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Design and Stress Analysis of Heavy Commercial Vehicle Ladder Chassis by Finite Element Method using ANSYS

[1] Sivaramapandian J, [2] Vikram H, [3] Sreesakthivel K
[1][2][3] Department of Mechanical Engineering, Sri Venkateswara College of Engineering, India.

Abstract: **Automotive chassis frame is most crucial element that gives strength, stability and is the structural backbone of any vehicle whose role to provide skeletal frame to which the body of an engine, axle assemblies are affixed. The chassis frame must be rigid enough to withstand the stresses, shocks and deformation occurring and its main function is to carry the maximum load for all designed operating conditions with safety in mind. Considering the fact that in India commercial vehicles carry non-uniform loads, that leads to the failure possibilities in the chassis frame. An important consideration in chassis design is to have adequate bending stiffness along with strength for better handling characteristics. Therefore, maximum shear stress, stiffness and deflection are important criteria for the chassis design. After a careful analysis of various research studies conducted so for it has been found that sufficient studies have not been conducted on variable section chassis concept. This paper emphasises on design modification in the Section of a frame and comparison of structural analysis of those sections and conventional type frame for higher strength. In this research work, we authors have adopted the dimensions of an existing heavy vehicle frame for conceptual structural changes through modelling and analysis with the help of ANSYS software.**

Index Terms— Ansys, Automotive Chassis, Computer Aided Design, FEA, FME, Modeling, Structural Stiffness.

INTRODUCTION

Automotive chassis is a French word that was initially used to represent the basic structure. It is the supporting frame like backbone of any automobile to which the body of an engine, axle assembles are affixed. Tie bars, which are essential parts of frames, are fasteners that bind different automotive components together [7]. Automotive chassis gives strength and stability to the vehicle under different conditions. At the time of manufacturing the body of the vehicle is flexibly moulded according to the structure of chassis [2]. Automobile chassis is usually made of light sheet metal or composite plastics. Frames provide strength as well as flexibility to the automobiles. Also, it provides strength to withstand payload placed over it. Automobile chassis can be classified into Ladder, Monocoque and Backbone chassis [1].

A. Ladder Chassis

Ladder chassis is one of the oldest forms of automotive chassis which are still used in most of the SUVs today. It is clear from its name that ladder chassis resembles a shape of a ladder having two longitudinal rails inter linked by lateral and cross braces [9].

B. Monocoque Chassis

Monocoque Chassis is a one-piece structure which is the overall shape of a vehicle. Such type of automobile chassis is manufactured by welding floor pan and other pieces together. Therefore, monocoque chassis is cost effective and suitable for robotised production. Nowadays most of the vehicles make use of steel plated monocoque chassis [6].

C. Backbone Chassis

Backbone chassis is a rectangular tube type chassis, which is usually made up of glass fibre used for joining front and rear axle together. This type of automobile chassis is strong and powerful enough to provide support for smaller sports car and is easy to manufacture and cost effective [9].

II. PROBLEM DESCRIPTION

The chassis used for study has a narrow body with a gross weight of 4.5 tons and a pay load of 2500kg. It consists of 2 C-channel side rails and have 5 cross members like flat and gusset brackets at the joint between side rails and cross members to strengthen the joints. Towards the middle is a top hat cross member to provide space for mounting of the gear box. The final cross member is C - channel and top hat member. These are located exactly, where the rear suspension is mounted. It is to strengthen the chassis frame as the suspension mounting point is highly stressed area. The material of chassis is AISI 4130 alloy with quenching and tempering treatment.

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The chassis is usually loaded by static, dynamic and cyclic loading. The existing truck chassis is designed based on static analysis. In this study, we have constructed a new cross-section "X" frame for the chassis [8]. We have also compared both conventional frame with the new cross section for various stress and load analysis using FEA method with the help of ANSYS software.

III. METHODOLOGY

Design may be done in two ways. One way is the component design which is done by improving the existing ones. The other is conceptual design where there is no reference and creation of new machines. Initially, the drawings must be drawn in user friendly software and they must be converted into a 3D model. This 3D model must be imported into an analyzing medium where it is structurally or thermally analyzed to sustain the need. Different steps involved in designing a component are Part Drawing, Modeling and structural analysis [5].

