn M D, TYA "ROLLOVER RISK AND SAFE DRIVING WITH HIGH CENTRE OF GRAVITY" shows that study of rollover risks, influencing factors, and how to protect it. It also includes the driver's responsibility to reduce rollover. He also wrote about how to reduce the risk of rollover for all type of trucks and also to load conditions for trucks. The author mentioned how to create the safest possible conditions for avoiding rollover accidents[1]. Some of them are:

- Aim for a low centre of gravity for both the vehicle and load.
- Ensure that the load is secured correctly.
- Good knowledge of the vehicle and its equipment.
- Use vehicles equipped with ABS, ESP and/or similar support systems.
- Consult with loading/terminal staff or the driver who last used the vehicle.
- Comply with laws and regulations (such as traffic laws, driving and rest time limits, alcohol and drugs)[1].

2.The research study was done by Mario Ligovic, Volvo Truck Corporation, Gothenburg, Sweden "Volvo Trucks view on Truck Rollover Accidents" shows that about rollover, statistics of rollover accidents[3]. He mentioned about the tests made to study of rollover. He has studied about full-scale rollover test in which truck is accelerated to approx. 80 Km/h and roll over was initiated when the truck far side wheels ran over a ramp. As a fact that the physical tests are way too expensive, MADYMO simulations are performed to analyse in-depth study of the occupant kinematics. Results from physical tests are implemented for correlation reasons. The Rollover Model's motion is represented by the x, y and z acceleration pulses, and the rotational displacement signal. The results from the rollover tests are compared with the simulation results from the MADYMO kinematics. Below mentioned are the three cases from MADYMO kinematics rollover cases[3]:

- Near side rollover where the driver is belted.
- Far side rollover where the driver is belted.
- Far side rollover where the driver is un-belted[3].

3.The research carried out by IRTE, a professional sector of SOE "Vehicle rollover" shows that reported accidents occurred in the UK[2]. It is mentioned in this why do rollover occur. In this research, it is mentioned about the prevention of rollover and future developments. Several ways in which vehicle roll-over can be shut out; although, altering drivers' behaviour is vital. Teaching the risks of vehicle roll-over to the drivers', and the ways to avoid the chances of rollover and to reduces the possibilities will prominently help in reducing the number of fatal incidents we see everyday accounting a low count. In addition, basic vehicle design, that reduces the centre of gravity, would contribute in restricting roll-over. The below mentioned reasons would result in noteworthy contribution to driver's part in reduction of rollover chances[2]:

- Drivers are advised to pay attention to the road ahead of them.
- Limiting the speed at the corners
- Understanding the situation to drive depending on the load being carried and make sure there is no restraining force acted on the load of the vehicle

- Air pressures in the vehicle is checked to ensure there will no problems caused due to the tyres.
- Proper training is given to the driver so that, better and smooth driving techniques are employed while driving in the curves to make sure there is catastrophe occurred while driving[2].

4.The research conducted by AJ McLean, CN Kloeden, G Ponte, MRJ Baldock, VL Lindsay, AL van den Berg, Centre for Automotive Safety Research, The University of Adelaide, Australia on "Rollover crashes" shows the research about the police reports on rollover crashes. It is also mentioned investigation of rollover crashes, vehicle characteristics and rollover protection. They have studied about characteristics of the sample of crashes, rollovers alone and after a collision, road alignment and speed limit, injury severity, vehicle movements preceding rollover. They have also studied vehicle characteristics and rollover prevention, static rollover stability, dynamic rollover stability, rollover resistance ratings, electronic stability control, assessment of rollover resistance and electronic stability control[5].

5.The research conducted by Asad J. Khattak, Robert Schneider, Felipe Targa on "Risk factors in Large Truck Rollovers and Injury Severity: Analysis of Single-Vehicle Collisions" shows the truck crashes happened in the US every year in which 700 large truck crashes and 400 single vehicle truck crashes occurs, in this many involve rollover crashes[6]. He also explained about risk factors in single-vehicle truck crashes, which include:

- Dangerous truck-driver behaviours, particularly speeding, reckless driving, alcohol; and drug use, non-use of restraints, and traffic control violations;
- Truck exposure to roadways that have dangerous geometry, particularly more curves;
- Trucks that transport hazardous materials and post-crash fires[6].

6.The research was done by Chris Winkler, University of Michigan Transportation Research Institute on "Rollover of Heavy Commercial Vehicles" shows that rollover and accident severity, roll stability and the occurrence of rollover accidents, the mechanics of static roll stability, measuring of rollover using tilt table experiments. He mentioned about accidents taking place in the US every year that is 15000 rollover accidents. The commercial truck rollover is strongly associated with severe injury and fatalities in highway accidents. The low level of primary roll stability of commercial trucks sets them apart from light vehicles and appears to be a significant contributing cause of truck rollover accidents[7].

7.The research study conducted by National Highway Traffic Safety Administration on Heavy Truck Crashworthiness: "Injury Mechanisms and Countermeasures to Improve occupant safety" shows those cab integrity standards, investigation of cab strength using dynamic loading in the front and Quasi-static loading. It also shows the test has been done to see the strength of the cab to know the safety of the occupant using UN ECE Regulation R29. They have tested using Frontal Impact Test, Front Pillar impact test, Roof strength test. It also shows that they have studied about truck driver injury and injury mechanisms, annual estimates of truck driver injury, seat belt use[8].

2. Theoretical Background

Rollover considered as one of the most catastrophic types of accident which causes significant damage to the truck structure and severe injuries to the driver and co-driver. While there are many regulations to determine whether the superstructure is strong enough to withstand all kinds of impacts during an accident question still arises how a super moving truck with a certified superstructure undergoes rollover and what makes rollover a severe type of accidents than compared to other accidents. The answer to this question lies in a few factors like human, road conditions, climate and other environmental conditions[9].

2.1. Causes for Rollover Accident

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

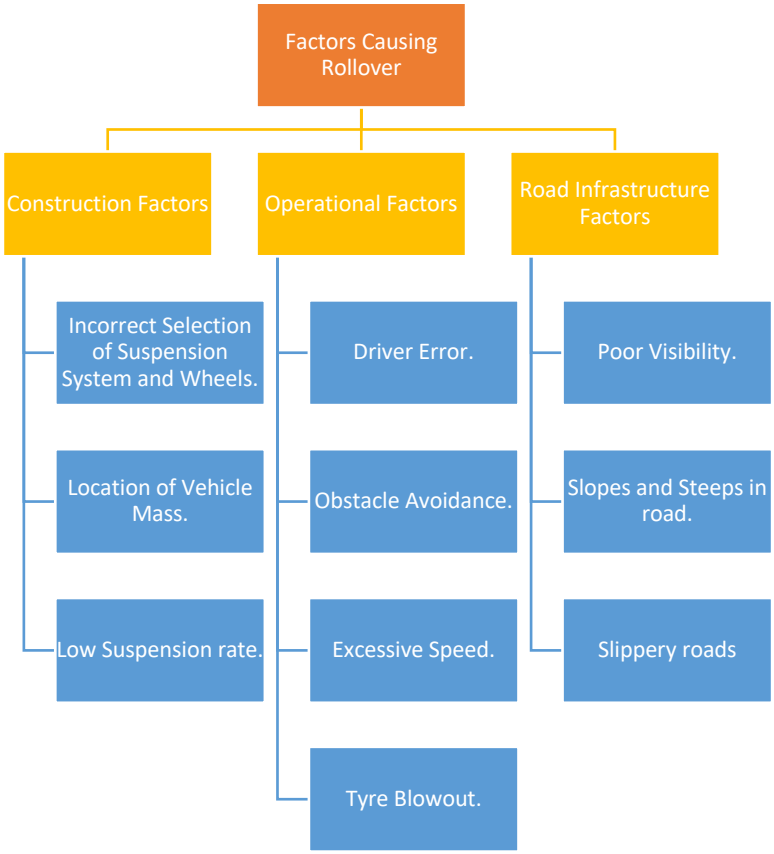

Fig. 1. Factors Causing Rollover

2.1.1. Construction Factors

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

- Incorrect selection of Suspension System and Wheels

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

- Location of Vehicle Mass

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

- Low Suspension Rate

Suspension rate or spring rate is a critical component that is used to adjust or set the vehicle's ride height or its location in the suspension [12]. This, in turn, deals with choosing appropriate spring structures for the suspension system. The suspension system of heavy vehicles like trucks should have a heavier spring to compensate for the weight of the vehicle; otherwise, the suspension system will break, causing a rollover situation. Hence the suspension rate should be higher, and the low suspension rate of the vehicle, especially trucks, should be avoided.

2.1.2. Operational Factors

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

- Driver Error

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

- Excessive Speed

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

- Obstacle Avoidance

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

- Tyre Blowout

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

2.1.3. Road Infrastructure Factors

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

- Poor Visibility

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

- Slippery Roads

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

- Slippery Roads

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

2.2. Severity of Rollover Accidents

Rollover is an important type of truck accident which causes severe damage to the truck structure and lives hoods of driver and co-driver. As per the previous researcher's rollover occurs less frequently than another type of accidents like frontal impact collision and rear impact collision. Although it occurs less frequently, some common question arises:

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

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

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

- One important thing to consider in case of a rollover accident is that rollover can lead to other types of accidents and damages to truck structures. Since the trucks are rotating one or more quarter turns the fuel tanks of the trucks gets ruptured and can lead to fire accidents, which will risk the lives of driver and co-driver. About 2-5% of rollover accidents result in fire accidents causing it difficult to rescue the driver and co-driver. This type of rollover is called combined rollover accidents.
- Both ECE R29 and AIS 029 regulations mainly focus on the superstructure of the trucks because of the reason that these structures will withstand all kind of impact created during the rollover accidents and protects the residual space without any damage to goods or injuries to the driver and co-driver.
- In case of a severe rollover, the driver and co-driver body hit many times with the inner compartment of the truck causing severe damage to the driver and co-driver. Since the trucks are revolving one or more quarters, this causes the driver, and co-driver body hit the inner compartments many times, leading to severe head injuries and other several types of injuries.

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

2.3. Injury Mechanisms in Rollover

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

- Intrusion: Intrusion is a type of injury mechanism in which the superstructures of the truck intrude into the residual space of the driver compartment. The intruded elements of the superstructures can contact the driver's body, causing severe damages to them.
- Projection: Projection is another type of injury mechanism in which the driver themselves hits the superstructures of the truck bodies. This is due to a non-controlled movement of the driver's body inside the driver compartment. This is mainly occurring during the time when the truck begins to slip over.
- Partial Ejection: This injury mechanism happens in the event of a weak superstructure. Since the truck's rollover on its side, the superstructure may break, causing the drivers to eject outside from their seats.
- Complete Ejection: Complete ejection appears in case of a severe truck rollover, and it is one of the worst scenarios that cause death. In case of a complete ejection, the driver is ejected from their seat and thrown outside or under the rolling truck due to broken windows or damaged superstructures. The thrown-out driver has a risk of being crushed by the superstructures of the truck, which cause death.

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

3. Research Methodology

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

- To ensure that the truck is designed according to the regulations mentioned by the Automotive Industry Standard AIS 029.
- To ensure that the superstructure of the truck is designed to withstand all kind of impacts created during rollover of the truck.
- To make sure that the residual space of the truck is unharmed before and after rollover accident.
- To optimize the topology of the superstructure of the truck.
- To study the deformation of the superstructure of the truck by using different materials.
- To propose suitable corrections that can be amended to AIS 029 regulations.

