STRENGTH EVALUATION OF TIPPER CHASSIS UNDER STATIC AND DYNAMIC LOAD CONDITONS

VIJAY KUMAR MULAKALAPALLI[1], I.R.K RAJU[2]

[1]Post Graduate Student, Dept. of Mechanical Engineering, Chaitanya Engineering College, afflicted to JNTUK, Andhra Pradesh, India
[2]Professor, Dept. of Mechanical Engineering, Chaitanya Engineering College, afflicted to JNTUK, Andhra Pradesh, India

---***---

ABSTRACT - Transportation industry plays a major role in the economy of modern industrialized and developing countries. 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. The design of a vehicle structure plays an important role in the functionality of the vehicle. Generally, truck is any of various heavy motor vehicles designed for carrying the attached loads, such as the engine, transmission and suspension as well as the passengers and payload. The major focus in the truck manufacturing industries is design of vehicles with more pay load.. The chassis of trucks, which is the backbone of vehicles that integrates the main truck component systems such as the axles, suspension, power train, cab etc.,is one of the possible candidates for substantial weight reduction. Along with strength, an important consideration in chassis design is to have adequate bending and torsional stiffness for better handling characteristics. Therefore, strength and stiffness are two important criteria for the design of the chassis. 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 .The vehicle design starts up with conceptual studies to define size, number and location of driven and drive axles, type of suspension, engine power, transmission, tire size and axle reduction ratio, cab size and auxiliary equipment. The selected configuration has to be suitable for the considered transportation tasks and should match the existing production line . In general, there are two approaches to simulate truck chassis using FEA methods: one is stress analysis to predict the weak points and the other is fatigue analysis to predict life of the frame.

Keywords: Truck Chassis, Hyper mesh, Nastran, Stress Analysis, Dynamic analysis, FEM.

1. INTRODUCTION

1.1 ROLE OF CHASSIS IN AUTOMOTIVES - Every vehicle body consists of two parts; chassis and bodywork or superstructure. The chassis is the framework of any vehicle. Its principal function is to safely carry the maximum load for all designed operating conditions. It must also absorb engine and driveline torque, endure shock loading and accommodate twisting on uneven road surfaces. The chassis receives the reaction forces of the wheels during acceleration and braking and absorbs aerodynamic wind forces and road shocks through the suspension. Therefore, the chassis should be engineered and built to maximize payload capability and to provide versatility, durability as well as adequate performance. To achieve a satisfactory performance, the construction of a heavy vehicle chassis is the result of careful design and rigorous testing.

It should be noted that this 'ladder' type of frame construction is designed to offer good downward support for the body and payload and at the same time provide torsional flexibility, mainly in the region between the gearbox cross member and the cross member ahead of the rear suspension. This chassis flexing is necessary because a rigid frame is more likely to fail than a flexible one that can 'weave' when the vehicle is exposed to arduous conditions. A torsionally flexible frame also has the advantage of decreasing the suspension loading when the vehicle is on uneven surfaces.

The chassis, which is made of pressed steel members, can be considered structurally as grillages. It acts as a skeleton on which, the engine, wheels, axle assemblies, brakes, suspensions etc. are mounted. The frame and cross members form an important part of the chassis. The frame supports the cab, engine transmission, axles and various other components. Cross members are also used for vehicle component mounting, and protecting the wires and tubing that are routed from one side of the vehicleto the other. The cross members control axial rotation and longitudinal motion of the main frame, and reduce torsion stress transmitted from one rail to the other.

1.2 CHASSIS MATERIAL

Heavy-duty chassis are usually manufactured with either frame rails of steel or aluminum alloy. Each material must be handled in a specific manner to assure maximum service life. Many heavy-duty trucks are presently manufactured with frame rails of mild steel high-strength low-alloy steel or heat treated steel. Material thickness increases, as the truck's intended duty becomes more severe. The depth of the rail also increases with duty severity. The on-road tractor rails will usually be less, than the damper rails.

Aluminum alloy frames weigh less than their steel counter parts, but are not considered as strong. The two most common aluminum frames are made medium of strength magnesium-silicon-aluminum alloy and high-strength copper-aluminum alloy, both of which are heat treated.

1.3 LOADS ON THE CHASSIS FRAME

The chassis frame in general are is subjected to the following loads:

1. Weight of the vehicle and the passengers, which causes vertical bending of the side members
2. Vertical loads when the vehicle comes across a bump or hollow, which results in longitudinal torsion due to one wheel lifted (or lowered) with other wheels at the usual road level
3. Loads due to the camber, side wind, cornering force while taking a turn, which result in lateral bending of side members
4. Loads due to wheel impact with road obstacles may cause that particular wheel to remain obstructed while the other wheel tends to move forward, distorting the frame to parallelogram shape
5. Engine torque and braking torque tending to bend the side members in vertical plane

2. LITERATURE REVIEW

The investigation on static and dynamic behavior of chassis has been a topic of interest for well over a century, and is especially so in recent years. To determine the static and dynamic behavior many methods have been employed, out of them the generally used methods are finite element analysis and multi body simulation methods. Many engineers have already worked in this area and come out with some useful results. Finite element method has been the most commonly used technique for predicting the performance of chassis and other automobile components. Multi-body simulation is another recent technique adopted for analysis of automotive systems like suspension, steering, chassis etc.

Arborio, N., et al [1] have developed a methodology to simulate vehicle dynamics through ADAMS car and Matlab co-simulation. To compare the performance obtainable considering different active systems, a mathematical model of a new car was implemented through Adams Car. The model was completed with a power train specifically conceived in Matlab environment to overcome problems due to an Adams Car modelling not suitable to describe every operating condition. The methodology developed was applied to evaluate a control strategy developed to carry out vehicle dynamics control.

Dr. A.Costa Neto et al [2] describes the modeling and analysis processes of a medium sized truck manufactured with regard to vibration and comfort behavior. The vehicle model includes Hotchkiss suspensions front and rear with shackle and with a double stage with bump stops at the rear. It is also included frame flexibility in ADAMS in an approximate manner based on a Finite Element Analysis of the frame. Nonlinear shock absorber curves are also represented for the vehicle and cab suspensions. Random track profile is generated as input and vehicle comfort is described in terms of the ISO 2631-85 Standard. The effect on vehicle comfort of changing a design parameter can be predicted in the model and verified experimentally.

Lonny L.Thompson, et al [3] determined that a high sensitivity value indicates a strong influence on the torsional stiffness of the overall chassis. Results from the sensitivity analysis are used as a guide to modify the baseline chassis with the goal of increased torsional stiffness with minimum increase in weight and low center-of-gravity placement. The torsional stiffness of the chassis with various combinations of added members in the front clip area, engine bay, roof area, front window and the area behind the roll cage was predicted using finite element analysis. They concluded that with strategic placement of structural members to a baseline chassis, the torsional stiffness can be more than tripled with only a 180 N increase in weight.

Kim, H.S et al.[4] have presented a method for dynamic stress analysis of structural components of bus systems. They have used the hybrid superposition method that combines the finite element static and eigen value analysis with flexible multibody dynamic analysis. In the stress recovery, dynamic stresses are estimated as a sum of pseudostatic stresses and modal acceleration stresses, which are obtained by applying the principle of linear superposition to the modal acceleration method.