A. Part Drawing

It is a document that includes the specifications for a part's production. The part drawings are drawn to have a clear idea of the model to be produced. The part drawing of the entire frame is drawn with all the views in AUTO CAD 2016.

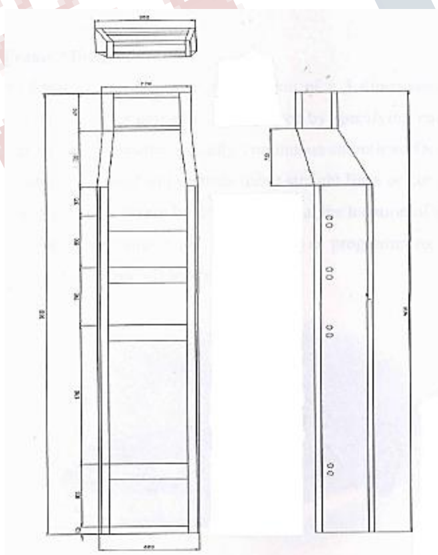


Fig. 1 Part Drawing

A solid model of an object is a more complete representation than its surface (wireframe) model. It provides more topological information in addition to the geometrical information which helps to represent the solid unambiguously. In this project the frame is modeled by using CREO 3.0. All the parts that are required for constructing the frame are modeled in part module and assembled.

B. Structural Steel

It is steel construction material, a profile, formed with a specific shape or cross section and certain s tandards of chemical composition and mechanical properties. Composition 0.565% C, 1.8% Si, 0.7% Mn. 0.045% P and 0.045% S.

C. Mass of Reference

The mass of an object is a fundamental property of the object, a numerical measure of its inertia, a fundamental measure of the amount of matter in the object. Mathematical equation for mass is Mass = Volume x Density. We know, Density of steel = 7850kg/m3; Volume of frame = 4.9104x10-2 m3; Total mass of frame = 7850 x 0.049104 = 385.46 kg.

D. Stress Developed in Frame

The value should not exceed the yield strength of the material. In some of the situations design is safe if its value is less than the yield strength of the material. The normal stress distribution in the frame for structural steel is as shown in Fig. 3. Hence, can be inferred that Maximum normal stress = 3359 Mpa Minimum normal stress = - 6317 Mpa.

Table I: Dimensional specification of Reference Chassis

S no.	Description	Dimensions (mm)
1	Wheel base	3600
2	Front track	1800
3	Rear track	1690
4	Overall length of vehicle with load body	6600
5	Max. Width	2270
6	Frame length	5620

Table II: Physical Properties of Chassis

S No.	Description	Weight (Kg)
1	Max.Permissible Faw	7950
2	Max.Permissible Raw	3950
3	Max.Permissible Gvm	11900
4	Passing Payload for Cab Load Body	8315

IV. PROPERTIES AND FEA ELEMENT DETAILS

The properties of the material are listed below:

Table III : Material Properties

Properties	
Name:	Alloy Steel
Model type:	Linear Elastic
Default failure criterion:	Isotropic Max von Mises Stress
Yield strength:	$6.20422e^{8}$ N/m^2
Tensile strength:	$7.23826e^{8}$ N/m^2
Elastic modulus:	$2.1e^{11}$ N/m^2
Poisson's ratio:	0.28
Shear modulus:	$7.9e^{10}$ N/m^2
Thermal expansion coefficient:	$1.3e^{-5}$ K

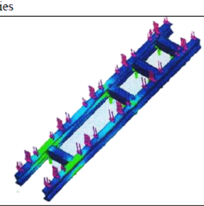


Table IV: Mesh Details

Mesh type	Solid Mesh	Total Nodes	49190
Mesh Used:	Standard mesh	Total Elements	25532
Automatic Transition:	Off	Maximum Aspect Ratio	51.926
Include Mesh Auto Loops:	Off	% of elements with Aspect ratio < 3	0.302
Jacobian points	4 Points	% of elements with Aspect Ratio > 10	2.58
Element Size	47.6229 mm	% of distorted elements(Jacobian)	0
Tolerance	2.38114 mm	Time to complete (hh:mm: ss)	00:32:00

V. FINITE ELEMENT ANALYSIS OF TRUCK CHASSIS

The finite element method (FEM) is a computational technique used to obtain approximate solutions of boundary value problems in engineering. Simply stated, a boundary value problem is a mathematical problem in which one or more dependent variables must satisfy a differential equation everywhere within a known domain of independent variables and satisfy specific conditions on the boundary of the domain. This process results in a set of simultaneous algebraic equations. In stress analysis, these equations are equilibrium equations of the nodes. There may be several hundred or several thousand such equations, which mean that computer implementation is mandatory [3].