3.1. Research Methods

This research study is an investigation based on the testing procedures, as mentioned in AIS 029 and ECE R29 regulations for rollover of trucks. A well-defined research method, as proposed by these regulations, is used in this work for successful validation of results. The thesis is organised into five different types of methods which are listed below figure:

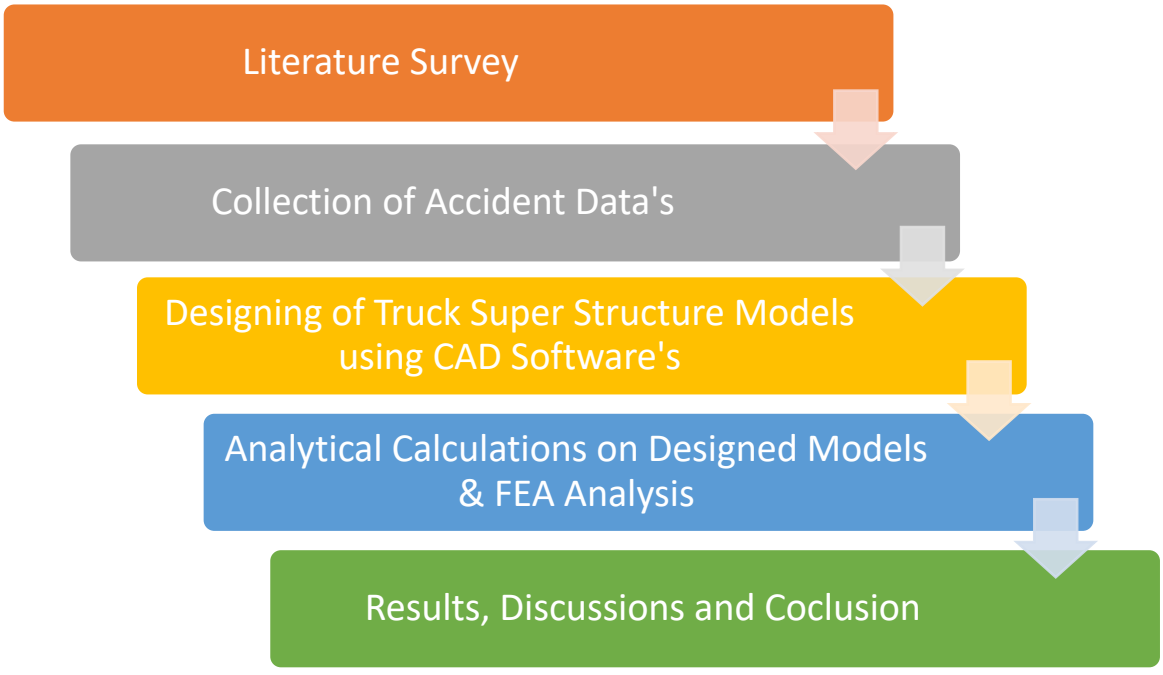

Fig. 2. Research Methodology

In the above-mentioned research methodology, the first step or process is the literature review, which is based on the previous research work done by various researchers in the field of a truck rollover. This section is used to determine the severity of rollover accidents and the main problems that are related to the rollover analysis is identified. The second process is the collection of rollover

accident data's that happened during the last few years. This data is used in understanding the severity of rollover accidents and the reasons and fatality rates in those accidents.

The next process is choosing a valid model for the research to carry forward. A suitable model that is designed for Indian roads is chosen, and the model is designed using CAD software. In this work, SOLIDWORKS is used as CAD software for the designing of the model. The fourth process is the vital process in which the designed model is analysed with the help of analysis software. The testing procedures mentioned in AIS 029 and ECE R29 regulations are used to calculate the theoretical values which are then compared with the analytical solutions. The last step is the discussions section in which the results are discussed and some suitable correction to amend AIS 029, and ECE R29 regulations are discussed.

3.2. Problem Identification

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

- Rollover should be considered as one of the essential types of accidents, although it occurs less frequently. The severity of rollover accidents and the average fatality rate makes it one of the dangerous type of accidents compared to other types.
- The superstructure of the truck should be designed and tested according to the specifications mentioned in ECE R29 and AIS 029 regulations. The residual space must be unharmed before and after the testing, which is the only means to identify whether the superstructure is strong enough or not to withstand all kind of impacts.
- Also, from the literature studies, it is noted that a computer simulation on rollover protection is preferred than the physical rollover testing because the later includes a lot of time, money and human power.
- A significant drawback of AIS 029 regulation is the lack of a computer simulation for rollover testing, which could be an easier and faster way to perform rollover analysis than physical rollover tests. This problem should be given prior importance and can be solved by proposing possible amendments to AIS029 regulations.

3.3. Accidents Statistics

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

3.3.1. Accident Statistics of India

India is one of the countries in the world in which a vast number of peoples are killed in road accidents every year. The amount of fatalities is higher in India Than the entire European Union. Because of its populous nature, a more significant number of accidents are happening in India. Truck transport is considered as one of the largest modes of goods transportation in India, and everybody uses trucks for goods transportation. Most of the traders will use the trucks for goods transportation from one city to another city or one place to another place.

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

Ministry of Road Transport and Highways (MRTH) is a special ministry of the Indian government that is responsible for the development of road transport in India. MRTH aims to reduce the road accidents in India and it along with the association from ARAI published the AIS standards for manufacturers and operators. AIS 029 is one such regulation which is mainly focused on the rollover of trucks. The Transport Research Wing (TRW) is a nodal agency of MRTH which provides the accident data in the form of a report that is released every year in the name 'Road Accidents in India'.

In this section, the reports published by the TRW and MRTH is used to determine the severity of rollover accidents in India. According to this report, the total number of road accidents that happened in India during the year 2007 – 2015 is 5,01,423 in which 1,46,133 fatalities were reported. Motorized vehicles account for the enormous number of accidents in roads and out of these 26.6 percentage of accidents are involving accident of trucks. In the case of truck accidents in these years, the number of people killed is 39,504 and 91,784 are injured. Out of these truck accidents, large accidents are happened due to rollover of trucks; rollover accounts for about 32 percentage of truck accidents. Other types of truck accidents include 40 percentage of frontal/ head-on collision, 20 percentage of side-impact collision, about 3 percentage of rear impact collision and 5 percentage accidents are resulted due to other factors like fire etc., The following pie chart shows about the type of truck rollover accidents that happened during the year 2007 – 2015:

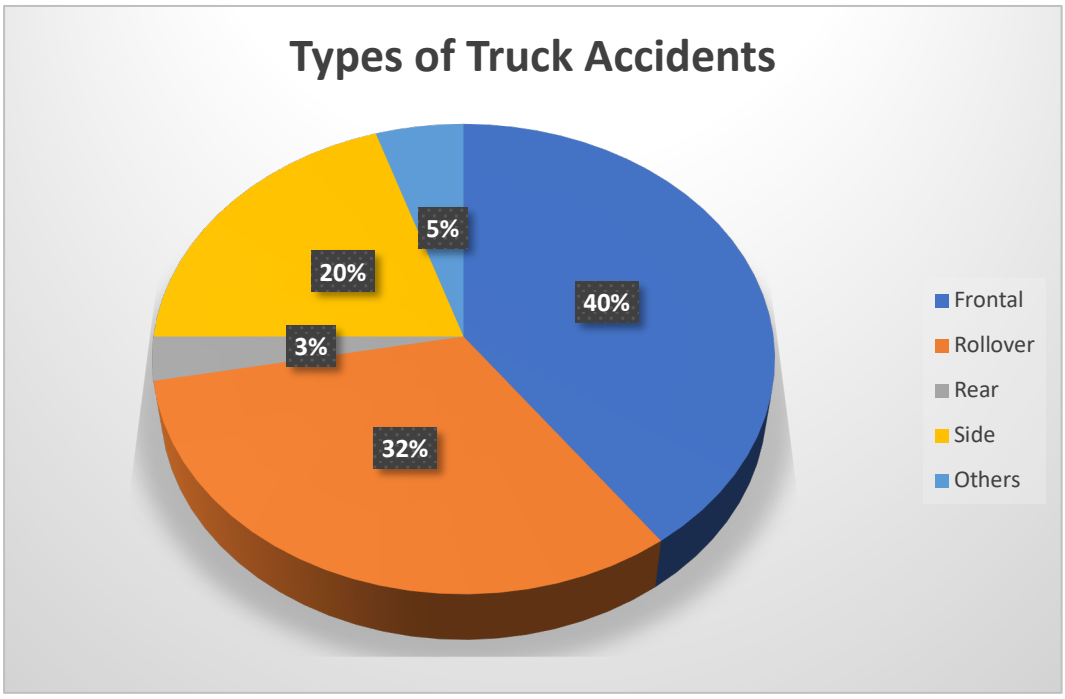

Fig. 3. Types of Truck Accidents

Truck rollover accidents in India accounts for about 39,504 deaths and injury to 91,784 peoples. Although frontal or head-on collision accounts for a large number of accidents then roll over, a rollover should be considered as a catastrophic type of accident because of its vast fatality rate. A frontal collision occurs frequently, and hence it tops the table whereas rollover, on the other hand, occurs less frequently but accounts for a vast number of deaths. The following table shows the occurrence percentage of truck rollover accidents in different road conditions.

Table 1. Rollover Accidents on different types of Roads

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

From the above table, it is noted that single lane roads and hilly roads account for an enormous number of rollover accidents.

3.3.2. Accident Statistics of Europe

Europe is one of the areas in the world where the safety of passengers is given a vital role. The Economic Commission for Europe, as well as the statutory bodies of each European countries, have enforced several regulations that focus on the safety of driver and co-driver in the truck and also damage to the goods in the truck. The ECE is one of such bodies which enforced the safety regulations for truck prior to other countries. The ECE R29 is one such regulation that comes to force from 1974 itself. During that time, safety is not given a key factor role in developing countries like India. Also, the ECE R29 regulations is a back model for deriving the AIS 029 regulations.

The European Commission aims to reduce its fatality rate to zero in the year 2020. In 2011, about 30,000 peoples died in road accidents in Europe. Various European researchers had done research on the truck rollover protection much prior before the world was aware of rollover. Truck rollover statistics were researched by some of the researchers, which shows that rollover is one of the most severe types of truck accidents in Europe. In the year of 2009 about 35,500 fatalities in traffic accidents, heavy trucks are involved in about 17 percentage of the fatalities. The following table shows about accidents statics between 2005 – 2008.

Table 2. Accident Statistics of Europe 2005-2008

Number of Bus Rollover Accidents	8520
Fatalities	7200
Serious Injuries	21900
Light Injuries	83900

3.4. Model description

For investigation rollover protection in Indian trucks, a better model needs to be chosen, which is an important part to be considered. For this purpose, 'Ashok Leyland U3118' is chosen to be the model in which a rollover investigation is done with the help of AIS 029 and ECE R29 regulations.

With an increasing growth from 70 years, Ashok Leyland assembling 350 comet trucks in 1951, to a company that has registered sales of more than 1,00,000 medium and heavy domestic trucks sales in the domestic market, during last year [13]. Ashok Leyland is the second largest commercial vehicle manufactured in India and fourth largest in the world [15].

ASHOK KEYLAND U3118

Essential, time-sensitive transporting applications like bulkers, tankers and cement transportation demand a high degree of reliability and uninterrupted uptime. The U3118, with rugged aggregates, superior performance and fuel economy, is the ideal platform for cost-sensitive long-haul applications.

Every aspect of the U-Truck is designed with you – the customer – in mind. Performance is at the heart of these vehicles, infused all along the driveline. The H-Series, 180 HP Common Rail System (CRS) engine with a reliable CB18 fuel injection system offers a high initial pickup, better fuel economy and a smoother drive. Coupled with clutch booster actuation, the vehicle has better power transmission. The ALGB940 6-speed gearbox has a high first gear ratio of 9.04:1 and is capable of withstanding a high torque input of 893 Nm. The FA99 pusher lift front axle brings improved manoeuvrability, better stability and safety to the drive.