A method for vehicle analysis based on finite element technique has been proposed by **Johansson, I., and Gustavsson, M., [5]**. Vehicle dynamics and durability have been taken into account in their work and an in-house developed pre and post processor is used to achieve effectiveness.

Oijer, F., [6] has proposed a method for force and stress calculation using complete vehicle models in MSC.Nastran, where variables such as road profile and curve radii are used as input. This, in combination with modal superelement reduction, will result in faster design studies. Accurate calculations of force histories are of utmost importance for reliable fatigue life estimates. The forces are often calculated by the use of multi-body software (MBS) and used as input forstress analysis in a finite element package. A drawback is that the MBS calculations are very time consuming, especially if flexible bodies are included, and are thus, not well suited for fast parameter studies. This literature survey reveals that there is a strong need to predict the transient response of truck chassis when subjected to dynamic loads while it encounters a bump with different speeds of vehicle.

The stress analysis of truck chassis using riveted joints has been performed by **Cicek Karaoglu et al [7**], in order to achieve a reduction in the magnitude of stress near the riveted joint of the chassis frame. Side member thickness, connection plate thickness and connection plate length were varied. Numerical results showed that stresses on the side member can be reduced by increasing the side member thickness locally. If the thickness change is not possible, increasing the connection plate length may be a good alternative.

In order to investigate the transient response of a vehicle–structure interaction system in time domain, **Tso-Chien Pan et al [8]** developed a dynamic vehicle element (DVE) method. The DVE method treats the vehicle as a moving part of the entire system, which considers the vehicle influence at the element level by incorporating the detailed interaction between multiple vehicles and the structure induced by irregular road profiles. In addition, a simplified decoupled dynamic nodal loading (DNL) method is proposed. The DNL method generates a time series of concentrated nodal loading which represents the vehicle reaction force on the structure. The DNL method therefore, accounts for the road irregularities and vehicle inertia effect, but neglects the interaction between the two subsystems. Parametric studies for the effects of road roughness, speed parameter, mass ratio, and frequency ratio on the dynamic vehicle–structure interaction are then carried out using the DVE and DNL methods.

A.V. Pesterev et al [9] determine the dynamic amplification factor function for an irregularity represented as a superposition of simpler ones. Another purpose of this paper is to demonstrate the application of the pothole dynamic amplification factor (DAF)functions technique to finding a priori estimates of the effect of irregularities with a repeated structure. Specifically, the problem can be solved by finding the conditions under which the dynamic effect of two identical potholes located one after another is greater than that due to the single pothole. We also find the estimate for the number of periods of a periodic irregularity that are sufficient in order to consider the oscillator response as steady state.

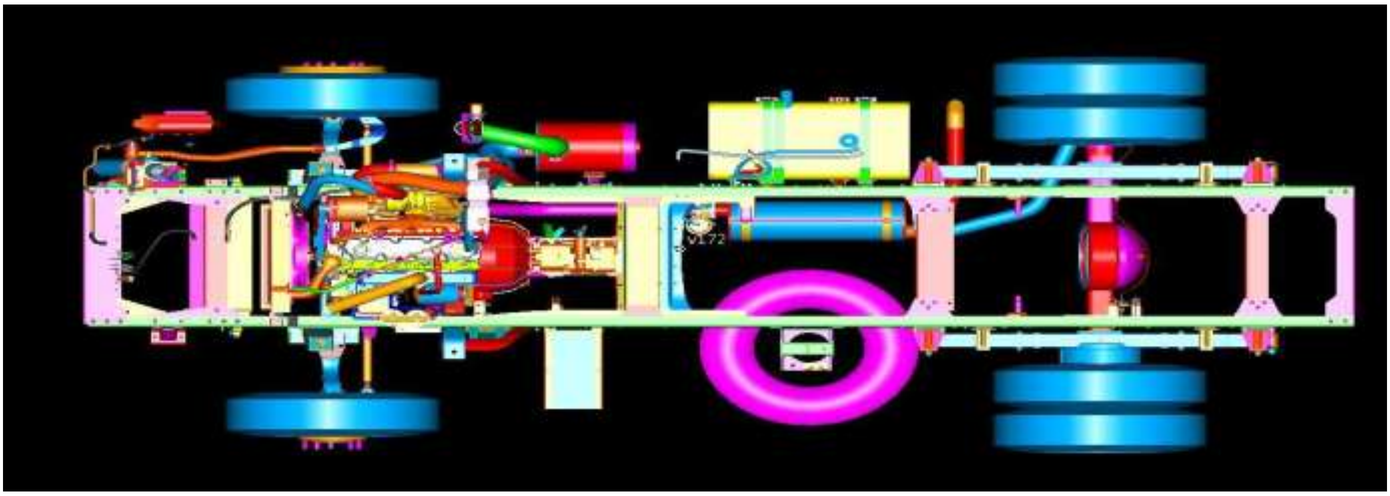
3. MODELING OF CHASSIS

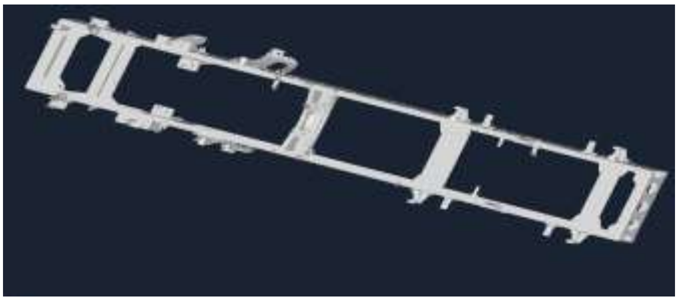
3.1 MODELING AND ANALYSIS SOFTWARES FOR TRUCK CHASSIS

Pro-e	Cad Modelling
Hyper mesh	Finite Element Modelling
Nastran	Analysis
Hyper view	Post-processing

3.2 GEOMETRIC MODEL OF CHASSIS

Geometric modeling of the various components of chassis has been carried out in part mode as 3-D models using Pro/ENGINEER. The properties, viz., cross-sectional area, beam height and area moment of inertia of these 3-D modelled parts are estimated in Pro/ENGINEER. These properties have been used as input while performing the finite element analysis.





4. MATERIAL PROPERTIES

4.1 MATERIAL PROPERTIES & MECHANICAL PROPERTIES:

Material	Young's Modulus (Mpa)	Poisson's Ratio	Density (tonnes/mm3)
Steel	**2.1e+05**	**0.3**	**7.8e-09**
SG Iron	**1.7e+05**	**0.275**	**7.1e-09**

4.2 MATERIAL PROPERTIES OF CHASSIS LONG MBRS:

Material	Tensile Strength	Min. Yield Stress
HR Steel	510-620 N/mm2	355 N/mm2

4.3 MECHANICAL PROPERTIES OF SG IRON

Tensile Strength	**31,000 Psi**
Compressive Strength	**10,900 Psi**
Torsional Shear Strength	**40,000 Psi**
Reversed Bending Fatigue	**14,000 Psi**
Brinnel Hardness No	**201**

5. LOAD CALCULATIONS

Analysis is carried out for the given Chassis under 6 different cases.3 cases in UDL condition and 3 cases in PIVOT load condition.

(a). UDL Condition:

When the Rear body is in horizontal position, the weight of the rear body will act as a uniform pressure on the Chassis. The Chassis has been analyzed in 3 different load cases **(Bending, Torsion, and Articulation)** in this condition.

Load case:

3-2-1 Front:3g vertical, 2g longitudinal, 1g braking load is applied at LH side of front axle. At remaining axle location 1g vertical load to be applied.
3-2-1 Rear:3g vertical, 2g longitudinal, 1g braking load is applied at LH side of front axle. At remaining axle location 1g vertical load to be applied.

UDL calculation:

Rear body weight + External load	=	1370+6000 kgs	=	216899.1 N

Which is complete weight acting on the chassis from rear end to cabin mountings and is applied on areas of contact as a U.D.L.

Total Contact Area	=	2*168926.908 mm^2
UDL	=	216899.1/(2*168926.908) Mpa
	=	0.642 Mpa

Mass Calculations:

Cabin weight + Passengers	=	400 kgs	=	11772 N
Engine weight	=	350 kgs	=	10300.5 N
Transmission weight	=	60 kgs	=	1765.8 N
Fuel Tank weight	=	90kgs	=	2648.7 N
Battery weight	=	146.6 kgs	=	1438.146 N

(b). PIVOT Load Condition:

When the Rear body is at inclined position, the weight of the rear body will act as a concentrated load at the rear end of the Chassis. The Chassis has been analyzed in 3 different load cases **(Bending, Torsion, and Articulation)** in this condition.

Load case:
1G condition

PIVOT Load calculation:

Rear body weight + External load	=	1370+6000 kgs	=	**72299.7 N**

Which is inclined weight acting on the chassis at 2 locations rear end applied equally

PIVOT Load	=	72299.7 /2 N	=	**36149.85 N**

Mass Calculations:

Cabin weight + Passengers	**=**	400 kgs	**=**	3924 N
Engine weight	**=**	350 kgs	=	3433.5 N
Transmission weight	**=**	60 kgs	**=**	588.6 N
Fuel Tank weight	=	90kgs	**=**	882.9 N
Other weight	**=**	146.6kgs	**=**	1438.146

6. LOADINGS, RESULTS AND DISCUSSIONS

1. Bending (Pivot Load) Case

1.1 Modelling Set-up

Constraints:

The Spring Mounting Locations (F-2, R-2) are arrested in all d.o.f.

Reactions: No Reactions

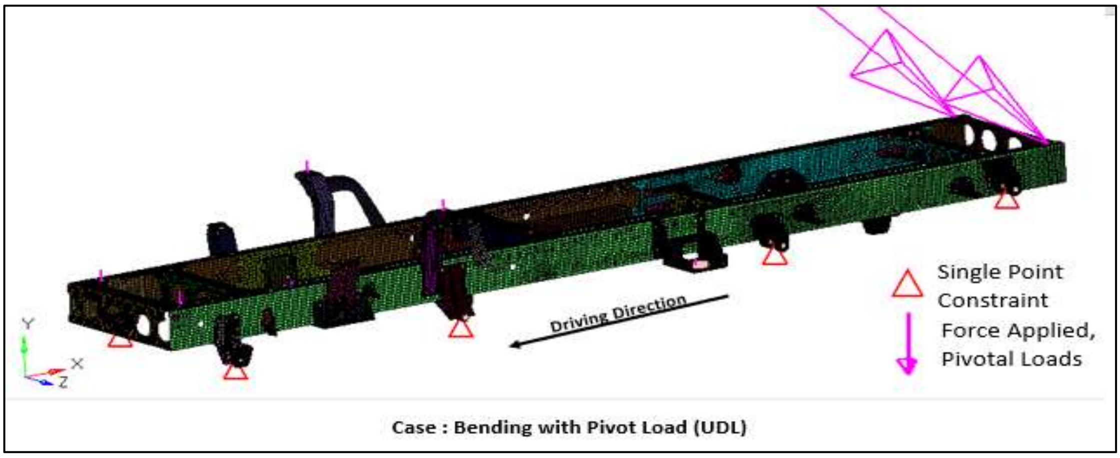


Figure 1: Bending Pivot Load

1.2Analysis Results

1.2.1 Displacement Plot3

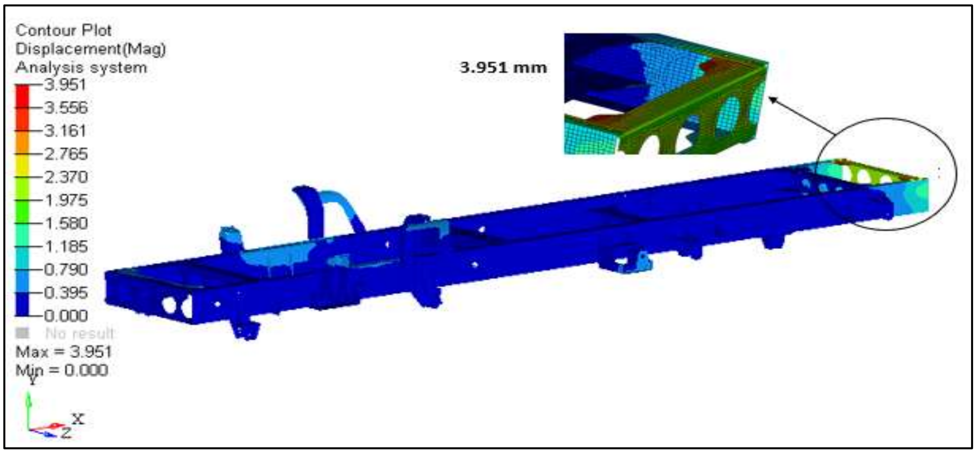


Figure 1: Bending Pivot-Displacement

1.2.2 Von Mises Stress Plot

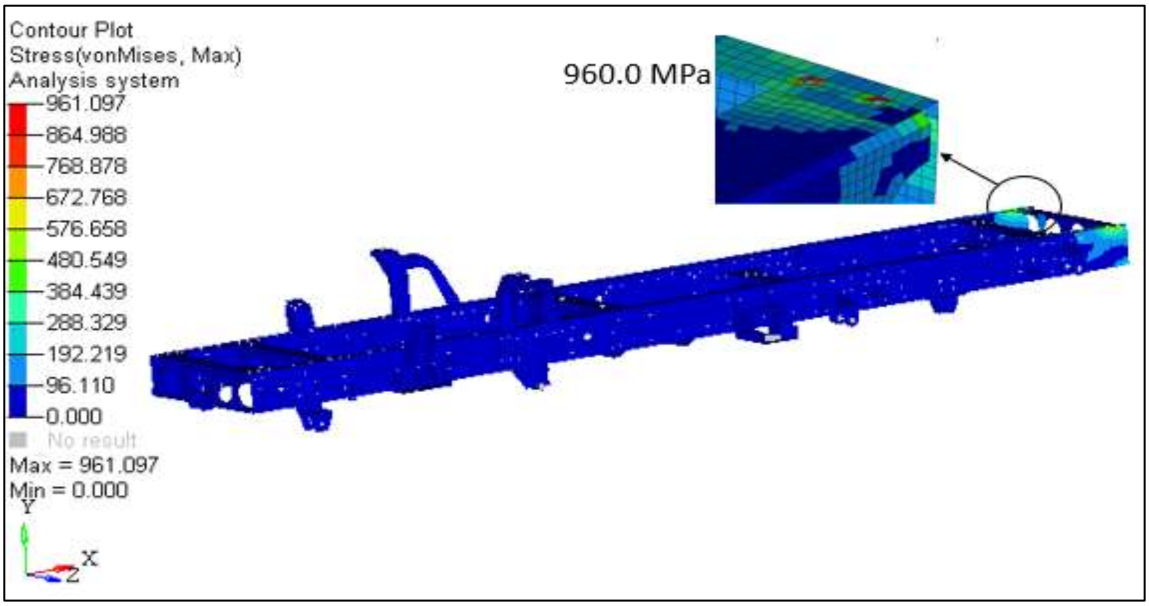


Figure 2: Bending Pivot: Stress

2. Bending Uniform Distributed Load Case

2.1 Modelling Set-up
Constraints:

The Spring Mounting Locations (F-2, R-2) are arrested in all d.o.f.
Reactions: No Reactions

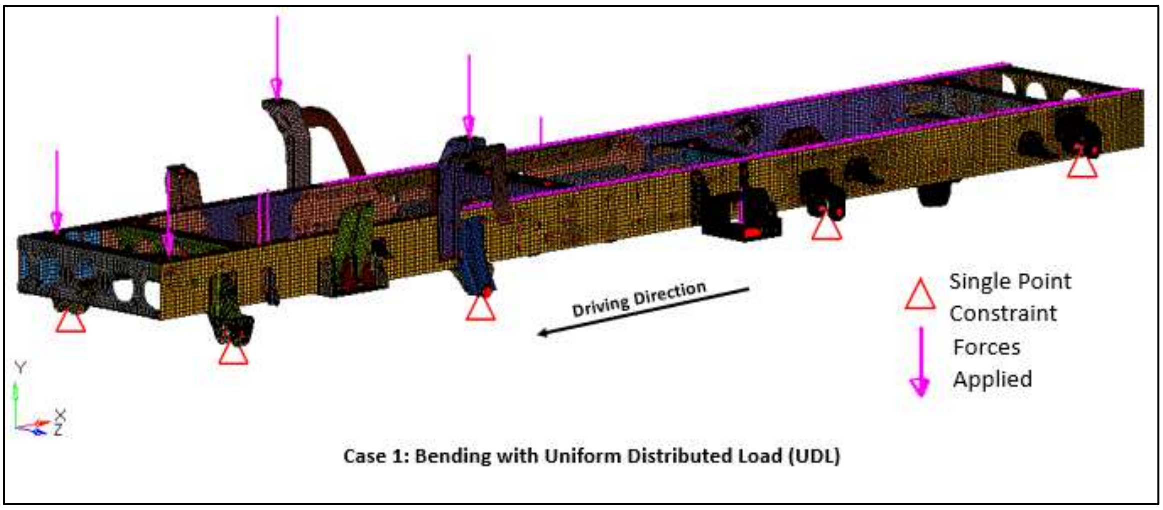


Figure 3: Bending UDL load

2.2 Analysis Results

2.2.1 Displacement Plot

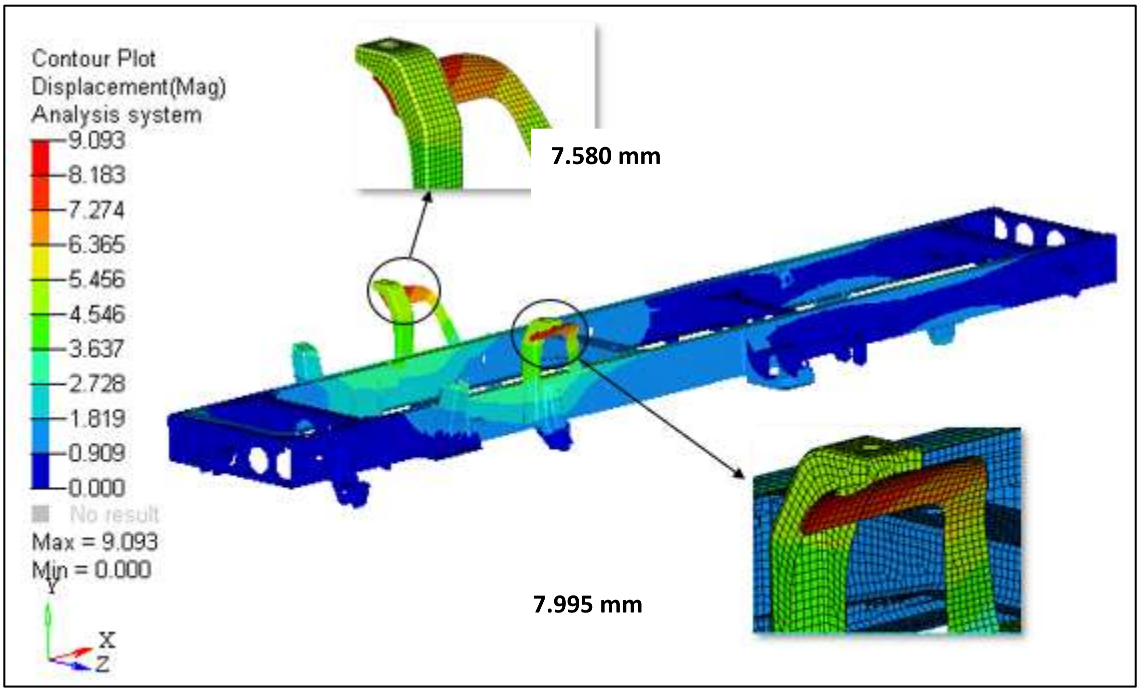


Figure 5: Bending UDL Displacement

2.2.2 Von Mises Stress Plot

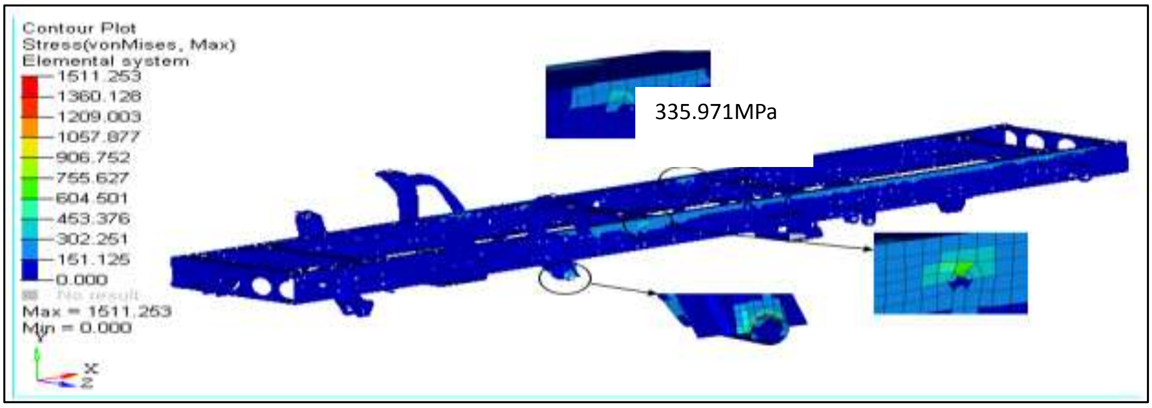


Figure 6: Bending UDL: Stress

3. Articulation Uniform Distributed Load Case

3.1 Modelling Set-up

1448.95 MPa 686.326MPa

Constraints:

The Spring Mounting Locations (F-2, R-2) are arrested in all d.o.f.
Reactions: No Reactions

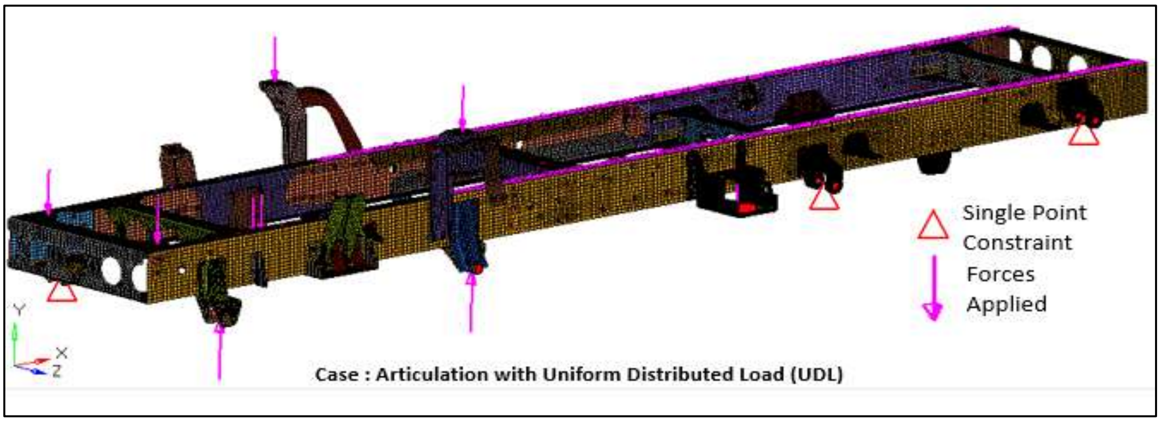


Figure 7:Articulation UDL loading

3.2 Analysis Results

3.2.1 Displacement Plot

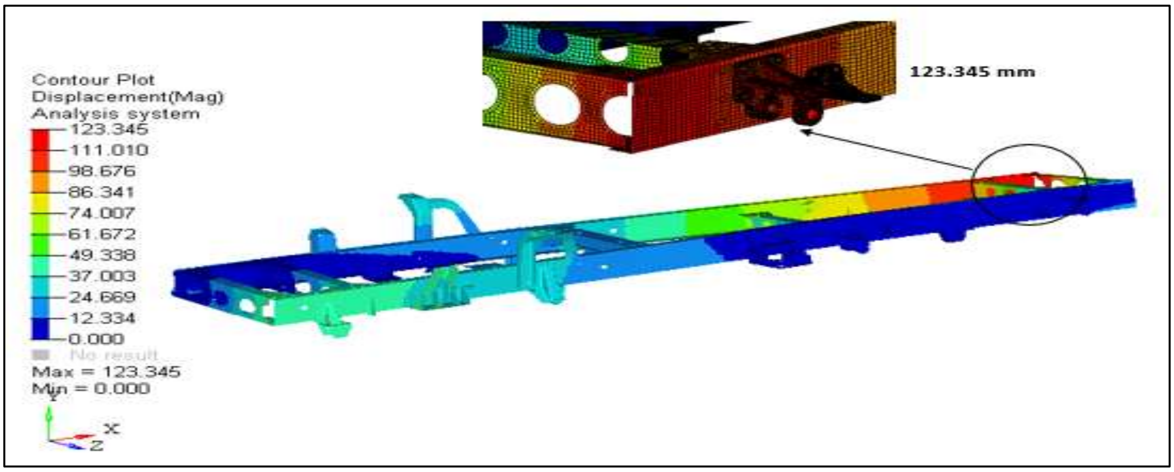


Figure 8: Articulation UDL - Displacement

3.2.2 Von Mises Stress Plot

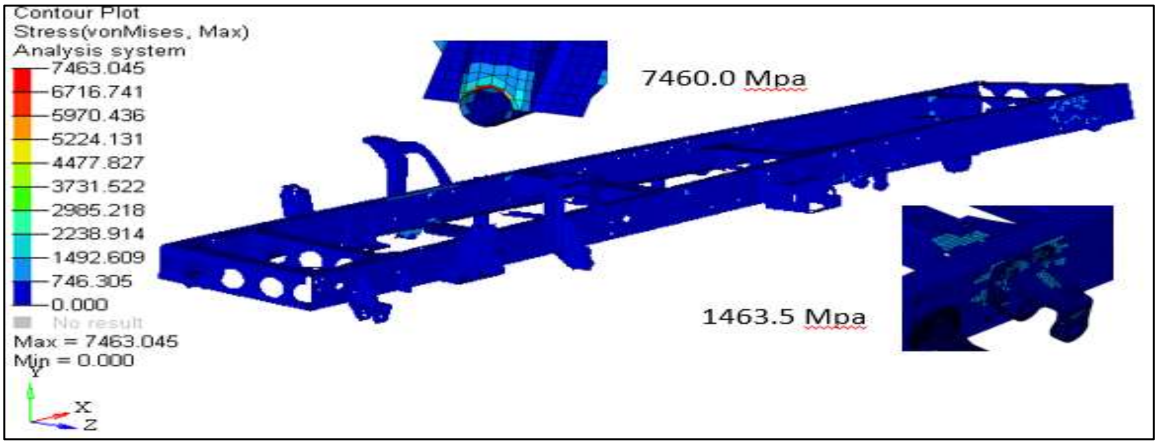


Figure 9: Articulation UDL - Stress

4. Articulation Pivot Load Case

4.1 Modelling Set-up

Constraints:

The Spring Mounting Locations (F-2, R-2) are arrested in all d.o.f.

Reactions: No Reactions

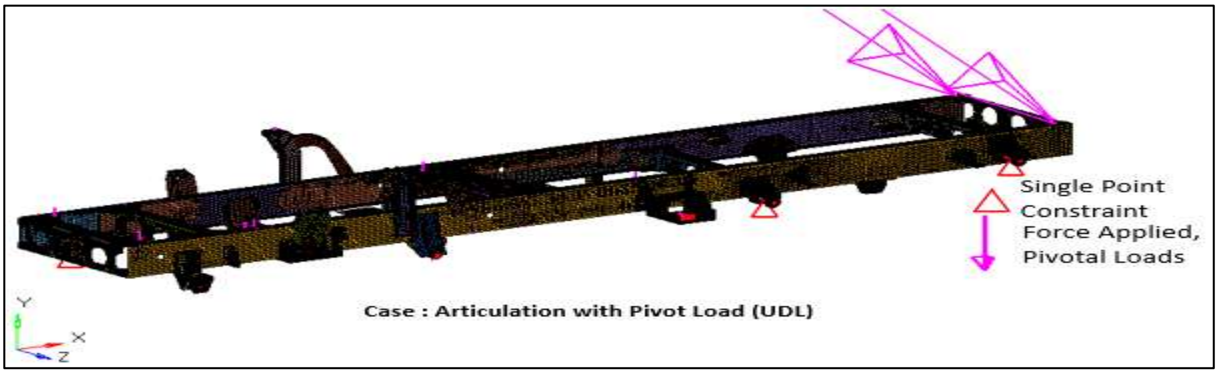


Figure 40: Articulation Pivot

4.2 Analysis Results

4.2.1 Displacement Plot

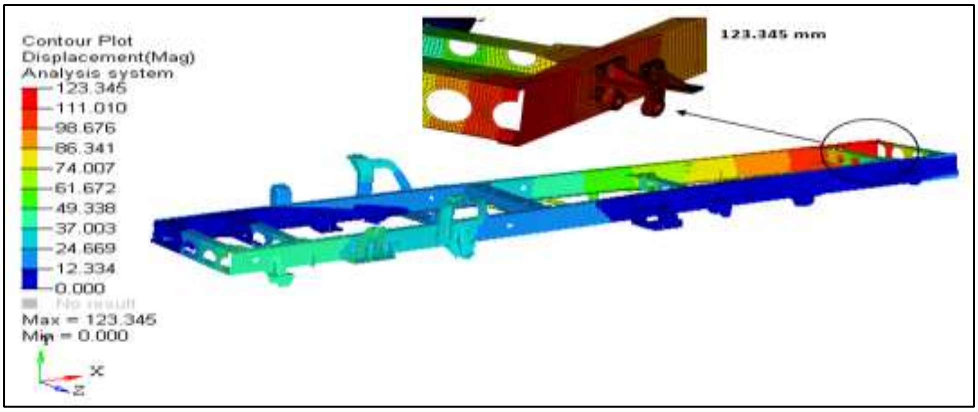


Figure 51: Articulation Pivot - Displacement

4.2.2 Von Mises Stress Plot

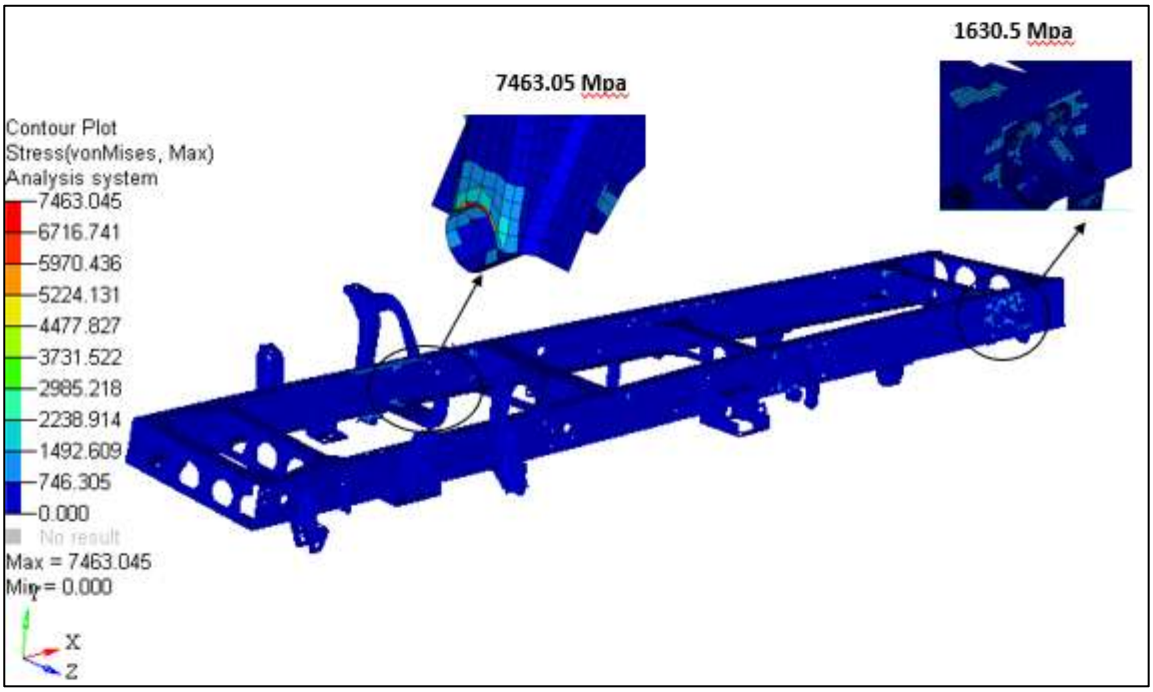


Figure 16: Articulation Pivot - Stress

5. Torsion Uniform Distributed Load Case

5.1 Modelling Set-up

Constraints:

The Spring Mounting Locations (F-2, R-2) are arrested in all d.o.f.

Reactions: No Reactions

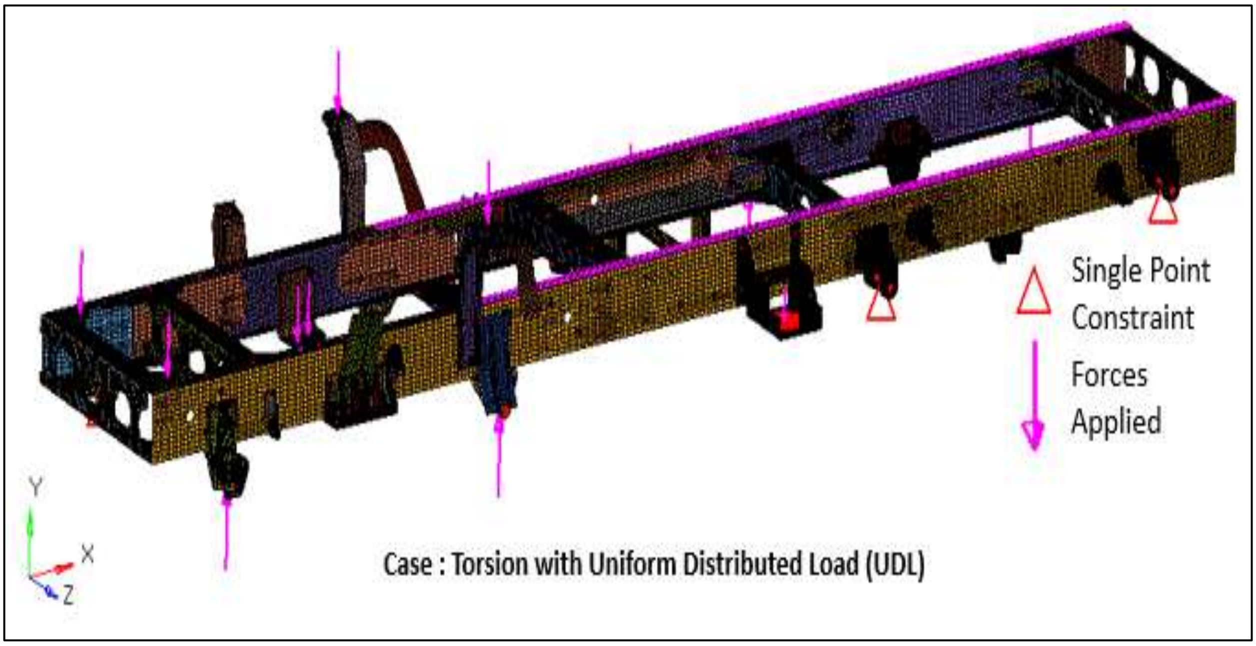


Figure13: Torsion UDL

5.2 Analysis Results

5.2.1 Displacement Plot

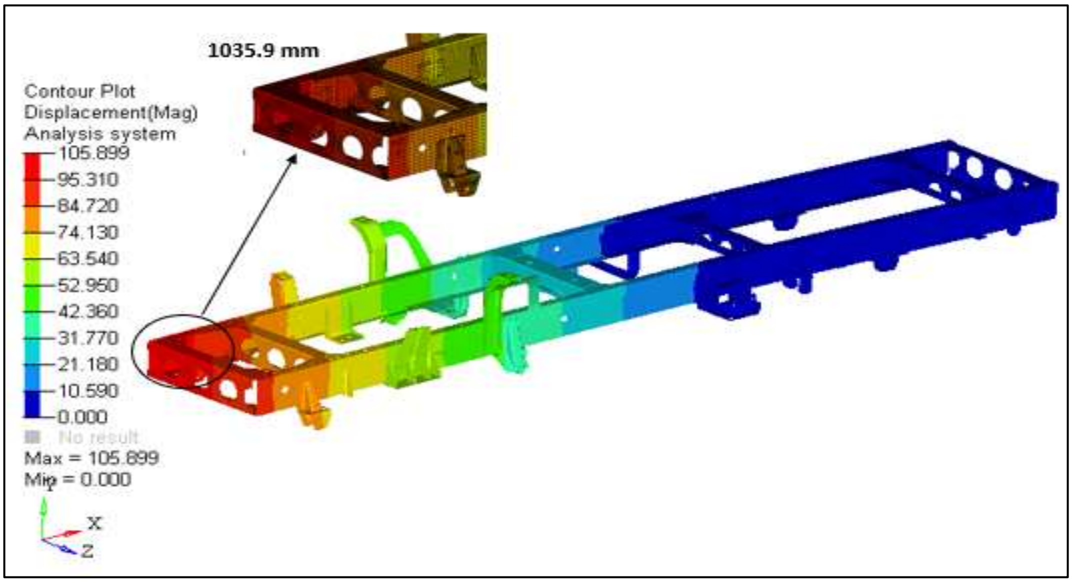


Figure 14: Torsion UDL - Displacement

5.2.2 Von Mises Stress Plot

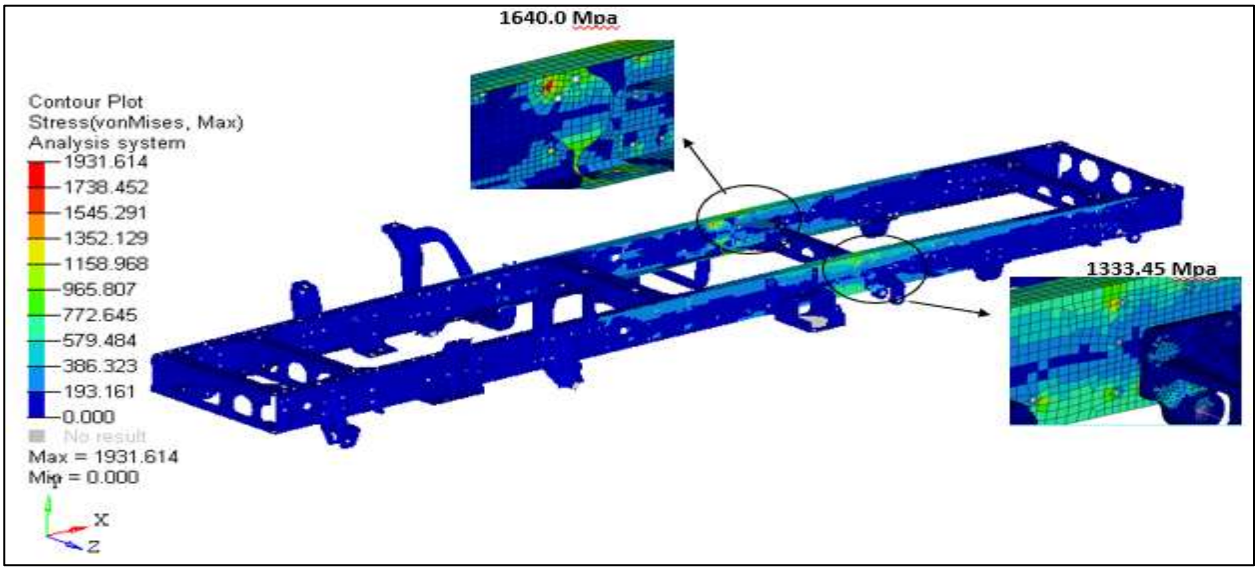


Figure 15: Torsion UDL - Stress

7. MODAL ANALYSIS USING FEM

The goal of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibration. It is common to use the finite element method (FEM) to perform this analysis because, like other calculations using the FEM, the object being analyzed can have arbitrary shape and the results of the calculations are acceptable. The types of equations which arise from modal analysis are those seen in eigensystems. The physical interpretation of the eigenvalues and eigenvectors which come from solving the system are that they represent the frequencies and corresponding mode shapes. Sometimes, the only desired modes are the lowest frequencies because they can be the most prominent modes at which the object will vibrate, dominating all the higher frequency modes.It is also possible to test a physical object to determine its natural frequencies and mode shapes. This is called an Experimental Modal Analysis. The results of the physical test can be used to calibrate a finite element model to determine if the underlying assumptions made were correct (for example, correct material properties and boundary conditions were used).

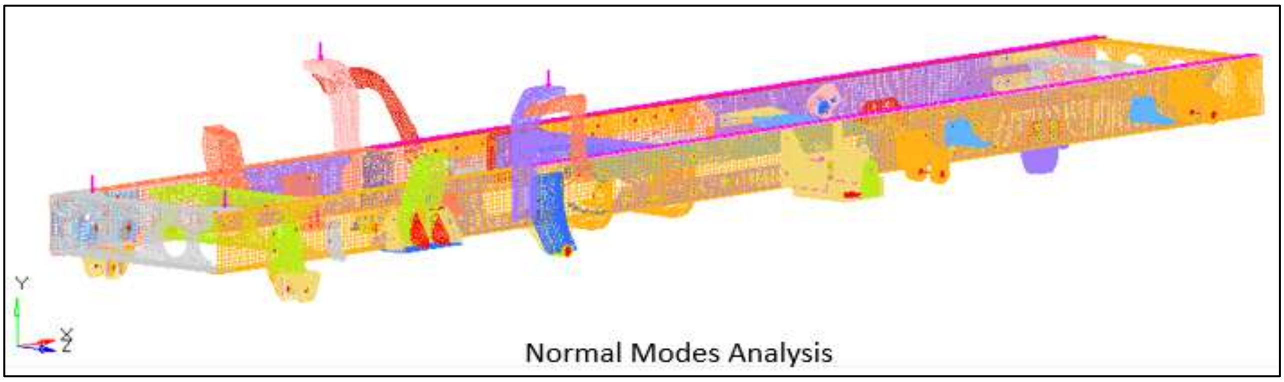
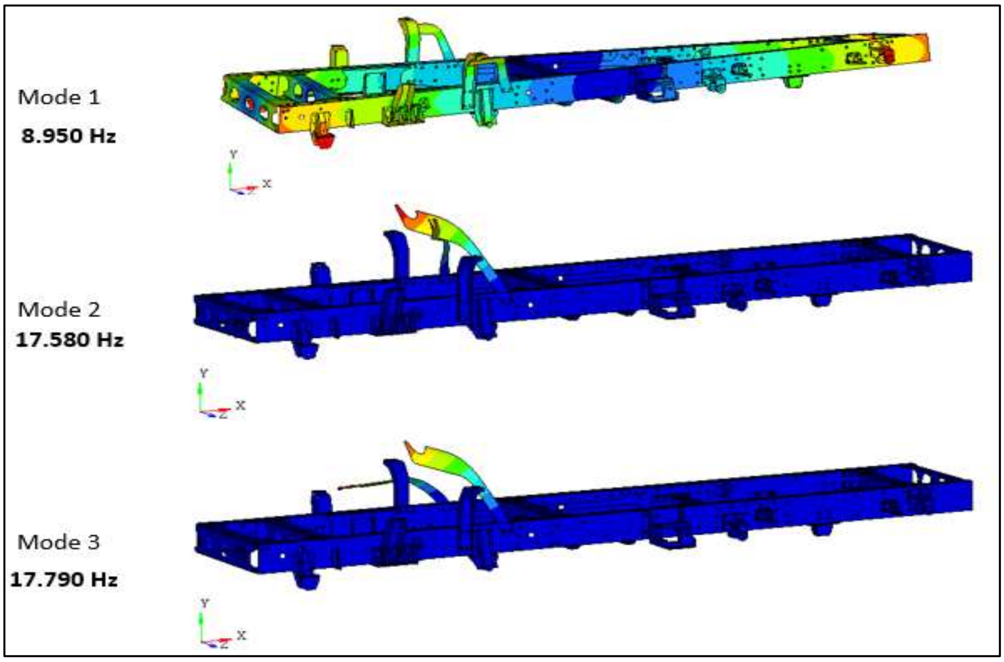


Figure 16: Normal Modes Analysis



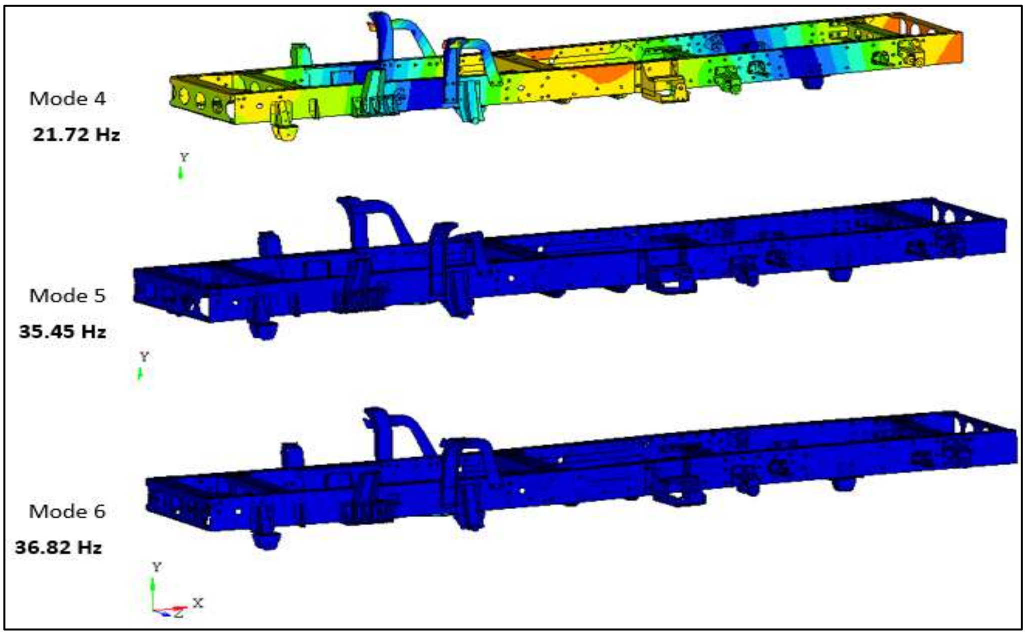


Figure17: Normal Modes - First Six

8. CONCLUSION

This thesis comprises of the Durability and Strength analysis of Truck Chassis Frame. Chassis is one of the major part of the superstructure, which supports the whole automotive in its entirety. Hence the analysis of such an important component is of utmost priority.

The analysis comprised of different loading conditions, which the structure/chassis is expected to being subjected, as well as endures in its entire life of the vehicle. Most of the analysis yielded results which showed major critical area near the Leaf Spring/Supports, Reinforcement Brackets which supports subassemblies to the chassis , Washer and Weld locations.

Upon further scrutiny, a few other locations were visibly weak in or on the other loading cases. There are various methods of enhancing the stress/strength of weak locations as such. The following are a few methods for improving the strength and durability of chassis. Nevertheless, the feasibility of such implementations should be thoroughly assessed before practical acceptance.

1) Reinforcement Brackets
2) Gussets, Angular Brackets
3) Design Modifications
4) FE modelling improvements
5) Optimization studies

8. SCOPE OF FURTHER WORK

For each design change, we cannot perform physical testing, as it will be very expensive; so CAE simulations are preferred in order to reduce the number of physical testing runs and thereby save cost.

- Frequency response analysis for dynamic inputs is to be performed to understand the dynamic behavior of the Chassis.
- Torture Track Analysis is to be carried out to assess the durability/high stress areas under various operating conditions
- Fatigue Life Simulations are necessary as well for understanding the lifing of the chassis.
-

The design of the chassis can be finalized once the above mentioned analyses are successfully performed along with the analysis carried out so far once again, till all the stresses are within agreeable limits.

9. REFERENCES

1. Vehicle Dynamics and Stability Analysiswith Matlab and Adams Car N.Arborio, P.Munaretto, M.Velardocchia, N. Riva, E. Suraci

2. Comfort Study of a Medium Sized Truck Considering Frame Flexibility with the use of ADAMS ® 2 Neto, A., Ferraro, L., Veissid, V., Freitas, C. et al., SAE Technical Paper 1999-01-3734

3. The Effects of Chassis Flexibility on RollStiffness of a Winston Cup Race Car Lonny L. Thompson, Pipasu H. Soni, Srikanth Raju and E. Harry Law

4. Dynamic Stress Analysis of a Bus Systems H. S. Kim, Y. S. