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# Automotive Chassis Frame Structural Analysis and Design Modification for Weight Reduction.

***N.FRANCIS, S.KAMALESH RAO***
***Assistant professor., Assistant professor,.***
***Department of MECHANICAL***
***St.Johns College of Engineering and Technology, Yemmiganur, Kurnool (Dist).***

**Abstract:**

***Automobile chassis usually refers to the lower body of the vehicle and it is an important part of an automobile. The chassis serves as a frame work for supporting the body and different parts of the automobile. Also, it should be rigid enough to withstand the shock, twist, vibration and other stresses. Along with strength, an important consideration in chassis design is to have adequate bending stiffness for better handling characteristics. So, maximum stress, maximum equilateral stress and deflection are important criteria for the design of the chassis. In this present study work is performed towards the optimization of the automotive chassis with constraints of equivalent stress and deflection of chassis. Sensitivity analysis is carried out for thickness and height by keeping width constant. Structural systems like the chassis can be easily analyzed using the finite element techniques. So a proper finite element model of the chassis developed. FEA is done on the modeled chassis using the ANSYS Workbench. Initially structural analysis was carried out for old and optimized design. Optimized chassis have lower stresses and deflections. Modal analysis is carried out to find natural frequencies and mode shapes of the existing as well as modified chassis. It is observed that all the natural frequencies of optimized chassis were below 100 Hz, varying from 14 Hz to 27 Hz for first three mode shapes. Almost all of the truck chassis designs were based on these frequency ranges to avoid the resonance during the operating condition.***

## Introduction

Automotive chassis can be considered as the backbone of any vehicle. Chassis is tasked at holding all the essential components of the vehicle like engine, suspension, gearbox, braking system, propeller shaft, differential etc. To sustain various loads under different working conditions it should be robust in design. Moreover chassis should be stiff and strong enough to resist severe twisting and bending moments to which it is subjected to. It should be strong to withstand vibrations. The Automotive chassis has two main goals.

• Hold the weight of the components

• To rigidly fix the suspension components together when moving The first item is an easy design solution and is also the basis of the original chassis designs that were taken from horse drawn carriages. One of the most effective shapes for supporting point loads fixed at two ends is an I-Beam, a box tube, or a C-Beam. One beam on an either side, I or C beams can hold tremendous weight. Truck frames still use this construction as it is an easy and effective method of supporting heavy loads.

The chassis frame consists of side members attached with a series of cross members. Stress analysis using finite element method (FEM) can be used to locate the critical point which has the highest stress. This critical point is one of the factors that may cause the failure. Along with strength, an important consideration in chassis design is to have adequate bending stiffness for better handling characteristics. So, maximum stress, maximum equilateral stress and deflection are important criteria for the design of the chassis. In this thesis work is performed towards the optimization of the automotive chassis with constraints.

Automobile chassis usually refers to the lower body of the vehicle including the tires, engine, frame, driveline and suspension. Out of these, the frame provides necessary support to the vehicle components placed on it. Also the frame should be strong enough to withstand shock, twist, vibrations and other stresses. The chassis frame consists of side members attached with a series of cross members Stress analysis using Finite Element Method (FEM) can be used to locate the critical point which has the highest stress.

This critical point is one of the factors that may cause the fatigue failure. The magnitude of the stress can be used to predict the life span of the truck chassis. The accuracy of prediction life of truck chassis is depending on the result of its stress analysis.

Proper chassis design not only helps in strengthening the chassis but it is also a useful tool in optimization of safety and fuel economy requirements. But before doing this, the challenge that is faced by the various OEM's is the stability of the chassis under all operating conditions. The ladder frame chassis in an automobile is subjected to various kinds of external forces i.e. Vertical force, longitudinal force, side force, twisting moment, wind-up moment etc. Basically, it is the duty of the chassis to sustain all these forces, but the most important factor taken into account is its behavior to the vertical forces. Also the structural integrity of the chassis should be such that it should not collapse in the event of crash and should be able to protect the occupants. Apart from these, there are also various dynamic forces which have a great impact on designing the chassis.

Precise knowledge about behavior of chassis under natural frequenciesis mandatory for all design engineers. A natural frequency is the frequency of the body at which it would oscillate after being disturbed from its rest position and then allowed to vibrate freely. There will be at least one natural frequency for all structures. But most structures contain multiple natural frequencies. Resonances or Modes are also area of concern while designing. These are inherent properties of a structure that are controlled by the material properties and boundary conditions. The natural frequency defines each mode and its mode shape. The modes will change if the material properties or the boundary conditions of a structure changes. In order to study all these phenomena, the development of any new product/prototype is expensive and time consuming and also requires a lot of accuracy. Therefore, software based Finite element methods are implemented on the solid modeling of the product. Proper material selection is done on the CAD model before performing any kind of analysis.

Chassis is a major component of a vehicle system. It consists of internal framework that supports man-made object. It is the underpart of the vehicle which consists of frame and running gear like engine, transmission system, suspension system etc. The automotive chassis is tasked with keeping all components together while driving and transferring vertical and lateral loads, caused by acceleration, on the chassis through suspension and the wheels. The key to good chassis design is that further the mass is away from the neutral axis the more rigid it is.

In this project, Unigraphics is the software used for the modelling of the chassis. It is an advanced CAD/CAM/CAE software and is used for analysis (static, dynamic, electro-magnetic, thermal) using Finite element method . Stress anaylsis is a key characteristics of a chassis . The design and analysis of chassis is done by identifying the location of high stress areas. The chassis design used in this project is the ladder frame chassis.

The reason for ladder frame type of chassis is that here it is easier to change the design without having to change the chassis thereby saving overall design time. It also provides a good beam resistance because of its continuous rail from front to rear. The disadvantage with using this type of chassis is that it has poor torsion stiffness , higher fuel consumption and also heavier than a unibody.

The design of an automotive structure is an important aspect in the overall vehicle design process. The vehicle structure is important to ensure that the weight of various components and loads applied during vehicle operation are adequately supported without substantial deflection. The structure is also responsible for protecting occupants and payloads during collisions. A vehicle structure must accomplish these two objectives while maintaining a low weight. The weight of the structure has become increasingly important as the fuel efficiency and emissions standards have increased. During the conceptual design stage, when changes to the design are easiest to implement and have lower impact on overall project cost, the weight and structural characteristics are mostly unknown since detailed vehicle information is unavailable at this early stage. This lack of knowledge about the design problem can be seen below in Figure 1, while the impact on overall vehicle development cost is illustrated in Figure 2.

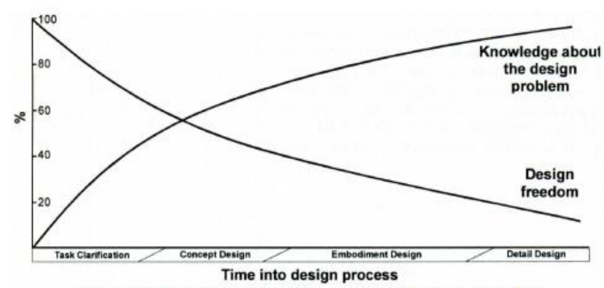


**Figure 1: Design information compared during design process [2]**

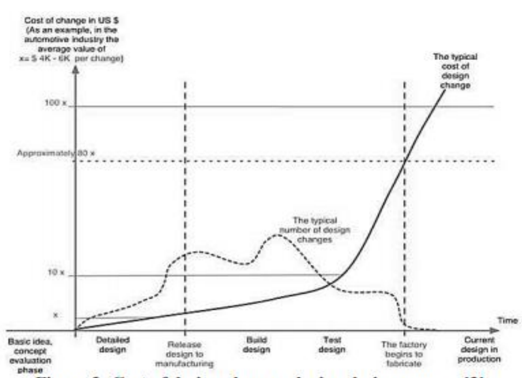


**Figure 2: Cost of design changes during design process [3]**

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However, even with insufficient information, the structural characteristics need to be considered and included in the design process from the outset of the conceptual stage. For the reasons given above the work presented here focuses on the conceptual design stage of an automotive structure. Ensuring the vehicle structure has sufficient load bearing capabilities, while maintaining a low weight, during the conceptual design stage will improve the overall vehicle design and mean fewer design changes are required during the detailed design process.

Several parameters are available for testing the vehicle structural characteristics; however two important parameters are the chassis bending and torsional stiffness's. The stiffness of a vehicle structure has an impact on the overall vehicle performance, as well as the Noise, Vibration and Harshness (NVH) of the vehicle [4,5,6]. Also sufficient stiffness is sought to ensure that the relative displacement of vehicle components is not substantial enough to cause damage to the vehicle. Other structural characteristics for evaluating the design, such as the NVH properties as well as the crashworthiness, are better utilized during the detailed design stage. 15 The work presented here focuses on the stiffness and weight during the conceptual stage and seeks to develop an optimized preliminary vehicle structure as an input for the detail design activities where every aspect of the vehicle design can be considered.

## LITERATURE REVIEW

A chassis should be designed in such a way that it should have adequate bending stiffness along with strength for better handling characteristics Tomar A et al. have modeled a chassis frame of anEicher Truck in CAD software and have studied the behavior of the chassis for Steel-52 and two composite materials like carbon fiber and E -Glass Epoxy. Modal analysis was performed to determine the natural frequencies of the chassis and their maximum deformation. After that, Harmonic analysis was carried out to investigate the Von – Mises stress at the frequency which produces the maximum deformation.

