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Static and Modal analysis of heavy duty vehicle chassis

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ABSTRACT

Chassis is an important part of an vehicle which serves as a frame work for supporting the body and different parts of the automobile, it should be rigid enough to withstand the shock, twist, vibration and other stresses & its function is to carry the maximum load for all designed operating condition safely.This paper discusses the stress and modal analysis of heavy duty truck ladder chassis with and without crack. The presence of cracks in a structural member, causes local variations in stiffness, the magnitude of which mainly depends on the location and depth of the cracks. The presence of cracks causes changes in the physical properties of a structure. At the first stage, in order to design a chassis for self-weight reduction, material type and cross section profiles of chassis are selected according to a maximum normal stress and maximum strain. The structural chassis frame is modelled using CATIA V5R18 software. Then, the stress analysis of truck chassis has been carried out by LS DYNA software to determine maximum transverse deflection and stress distribution. In the next stage, the prediction of the vibrational properties of the chassis which is of great significance in determining the natural frequencies of the structure, are considered. For this purpose, the modal analysis has been accomplished by the finite element packaged LS DYNA software, and natural frequencies and mode shapes have been determined. In the final stage, the natural frequency of chassis with crack, is investigated. The results are compared with that of the chassis without crack. The results obtained from the vibration analysis of the chassis will show that the lowest fundamental frequency of the chassis without crack is higher than the lowest frequency obtained with cracks.

Keywords— Ladder Chassis Frame, Crack, LS DYNA, Static analysis, vibration analysis.

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I. INTRODUCTION

Transportation industry plays a major role in the economy of modern industrialized and developing countries. The total and relative volume of goods carried on heavy trucks is dramatically increasing. Automotive chassis is a skeletal frame on which various mechanical parts like engine, tires, axle assemblies, brakes, steering etc. are bolted. The chassis is considered to be the most significant component of an automobile. It is the most crucial element that gives strength and stability to the vehicle under different conditions. Automobile frames provide strength and flexibility to the automobile.

The backbone of any automobile, it is the supporting frame to which the body of an engine, axle assemblies are affixed. Tie bars, that are essential parts of automotive frames, are fasteners that bind different auto parts together [11]. The chassis structure must safely support the weight of the vehicle components and transmit loads that result from longitudinal, lateral, and vertical accelerations that are experienced in a racing environment without failure. There are many aspects to consider when designing a chassis, including component packaging, material selection, strength, stiffness and weight. The primary objective of the chassis is to provide a structure that connects the front and rear suspension without excessive deflection [12].

Fig 1: Model of C cross section type of ladder chassis [7]

In this study, ladder type chassis frame is analysed. The Chassis consists of side members attached with a series of cross members to complete the ladder like structure, thus its name.

Static structural analysis is performed to identify critical regions and based on the results obtained design modification has been done. The modal analysis of the chassis frame is carried out to determine the natural frequency and mode shapes of the system. The rigidity of the system was analyzed and their resonance could be avoided [2].Most of the members of engineering structures operate under loading conditions, which may cause damages or cracks in overstressed zones. The presence of cracks in a structural member causes local variations in stiffness, the magnitude of which mainly depends on the location and depth of the cracks. The presence of cracks causes changes in the physical properties of a structure which in turn alter its dynamic response characteristics. The monitoring of the changes in the response parameters of a structure has been widely used for the assessment of structural integrity, performance and safety. A local flexibility will reduce the stiffness of a structural member, thus reducing its natural frequency. Thus most popular parameter applied in identification methods is change in natural frequencies of structure caused by the crack [4]. In this paper, the natural frequencies of cracked and un-cracked beams have been calculated using Finite element software LS DYNA.