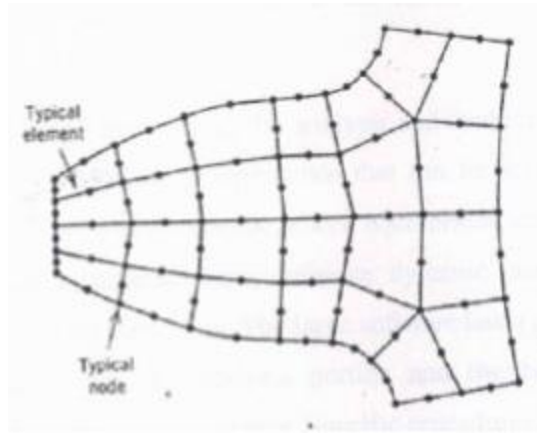


Fig. 2 FEA Element

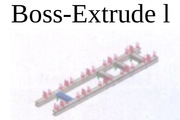
A. General Procedure For FEA

There are certain common steps in formulating a finite element analysis of physical problem, whether structural, fluid flow, heat transfer and some others problem. There are three main steps, namely: pre-processing, solution and postprocessing. This step includes: define the geometric domain of the problem, the element type(s) to be used the material properties of the elements, the geometric properties of the elements (length, area, and the like), the element connectivity mesh the model), the physical constraints (boundary conditions) and the loadings. The final step is postprocessing, the analysis and evaluation of the result is conducted.

B. Static Analysis

A Static Structural analysis control the stresses, strains, displacements and forces that act in components caused by load that do not induce significant inertia and damping effects. A static analysis computes the effects, such as those caused by time –varying loads. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary gradually with respect to time. A static structural load is performed using softwares like ANSYS software.

Table V: Analysis Report

Document Name and Reference	Treated As	Volumetric Properties
Boss-Extrude 1 	**Solid Body**	Mass:29.3216 kg Volume:0.003808 m^3 Density:7700 kg/m^3 Weight:287.352 N

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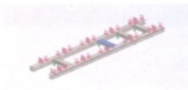
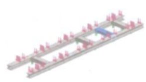
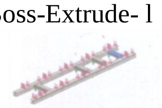
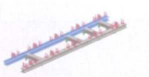
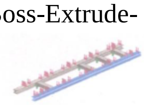
Boss-Extrude- l 	**Solid Body**	Mass:29.3216 kg Volume:0.003808 m3 Density:7700 kg/m3 Weight:287.352 N
Boss-Extrude- l 	**Solid Body**	Mass:29.3216 kg Volume:0.003808 m3 Density:7700 kg/m3 Weight:287.352 N
Boss-Extrude- l 	**Solid Body**	Mass:29.3216 kg Volume:0.003808 m3 Density:7700 kg/m3 Weight:287.352 N
Boss-Extrude- l 	**Solid Body**	Mass:217.931 kg Volume:0.0283028 m3 Density:7700 kg/m3 Weight:2135.73 N
Boss-Extrude- l 	**Solid Body**	Mass:217.931 kg Volume:0.0283028 m3 Density:7700 kg/m3 Weight:2135.73 N