It was observed that the composite materials showed lower Von – Mises stress compared to Steel-52 at the natural frequency indicating the maximum deformation and hence was found to be safe at that resonating frequency. Singh A et al. have presented a paper on the structural analysis of a ladder chassis for higher strength. Their work includes designing of a TATA bus chassis in PRO-E software with exact dimensioning and material selection. Four different cross-sections of the vehicle chassis were modeled namely C section, I section, Rectangular Box (Hollow) and Rectangular Box (Intermediate) type cross sections. Finite element analysis was then carried out using Hyper-mesh software and the effects of stress, strain and displacement are computed in the structural analysis under the varying load condition. It is observed from the results that the Rectangular Box (Intermediate) section have more strength compared to the conventional steel alloy chassis having C, I and Rectangular Box (Hollow) section design and it showed the least deflection which was 1.839 mm. Anurag et al. have designed a truck chassis using the CAD software CREO and had performed static analysis using ANSYS software in order to investigate the various stresses acting on it and their resultant deformation. Since the truck chassis has to carry a large amount of load, its design should be such that it can withstand all the forces acting on it. Here in this paper, after modeling the 3-D design of the chassis using CREO, the design was imported in ANSYS workbench in IGES file format. Selecting HLSA steel as the material used for chassis, the static analysis was performed to observe the maximum principal stress, maximum shear stress and corresponding Von Mises stress.

The maximum deformation observed was 0.0084 mm and the design was found to be safe. Khannukar K et al. have performed the dynamic analysis of an automotive chassis using Finite element analysis. Modal analysis was performed to study the various natural frequencies and their mode shapes.

Both the theoretical and analytical results were found to be close to each other. Also the structure of the chassis was optimized with the help of acceleration response of the system.

there are two main objectives, which involves on the development of truck chassis. firstly, the appropriate static and dynamic characteristics of the existing chassis have to be determined. Secondly, structural development process in order to achieve high quality of the product. There are many factorsinvolve and must take into account, which can affection the vechile rolling, handling, ride stability and etc. today, there are many researches and development program available in the market especially by theinternational truck manufacturers, which are very much related to this study. Therefore, there are several technical papers from the 'engineering socirty for advancing mobility land sea air & space'(SAE) and some other sources which are reviewed and discussed in this chapter.

Vehicle structural design and optimization has been the focus of a number of previous works. The following is a review of some of the previously conducted work related to vehicle structural design, analysis and optimization. 20 The finite element method has been utilized in vehicle structural design for a number of purposes, including design analysis and optimization. The finite element method was applied for stress analysis of a vehicle chassis, as well as a truck chassis with riveted joints. Both of these previous works were more preliminary in nature and provided general information that forms part of the foundation of the work here; however existing software is utilized as the analysis being conducted is occurring at a later stage in the design process. Kim et al. used finite element analysis to study the dynamic stress of a vehicle frame. This work again utilizes commercial software to conduct dynamic analysis of the structure which is beyond the scope of the work presented here, but shows the potential of the finite element method as it relates to vehicle structure. Wang et al.

applied the finite element method to reinforce the body structure using an optimization process. This work provides further motivation for conducting the research conducted here; however it uses a detailed vehicle structure undergoing optimization in commercial software. Yanhong and Feng used finite element analysis and an optimization process were also applied to the sub-frames of a commercial vehicle.

This work provides a good reference related to how an optimization process can be performed on a vehicle structure and as such is relevant to the research being conducted. Kim, Mijar and Arora previously developed a simplified vehicle structure model for the design and optimization of a vehicle based on crashworthiness. The objective of this work was very similar to the focus of the research being presented as a simplified structural model was developed and optimized; however the difference is the focus of the previous work is on crashworthiness instead of static structural characteristics. Beam element structural models have been used in a number of previous works, some of which 21 are described here. The beam model was used to approximate the vehicle panels for implementation in computational methods. This work is a general overview of how the beam model can be utilized in analysis and is a foundation work, but does not contribute specific details to this research. Shiu, Ceglarek and Shi use beam elements to model a vehicle

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structure has been used to model a sheet metal body assembly for dimensional control. Their work is central to the development of the research being conducted and in it they take an existing vehicle structure, in this case a van, and generate a beam equivalent. Their work does differ from the current research as optimization is not conducted and instead of substructure analysis for sheet metal analysis the sheet components are reduced to an equivalent series of small beams as needed. Mundo et al. previously used a beam structure has been to simplify the vehicle structure model to conduct NVH optimization of a vehicle Body-In-White (BIW). The work conducted here is similar in nature to the presented research as an optimization process is implemented; however the difference is in the objectives for optimization and the more complex beam sections possible in existing software. While there are differences the work conducted by Mundo et al. is also conducted during the early design stages. Donders et al. used the beam structure has also been combined with a detailed joint model in order to optimize the global body dynamics. This work is an extension of the work conducted by Mundo et al., but is focused on the joint design as part of optimization.

As part of the optimization program that is used a method of determining the stiffness properties of a vehicle structure was required. Law et al. previously studied the effect of the structure torsion stiffness on vehicle roll stiffness has been previously studied. Their work is not essential for this research, but shows how torsion stiffness can affect vehicle performance and why it is important to have high stiffness. Thompson, Raju and Law have conducted the design of a race car chassis based on torsion stiffness. This work seeks to design a vehicle based on stiffness which is similar in nature to the work presented here; however their optimization is based on element sensitivities and is conducted in commercial software. Finally Thompson, Lampert and Law used an experimental method of estimating the vehicle torsion stiffness. This last work was used to illustrate how the stiffness of a chassis can be calculated based on the presented experimental method.

## Methodology

The word “modification” means, “a slight change in order to make something more suitable for a particular purpose” will also be used for conversion (complete change) for the purpose of this research. Slight change: this is when a part of the vehicle is modified in order to achieve desired performance. For example, lengthening trailer size to carry more loads or shortening it for easy manoeuvring in certain narrow areas. Complete change: this is when the whole vehicle is converted from its present form to an entirely new form. Typical example of complete change is the conversion of a cargo truck to a tipper truck and a flat bed trailer to a cargo trailer. A modification is usually carried out if for example a tipper truck is needed and a cargo truck is cheaper, the cargo truck is purchased and modified to meet the purpose of a tipper truck. In some cases, only the trailer head is bought and whatever is desired is built and connected to the head. These modifications are by themselves legitimate.

However, the manner in which they are carried out may not conform maximum shear stress, equivalent stress and deflection of chassis under maximum load. Chassis frame is analysed using the finite element techniques (ANSYS Workbench). A sensitivity analysis will be carried out for weight reduction II.

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**TYPES OF CHASSIS:**

A chassis is defined as a structural unit that will support the full load of the vehicle drive train, body and all ancillary components. The body and chassis are detachable by means of standard fasteners and the chassis must not rely on the body for strength. The chassis is the framework that is everything attached to it in a vehicle. In a modern vehicle, it is expected to fulfil the following functions: i. Provide mounting points for the suspensions, the steering mechanism, the engine and gearbox, the final drive, the fuel tank and the seating for the occupants; ii. Provide rigidity for accurate handling; iii. Protect the occupants against external impact. While fulfilling these functions, the chassis should be light enough to reduce inertia and offer satisfactory performance.

It should also be tough enough to resist loads that are produced due to interaction between the driver, engine, power transmission and road conditions. Chassis can be broadly classified into following types which are commonly used:

A. Ladder Chassis
B. Twin Tube
C. Space Frame
D. Backbone Chassis
E. Tub Chassis
F. Monocoque Chassis

## III.CHASSIS MODIFICATION

The word "modification" means, "a slight change in order to make something more suitable for a particular purpose" will also be used for conversion (complete change) for the purpose of this research. Slight change: this is when a part of the vehicle is modified in order to achieve desired performance. For example, lengthening trailer size to carry more loads or shortening it for easy manoeuvring in certain narrow areas. Complete change: this is when the whole vehicle is converted from its present form to an entirely new form. Typical example of complete change is the conversion of a cargo truck to a tipper truck and a flat bed trailer to a cargo trailer. A modification is usually carried out if for example a tipper truck is needed and a cargo truck is cheaper, the cargo truck is purchased and modified to meet the purpose of a tipper truck. In some cases, only the trailer head is bought and whatever is desired is built and connected to the head. These modifications are by themselves legitimate.

However, the manner in which they are carried out may not conform to lay down regulations by the various international and national transport authorities in chargevehicle registration and licensing and the manufacturers of the vehicles. Following are some standard practices used in chassis modifications.

### A. Boxing

The addition of a 3mm or thicker plate welded into the opening of a "C" channel to form a box section. This section can either be the full length of the side rail, or added to areas requiring extra

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strength. Boxing plate attachment should be carried out as shown Fig. 1

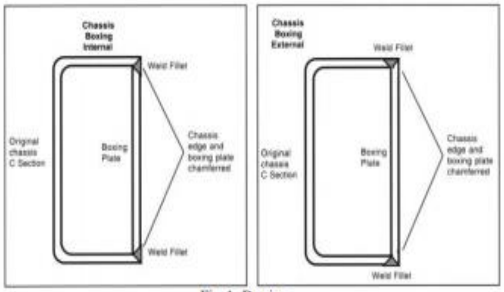


Fig.1 Boxing

**B. Laminating**

The attaching of an additional 3 mm or thicker plate to a chassis side rail is called as laminating. Large lamination plates may require the addition of plug welds to ensure full contact with side rails.

**C. Gusseting**

A gusset is usually triangular in shape and is connected between butt welded chassis parts. An example of gusseting is given in Fig. 2.

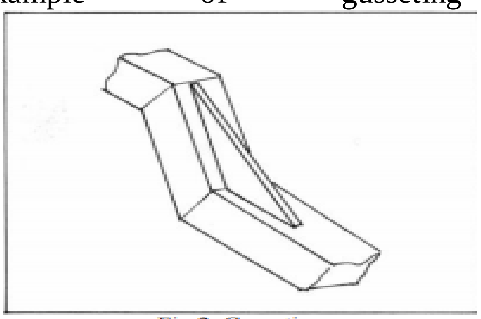

Fig.2 Gusseting

**D. Fish-Plates**

A fish-plate is similar to a lamination plate, and is affixed when a gusset cannot be easily utilized, or a vertical slice, pie cut or section has been removed and the parts are butt welded together. Fish-plates should be twice as long as the chassis vertical height with triangular extensions to increase weld length. An example of a “fish-plate” is shown in Fig. 3.

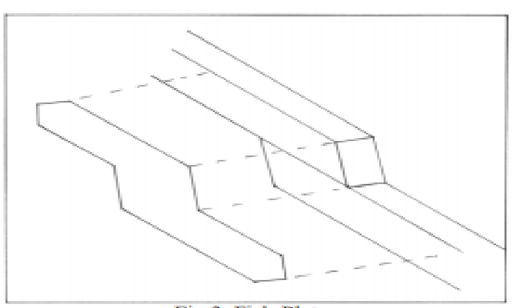

Fig.3 Fish-Plates

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TABLE I
TATA 2515EX SPECIFICATIONS

| Sr. No. | Parameters | Value |
|---|---|---|
| 1 | Total length of the chassis | 8200 mm |
| 2 | Width of chassis | 65 mm |
| 3 | Height of chassis | 285 mm |
| 4 | Thickness of chassis | 7 mm |
| 5 | Front cabin chassis length | 2400 mm |
| 7 | Front cabin chassis applying load | 19620 N |
| 8 | Back body chassis length | 5800 mm |
| 10 | Back body chassis applying load | 196200 N |
| 11 | Young's Modulus of steel chassis | 2.0e5 N/mm2 |
| 12 | Density of steel chassis | 7.85*10-6 N/mm2 |
| 13 | Total load on the chassis | 215820 N |

C-Type of cross section will be considered for chassis modeling as shown in Fig. 4.

The chassis model is loaded by static forces from the body and load. For this model, the maximum loaded weight of truck plus body will be considered. The load is assumed as a uniform distributed obtained from the maximum loaded weight divided by the total length of chassis frame.

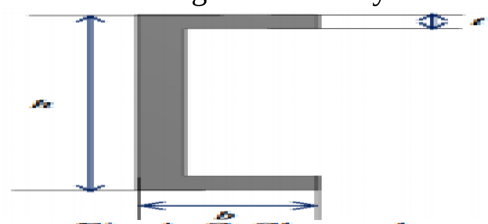

Fig.4 C-Channel

Analyse the sensitivity of frame web height to the change in thickness and vice-versa for the approximately same section modulus and flange width. Section modulus (Z)

$$Z = \frac{bh^3 - b_1 h}{6h}$$

But,
$t < b$
$t << h$
Taking,
$b - t = b_1$
$b - 2t = h_1$

$$Z = \frac{bh^2}{6} - \frac{(b-t)(h-2}{6h}$$

Solving equation 2 we will get,

$$\frac{6Z}{b} = h^2 - (h - 2t$$

But Z and b are constants,
Assuming,

$$\frac{6Z}{b} =$$

We will get,

$$K = h^2 - (h - 2t$$

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Section modulus and flange width being constant K is constant parameter. Take “h” as dependent parameter and “t "as independent parameter.

Types of Chassis

Chassis have to be stiff enough so that they withstand the forces applied to them. This is point is really important in the suspension settings. If the chassis bends a little the car in not going to behave as expected (as linear) because the ride is being modified, in short, the suspension settings are modified. However, you can not make the chassis completely stiff. That would cause it to be brittle. There will start to appear weak points and it would end breaking throw the weakest. So you need to reach a point where it is neither too stiff nor too weak. As said before, the car needs to withstand various forces, so which are these forces:

Lateral G (Cornering speed)

Longitudinal G (acceleration and braking)

Load (Passenger and goods)

Road irregularities (bumps, pot holes etc)

The main materials used to build chassis are steel alloys , aluminium alloys, titanium alloys composites etc. Every one of those has different properties and applications. Prices vary vastly. These materials are joined in various ways: riveted, bolted, welded, glued together to make chassis.
There are several types of chassis :

Ladder frame

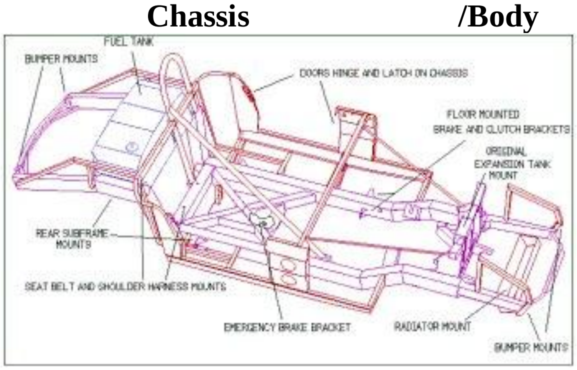
Space frame

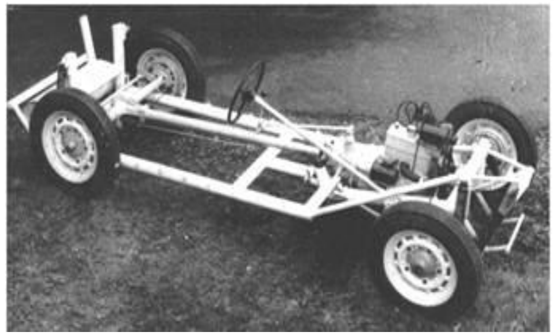
Torsion box

Monococque

Combination

**Ladder Chassis /Body on chassis**





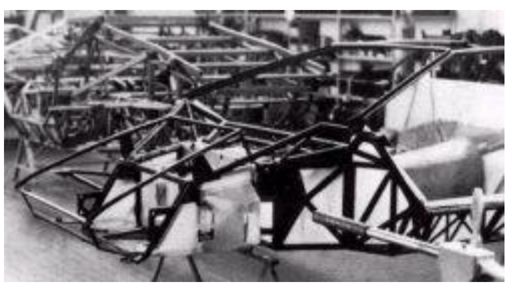
AC Cobra's chassis.

This is the earliest kind of chassis. From the earliest cars until the early 60s, nearly all cars in the world used it as standard. Even in today, most SUVs still employ it. Its construction, indicated by its name, looks like a ladder - two longitudinal rails interconnected by several lateral and cross braces. The longitude members are the main stress member. They deal with the load and also the longitudinal forces caused by acceleration and braking. The lateral and cross members provide resistance to lateral forces and further increase torsional rigidity.

Advantage: Well, it has no much advantage in these days ... it is easy and cheap for hand build, that's all.

Disadvantage: Since it is 2 dimensional structures, torsional rigidity is very much lower than other chassis, especially when dealing with vertical load or bumps.

Who use it ? Most SUVs, classic cars, Lincoln Town Car, Ford Crown Victoria etc.



Lamborghini Countach

As ladder chassis is not strong enough, motor racing engineers developed a 3 dimensional design - Tubular space frame. One of the earliest examples was the post-war Maserati Tipo 61 "Birdcage" racing car. Tubular space frame chassis employs dozens of circular-section tubes (some may use square-section tubes for easier connection to the body panels, though circular section provides the maximum strength), position in different directions to provide mechanical strength against forces from anywhere. These tubes are welded together and forms a very complex structure, as you can see in the above pictures.

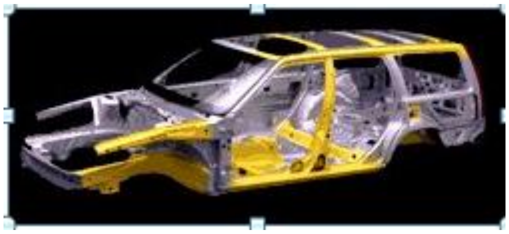
For higher strength required by high performance sports cars, tubular space frame chassis usually incorporate a strong structure under both doors (see the picture of Lamborghini Countach), hence result in unusually high door sill and difficult access to the cabin.
In the early 50s, Mercedes-Benz created a racing car 300SLR using tubular space frame. This also brought the world the first tubular space frame road car, 300SL Gullwing. Since the sill

dramatically reduced the accessibility of carbin, Mercedes had to extend the doors to the roof so that created the "Gullwings".