3.4.1. Customer-Inspired Cabin Design

The durable, crash-tested cabin with an all-steel bumper guarantee high safety standards. The designed interiors – ergonomic seat, getting in and out of the cabin is itself designed to invoke comfort. With one of the largest windscreens in trucks, it's class, the U-Truck allows for maximum visibility. Comfortable bucket seats with integrated headrest for both driver and co-driver ensure ergonomic comfort. Apart from the primary shock absorber in the axle, a secondary shocker in the cab isolates bumps and turbulence. The cab is fixed with pivot arrangement for minimal rolling during cornering, particularly in tanker applications.

Fig. 4. Ashok Leyland U 3118

Table 3. Technical specifications [14]:

Engine	H series CRS engine with iEGR technology
Maximum power	180 HP @ 2400 rpm
Maximum torque	660 Nm @ 1200-1900 rpm
Clutch	380 mm dia, single plate dry type with clutch booster
Rear axle	Fully floating, single speed hypoid, with 5.83:1 RAR
Rear axle	Fully floating, single speed hypoid, with 5.83:1 RAR
Frame	275 X 90 X 6 mm
Suspension	Semi-elliptic multileaf with shock absorbers in front and equalizer link rod in rear
Brakes	Full air dual line with ABS
Parking brakes	Pneumatic flick valve operated on rear wheels only
Fuel tank capacity	400 lts cross link polymer
Battery	2 X 12V
Tyres	10.00X20 - 16PR radial

3.5. Solidworks Model

Solidworks is used as design software to model the chosen truck. Solidworks is a designing software developed by the French company Dassault Systems. Solidworks is the acronym for Computer Aided Three-Dimensional Interface application. It is one of the widely used software in the aerospace and automotive industries. Only the superstructure of the truck is designed as per the manufacturer's specifications. The cabin of the truck is designed to do tests in analysis software. The designed CAD model of the truck cabin superstructure is shown below:

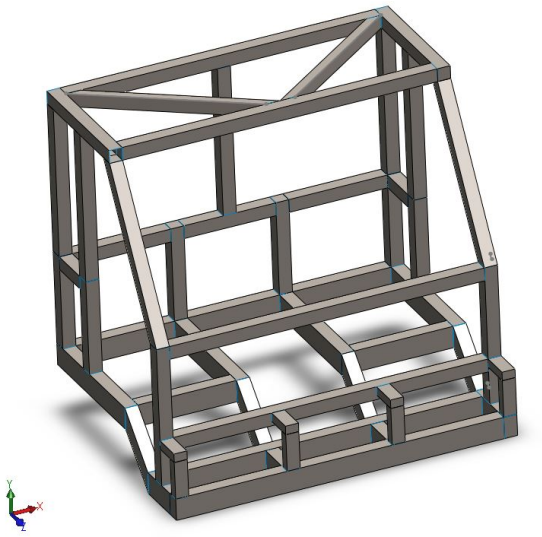

Fig. 5. Superstructure model for roof load

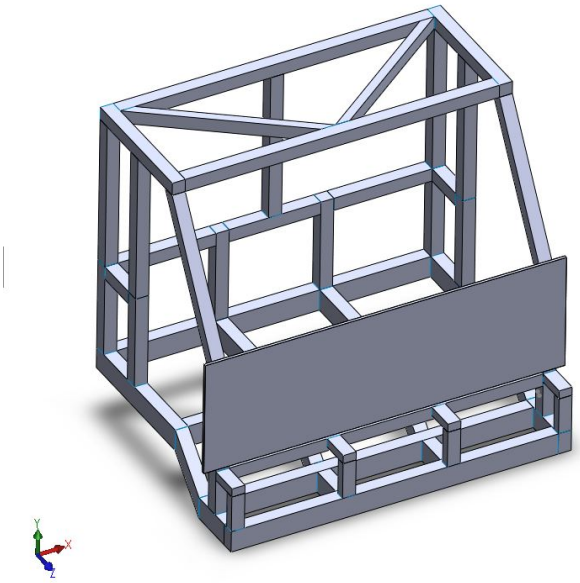

Fig. 6. Superstructure model for frontal impact load

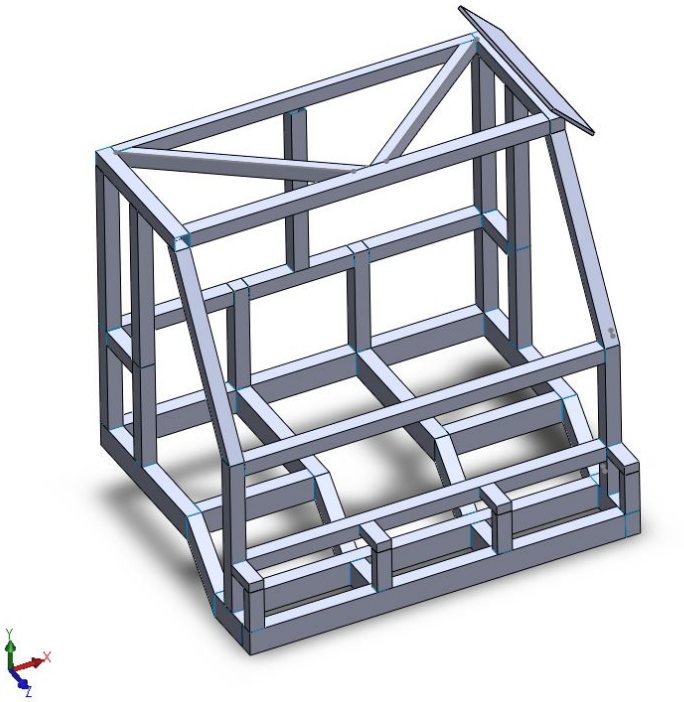

Fig. 7. Superstructure model for side impact load

3.6. Topology optimization

In this section topology of the superstructure which is modelled before is optimized to give better results for the static loading. There are three types of optimization which includes size, shape and topology optimization. Design optimization is main factor in any complex design. Topology optimization shows the unknown structural connectivity, size and shape which will reduce the deformation taking place to the cab structure. The process of topology optimization is shown in below figure.

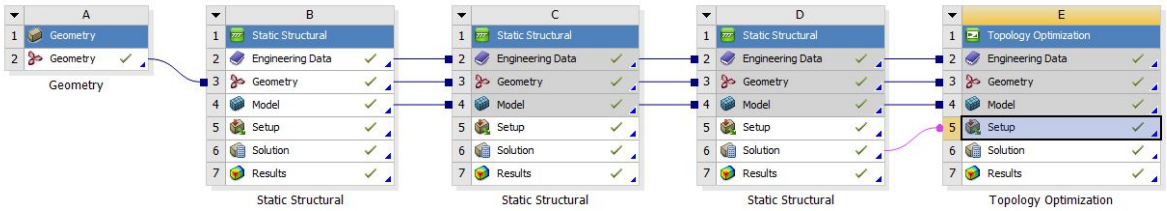

Fig. 8. Topology optimization process

The below figure shows the topology density of the structure where the connectivity can be given so that the deformation is reduced. The grey coloured part should be retained to get less deformation.

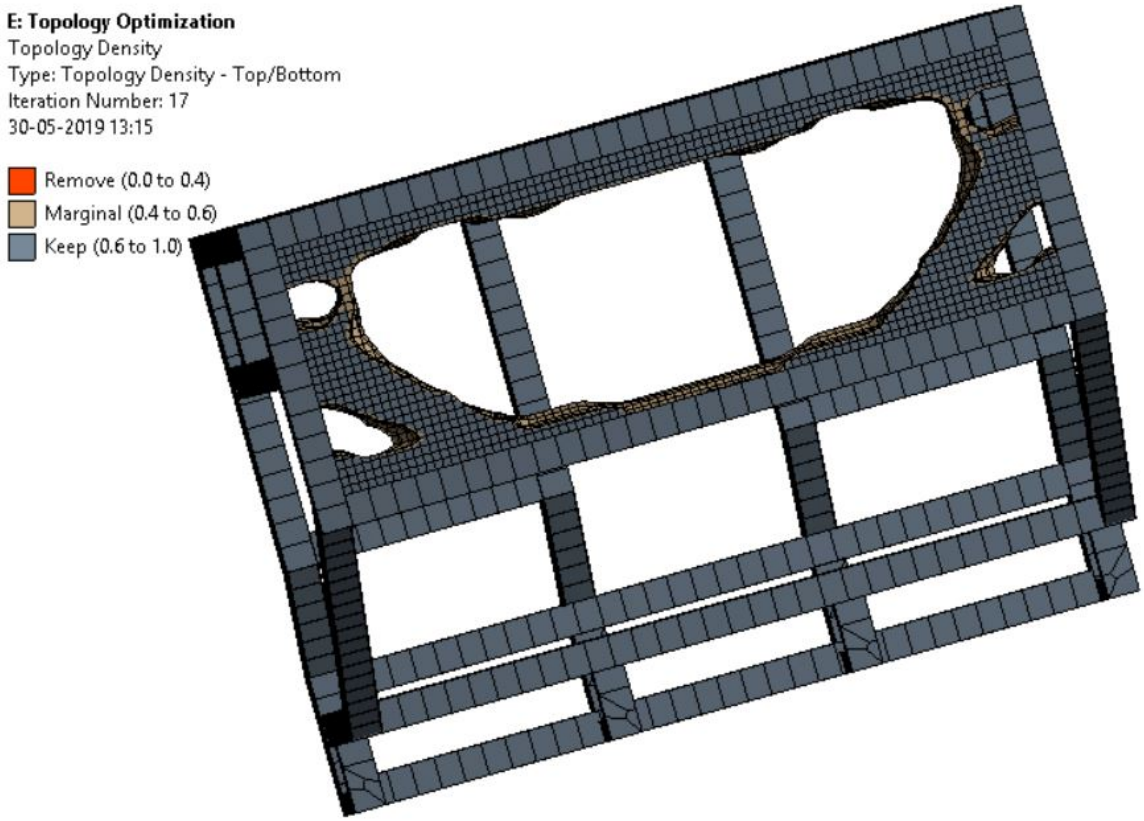

Fig. 9. Topology density

4. Calculations

4.1. Finite Element Calculations Using Ansys

The next step in the calculation and the final step in this thesis is the finite element calculation of the chosen truck model. A computer simulation is used to determine the strength of the superstructure due to the fact that it is faster, cheaper and less time consuming than the physical rollover test. A significant drawback of AIS 029 regulation is the lack of computer simulation for rollover testing, which could be an easier and faster way to perform rollover analysis than physical rollover tests. This problem should be given prior importance and can be solved by proposing possible amendments to AIS 029 regulations. For this purpose, a computer simulation rollover testing method proposed in ECE R29 regulations is chosen, and the analysis is done to determine the strength of superstructure, and the results of this analysis are compared with the analytical calculations done in the previous sections. The detailed description of the computer simulation, the method proposed by ECE R29 regulations are described in Appendix

For finite element analysis, ANSYS Workbench software is used. ANSYS is a computer-aided engineering software which is used to determine finite element, structural analysis, Computational Fluid Dynamics analysis, Explicit and Implicit methods. For our case, finite element static structural and Explicit dynamics analysis is chosen and used. The finite element calculation is done to determine the deformation of the structure and other parameters such as the stress and energy absorbed by the structures. These calculations are then checked with the theoretical calculations to determine the strength of the superstructures. In finite element analysis, the entire truck superstructure is discretized into smaller elements called as finite elements and the analysis is done on all these finite elements. The accuracy of the elements depends on the accuracy of the meshing. ANSYS software is used as a simulation program as it satisfies the requirements as mentioned by the ECE R29 regulation.