II. PROBLEM STATEMENT AND OBJECTIVE

A. Problem Statement

The chassis frame forms the backbone of the truck and its chief function is to safely carry the maximum load wherever the operation demands. Basically, it must absorb engine and axle torque and absorb shock loads over twisting and uneven roadbeds when the vehicle moving along the road. For this project, the truck chassis is categorized under the ladder frame type chassis. A ladder frame can be considered structurally as grillages. It consists of two side members bridged and held apart by a series of cross members. The side members function as a resistance to the shear forces and bending loads while the cross members give torsion rigidity to the frame. There are some advantages and disadvantages when using ladder frame chassis. One of the advantages is the ease of mounting and dismounting the body structure. Various body types ranging from flat platform, box vans and tankers to detachable containers can be adapted easily to a standard ladder frame chassis. While the main disadvantages of the ladder frame is its torsion rigidity. Since it is a two-dimensional structure, its torsion rigidity is very much lower than other chassis, especially when dealing with vertical load or bumps. The weight of the ladder chassis is also high compare to other types of chassis. Also presence of a crack in structures modifies its dynamic behavior. The natural frequency changes substantially due to the presence of cracks depending upon location and size of cracks[4][5].

B. Objectives

The objectives of this project are:

- To determine the static and dynamic mode shape of the truck chassis by using modal analysis and finite element method.
- To improve the static and dynamic behavior of the truck chassis by changing the geometrical dimension and structural properties.
- To study the dynamic behaviour of structure with and without presence of crack.

C. Expected Outcomes

- Maximum Strength
- Minimum Deflection
- Mode shapes and frequency
- Analysis of effect of crack on chassis.

III.BASIC CALCULATION OF CHASSIS FRAME

A. Material Properties

TABLE I

Number of Factors	Number of Levels per Factor	Number of Runs Full Factorial
2	2	4
2	3	9
3	2	8
3	3	27
4	2	16
4	3	81
5	2	32
5	3	243
6	2	64
6	3	729
7	2	128
7	3	2187
8	2	256
8	3	6561

Material Properties

The load application is the major part in the analysis of a component. There may be different types of loads like Uniformly Distributed Load, Uniformly Varying Load and Point Load. The present frame carries the UDL throughout its length [15].

Max. Permissible FAW = 7950 kgs.
Max Permissible RAW = 3950 kgs.
Total Gross vehicle weight = 11900 kgs.

All parts of the chassis are made from "C" Channels with 228.6 mm X 76.2 mm X 6.35 mm and length 7720 mm. Each truck chassis has two beam. So load acting on each beam is half of the Total load acting on the chassis [9],[1],[6].

- Load acting on each member = Total load acting on the chassis / 2= 11900/2= 5950 kgs.
- Load Area of each member = Length of member X width = 7720 X 76.2 = 588264 mm^2
- Total Pressure applied = 5950/588264= 0.01011 kg/mm^2 = 0.0992 N/mm^2

IV. METHODOLOGY

FEA method have been used for static and dynamic analysis of chassis. The main objective of static analysis is to determine the deflection of chassis, while dynamic (modal) analysis used to determine the mode shapes and natural frequencies of the structure.

A. Design Of Experiments (DOE)

The Design of experiments (DOE) is a systematic, rigorous approach to engineering problem-solving that applies principles and techniques at the data collection stage so as to ensure the generation of valid, defensible, and supportable engineering conclusions.

B. Components of Experimental Design

- Factors or inputs to the process. Factors can be classified as either controllable or uncontrollable variables.
- Levels or settings of each factor in the study.
- Response or output of the experiment.

A well-designed experiment is as simple as possible - obtaining the required information in a cost effective and reproducible manner.

C. Multi-Factor Experiments

Multi-factor experiments are designed to evaluate multiple factors set at multiple levels. One approach is called a Full Factorial experiment, in which each factor is tested at each level in every possible combination with the other factors and their levels. The advantage is that all paired interactions can be studied. However, the number of runs goes up exponentially as additional factors are added.

TABLE II

Full Factorial Experiment

Material used	Carbon steel, AISI 1080 (tempered @ 205 C, oil quenched)
Young's modulus (E)	215 GPa
Yield strength	800 MPa
Poisons ratio	0.285
Density	7800kg/m^3
Composition	C=0.74-0.88% Fe=98.13-98.66% Mn=0.6-0.9% P= 0.0-0.04% S=0.0-0.05%

D. Taguchi Methods

Dr. Genichi Taguchi is a Japanese statistician and Deming prize winner who pioneered techniques to improve quality through robust design of products and production processes. Taguchi describes a continuous Loss Function that increases as a part deviates from the target, or nominal value. The Loss Function stipulates that society's loss due to poorly performing products is proportional to the square of the deviation of the performance characteristic from its target value.