Since the mid 60s, many high-end sports cars also adopted tubular space frame to enhance the rigidity / weight ratio. However, many of them actually used space frames for the front and rear structure and made the cabin out of monocoque to cut cost.

**3. Monocoque / Unibody**

Today, 99% cars produced in this planet are made of steel monocoque chassis, thanks to its low production cost and suitability to robotised production.



Monocoque is a one-piece structure which defines the overall shape of the car. While ladder, tubular space frame and backbone chassis provides only the stress members and need to build the body around them, monoque chassis is already incoporated with the body in a single piece, as you can see in the above picture showing a Volvo V70.
In fact, the "one-piece" chassis is actually made by welding several pieces together. The floorpan, which is the largest piece, and other pieces are press-made by big stamping machines. They are spot welded together by robot arms (some even use laser welding) in a stream production line. The whole process just takes minutes. After that, some accessories like doors, bonnet, boot lid, side panels and roof are added.
Monocoque chassis also benefit crash protection. Because it uses a lot of metal, crumple zone can be built into the structure.
Another advantage is space efficiency. The whole structure is actually an outer shell, unlike other kinds of chassis, therefore there is no large transmission tunnel, high door sills, large roll over bar etc. Obviously, this is very attractive to mass production cars.
There are many disadvantages as well. It's very heavy, thanks to the amount of metal used.

As the shell is shaped to benefit space efficiency rather than strength, and the pressed sheet metal is not as strong as metal tubes or extruded metal, the rigidity-to-weight ratio is also the lowest among all kinds of chassis bar the ancient ladder chassis. Moreover, as the whole monocoque is

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made of steel, unlike some other chassis which combine steel chassis and a body made of aluminium or glass-fiber, monocoque is hopelessly heavier than others.Although monocoque is suitable for mass production by robots, it is nearly impossible for small-scale production. The setup cost for the tooling is too expensive - big stamping machines and expensive mouldings.

I believe Porsche is the only sports car specialist has the production volume to afford that.

| | |
|---|---|
| Advantage: | Cheap for mass production. Inherently good crash protection. Space efficient. |
| Disadvantage: | Heavy. Impossible for small-volume production. |
| Who use it ? | Nearly all mass production cars, all current Porsche. |

ULSAB Monocoque:

Enter the 90s, as tougher safety regulations ask for more rigid chassis, traditional steel monocoque becomes heavier than ever. As a result, car makers turned to alternative materials to replace steel, most notable is aluminium. Although there is still no mass production car other than Audi A8 and A2 to completely eliminate steel in chassis construction, more and more cars use aluminium in body panels like bonnet and boot lid, suspension arms and mounting sub-frames. Unquestionably, this is not what the steel industry willing to see. Therefore, American's steel manufacturers hired Porsche Engineering Services to develop a new kind of steel monocoque technology calls Ultra Light Steel Auto Body (ULSAB). As shown in the picture, basically it has the same structure as a conventional monocoque. What it differs from its donor is in minor details - the use of "Hydroform" parts, sandwich steel and laser beam welding.
Hydroform is a new technique for shaping metal to desired shape, alternative to pressing. Conventional pressing use a heavy-weight machine to press a sheet metal into a die, this inevitably creates inhomogenous thickness - the edges and corners are always thinner than surfaces. To maintain a minimum thickness there for the benefit of stiffness, car designers have to choose thicker sheet metal than originally needed. Hydroform technique is very different. Instead of using sheet metal, it forms thin steel tubes.

The steel tube is placed in a die which defines the desired shape, then fluid of very high pressure will be pumped into the tube and then expands the latter to the inner surface of the die. Since the pressure of fluid is uniformal, thickness of the steel made is also uniformal.

As a result, designers can use the minimum thickness steel to reduce weight. Sandwich steel is made from a thermoplastic (polypropylene) core in between two very thin steel skins. This combination is up to 50 percent lighter compared with a piece of homogenous steel without a penalty in performance. Because it shows excellent rigidity, it is applied in areas that call for high bending stiffness. However, it cannot be used in everywhere because it needs adhesive bonding or riveting instead of welding.

Compare with conventional monocoque, Porsche Engineering claimed it is 36% lighter yet over 50% stiffer. Although ULSAB was just annouced in early 1998, the new Opel Astra and BMW

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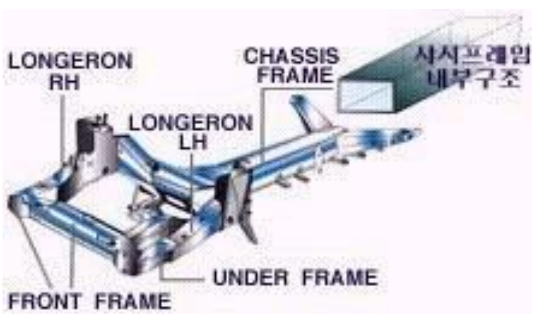
3-Series have already used it in some parts. I believe it will eventually replace conventional monocoque.

Advantage: Stronger and lighter then conventional monocoque without increasing production cost.

Disadvantage: Still not strong or light enough for the best sports cars.

Who use it ? Opel Astra, BMW 3-series

**5. Backbone Chassis**




Kia's version Lotus Elan Mk II

Colin Chapman, the founder of Lotus, invented backbone chassis in his original Elan roadster. After failed in his experiment of glass-fibre monocoque, Chapman discovered a strong yet cheap chassis which had been existing for millions of years - backbone. Backbone chassis is very simple: a strong tubular backbone (usually in rectangular section) connects the front and rear axle and provides nearly all the mechnical strength. Inside which there is space for the drive shaft in case of front-engine, rear-wheel drive layout like the Elan.

The whole drivetrain, engine and suspensions are connected to both ends of the backbone. The body is built on the backbone, usually made of glass-fibre.

It's strong enough for smaller sports cars but not up to the job for high-end ones. In fact, the original De Tomaso Mangusta employed chassis supplied by Lotus and experienced chassis flex. TVR's chassis is adapted from this design - instead of a rigid backbone, it uses a lattice backbone made of tubular space frames. That's lighter and stronger (mainly because the transmission tunnel is wider and higher).

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| | |
|---|---|
| Advantage: | Stong enough for smaller sports cars. Easy to be made by hand thus cheap for low-volume production. Simple structure benefit cost. The most space-saving other than monocoque chassis. |
| Disadvantage: | Not strong enough for high-end sports cars. The backbone does not provide protection against side impact or off-set crash. Therefore it need other compensation means in the body. Cost ineffective for mass production. |
| Who use it ? | Lotus Esprit, Elan Mk II, TVR, Marcos. |

**6. Hybrid design:**

The safety cell is made through Monocoque chassis construction. The rest of the chassis is made trough space frame design. Many unibody cars utilize some sort of front and rear sub-frame that bolts to the chassis. The sub-frames serve as mounting points for the suspension, engine, transmission and other mechanical components -- essentially all of the car's moving components.

Sub-frame designs are far more adaptable for use on different chassis, and are especially useful for designs that are identical but for their wheelbase (like coupe and sedan versions of the same car). The only down side to this design is that the chassis itself may twist between the subframes, but this is easily remedied by installing an X-brace subframe connector under the Car.

It has some of the advantages of each one. Another advantage is that is simpler and cheaper to produce than Monocoque alone.

Stress–strain analysisor simply stress analysis isa method that is used to determine the stresses and strains acting in materials and structures subjected to forces [10]. In engineering, stress analysis acts as a tool that adopts the macroscopic view of materials characteristics which takes geometrical description and the properties of the materials as input data and gives data output typically in the form of a quantitative description of the stress acting all over the structure. The two main types of methods for analyzing stresses are experimental methods and mathematical methods.

The different types of stress analysis that can be performed on a body are

**a. Static Analysis:**

Static Analysis is used to determine both linear and non-linear deformations under static loading conditions.

**b. Modal Analysis:**

Modal analysis is the study of the natural characteristics of body, i.e. the both natural frequency and mode shape which helps in designing the structural system for noise and vibration application.

**c. Harmonic Analysis:**

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Harmonic Analysis is used to determine the response of a structure to harmonically time-varying signals as superposition of basic waves.

**d. Transient Dynamic Analysis:**

Transient dynamic analysis is a technique used to determine the dynamic response of a structure under a time-varying load.

**e. Buckling Analysis:**

Buckling analysis is used to find out the failure of a structural member which is subjected to high compressive stresses.

**f. Power Spectrum Density Analysis:**

PSD analysis is also called random vibration analysis. The response of random vibrations is studied using PSD Analysis by probability statistics method. These vibrations are non-deterministic in nature. Modeling of a product is the first step that is performed by a design engineer after considering all the necessary dimensions. The basic geometry of a product is first designed in CAD software in a 2-D system which later is converted into a solid 3-D model. Finally, the assembly of various parts makes up an entire system.

The common methodology that is followed while designing a product is:

- Modelling of the geometry.
- Defining the element types to be used.
- Generating the finite element mesh by making approximation to the geometry.
- Calculating the nodes and elemental properties.
- Allowing for the specifications of the support conditions andloading conditions for the individual element position.
- Allowing the material properties to be specified.
- Generating the results showing various stress contours in terms of the values of stresses and displacements.