In our case, a new method of computer simulation is proposed in which ANSYS is used to determine the strength of the superstructure. Static Structural Analysis is chosen from the different types of analysis and the superstructure model designed in SOLIDWORKS is imported into ANSYS workbench. The steps included in ANSYS workbench is explained in below sections and are also mentioned in the below diagram:

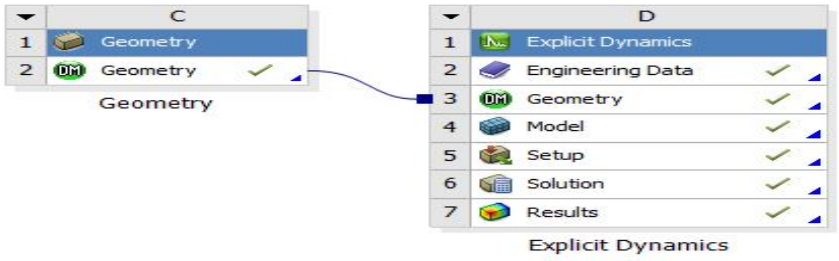

Fig. 10. ANSYS Workbench Analysis Steps

4.2. Calculation of load

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

The regulations mentioned by ECE R29 and AIS 029 states that the truck superstructure needs to withstand a load which is 1.5 times greater than the unladen mass of the vehicle. A much similar method is used by some of the previous researchers in their studies. One such study is done by Pankaj S. Deshmukh in which the author applies a load which is 1.5 times greater than the mass of the bus. Hence a similar method is used here in which a load which is 1.5 times greater than the mass of the vehicle is applied to the chosen side structure of the truck.

Unladen Mass of the truck = 3,160 Kg

Load to be applied = 3,160 * 1.5 * 9.81 =46,500 N

4.3. Imported Model

The designed model of the truck superstructure is now imported into the ANSYS for analysis purpose. Once the model is imported, the engineering data for the model is given. This includes the material data in which the material used for structures and their properties are chosen. For the truck superstructure, the material used is structural steel and structural steel NL. The imported model is shown in the below figure:

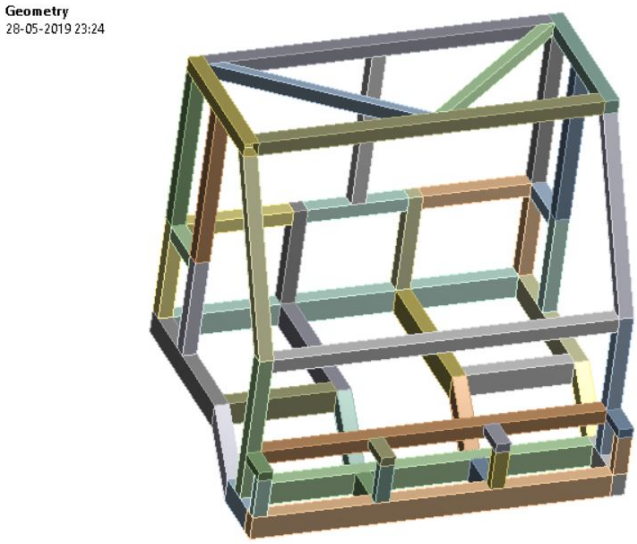

Fig. 11. Imported model for roof load case

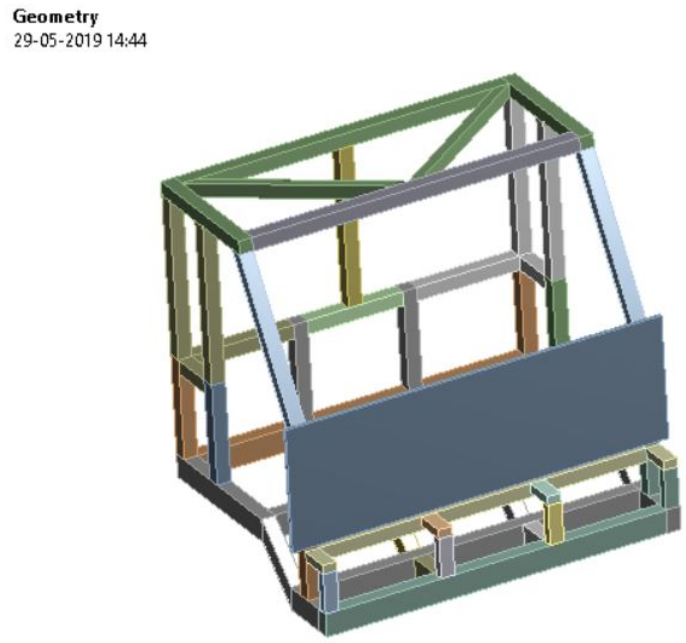

Fig. 12. Imported model for frontal impact load

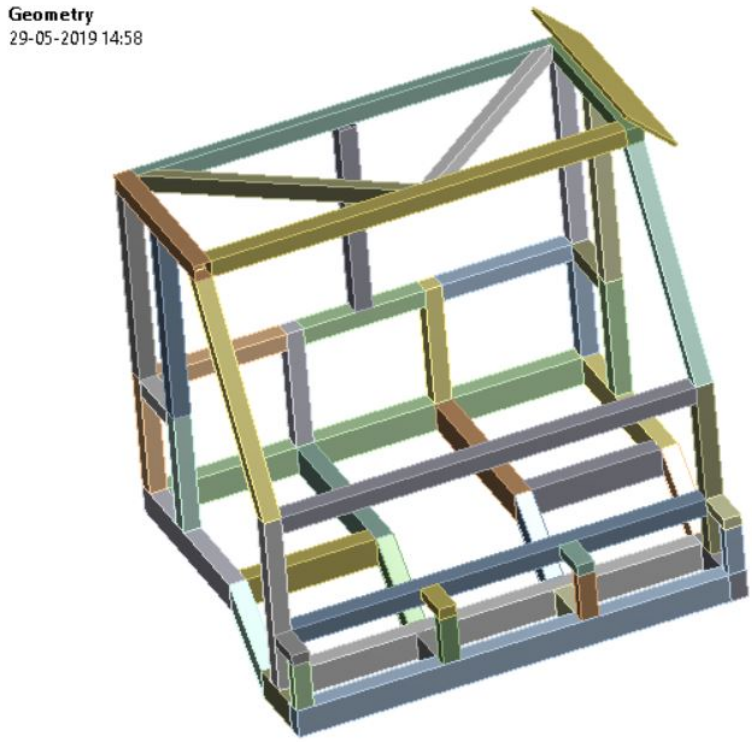

Fig. 13. Imported model for side impact load

4.4. Material Property

The next step in ANSYS workbench is the assigning of material to the model in which the imported model is assigned with the material. For this model, according to standards, AISI 4130 structural steel

is chosen. And also, the other material is used to compare for the dynamic analysis. The below table shows the material property of structural steel.

Table 4. Material Property

Property	Value	Units
Mass Density	7850	Kg/m^3
Tensile Strength	731	N/mm^2
Yield Strength	460	N/mm^2
Elastic Modules	205000	N/mm^2
Poisson's Ratio	0.285	N/A
Shear Modulus	80000	N/mm^2

Table 5. Material properties of other materials used

	AISI 1080	AISI 1060	AISI 1018
Young's Modulus (MPa)	205	205	205
Poisson's Ratio	0.28	0.28	0.29
Density (kg/m^3)	7860	7860	7865
Tangent Modulus (MPa)	5669	1468	763
Yield Strength (MPa)	870	430	315

4.5. Boundary Conditions

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

Fixtures: The truck superstructure is fixed in order to carry out the analysis process. The superstructure is fixed at four places below the chassis. The below diagram shows the fixtures in detail:

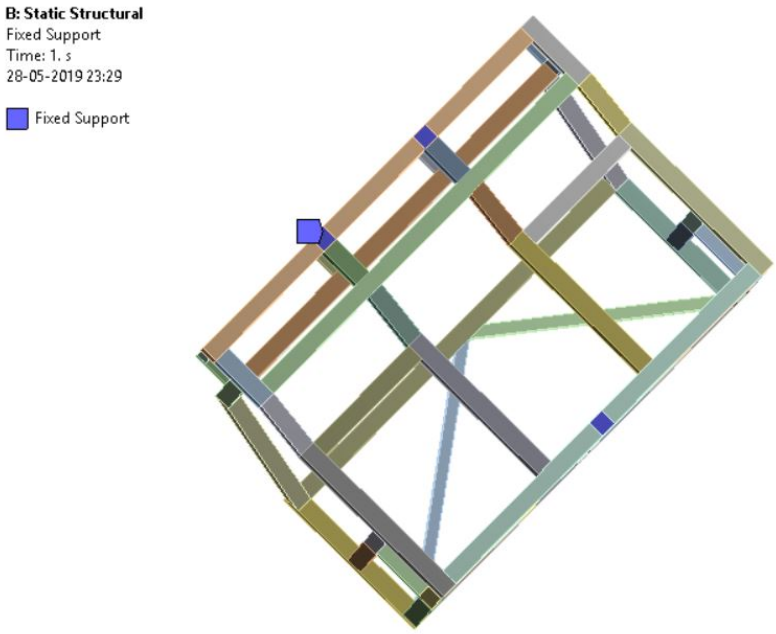

Fig. 14. Boundary condition Fixture

Loads: As mentioned in section 5.4.1 of thesis, the loads are calculated and are applied on the roof of the truck, for the frontal impact velocity is applied, and for side impact also velocity is applied. There are three load cases which are roof static load, frontal impact load and side impact load. Those three load cases are shown below.