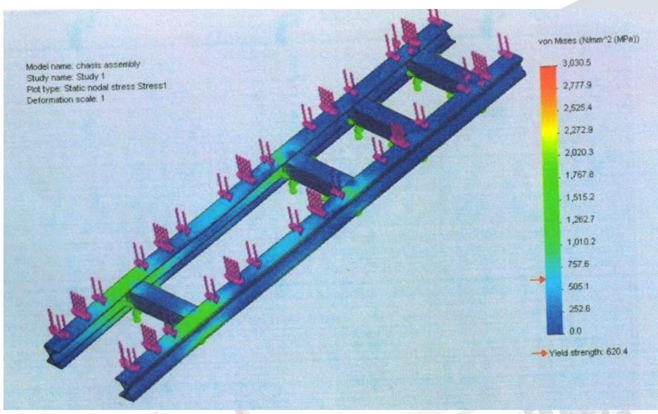


Fig. 3 Stress on "X" c/s type ladder chassis

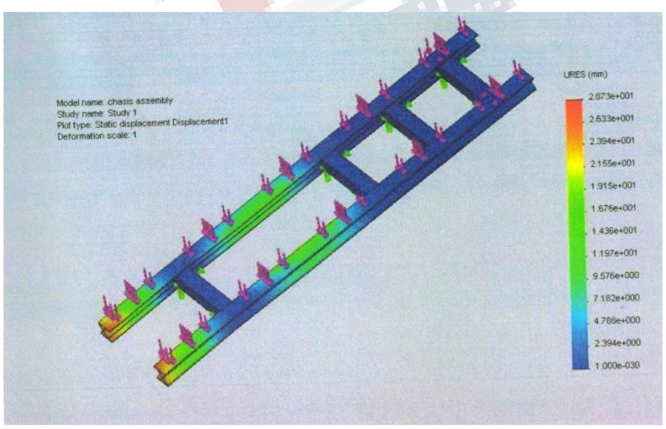


Fig. 4 Displacement on "X" c/s type chassis

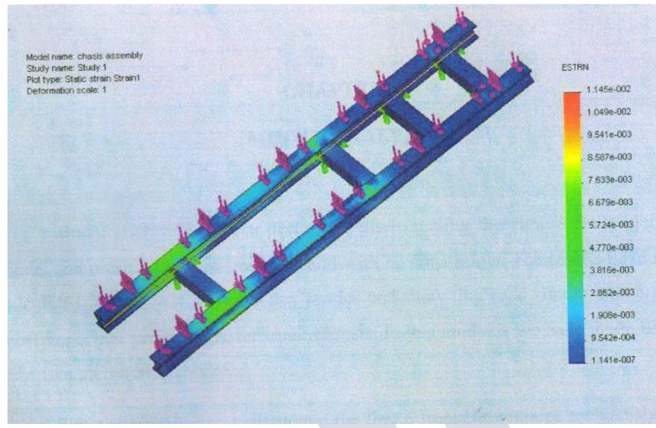


Fig. 5 Strain on "X" c/s type ladder chassis

VI. MODAL ANALYSIS

Modal analysis has been performed after creating the chassis finite element model and meshing in free-free state and with no constraints. The results have been calculated for the first 30 frequency modes and show that road simulations are the most important problematic for truck chassis. In this analysis, we have made use of subspace method in ANSYS. Since chassis has no constraints; the first 6 frequency modes are vanished. 3 modes are related to the chassis displacement in x, y and z directions and3 modes are related to chassis rotation about x, y and z axes. In Fig. 4 related natural frequencies and mode shapes for chassis with maximum displacement in y direction in each mode, have been shown.

The first, second and sixth modes are the global vibrations, while the others are local vibrations. Local vibration starts at the third mode at 10.661 Hz. The dominant mode is a torsion which occurred at 7.219Hz with maximum translation experienced by both ends of the chassis.

The second mode is a vertical bending at 7.49 Hz. At this mode, the maximum translation is at the front part of the chassis. The third and fourth modes are localized bending modes at 29.612 Hz and 33.517 Hz. The maximum translation is experienced by the top hat cross member.

The member also experienced big translation at fifth mode which is a localized torsion mode. The top hat cross member is the mounting location of the truck gear box. The sixth mode is the torsion mode at 38.475 Hz with maximum translation at both ends of the chassis. Found natural frequencies from modal analysis of truck chassis, are used for determining the suitable situations for truck parts in working conditions.