**A. Static Analysis**

The primary objective is to design a suitable pick-up truck chassis as per the present market standard. CATIA V5 R21 was used to model the three dimensional pick-up truck chassis. CATIA (Computer Aided Three-Dimensional Interactive Application) is one of the best CAD software available in the market and is most widely used by engineers and researchers. The specifications of the pick-up truck chassis is given in Table I. Considering the design according to payload of the chassis, a maximum of 2.5 ton payload is taken into account.

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TABLE I: Specifications of Pick-up Truck Chassis

| | |
|---|---|
| Overall Length (mm) | 4500 |
| Overall Width (mm) | 690 |
| Wheelbase (mm) | 2575 |
| Front Overhang (mm) | 650 |
| Rear Overhang (mm) | 1275 |
| Dimensions of Side Member (mm x mm x mm) | 120x50x5 |
| Type of Side Member | Rectangular Box Section Type |
| Type of Cross Member | Circular Type |
| Total No. of Cross Members | 3 |
| Gross Vehicle Weight (ton) | 4 |

Neglecting the unsprung weight,

Total weight of the vehicle body including the engine, cabin and the load body = 1350 kg

Vehicle payable load = 2500 kg

Total Passenger weight = Average passenger weight x Total number of passengers

= 75 kg x 2

= 150 kg

Therefore,

Gross Vehicle Weight (GVW) = (1350 + 2500 + 150) kg

= 4000 kg

So, Total load acting on the chassis frame = 4000 x 9.81

= 39240 N

In order to find the most suitable material for the pick-up truck chassis, a total of four different

materials were used. The materials used were ASTM A710 Steel, ASTM A320 Alloy Steel, HSLA Steel and ISO 1018 Steel. The various properties of the materials are given in Table II.

TABLE II: Different Materials and their properties

| Material | Density (kg/m3) | Young's Modulus (Pa) | Poisson's Ratio | Tensile Strength (Pa) |
|---|---|---|---|---|
| ASTM A710 Steel | 7850 | 8.00E+10 | 0.29 | 4.50E+08 |
| ASTM A320 Alloy Steel | 7790 | 7.80E+10 | 0.33 | 3.40E+08 |
| HSLA Steel | 7800 | 2.60E+11 | 0.3 | 3.10E+08 |
| ISO 1018 Steel | 7860 | 2.00E+11 | 0.266 | 2.50E+08 |

After modeling the pick-up truck chassis in CATIA V5 R21, the design was imported in ANSYS in IGES format. Thereafter the materials were defined one after another and finite element meshing was done. The mesh size for the pick-up truck chassis was defined as 10mm. The static, modal and harmonic analysis was performed taking all boundary conditions in to account.

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Static analysis is used to find all the possibilities of failure/fracture in the chassis/frame and minimise them taking into consideration the constraints of maximum shear stress, equivalent stress and deflection of the chassis under maximum load condition.

There are basically two methods i.e. theoretical analysis and finite element analysis to find the structural rigidity of the chassis.

i. Theoretical Analysis - The theoretical analysis was performed based on the maximum load and

reaction forces acting on the chassis. The pick-up truck chassis has two beams. So load acting on each beam is half of the total load acting on the chassis.

Load acting on each beam = 39240/2 = 19620 N

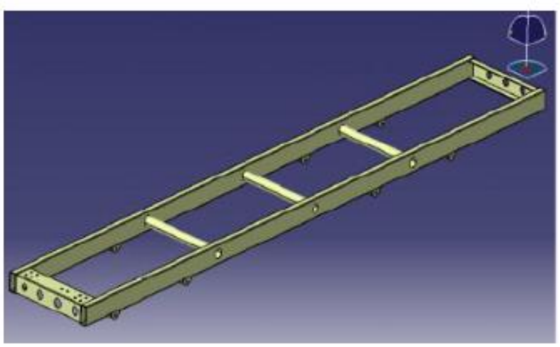
Since the beam is simply clamped with the shock absorber and leaf spring, so the beam is considered as a simply supported beam supported with uniform distributed load.

Therefore the uniformly distributed load = 19260/4500

= 4.36 N/mm

Taking moment about any of the two fixed supports, the reaction forces were calculated.

Furthermore, the shear force and bending moment was calculated followed by the bending stress and shear stress. The angle of twist was assumed to be 1 degree. According to the Von – Mises stress theory, the maximum Von – Mises stress along with the maximum shear stress,equivalent shear strain and total deformation of the chassis for different materials were calculated. The results for different materials are given in Table III.



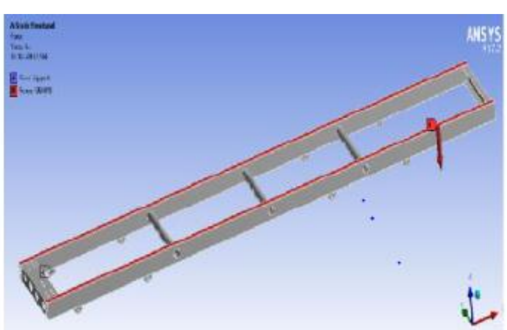



***Fig. 1. From L-R (a) 3-D model of Pick-up Truck Chassis modeled in CATIA V5 R21 and (b)***

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**Boundary Condition for Static Analysis**

ii. FEA Analysis - The Finite element analysis was performed in ANSYS 17.2 for the four different materials. After selecting each material one after another, proper meshing was performed throughout the chassis frame. The frame was fixed at the brackets which would connect the leaf springs with the chassis. A total force of 39240 N was subjected to the frame in the vertical direction. The results were calculated using the post-processor of the ANSYS software. The FEA results obtained are given in

Table IV.

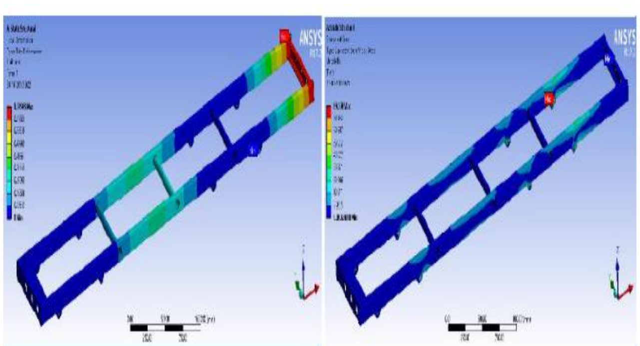
TABLE III: THEORETICAL RESULTS OF STATIC ANALYSIS FOR PICK-UP TRUCK CHASSIS

| Material | Von - Mises Stress (MPa) | Maximum Shear Stress (MPa) | Equivalent Elastic Strain (mm/mm) | Total Deformation (mm) |
|---|---|---|---|---|
| ASTM A710 Steel | 112.76 | 61.54 | 0.972 | 3.045 |
| ASTM A320 Alloy Steel | 114.23 | 62.1 | 0.942 | 3.167 |
| HSLA Steel | 111.3 | 60.3 | 0.369 | 1.17 |
| ISO 1018 Steel | 143.04 | 69.54 | 0.2 | 1.53 |

TABLE IV: FEA RESULTS OF STATIC ANALYSIS FOR PICK-UP TRUCK CHASSIS

| Material | Von - Mises Stress (MPa) | Maximum Shear Stress (MPa) | Equivalent Elastic Strain (mm/mm) | Total Deformation (mm) |
|---|---|---|---|---|
| ASTM A710 Steel | 89.553 | 50.031 | 0.0012804 | 2.4367 |
| ASTM A320 Alloy Steel | 89.713 | 50.015 | 0.001307 | 2.5005 |
| HSLA Steel | 89.589 | 50.031 | 0.00039352 | 0.74988 |
| ISO 1018 Steel | 137.12 | 50.025 | 0.00051352 | 0.97431 |

By comparing the theoretical and FEA results,it was observed that the FEA analysis generated better and much accurate results compared to the theoretical analysis. Finite element analysis effectively utilizes the engineering tools for addressing the conceptualization and formulation for the all design stages. It was observed that HSLA Steel proved to be the best material for the pick-up truck chassis with a maximum deformation of 0.74988 mm under maximum loading condition which is the lowest compared to the deformations shown by the other materials.