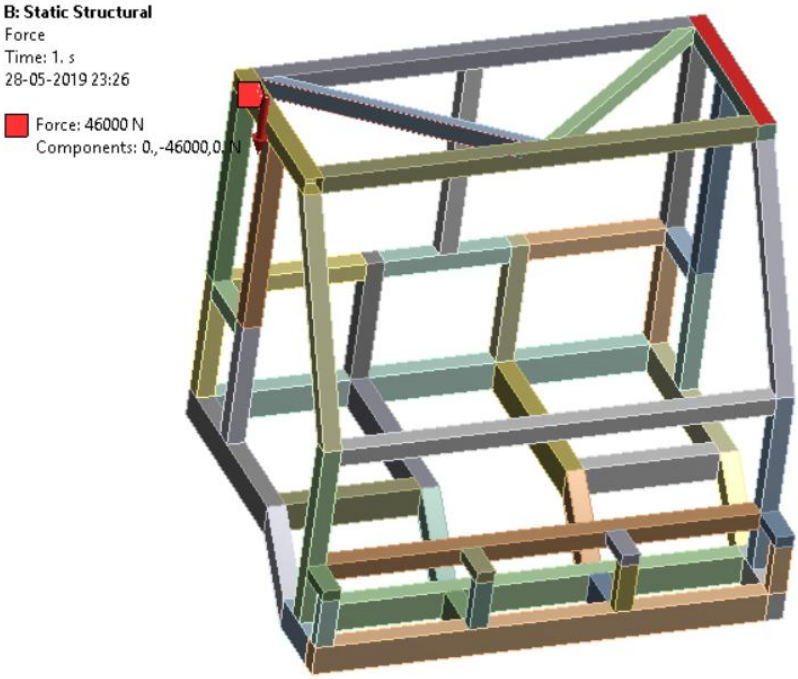

Fig. 15. Boundary condition Roof load

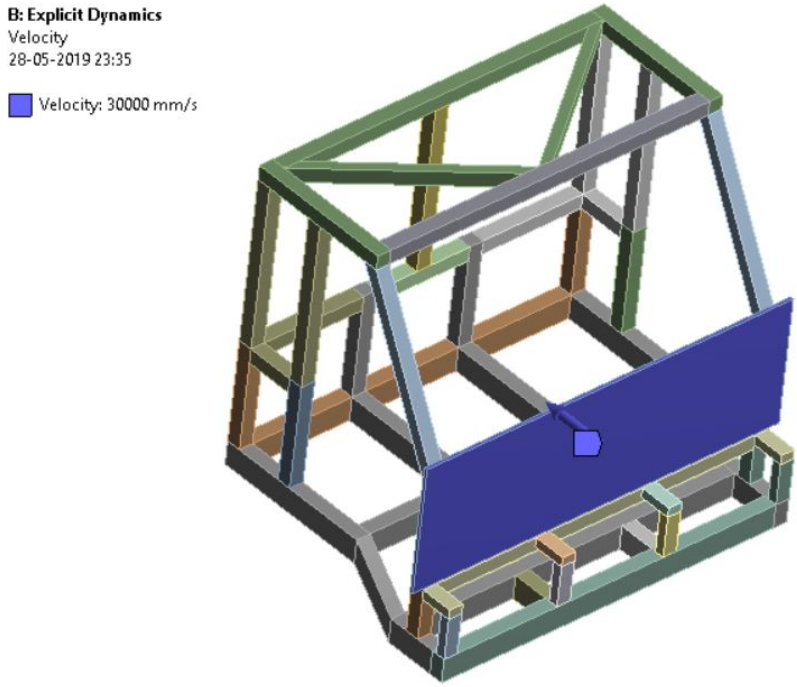

Fig. 16. Initial conditions Velocity for frontal impact

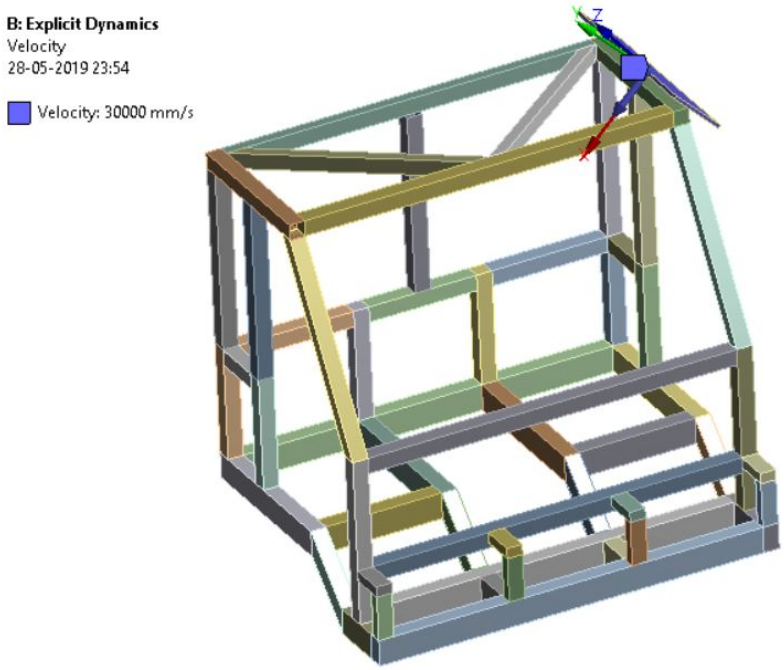

Fig. 17. Initial conditions velocity for side impact

4.6. Mesh

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

Table 6. Mesh Quality Details

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

The below figure shows for the mesh condition where there is coarse mesh is done.

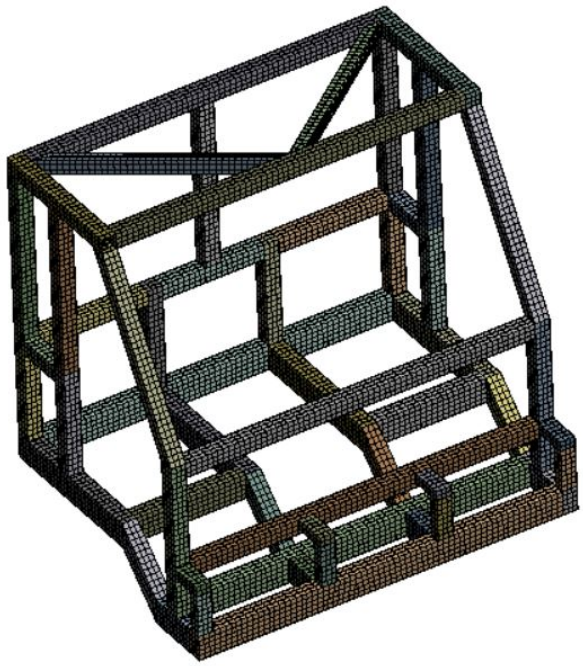

Fig. 18. Mesh condition

5. Results and Discussions

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

5.1. Finite Element Analysis Results

The superstructure of the truck in analysed in ANSYS with a given load as calculated above. Three solutions which are required for rollover of trucks are obtained from the finite element analysis and are shown below:

- Total deformation
- Energy Probe
- Energy summary graph

5.1.1. Total deformation

Deformation is one of the essential analysis results that show whether the truck superstructure intrudes into the residual space or not. The truck superstructure is found to be safe if it withstands the impacts created during a rollover accident and deforms in a lesser amount. The below diagram shows the deformation of the superstructure in the roof load case. The maximum deformation occurs at the roof section, which is coloured in red.

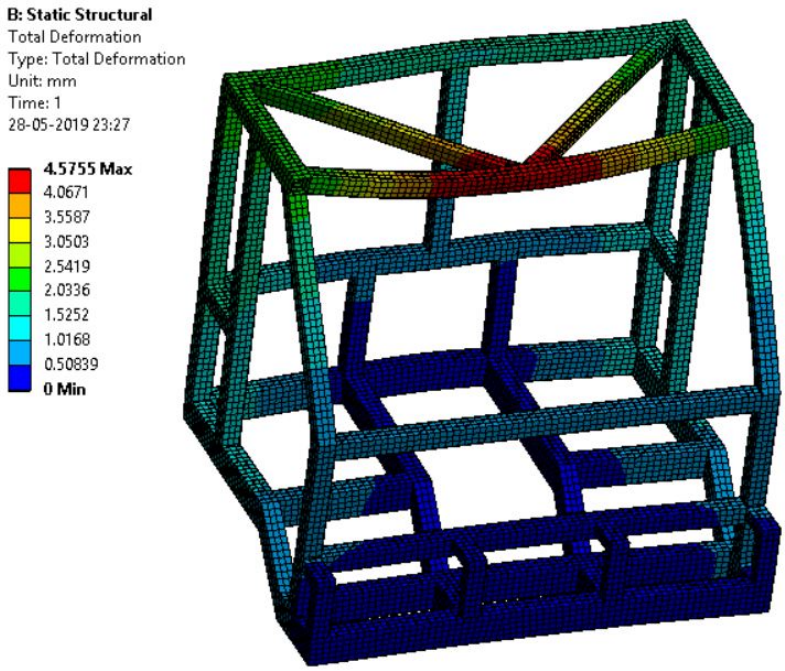

Fig. 19. Deformation for roof load

The below figure shows the deformation of superstructure after the topology optimization. In which it can be noticed that the deformation is less compared to the normal structure. So optimised superstructure is safer.

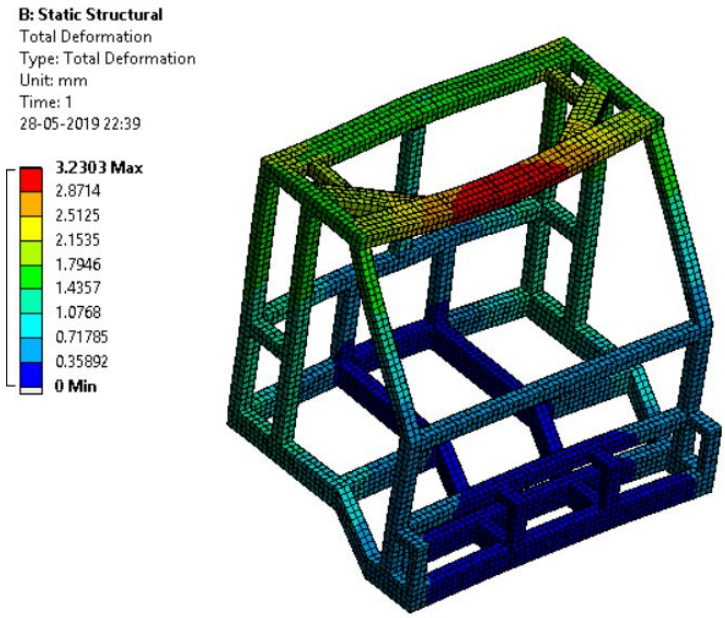

Fig. 20. Deformation for roof load for topology optimized structure

The below diagram shows the deformation of the superstructure in the frontal impact load case. The deformation occurs at the front of the cabin section, which is coloured in red.

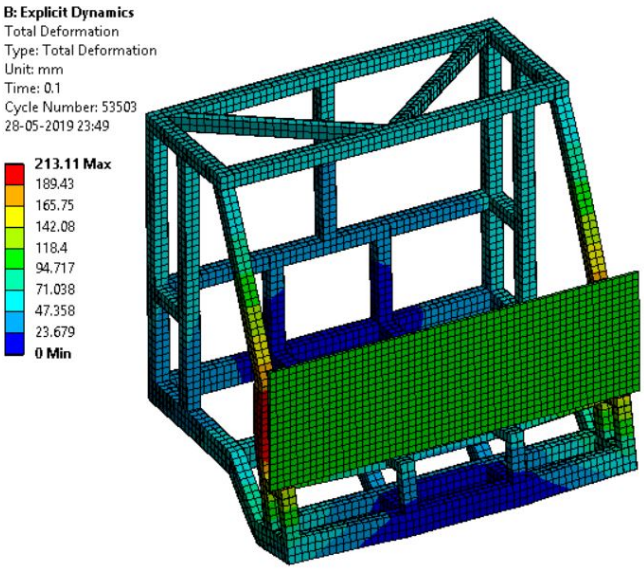

Fig. 21. Deformation for front impact for material AISI 1430

The below figure shows the total deformation for the material AISI 1080 which is used to know the difference between the deformation of other materials.

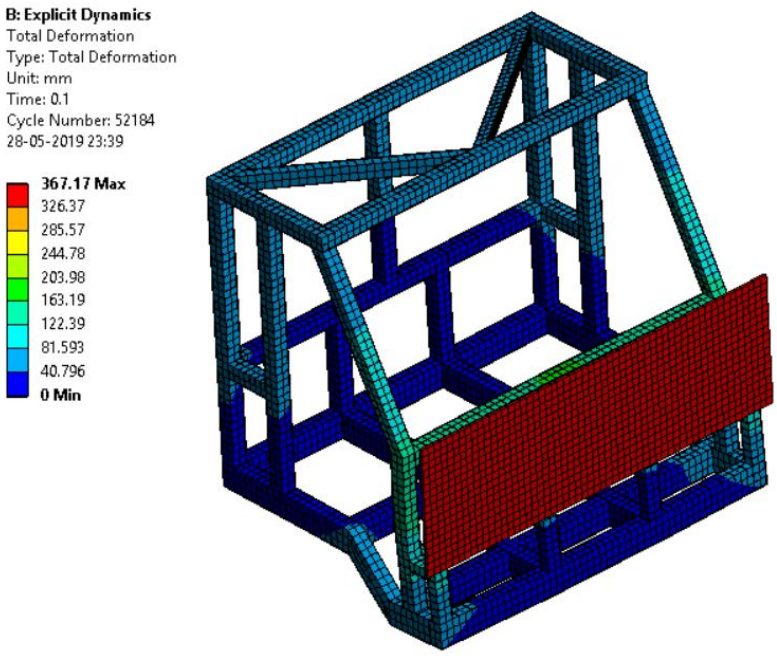

Fig. 22. Total deformation for the material AISI 1080

The below figure shows the total deformation for the material AISI 1060 which is used to know the difference between the deformation of other materials.

