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Structural Analysis of Automotive Chassis Frame and Design Modification for Weight Reduction

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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.

Keywords- Design Optimization, Finite Element Analysis (FEA), Maximum Equivalent Stress, Modal Analysis, Sensitivity Analysis

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I. 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,

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

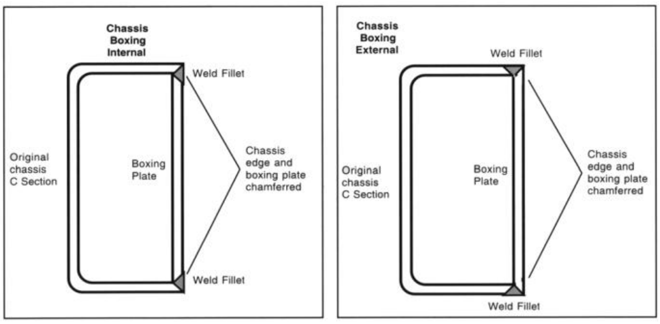

Fig.1 Boxing

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.

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.

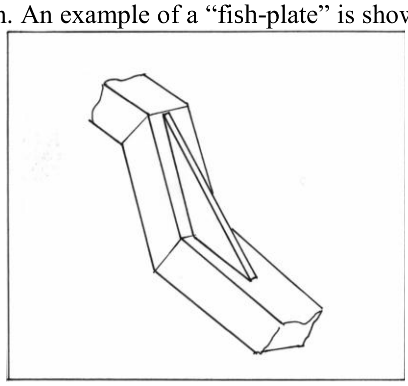

Fig.2 Gusseting

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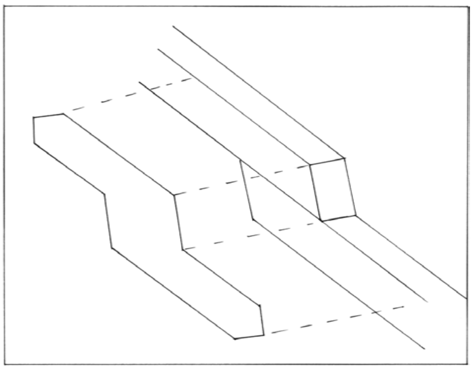

Fig.3 Fish-Plates

IV. SENSITIVITY ANALYSIS

Model = TATA 2515EX Specifications:

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.

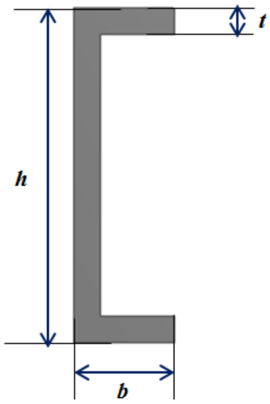

Fig.4 C-Channel

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):

$$Z = \frac{bh^3 - b_1 h}{6h} \qquad (1)$$

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

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

Solving equation 2 we will get,

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

But Z and b are constants,
Assuming,

$$\frac{6Z}{b} = \qquad (4)$$

We will get,

$$K = h^2 - (h - 2t \qquad (5)$$

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

Differentiating the equation 5 we will get,

$$h = -t \qquad (6)$$

This concludes that with increase in web height, thickness of frame can be reduced with this relation an approximate value can be obtained. By using above equation different cross section can be produced. Values obtained for height by varying thickness and keeping width constant. Equation 6 is used for the calculations and

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obtained parameters are shown in Table II. With three cases which are considered for the analysis. [2, 3, 5]

TABLE II
SENSITIVITY ANALYSIS

Sr. No	Section	Height (mm)	Width (mm)	Thickness (mm)
1	Existing Section	285	65	7
2	Case 1	306.92	65	6.5
3	Case 2	328.84	65	6
4	Case 3	350.76	65	5.5