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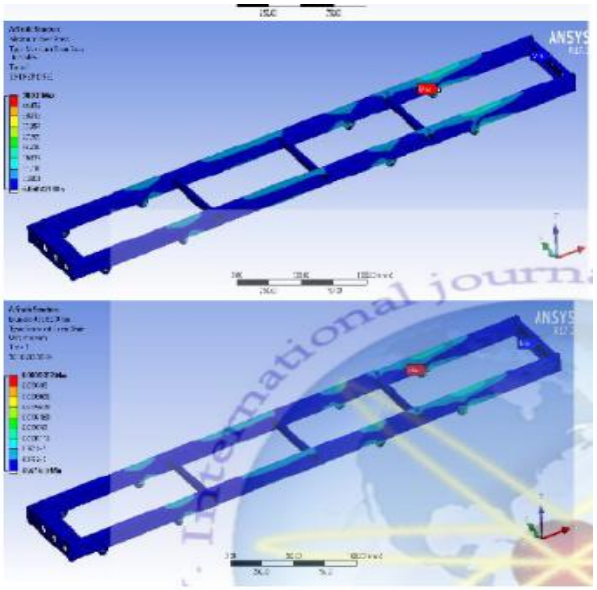


***Fig. 2. From L-R (a) Maximum deformation (b) Maximum Von-Mises Stress (c) Maximum Shear Stress and (d) Equivalent Elastic Strain of the Pick-up Truck chassis for HSLA Steel***

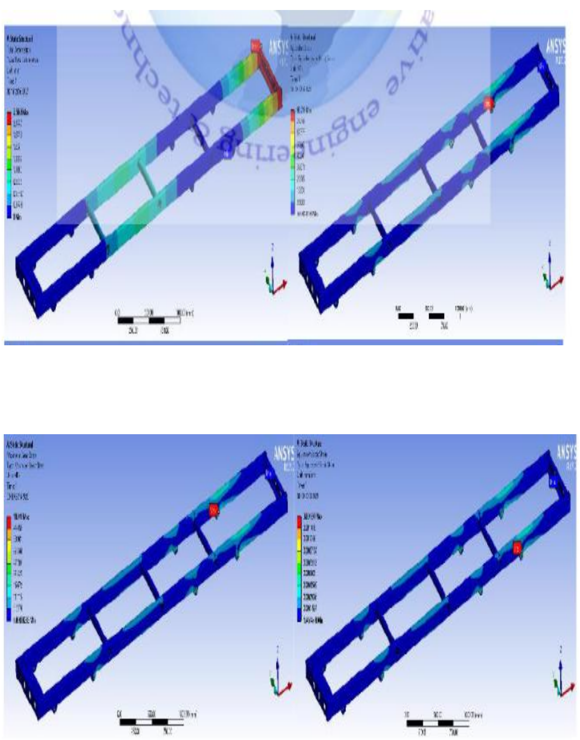


***Fig. 3. From L-R (a) Maximum deformation (b) Maximum Von-Mises Stress (c) Maximum Shear Stress and (d) Equivalent Elastic Strain of the Pick-up Truck chassis for ASTM A302 Alloy Steel***

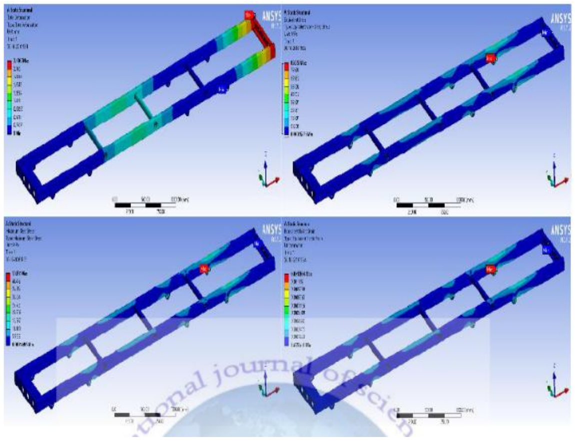

***Fig. 4. From L-R (a) Maximum deformation (b) Maximum Von-Mises Stress (c) Maximum Shear Stress and (d) Equivalent Elastic Strain of the Pick-up Truck chassis for ASTM A710 Steel***

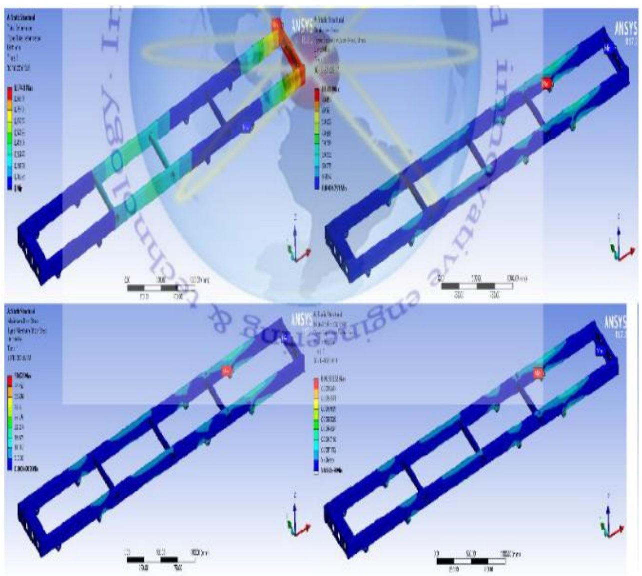

***Fig. 5. From L-R (a) Maximum deformation (b) Maximum Von-Mises Stress (c) Maximum Shear Stress and (d) Equivalent Elastic Strain of the Pick-up Truck chassis for ISO 1018 Steel***

## B. Modal Analysis

Noise and vibration of automobiles are an increasingly important issue in the automobile sector, for implications on both environmental noise pollution and comfort perceived by driver and passengers. Since noise and vibration performances affect the overall image of a vehicle, they are now considered important factors in the entire vehicle design process [14]. The pick-up trucks are sometimes used to carry animals on their loading beds apart from goods. Unlike the driver's cabin, the animals do not experience the same minimized vibrations [15]. Therefore it is essential to analyze these dynamic behaviors occurring due to excitations from engine, transmission and various road profiles since they also affect the dynamics of the pick-up truck. Vehicle dynamics deals with different effects in the vehicle that can be classified in three directions namely vertical, lateral and longitudinal that improves the overall performance of the vehicle in different driving conditions [16]. A basic understanding and knowledge about vehicle structural dynamics is required to find the relationship between the various frequencies and their respective modes in an automotive chassis. Research shows that it is very important to study the natural vibrations of an automobile and the vibrations occurring due to irregular road surfaces as they impose a great effect on the automobile as well as driver and on the loads carried by the vehicle [17]. Due to modernization, the analytical approaches when combined latest computer assisted techniques reduces design cycle time, offers cheap analysis of changes in geometry, material, loading, produces results through simulation, and lastly performs analysisfor product optimization and failure analysis . Conventionally the automotive frame design and validation were based on static analysis and the experience of the design engineer. Due to customer requirements and huge market demands in terms of comfort, convenience and safety, the modal analysis theory has also become more established in the automotive sector, vehicle frame design based on optimization of dynamic characteristics is slowly gaining huge popularity. Thus, FEM has become a robust and highly potential tool for the engineering problems for present day research. In our paper, modal analysis of the chassis was performed to obtain the first ten natural frequencies of the pick-up truck chassis and their respective mode shapes. The most suitable material as per the results of Static Analysis i.e. HSLA Steel was used as the material for modal analysis. The mesh size for the pick-up truck chassis was defined as 10 mm and the brackets which would connect the leaf springs with the chassis was considered as the fixed supports. The various natural frequencies and their respective deformation are given in Table V.

TABLE V: FIRST TEN NATURAL FREQUENCIES OF THE CHASSIS WITH THEIR RESPECTIVE DESCRIPTION AND DEFORMATION

| Mode | Natural Frequency (Hz) | Description | Deformation (mm) |
|---|---|---|---|
| 1 | 64.248 | Translation along Y - axis | 9.2477 |
| 2 | 98.942 | Translation of central portion of frame along Y - axis | 6.6776 |
| 3 | 101.53 | Translation along Z - axis | 10.013 |
| 4 | 145.6 | Twisting motion along X - axis | 11.846 |
| 5 | 197.43 | Translation of central portion of frame along Z - axis | 6.8667 |
| 6 | 211.9 | Twisting motion of central portion of frame along X - axis | 7.2601 |
| 7 | 229.71 | Lateral bending and twisting motion along Y - axis | 6.7823 |
| 8 | 260.88 | Lateral distortion and twisting motion along Y - axis | 9.1869 |
| 9 | 267.98 | Lateral distortion and twisting motion of the central portion of the frame along Y - axis | 8.7709 |
| 10 | 278.79 | Lateral Bending along Y - axis and Twisting motion along Z - axis | 9.6637 |

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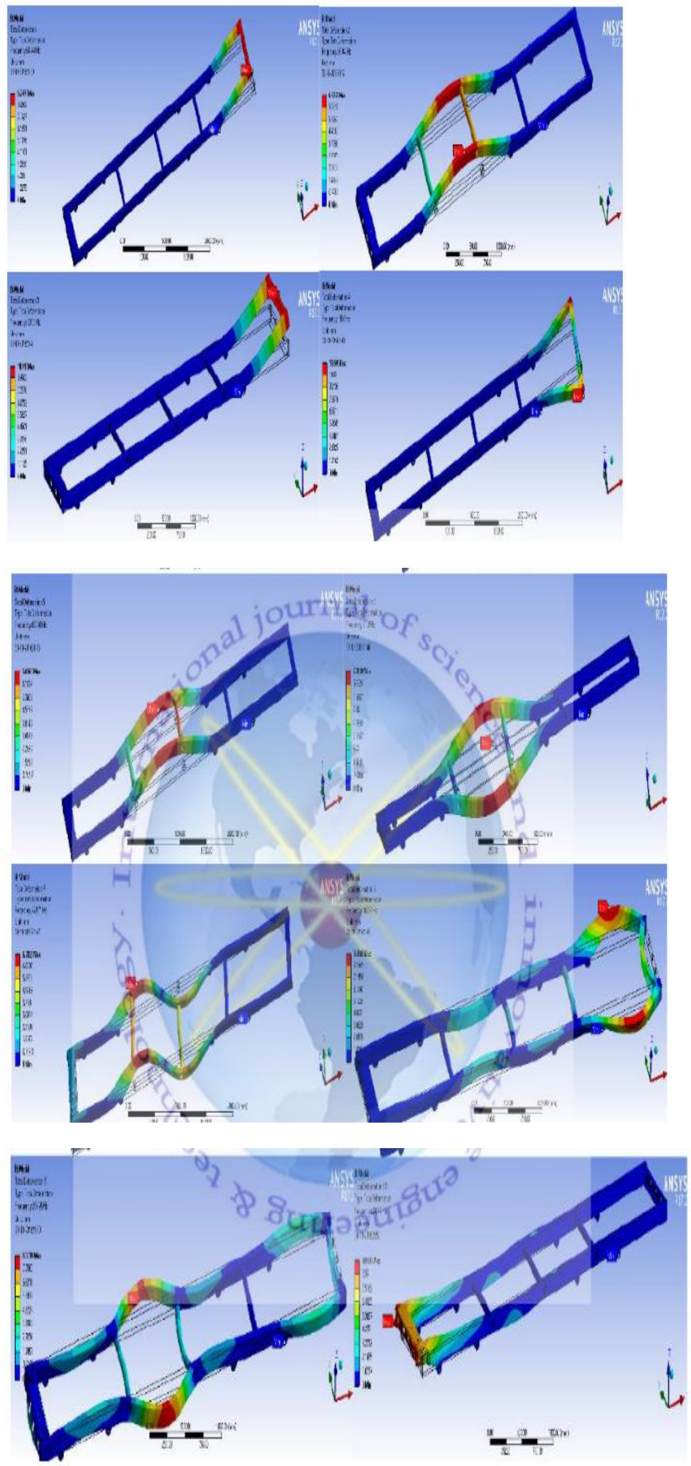

***Fig. 6.From L-R Mode Shapes of the pick-up truckchassis with respect its first ten natural frequencies.***

It can be observed that the natural frequencies of the pick-up truck chassis vary from 64.248 Hz to 278.79 Hz. The natural frequency (145.6 Hz) of the $4^{th}$ mode produces a maximum deformation of 11.846 mm which is the highest compared to all the deformation produced by other frequencies.

**2. Basic Calculation For Chassis Frame**

Model No. = 11.10 (Eicher E2)

Side bar of the chassis are made from “C” Channels with 210mm x 76 mm x 6 mm

Front Overhang (a) = 935 mm

Rear Overhang (c) = 1620 mm

Wheel Base (b) = 3800 mm

Material of the chassis is St 52

E = 2.10 x 105 N / mm2

Poisson Ratio = 0.31

Radius of Gyration R = 210 /2 =105 mm

Capacity of Truck = 8 ton

= 8000 kg

= 78480 N

Capacity of Truck with 1.25% = 98100 N

Weight of the body and engine = 2 ton

= 2000 kg

= 19620 N

Total load acting on chass is

= Capacity of the Chassis + Weight of body and engine

= 98100 + 19620

= 117720 N

Chassis has two beams. So load acting on each beam is half of the Total load acting on the chassis.

Load acting on the single frame = 117720/2

= 58860 N / Beam

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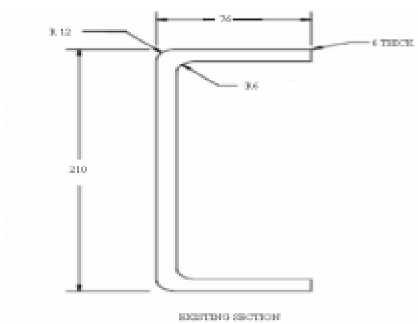
## 2. FE analysis of Existing Chassis Frame

For carrying out the FE Analysis of chassis as per standard procedure first it requires to create merge part for assembly to achieve the connectivity and loading and constraining is required to be applied also idealization of parts is done on structure this will lead to faster analysis since the connected structure will not be physical but it will be a sketch with mechanical properties of mechanical structure. Procedure is followed in this section.

### A. Cross Section of Main Frame

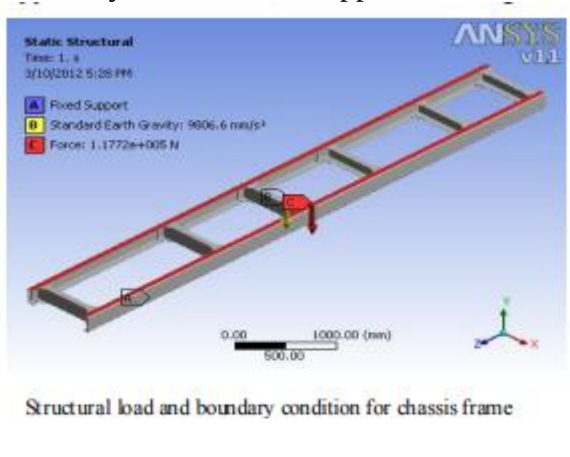
h = 210 mm, b = 76 mm, t = 6 mm




Existing main frame cross section

### B. Loading and Boundary condition

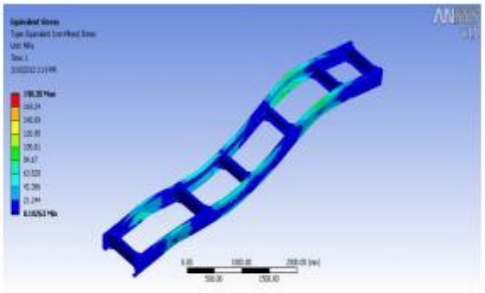
The truck chassis model is loaded by static forces from the truck body and load. For this model, the maximum loaded weight of truck plus body is 10.000 kg. The load is assumed as a uniform distributed obtained from the maximum loaded weight divided by the total length of chassis frame. Detail loading of model is shown in Figure. The magnitude of force on the upper side of chassis is 117720 N. Earth gravity is also considered for the chassis frame as a part of loading. There are 4 boundary conditions of model; the first two boundary conditions are applied in front of the chassis, the second and the third boundary conditions are applied in rear of chassis, there are shown in Figure.



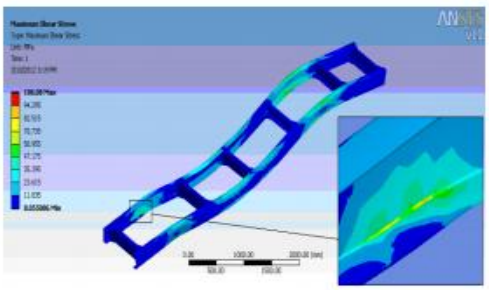

Structural load and boundary condition for chassis frame

**C. Results.**

The location of maximum Von Misses stress and maximum shear stress are at corner of side bar which in Figure. The Von Misses stress magnitude of critical point is 190.38 MPa and the maximum shear stress magnitude is 106.08 MPa.



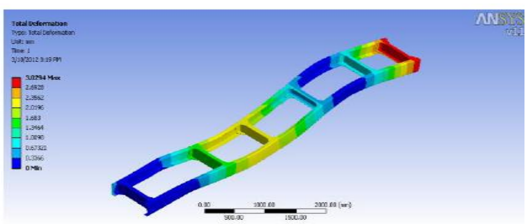
Equivalent stress in chassis frame



Maximum shear stress in chassis frame

**D. Displacement:**

The displacement of chassis and location of maximum displacement is shown in Figure. The magnitude of maximum displacement is 3.0294 mm.



Displacement in chassis frame

## 3. Design Modification for Weight Reduction

### A. Sensitivity analysis:

To analyze the sensitivity of frame web height to the change in thickness and vice-versa for the approximately same section modulus and flange width.

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$$\text{Section modulus } Z = \frac{bh^3 - b_1h_1^3}{6h}$$

$$= \frac{bh^2}{6} - \frac{(b-t)(h-2t)^3}{6h}$$

<< b and t << h so taking b - t =b and h - 2t = h)

$$= \frac{bh^2}{6} - \frac{(b-t)(h-2t)^2}{6}$$

$$\frac{6Z}{b} = h^2 - (h-2t)^2$$

$$K = h^2 - (h-2t)^2$$

Section modulus and flange width being constant K is constant parameter. Taking h as dependent parameter and t as independent parameter.

Differentiate equation the above equation we get,

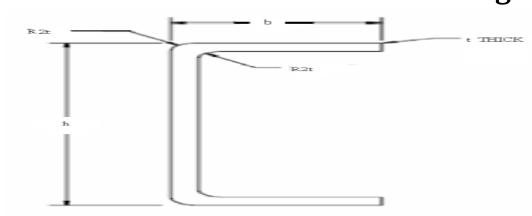
$$h = -t\frac{dh}{dt}$$

This concludes that with increase in web height, thickness of frame can be reduced with this relation an approximate value can be obtained. With increase in web height and decrease in thickness.

By using equation h=-t dh/dt three cases of different cross section are produced.

| Case 1 | Case 2 | Case 3 |
|---|---|---|
| h=227.5 mm | h= 236.25mm | h = 245mm |
| t = 5.5 mm | t = 5.25 mm | t = 5 mm |
| b = 76 mm | b = 76 mm | b = 76 mm |

**B. Modified cross section for the weight reduction:**




Modified cross section of chassis frame

Modification of cross section of chassis frame member is made in three different cases. The inside fillet radius is also increased by 2 times than the thickness of the cross section.

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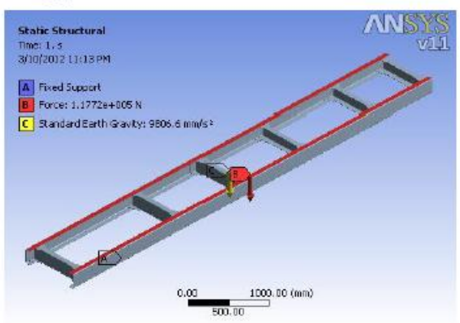
**4. FE analysis of modified cross section**

Case 1 (227.5 mm x 76 mm x 5.5 mm)

**A. Loading and Boundary condition**

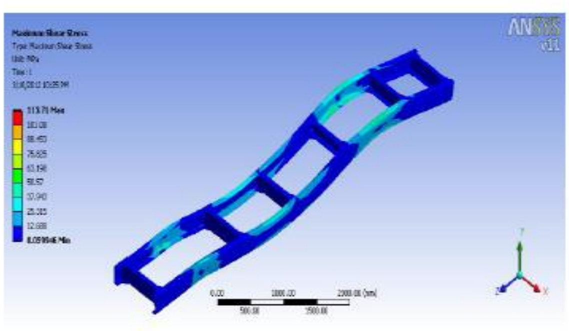
The truck chassis model is loaded by static forces from the truck body and load. For this model, the maximum loaded weight of truck plus body is 10.000 kg. The load is assumed as a uniform distributed obtained from the maximum loaded weight divided by the total length of chassis frame. Detail loading of model is shown in Figure. The magnitude of force on the upper side of chassis is 117720 N. Earth gravity is also considered for the chassis frame as a part of loading.

There are 4 boundary conditions of model; the first two boundary conditions are applied in front of the chassis, the second and the third boundary conditions are applied in rear of chassis, there are shown in Figure.

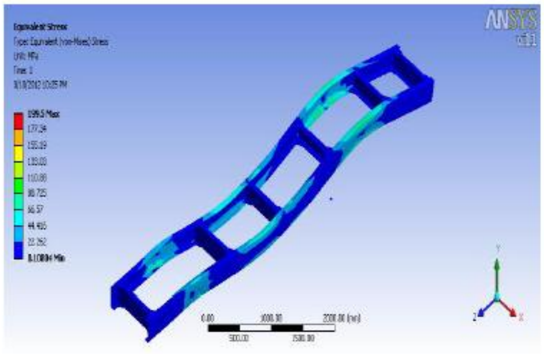



loading and boundary condition of modified chassis frame case1

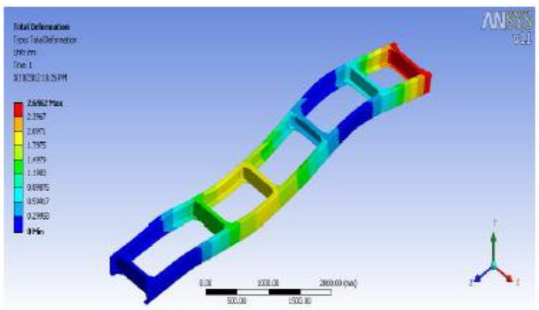
**B. Results**



Maximum shear stress in chassis frame




Equivalent stress in chassis frame

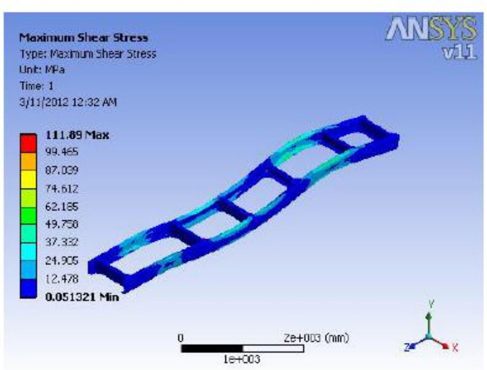



Deformation of modified chassis

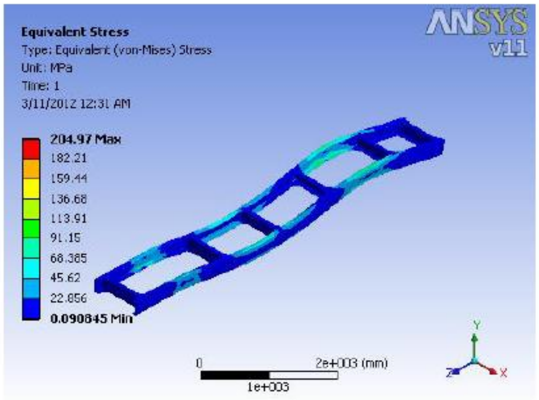
Case 2. Geometry (236.25 mm x 76 mm x 5.25 mm)

Loading and Boundary condition are same as the first case.

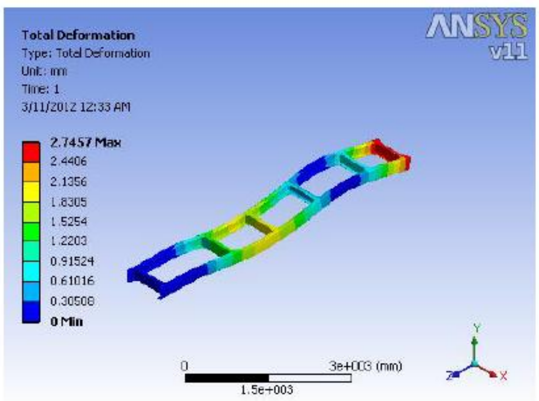
## A. Results




Maximum shear stress in chassis frame




Equivalent stress in chassis frame

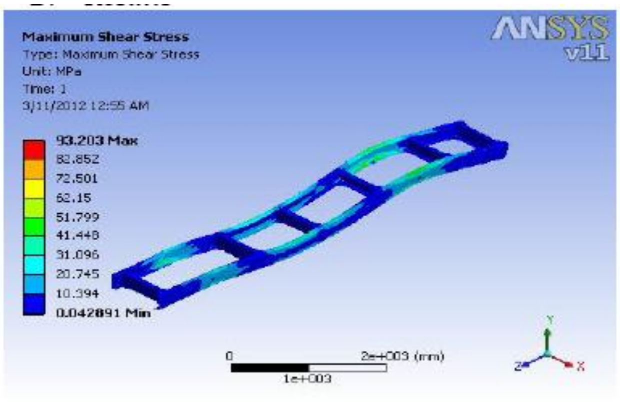



Deformation of modified chassis

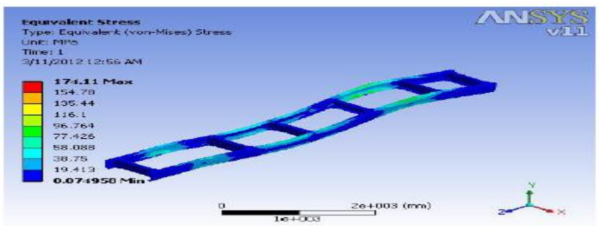
Case 3. Geometry (245 mm x 76 mm x 5 mm)

Loading and Boundary condition are same as the first case.

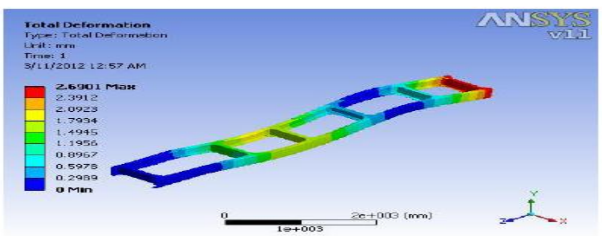
*B. Results*




Maximum shear stress in chassis frame




Equivalent stress in chassis frame




Deformation of modified chassis

## 5. Conclusion

Comparison of the result is shown in the table.

| Sr. No | Section | Chassis Weight (Kg.) | Shear Stress ( MPa) | Max. Displacement ( mm ) | Max Equivalent Stress (MPa) |
|---|---|---|---|---|---|
| 1 | Existing Section | 326.36 | 106.08 | 3.0294 | 190.38 |
| 2 | Case 1 | 318 | 113.71 | 2.6962 | 195.5 |
| 3 | Case 2 | 311.45 | 111.89 | 2.7457 | 204.97 |
| 4 | Case 3 | **304.57** | **93.203** | **2.6901** | **174.11** |

TABLE 1 COMPARISON OF CHASSIS FRAME

From the above result it is clear that the weight is reduced by 6.68 % of the chassis frame. The maximum

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shear stress, maximum equivalent stress and displacement are also reduced respectively 12.14 %, 8.55 % and 11.20 %. It is clear that design is safe. So it is concluded that by using FEM software we can optimize the weight of the chassis frame and it is possible to analyze modified chassis frame before manufacturing.

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