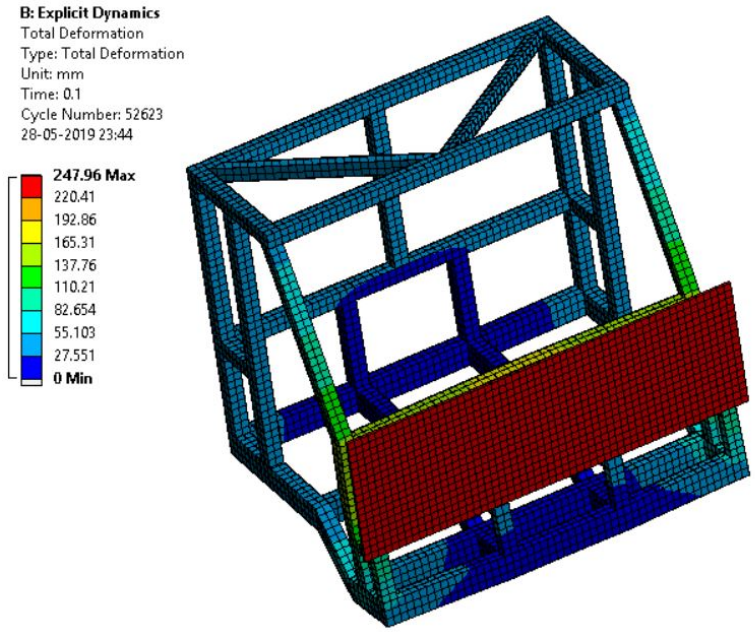

Fig. 23. Total deformation for the material AISI 1060

The below figure shows the total deformation for the material AISI 1018 which is used to know the difference between the deformation of other materials.

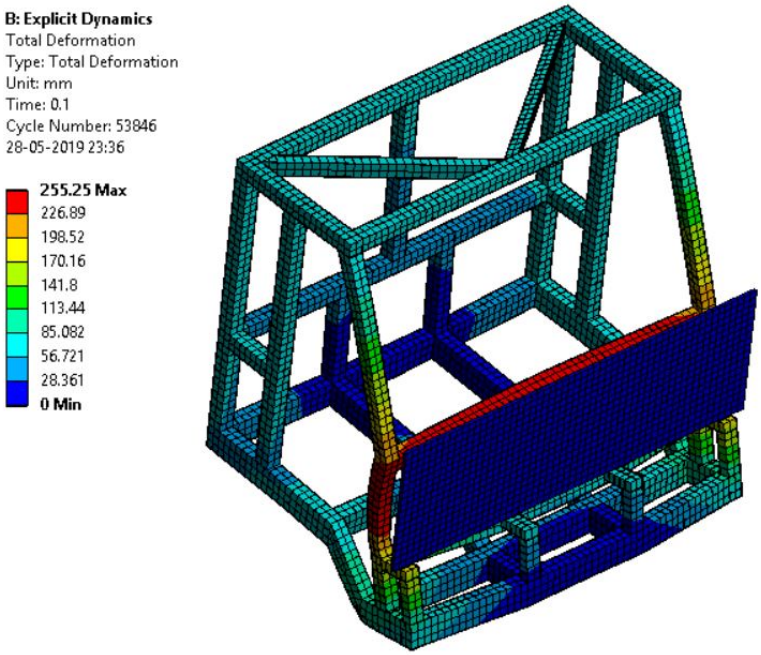

Fig. 24. Total deformation for the material AISI 1018

Considering above four figures it can be seen that the deformation of the superstructure is very less in the material AISI 1430 as the value is 213.11 mm and can defined as safe for the frontal impact.

The below diagram shows the deformation of the superstructure in the side impact load case. The deformation occurs at the side of the roof section of the cabin which is coloured in red.

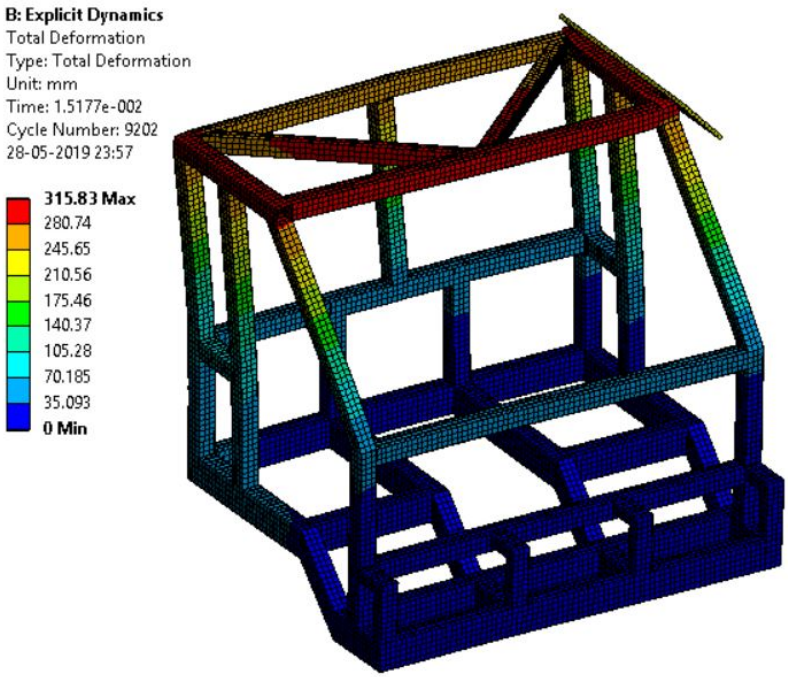

Fig. 25. Deformation for side impact for material AISI 1430

The below figure shows the total deformation for the material AISI 1080 which is used to know the difference between the deformation of other materials.

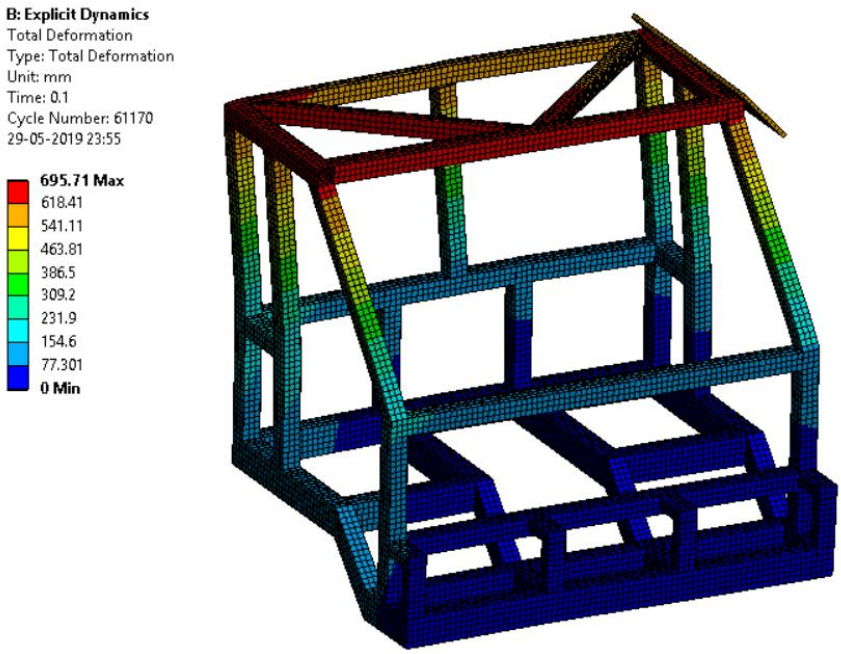

Fig. 26. Deformation for side impact for the material AISI 1080

The below figure shows the total deformation for the material AISI 1060 which is used to know the difference between the deformation of other materials.

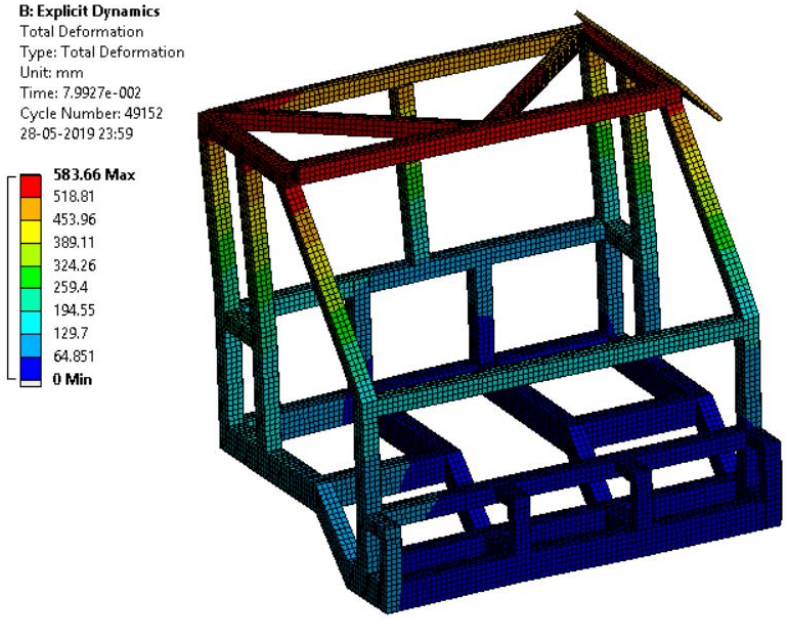

Fig. 27. Deformation for side impact for the material AISI 1060

The below figure shows the total deformation for the material AISI 1018 which is used to know the difference between the deformation of other materials.

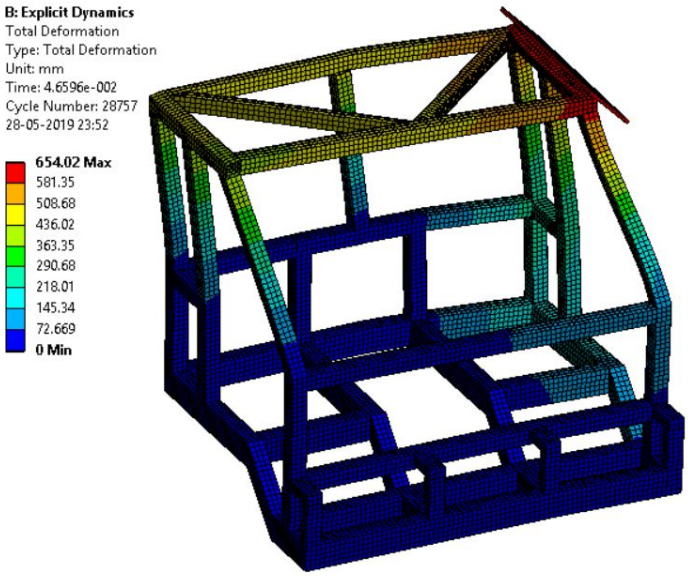

Fig. 28. Deformation for side impact for the material AISI 1018

Considering above four figures it can be seen that the deformation of the superstructure is very less in the material AISI 1430 as the value is 315.83 mm and can defined as safe for the side impact.

5.1.2. Energy probe

In this section energy absorbed by the superstructure is shown. Energy absorbed is the total energy absorbed by the superstructure when the load is applied, and this shows how much energy the superstructure can withstand. The below figure shows the strain energy for Roof load case using non-linear material, which shows the energy absorbed by the structure when the load is applied.