V.STRESS ANALYSIS USING FEM

ANSYS is well known for finite element analysis software suits among mechanical design engineers. It is one of the oldest and pioneers in this field. It has very large user base all over the world and I have been using it for many years. It has friendly solid modeling interface unlike its classic version. It has many advanced features and it has capability to perform different types of analyses – static, dynamic, harmonic, modal, transient, buckling, linear and nonlinear analyses, etc. One of its important features is parametric FEA modeling. A key component of Workbench is that it has been specifically developed to enable parameterization of the entire simulation model, including geometric, material and boundary condition variables. As ANSYS supports native, bi-directional, integration with the most popular CAD systems, the designer can make direct reference to parameters defined when initially creating the solid model. Consequently, a 'simulation-driven product development' strategy can be adopted by the user, where CAD modifications are automatically directed from the results of the simulation. Solid modeling is also possible now days in ANSYS Design Modeler. [1, 4, 5, 6, 8]

E. Solid Modelling

Preparing CAD model of chassis is an important step. ANSYS Design Modeler software tool is used for solid modeling. Solid model of chassis is shown in Fig. 5.

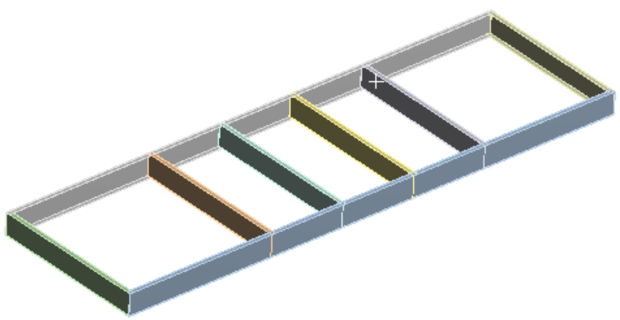

Fig.5 Solid Model

F. Solid Modelling

Analysis of chassis fame is done in ANSYS Workbench 12.1. Whole of the chassis model was made up of C-Channels. Three cases are considered along with existing section for the analysis through sensitivity analysis as shown in Fig. 6. Material used is ASTM low alloy steel a 710 C (Class 3) with 552 Mpa as yield strength.

Note: Sections shown in Fig. 6 are not to the scale.

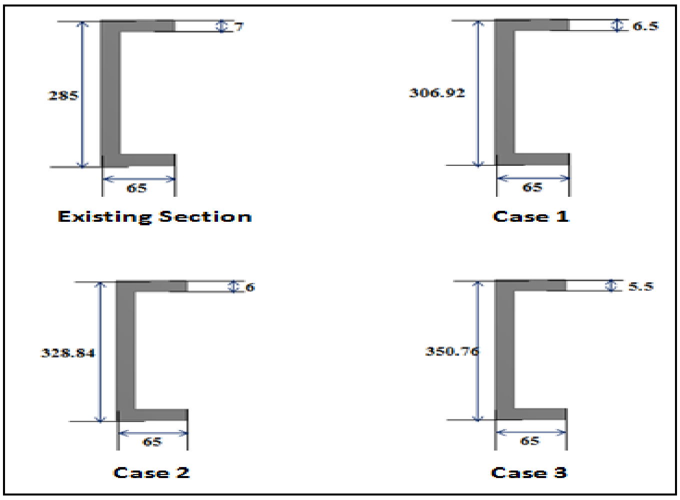

Fig.6 C-Sections

Meshing of the chassis is done in ANSYS Workbench using Solid hexagonal (Solid 186) elements. Mesh model is shown in Fig.7.

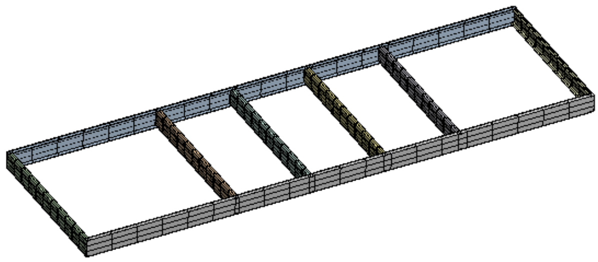

Fig.7 Mesh Model

Total load acting on the chassis is 215820 N. Fig. 8 shows applied load and supports given to the chassis. Standard earth gravity is also considered during the analysis.