Taguchi has envisaged a new method of conducting the design of experiments which are based on well-defined guidelines. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting the minimal number of experiments which could give the full information of all the factors that affect the performance parameter.

E. Typical orthogonal array

While there are many standard orthogonal arrays available, each of the arrays is meant for a specific number of independent design variables and levels. The L9 orthogonal array is meant for understanding the effect of 3 independent factors each having 3 factor level values. This array assumes that there is no interaction between any two factors.

TABLE III

Layout of L9(3^3) orthogonal array

L_9 (3^3) Orthogonal array				
	Independent Variables			Performance Parameter Value
Experiment #	Variable 1	Variable 2	Variable 3	
1	1	1	1	p1
2	1	2	2	p2
3	1	3	3	p3

4	2	1	2	p4
5	2	2	3	p5
6	2	3	1	p6
7	3	1	3	p7
8	3	2	1	p8
9	3	3	2	p9

F. Assumptions of the Taguchi method

The additive assumption implies that the individual or main effects of the independent variables on performance parameter are separable. Under this assumption, the effect of each factor can be linear, quadratic or of higher order, but the model assumes that there exists no cross product effects (interactions) among the individual factors. That means the effect of independent variable 1 on performance parameter does not depend on the different level settings of any other independent variables and vice versa. If at any time, this assumption is violated, then the additivity of the main effects does not hold, and the variables interact.

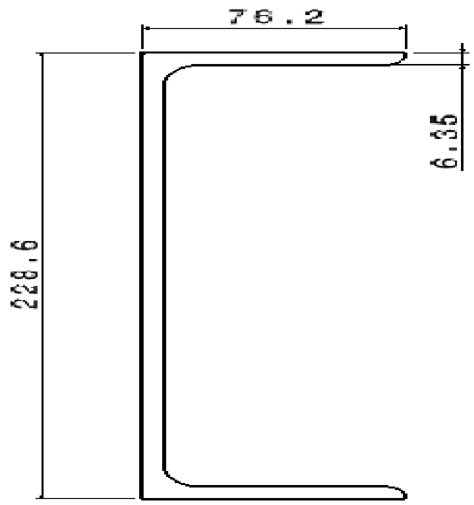
G. Software Details

TABLE IV
Software details

	Software Name	Version
CAD	CATIA	V5R18
Pre-Processor	ANSA	15.1.2
Solver	LS-Dyna implicit	mpp971s R6.1.0
Post-Processor	Meta-Post	15.1.2

H. Details of Analysis

1) CAD Modelling: As per the requirements CAD models are prepared using CATIA V5R18.



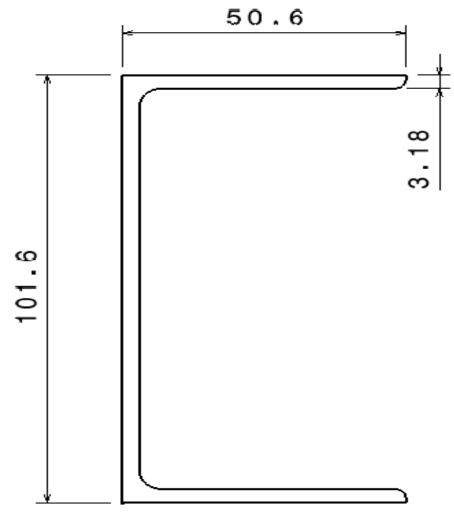


Fig 2 : Model of C cross section type main member and cross member [9]

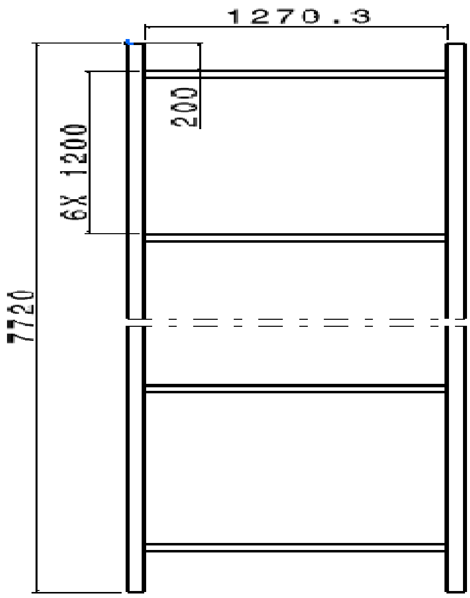


Fig 3 : Assembly of ladder type chassis

2) Pre-processing Steps:
   a. Meshing: All the CAD surfaced are meshed on the mid-surface with Quadrilateral elements.
   b. Thickness Assignment: Corresponding thickness properties are assigned to all parts
   c. Material Assignment: For every Load case appropriate material properties are assigned.
   d. Boundary Conditions applied.
3) Solution: FEA runs will be performed using LS-Dyna explicit code
4) Post Processing: The available results after completion of LS-Dyna run are post-processed using Meta-Post.

I. Introduction to crack analysis

In many industries it is extremely difficult to manufacture products that will be totally immune to cracking and breaking in service, making testing at the point of manufacture, and during use, essential. Cracks can occur

in a number of materials such as metals, composites, plastics and may indicate manufacturing failure in industries including automotive, aerospace, building, engineering and manufacturing. Crack An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it. Crack damage leads to reduction in stiffness also with an inherent reduction in natural frequency and increase in modal damping. So there is need to study feasible relationship between the modal natural frequency and the crack depth at different location [13]. The common structural defect is the presence of a crack. Cracks are present in structures due to various reasons. The presence of a crack could not only cause a local variation in the stiffness but it could affect the mechanical behavior of the entire structure to a considerable extent. Cracks may be caused by fatigue failure under operating conditions because of the limited value fatigue strength. They may be present due to mechanical defects. Some of cracks are initiated during the manufacturing processes. Generally they are small in sizes and shapes. Such small cracks are later on propagates due to fluctuating stresses acting on components. If these propagating cracks remain as it is and reach their critical size, then a sudden structural failure may occur. Hence it is possible to use natural frequency measurements to detect cracks [14]. Usually the physical dimensions, boundary conditions, the material properties of the structure play important role for the determination of its dynamic response. Their vibrations cause changes in dynamic characteristics of structures. In addition to this presence of a crack in structures modifies its dynamic behavior. The following aspects of the crack greatly influence the dynamic response of the structure.
(i) The position of crack
(ii) The depth of crack
(iii) The width of crack
(iv) The number of cracks

J. Discussion on FEA analysis

1) Inputs required for FEA modal analysis

   a. 3D modeled CAD data
   b. Meshing of CAD data
   c. Material Properties

Bolt and weld, are represented by Rigid Connections (Nodal-Rigid-Body)

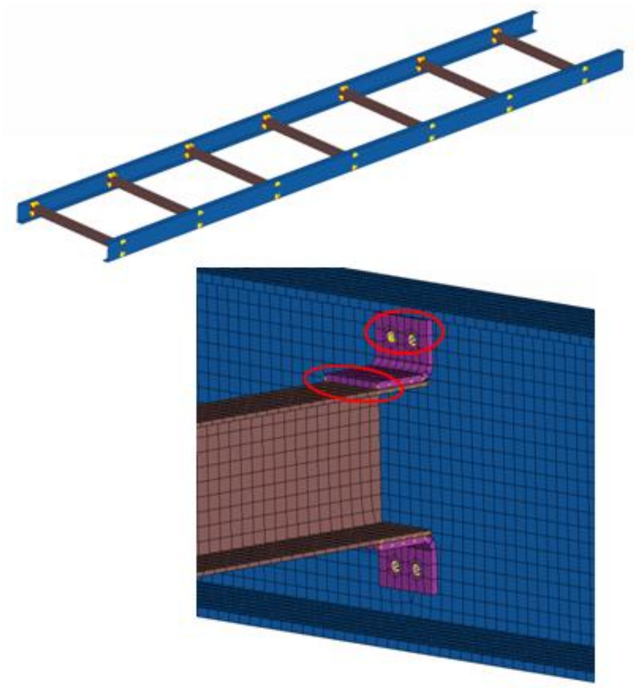


Fig 4 : Meshing and Rigid connections of Chassis

We have performed a Free-Free modal analysis. So first 6 modes (Zero frequency modes) are ignored. Listed below are the modes starting from 7^{th}.

K. Listing of FEA Results

Modal Analysis results for chassis without cracks

TABLE V
Mode Shapes and Frequencies

S No	Mode no.	Frequency Hz.
1	7	5.000
2	8	12.896
3	9	15.027
4	10	15.975
5	11	17.811
6	12	18.169
7	13	33.095
8	14	53.942
9	15	54.391
10	16	64.316

Mode shape	7	8	9	10	11
Frequency	5.000	12.896	15.027	15.975	17.811

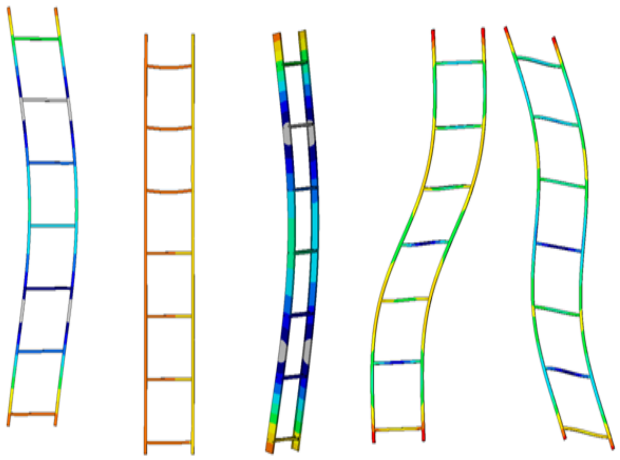


Fig 5 : Mode shapes 7 to 11 of chassis without crack

Mode shape	12	13	14	15	16
Frequency	18.169	33.095	53.942	54.391	64.316

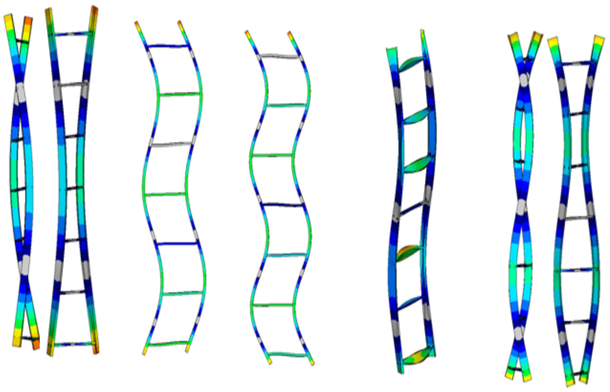


Fig 6 : Mode shapes 12 to 16 of chassis without crack

From modal analysis we got the lowest frequency of 5.000 Hz for respective mode shape no 7.

Von-mises Stresses for chassis without cracks.

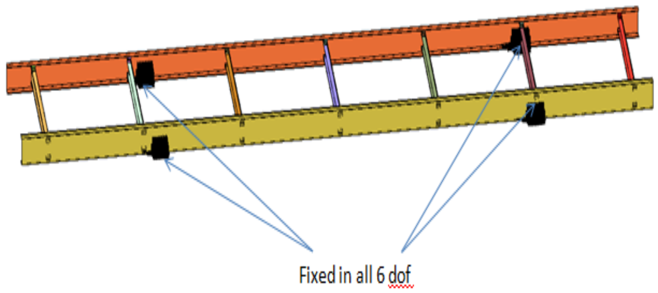


Fig 7 : Boundary condition for chassis

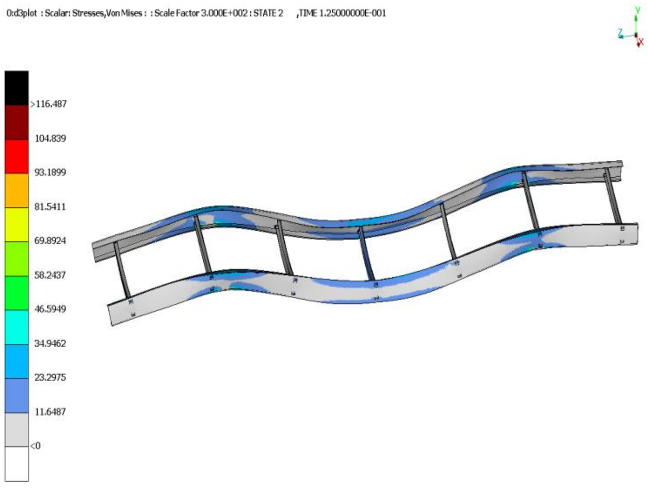


Fig 8 : Von-mises Stresses for chassis without cracks

Max deflection for chassis without cracks.

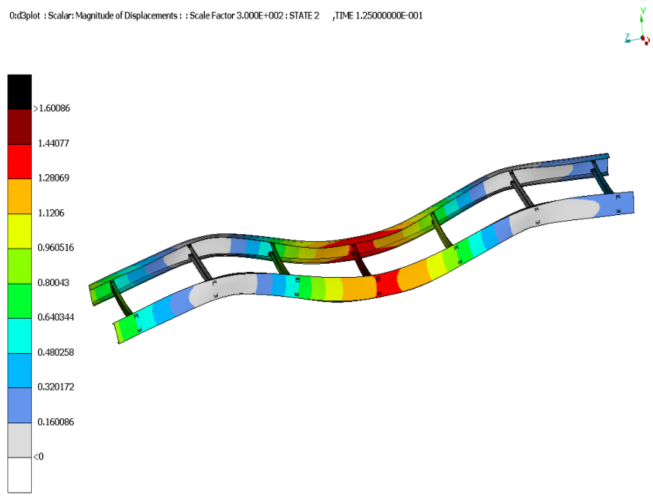


Fig 9 : Displacement for chassis without cracks

Static analysis for chassis without cracks, Max Von-mises stress is 116.487 MPa and Max displacement is 1.60086 mm.

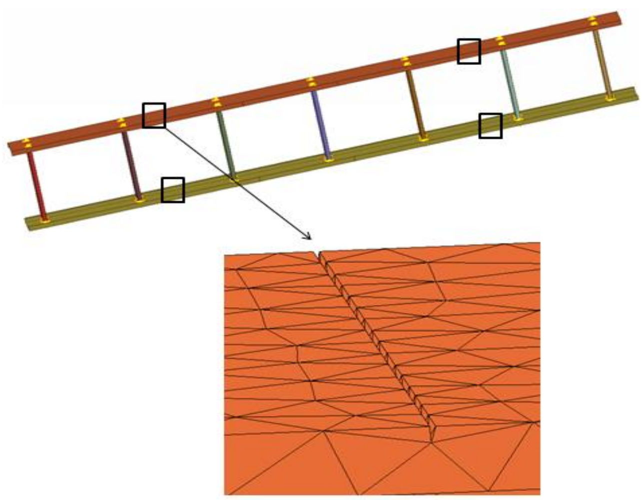


Fig 10 : Chassis with cracks

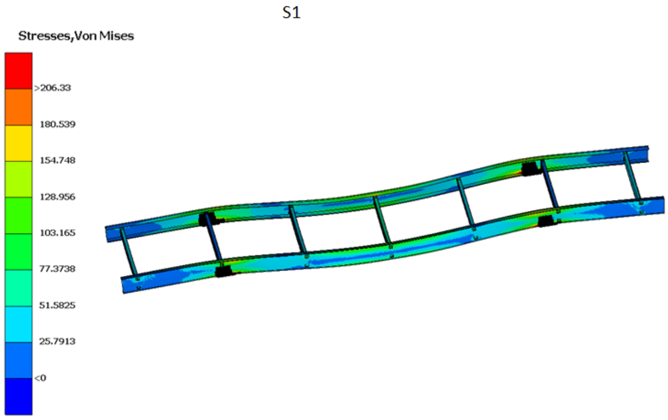


Fig 11 : Von-mises stresses for chassis with crack for S1 variables

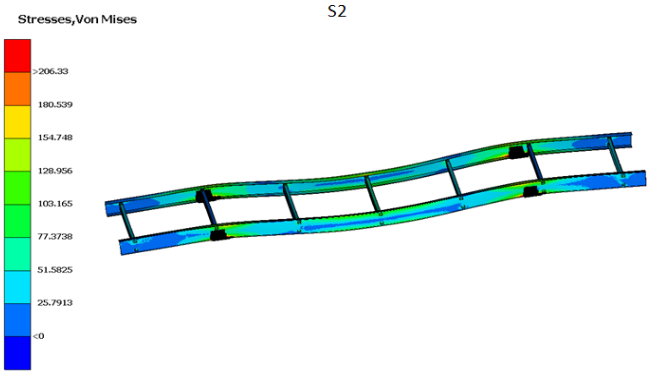


Fig 12 : Von-mises stresses for chassis with crack for S2 variables

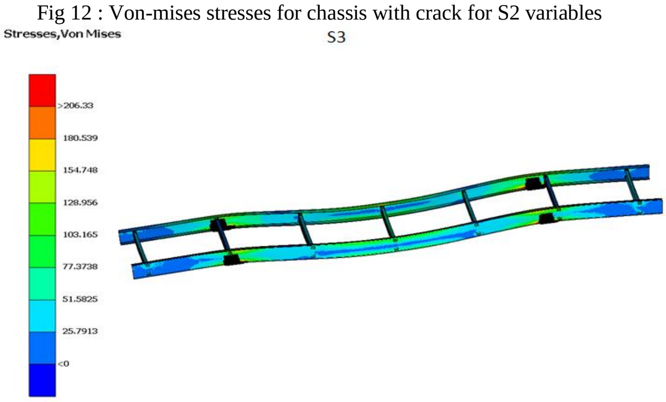


Fig 13 : Von-mises stresses for chassis with crack for S3 variables

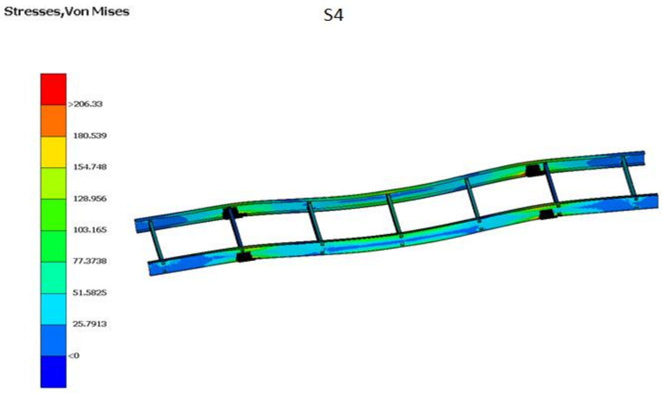


Fig 14 : Von-mises stresses for chassis with crack for S4 variables

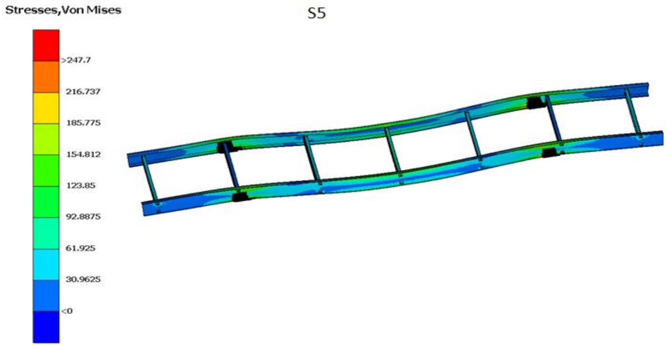


Fig 15 : Von-mises stresses for chassis with crack for S5 variables

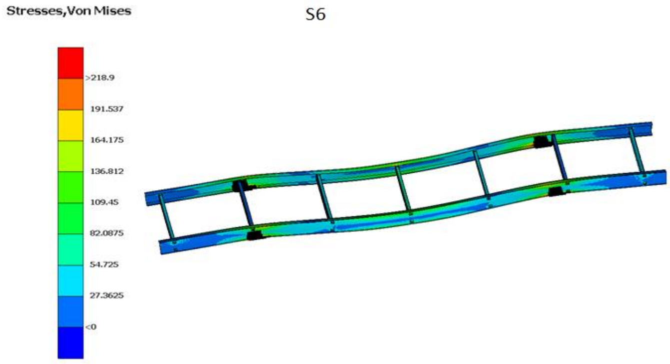


Fig 16 : Von-mises stresses for chassis with crack for S6 variables

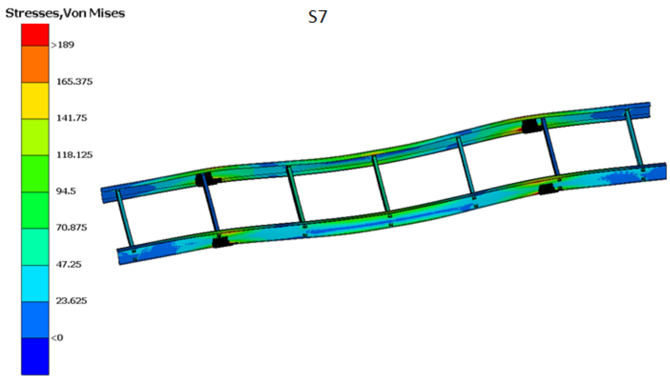


Fig 17 : Von-mises stresses for chassis with crack for S7 variables

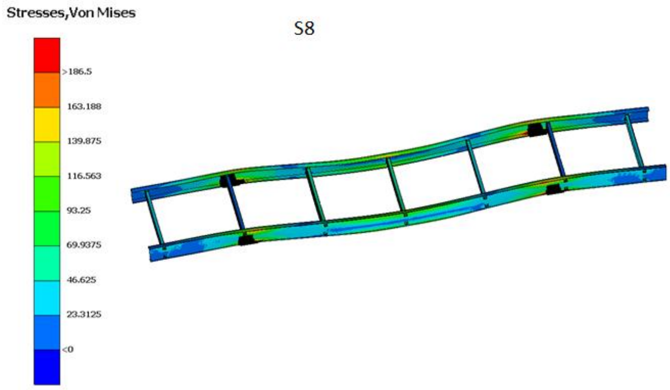


Fig 18 : Von-mises stresses for chassis with crack for S8 variables

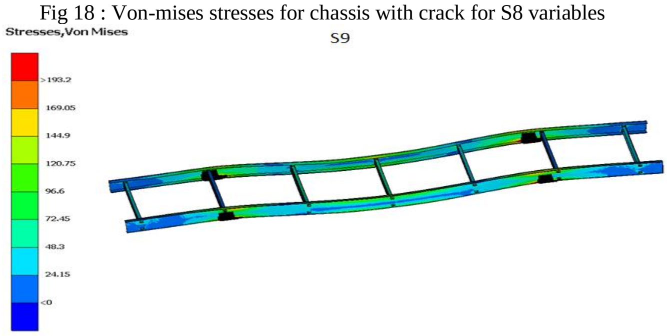


Fig 19 : Von-mises stresses for chassis with crack for S9 variables

TABLE VI
Simulation results

L_9 (3^3) Orthogonal array						
		Independent Variables			Output Parameters	
Exp No	Material	V1	V 2	V3	P1	P2
		Location of Crack	Width of Crack mm	Depth of Crack mm	Max Von Mises Stress MPa	Max Displacement mm
S0	AISI 1080	NA	NA	NA	116.48	1.60
S1	AISI 1080	300 mm	0.4	1.5	199.00	7.408
S2	AISI 1080	300 mm	0.5	2	205.00	7.626
S3	AISI 1080	300 mm	0.6	2.5	206.33	7.712
S4	AISI 1080	450 mm	0.4	2	236.69	7.704
S5	AISI 1080	450 mm	0.5	2.5	247.70	7.705
S6	AISI 1080	450 mm	0.6	1.5	218.90	7.7035
S7	AISI 1080	600 mm	0.4	2.5	189.00	7.704
S8	AISI 1080	600 mm	0.5	1.5	186.50	7.703
S9	AISI 1080	600 mm	0.6	2	193.20	7.7036

VI. CONCLUSION.

This work presents FEA of heavy duty vehicle chassis for deflection and modal analysis considering a) with cracks b) without cracks.

- The result of modal analysis shows that at 7^{th} mode shape the frequency is less ie 5.000Hz.
- The static analysis of chassis without cracks shows the Von-mises stress value of 116.487 Mpa.
- The static analysis of chassis without cracks shows the displacements value of 1.60 mm.
- The static analysis of chassis with crack shows the highest Von-mises stress value of 247.70 Mpa at S5 variables. Results shows presence of cracks increases the stresses in member and increase in crack size and depth increases the stresses in member.
- The static analysis of chassis with cracks shows the displacements value of 7.715 mm.

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