Details of "Strain Energy"	
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Strain Energy
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Results	
Minimum	0. mJ
Maximum	48.779 mJ
Total	15026 mJ
Minimum Occurs On	truck cabin surface-FreeParts|NONE[237]
Maximum Occurs On	truck cabin surface-FreeParts|NONE[176]

Fig. 29. Strain energy of Roof load

The below table shows the energy absorbed values for Frontal Impact load case using Non-linear material, which shows the energy absorbed by the structure when the load is applied. By seeing below table, it can be concluded that the energy absorption is more in material AISI 1430.

Table 7. Frontal Impact Energy absorption

Material Properties	Internal Energy (kJ)
AISI 1430	151.65
AISI 1080	137.11
AISI 1060	139.89
AISI 1018	138.92

The below table shows the energy absorbed values for Frontal Impact load case using Non-linear material, which shows the energy absorbed by the structure when the load is applied. By seeing below table, it can be concluded that the energy absorption is more in material AISI 1430.

Table 8. Side Impact Energy absorption

Material Properties	Internal Energy (kJ)
AISI 1430	283.14
AISI 1080	188.76
AISI 1060	264.38
AISI 1018	226.77

5.1.3. Energy summary graph

In this section energy absorbed by the superstructure while doing the dynamic analyisis is shown. The internal energy which is in pink shows the absorbed energy by the superstructure is shown in the below figure. The below figure shows the energy absorbtion for the material AISI 1430.

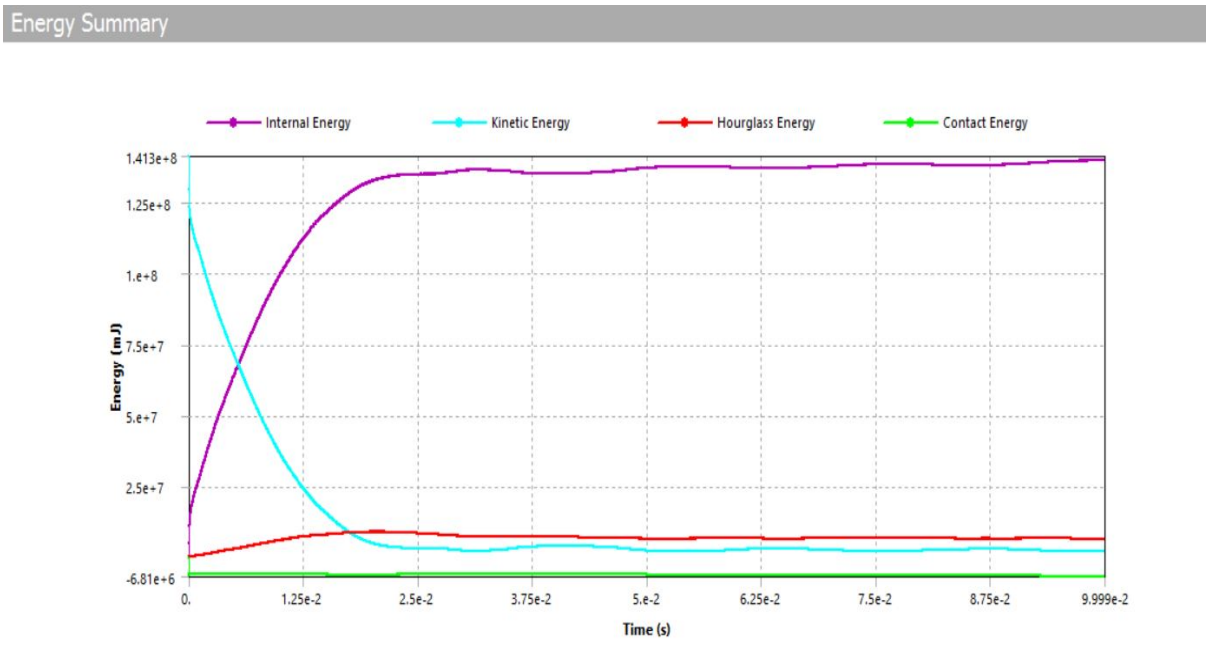

Fig. 30. Frontal impact energy graph for material AISI 1430

The below figure shows the energy absorption for the material AISI 1080 for the frontal impact dynamic analysis.

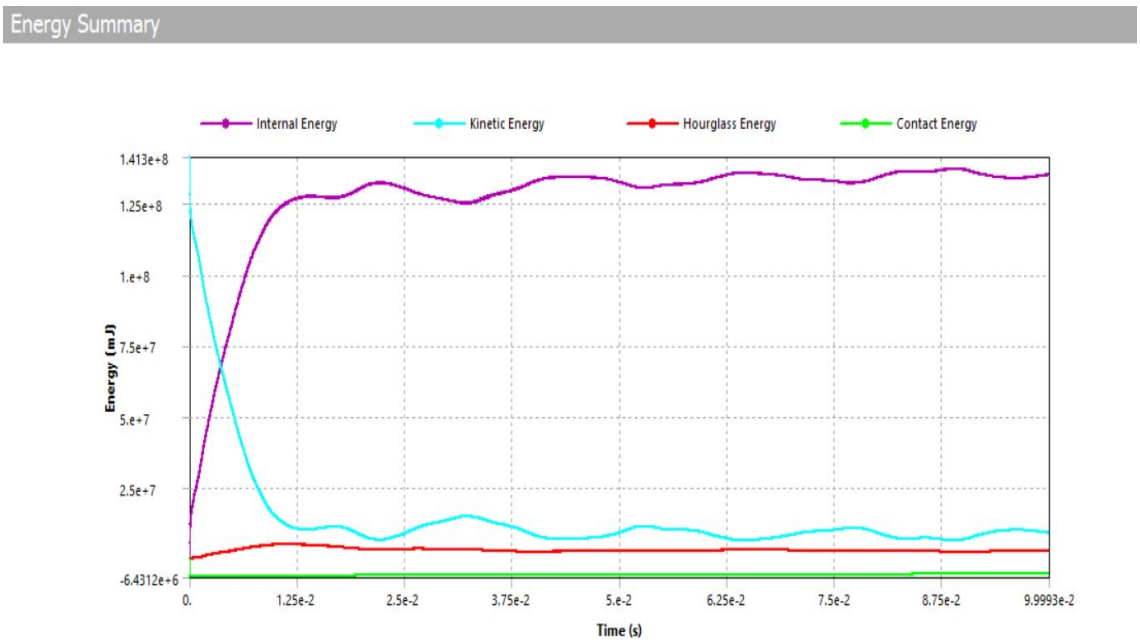

Fig. 31. Frontal impact energy graph for material AISI 1080

The below figure shows the nergy absorption for the material AISI 1060 for the frontal impact dynamic analysis.

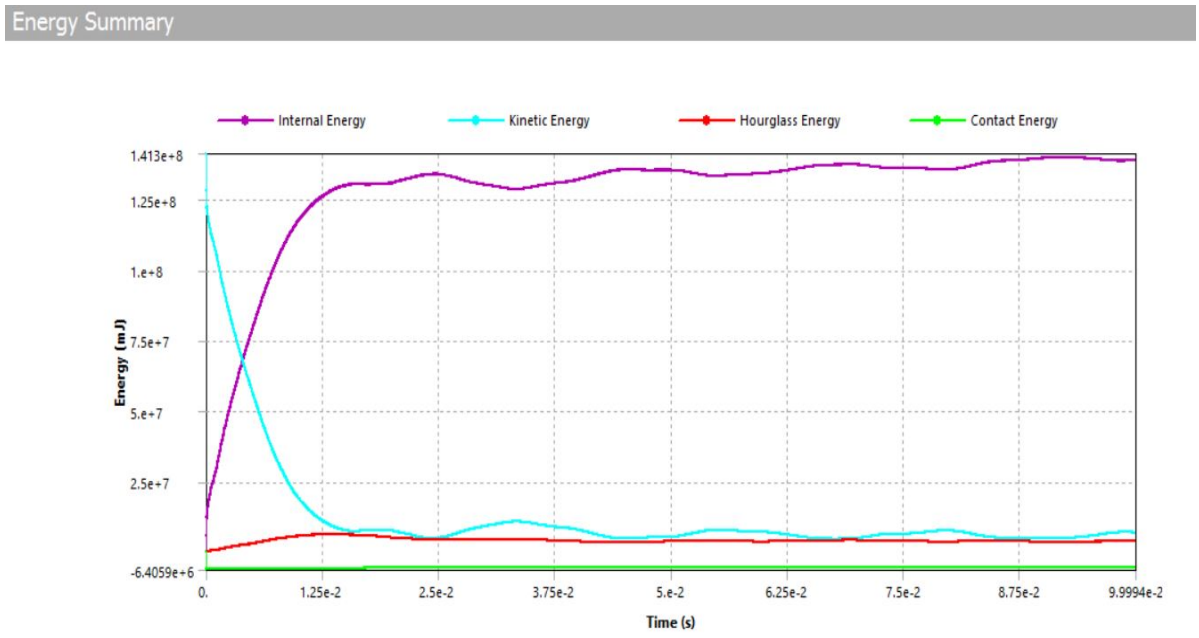

Fig. 32. Frontal impact energy graph for material AISI 1060

The below figure shows the energy absorption for the material AISI 1018 for the frontal impact dynamic analysis.

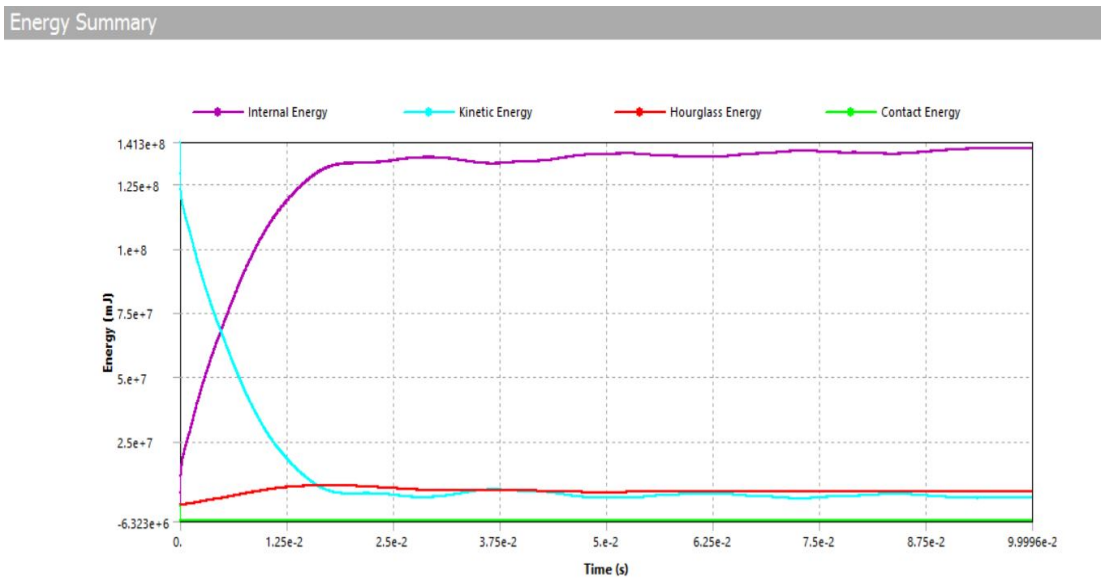

Fig. 33. Frontal impact energy graph for material AISI 1018

From above four graphs it can be seen that energy absorption is more in the material AISI 1430. So, the material AISI 1430 is good for the superstructure designed for the frontal impact analysis.

The below figure shows the energy absorption for the material AISI 1430 for the side impact dynamic analysis.