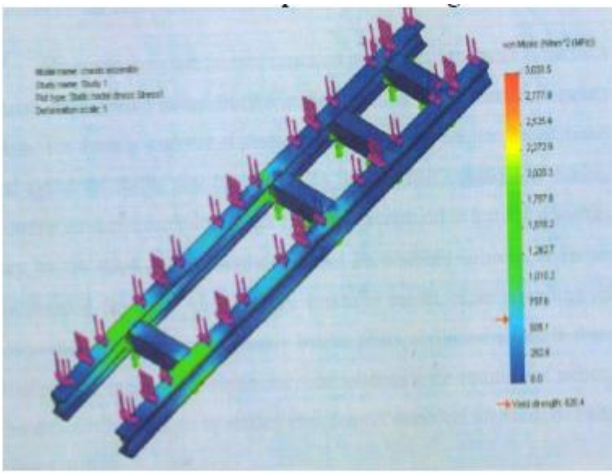


Fig. 6. Nodal Analysis

VII. STRESS – STRAIN ANALYSIS

Stress—Strain analysis (or stress analysis) is an engineering discipline covering methods to determine the stresses and strains in materials and structures subjected to forces or loads By Newton's laws of motion, any external forces that act on a system must be balanced by internal reaction forces, or cause the particles in the affected part to accelerate. In a solid object, all particles must move substantially in concert to maintain the object's overall shape. It follows that any force applied to one part of a solid object must give rise to internal reaction forces that propagate from particle to particle throughout an extended part of the system. With very rare exceptions (such as ferromagnetic materials or planet-scale bodies), internal forces are due to very short range intermolecular interactions, and are therefore manifested as surface contact forces between adjacent particles that is, as stress.

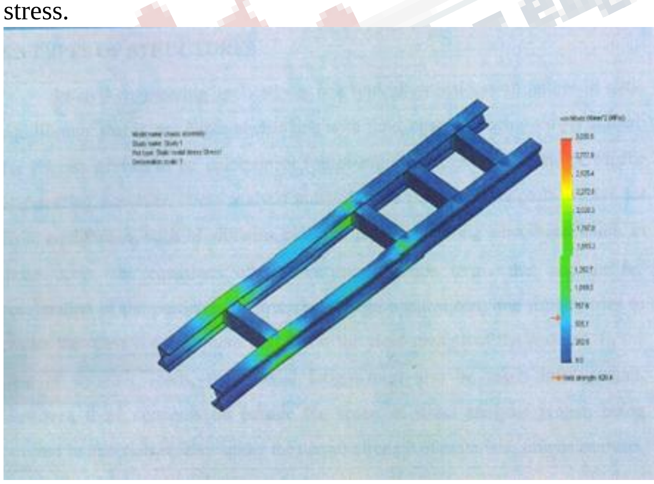


Fig. 7 Stress Analysis

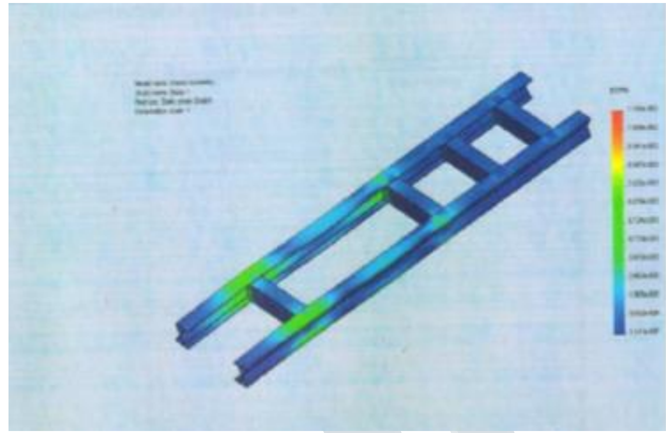


Fig. 8 Strain Analysis

CONCLUSION

From this study, we have observed that the (Intermediate) section has enough strength to withstand load more than that of conventional steel alloy chassis with “C” section. The (Intermediate)”X” section is having least deflection i.e., 1.84mm in all chassis of different cross-section. Finite element analysis is effectively utilized for addressing the conceptualization and formulation for design stages. The results obtained were quite favourable which was expected. The following results were achieved. The “X” cross sectional frame is safe under the given loading condition. To improve performance of the conventional design, geometry has been modified and analysed which enabled to reduce stress level marginally well below the yield limit.

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