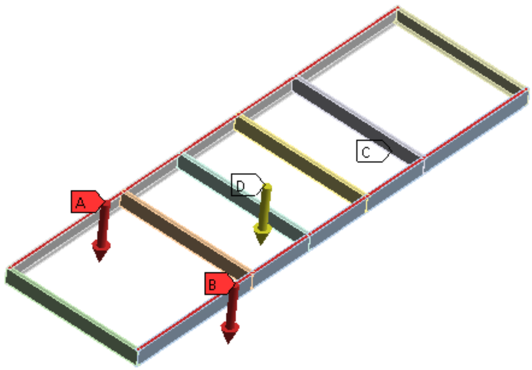

Fig.8 Load Boundary Conditions

Fig. 9 to Fig. 16 shows the equivalent stress and deflection results for the existing section and three optimized case through sensitivity analysis respectively. Table III shows all the results tabulated in it.

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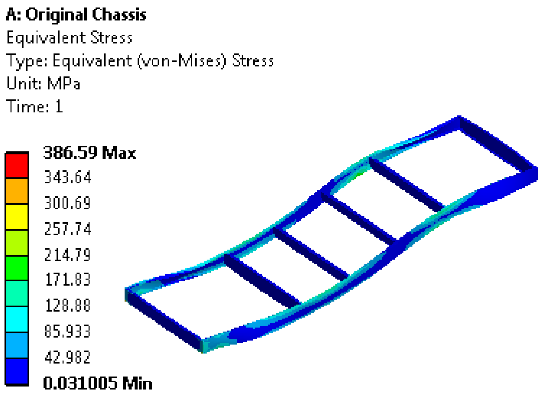

Fig.9 Equivalent Stress (Existing Section)

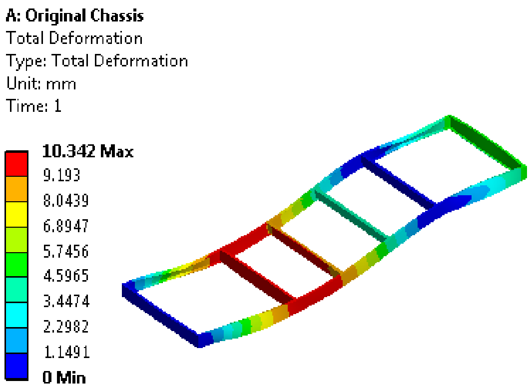

Fig.10 Total Deformation (Existing Section)

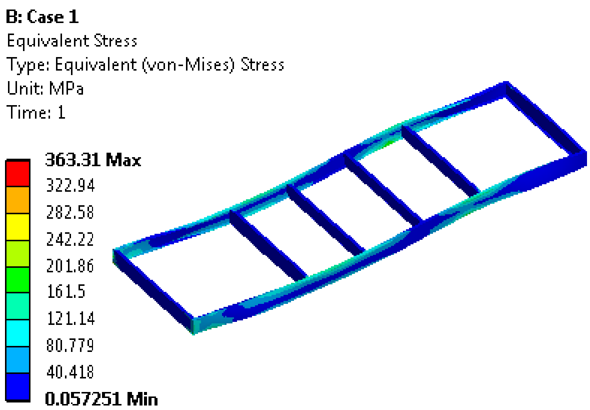

Fig.11 Equivalent Stress (Case 1)

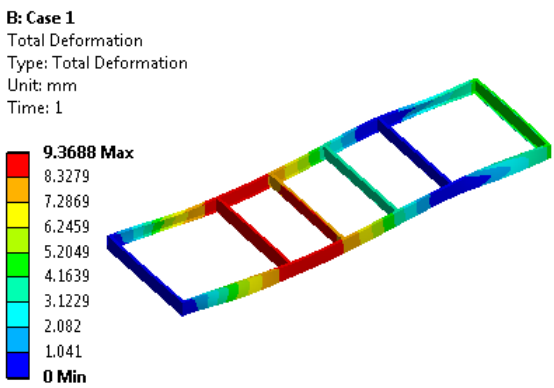

Fig.12 Total Deformation (Case 1)

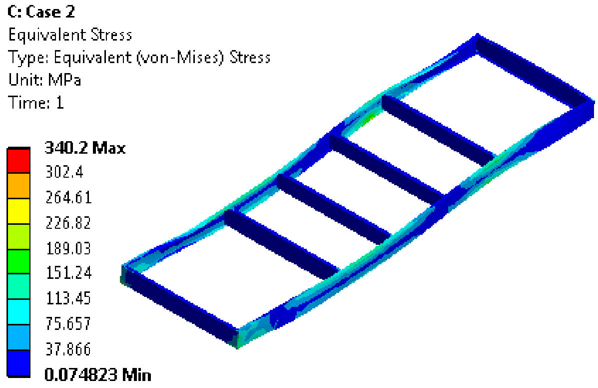

Fig.13 Equivalent Stress (Case 2)