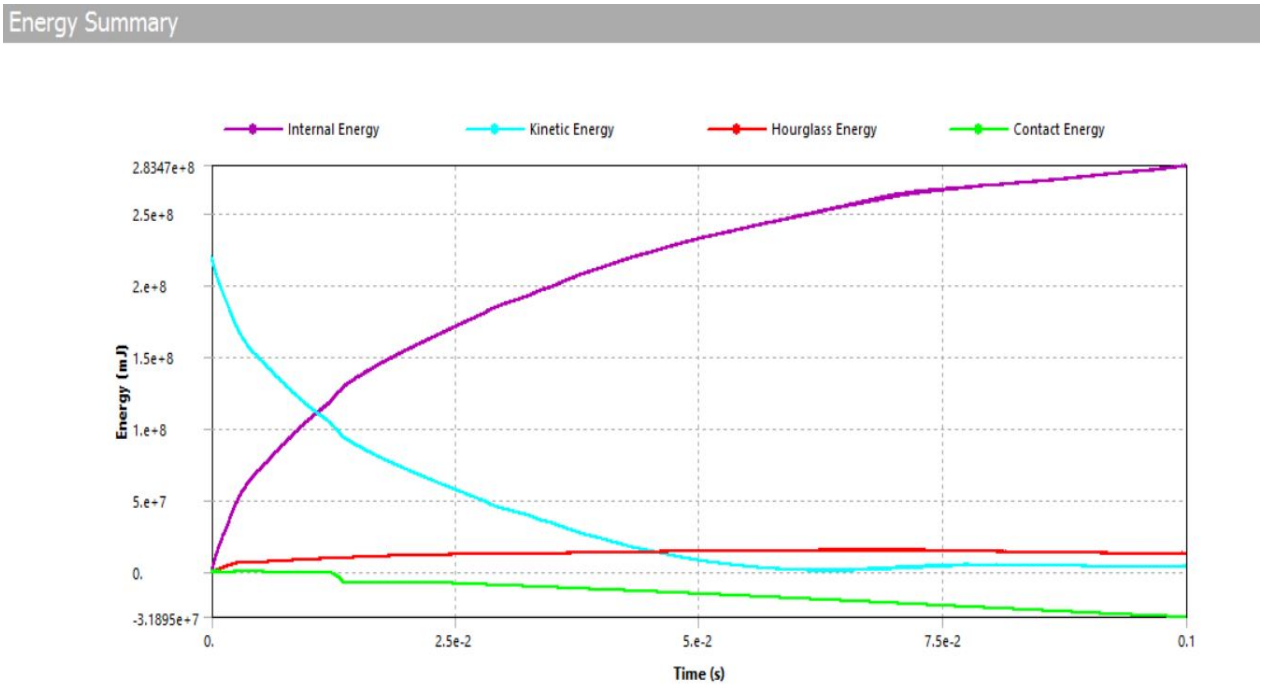

Fig. 34. Side impact energy graph for material AISI 1430

The below figure shows the energy absorption for the material AISI 1080 for the side impact dynamic analysis.

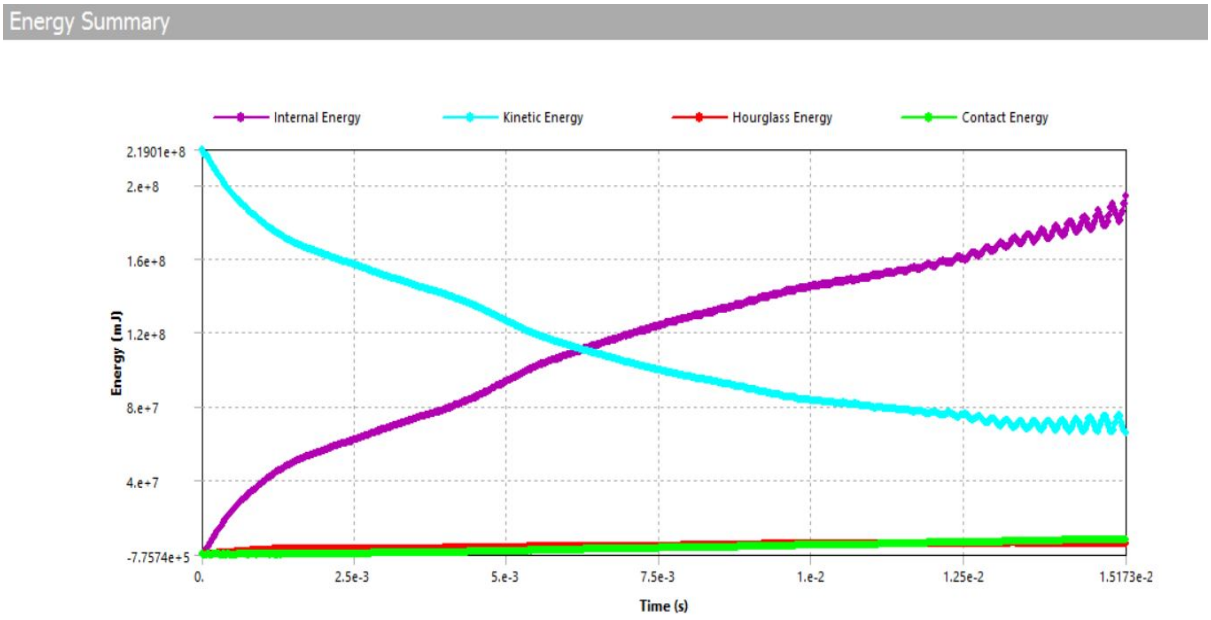

Fig. 35. Side impact energy graph for material AISI 1080

The below figure shows the energy absorption for the material AISI 1060 for the side impact dynamic analysis.

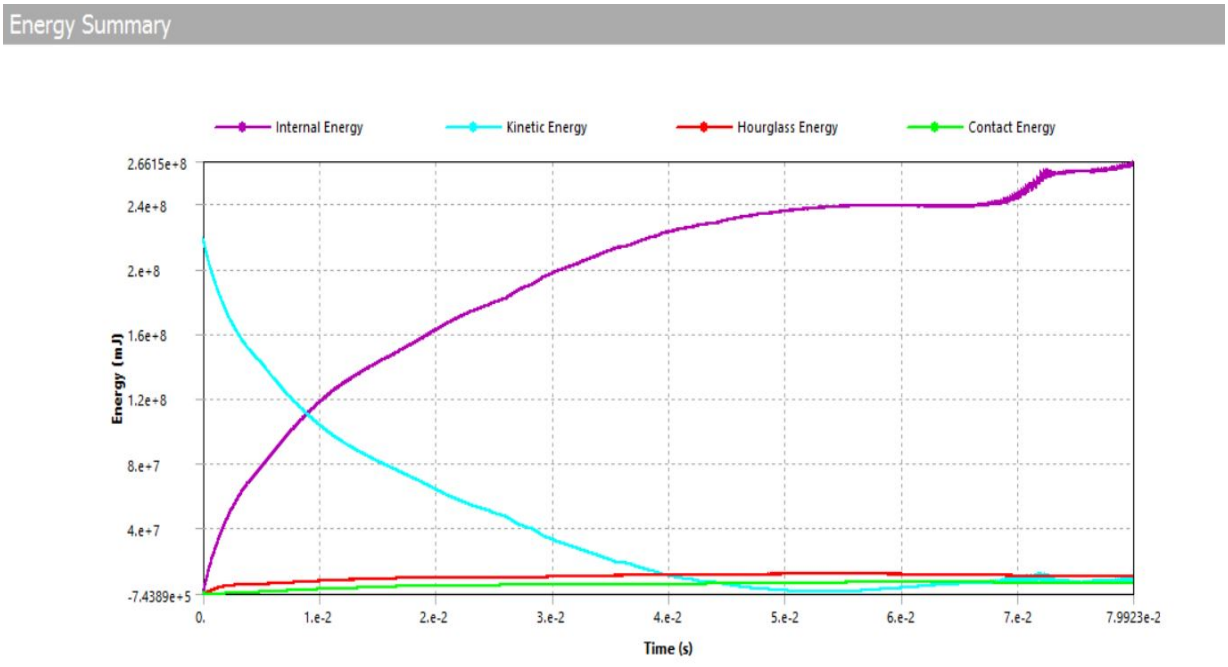

Fig. 36. Side impact energy graph for material AISI 1060

The below figure shows the energy absorption for the material AISI 1018 for the side impact dynamic analysis.

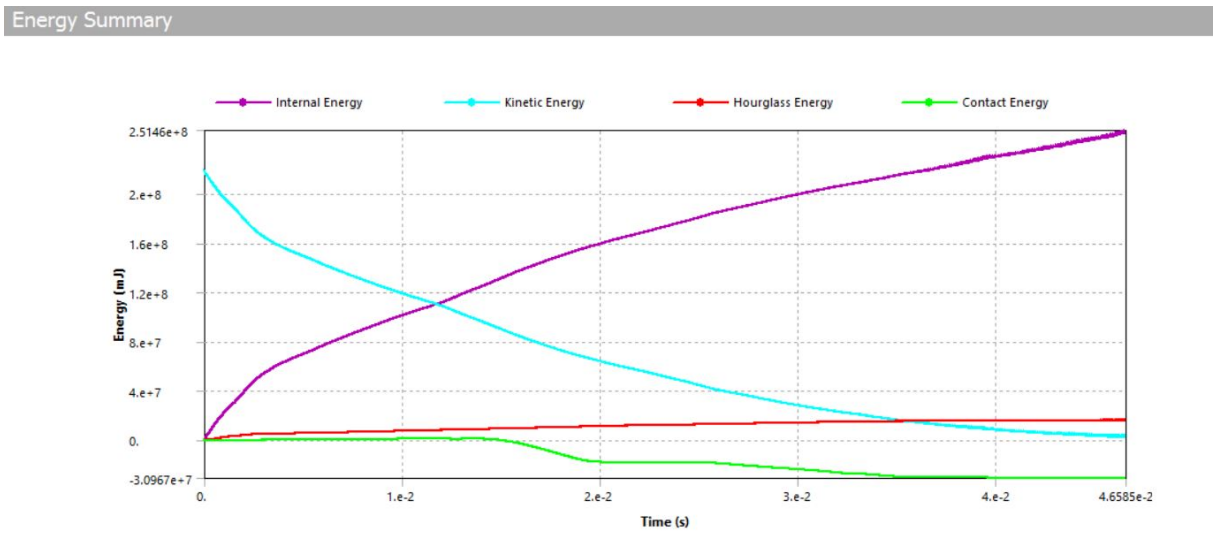

Fig. 37. Side impact energy graph for material AISI 1018

From above four graphs it can be seen that energy absorption is more in the material AISI 1430. So, the material AISI 1430 is good for the superstructure designed for the side impact analysis.

Conclusion

According to ECE R29 and AIS 029 regulations, the superstructure is certified to be safe and the main objectives of this study are satisfied as stated below:

1. The truck superstructure is designed according to the regulations mentioned by Automotive Industry Standards AIS 029 and chosen truck model “Ashok Leyland U3118” is safer for transportation.

2. The superstructure of the truck is designed to withstand all kinds of impacts created during the rollover of truck. The energy value obtained from the Ansys calculation satisfy this condition as the energy absorbed by the structure of truck is 283.14 kJ. This means that the structure is strong enough to withstand all kinds of impacts created during rollover accident.

3. The residual space of the truck is unharmed before and after rollover accident proving the rigidity of the material AISI 1430 for the superstructure. The deformation value obtained from the Ansys calculation satisfy this condition as the deformation of the superstructure is 213.11 mm. This shows that the residual space is unharmed before after the rollover accident.

4. The topological optimization of the superstructure is made, and the results is compared to show the optimizied structure is safer for the top load. The value of deformation which is observed in analytical calculation is 3.23 mm which is 29.32 percentage less deformation compared to the normal structure.

5. The study of deformation of the superstructure of the truck by using different materials is done and the best suitable material for superstructure is AISI 1430.

6. Suitable corrections can be made and can be amended to AIS 029 regulations according to the results mentioned above.

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