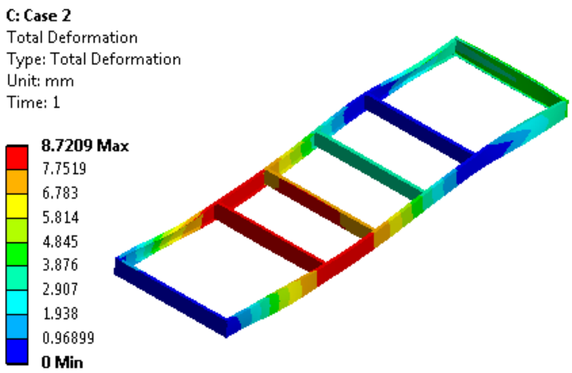

Fig.14 Total Deformation (Case 2)

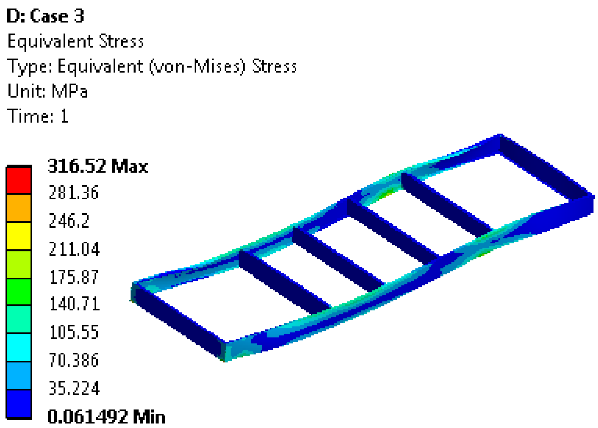

Fig.15 Equivalent Stress (Case 3)

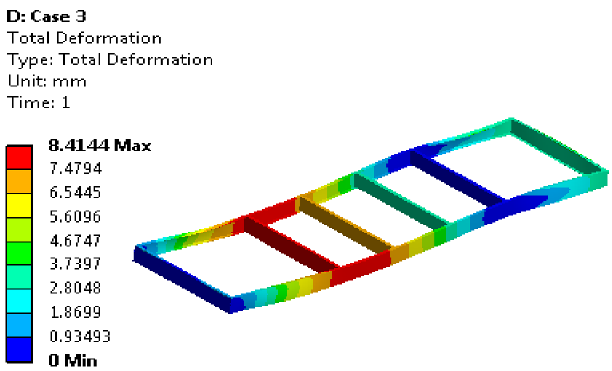

Fig.16 Total Deformation (Case 3)

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Comparison of the result is shown in the Table III.

TABLE III
STRESS ANALYSIS RESULTS

Sr. No	Section	Chassis Weight (Kg.)	Max. Displacement (mm)	Max Equivalent Stress (MPa)
1	Existing Section	670.9	10.3420	386.59
2	Case 1	659.9	9.3688	363.31
3	Case 2	643.2	8.7209	340.20
4	Case 3	**620.9**	**8.4144**	**316.52**

From the above Table III, it is clear that the weight is reduced by 8.06 % of the chassis frame. The maximum equivalent stress and displacement are also reduced respectively 18.13 % and 18.64 %.

So it is concluded that by using FEM software we can optimize the weight of the chassis frame and it is possible to analyse modified chassis frame before manufacturing.

VI.MODEL ANALYSIS

The modal analysis is the most basic and important part of analysis of dynamic character. This modern method used to find the natural frequency and mode shapes of the structures. The rigidity could be analysed and the resonance vibration could be avoided. The main characteristics of each mode of the structure can be figured out through the modal analysis, and the actual vibration response under this frequency range can be predicted. The results from modal analysis can be used as reference value for other dynamic analysis like random analysis, harmonic analysis etc. [8, 9]

G. Mode of Ladder Frame Deflection

The ladder frame chassis is subjected to three load cases: bending, torsion and dynamic loads when the truck is moving along the road. The bending and torsion load is used by the weight of the component and in cases like the truck hit a bump. The dynamic load case comprises of longitudinal and lateral loads during acceleration, braking and cornering. All these loading cases will cause the chassis to deflect. Fig. 17 to Fig. 20 shows the mode of chassis deflection. Strengthening of the ladder frame chassis is needed to reduce the effect of these deflections.

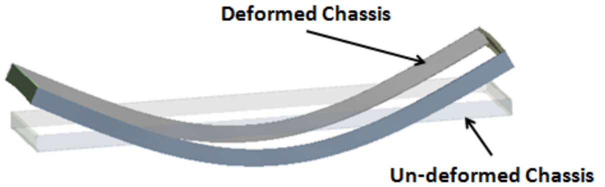

Fig.17 Equivalent Stress (Case 2)

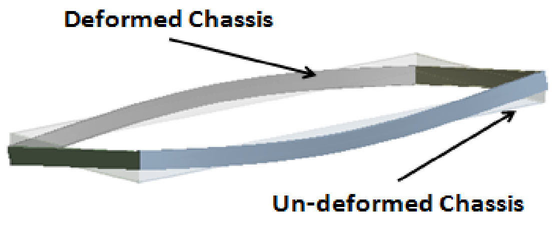

Fig.18 Total Deformation (Case 2)

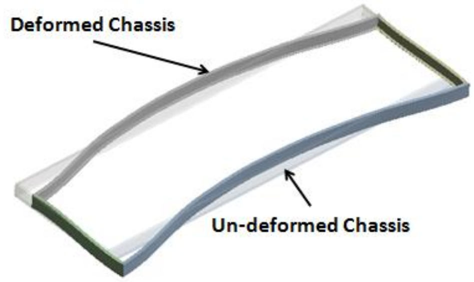

Fig.19 Equivalent Stress (Case 3)

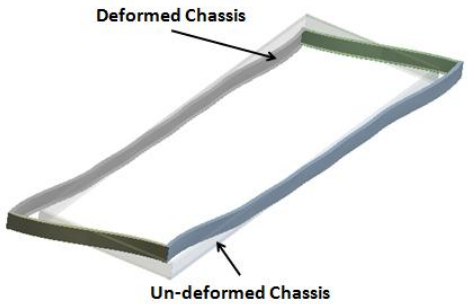

Fig.20 Total Deformation (Case 3)

In this work, 3-D FE analysis is carried out on the modal analysis of chassis frame. ANSYS Workbench was used to simulate the modal analysis. The results of natural frequencies and mode shape were obtained. The first 3 natural frequencies of a structural frame are extracted. The first, second and third modes are shown in below figures for existing chassis as well as modified chassis. Each natural frequency of respective mode shapes is listed in the Table IV. If any one of the natural frequency matches with excitation frequency the frame doesn't satisfies the dynamic characteristics.

It is observed that all the natural frequencies 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. Normally, the operating frequency is always related to dynamic forces induced by road roughness, bumps, engine, transmission and many more. Each of these forces has its own excitation frequency.

It has been reported that the operating frequency varies from 10-80 Hz for the engine, excitation from the transmission system, road excitation and many others. For the long distance traveling, the excitation frequencies were approximately 51-53 Hz. Thus, by comparing these excitation frequencies to the result, the chassis frequencies are away from the operating frequencies and there will be any resonance. From frequencies modified chassis design looks safe. It should be noted that these natural frequencies

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were for free-free boundary condition. In real situation, the chassis were pin supported at some points. However, such different only shifted the natural frequency at very small percentage.

There are two types of vibration, which are global and local vibrations. The global vibration means that the whole chassis structure is vibrating while local vibration means the vibration is localized and only part of the truck chassis is vibrating.

Fig. 21 to Fig. 32 shows the mode shapes of the truck chassis. The chassis experienced first and second bending mode in existing as well as modified designs where as third mode is bending plus twisting. All the modes falls under global vibration as the whole chassis follow to vibrate.

Please note that in modal analysis we only look towards the natural frequencies and mode shapes. Deformations are not the output of modal analysis as there deformations are not realistic and shown at exaggerated scale to understand the mode shapes.

One should not look after deformations in modal analysis, check only frequencies and mode shapes.

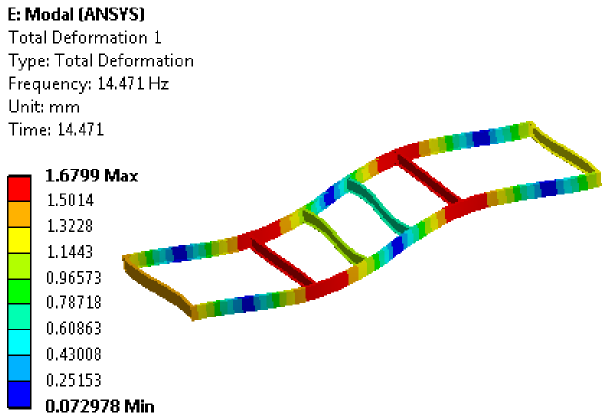

Fig.21 Mode 1 (Existing Chassis)

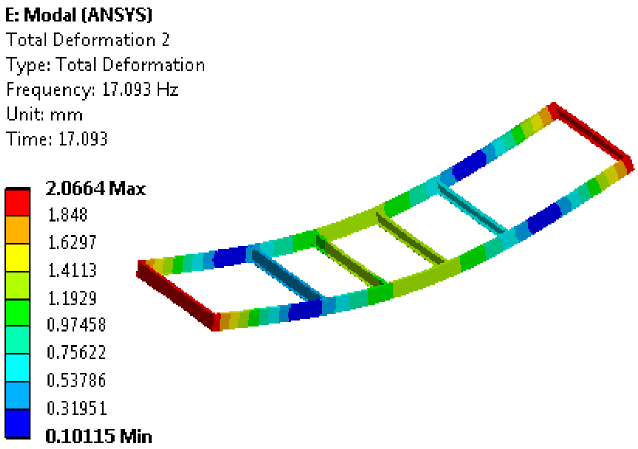

Fig.22 Mode 2 (Existing Chassis)

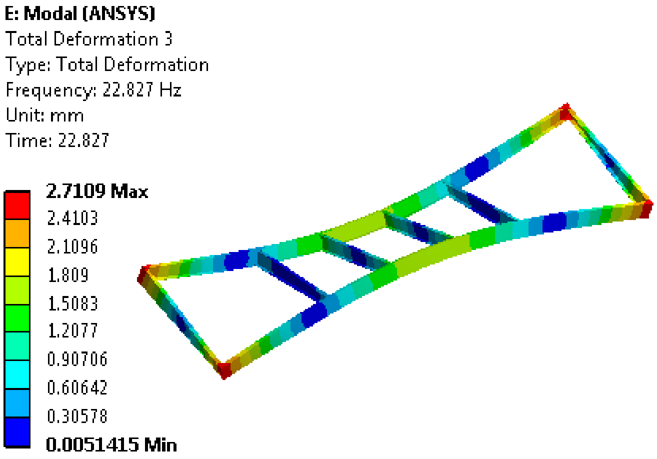

Fig.23 Mode 3 (Existing Chassis)

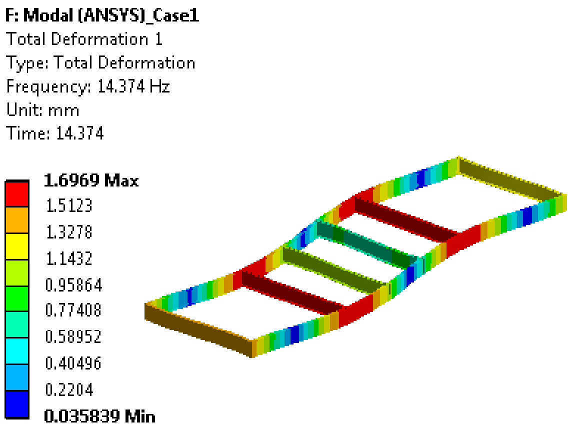

Fig.24 Mode 1 (Case 1)

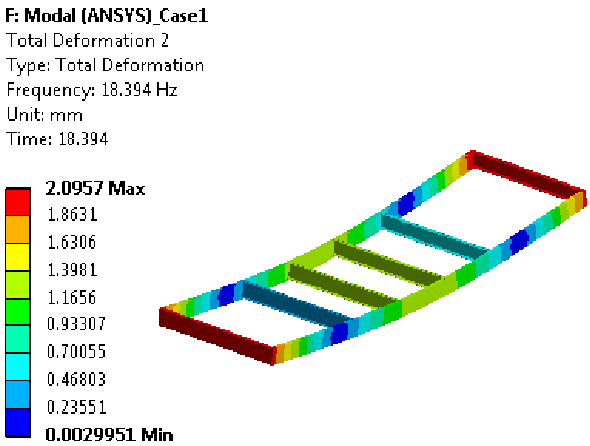

Fig.25 Mode 2 (Case 1)

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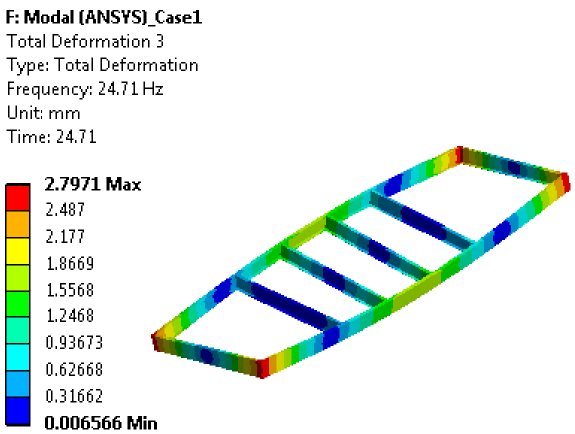

Fig.26 Mode 3 (Case 1)

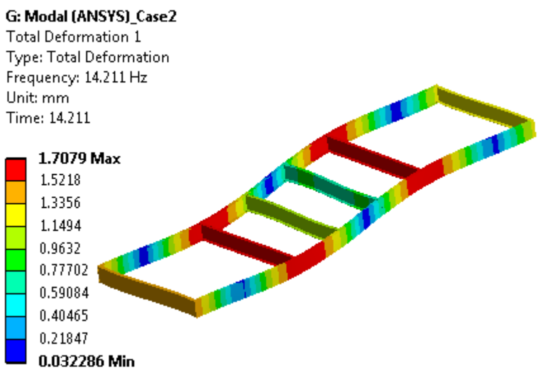

Fig.27 Mode 1 (Case 2)

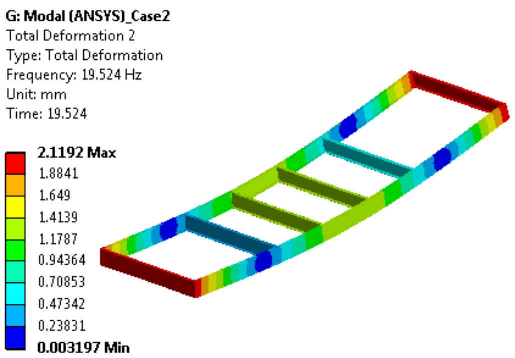

Fig.28 Mode 2 (Case 2)

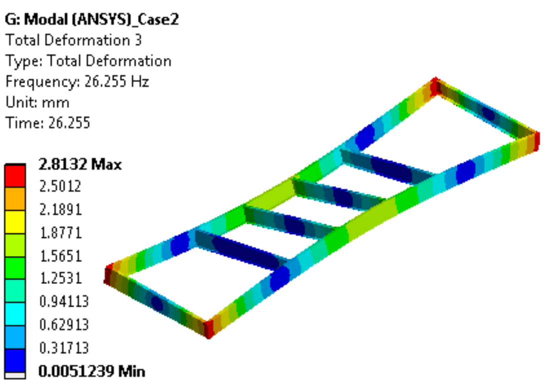

Fig.29 Mode 3 (Case 2)

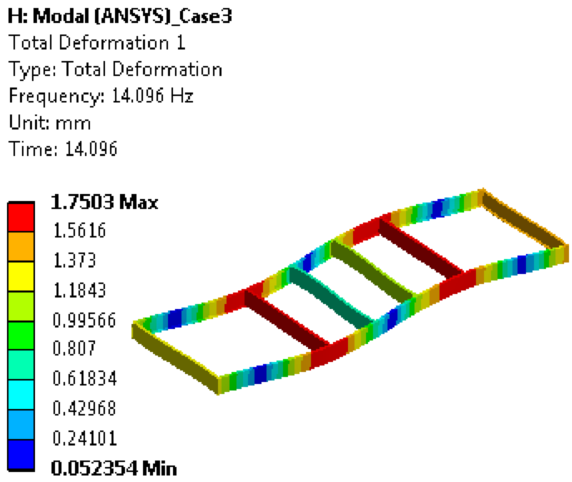

Fig.30 Mode 1 (Case 3)

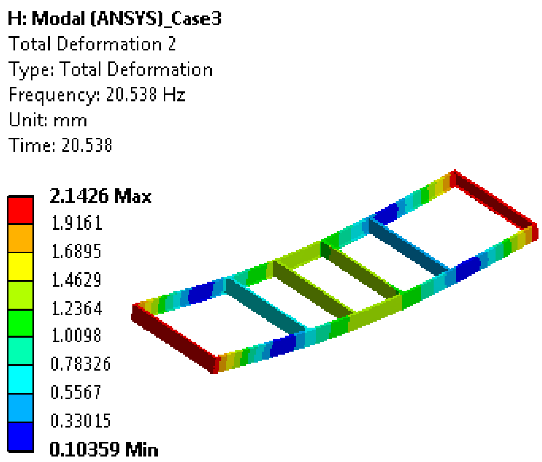

Fig.31 Mode 2 (Case 3)

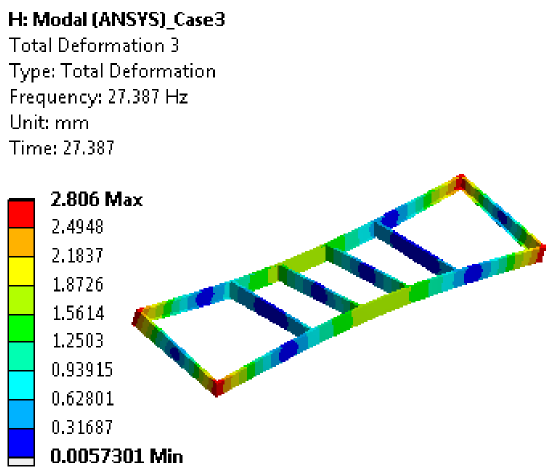

Fig.32 Mode 3 (Case 3)

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TABLE IV
MODAL ANALYSIS RESULTS

Sr. No	Section	Natural Frequency (Hz's)		
		Mode 1	Mode 2	Mode 3
1	Existing Chassis	14.471	17.093	22.827
2	Case 1	14.374	18.394	24.71
3	Case 2	14.211	19.524	26.255
4	Case 3	**14.096**	**20.538**	**27.387**

VII.CONCLUSION

Automotive chassis is considered to be one of the significant structures of an automobile. It is usually made of a steel frame, which holds the body and motor of an automotive vehicle. More precisely, automotive chassis or automobile chassis is a skeletal frame on which various mechanical parts like engine, tires, axle assemblies; brakes, steering etc are bolted. At the time of manufacturing, the body of a vehicle is flexibly moulded according to the structure of chassis. Automobile chassis is usually made of light sheet metal.

It provides strength needed for supporting vehicular components and payload placed upon it. Automotive chassis or automobile chassis helps keep an automobile rigid, stiff and unbending. Auto chassis ensures low levels of noise, vibrations and harshness throughout the automobile.

By using FEM software we can optimize the weight of the chassis frame and it is possible to analyze modified chassis frame before manufacturing. With increase in web height, thickness of frame can be reduced with this relation an approximate value can be obtained. Weight of the chassis is reduced by 8.06 % of the chassis frame. The maximum equivalent stress and displacement are also reduced respectively 18.13 % and 18.64 %.

Finally the natural frequency and corresponding vibration modes of existing as well as modified chassis are found by modal analysis. It is observed that all the modes are away from operating natural frequencies and there will not be any resonance. So modifies designs are safe.

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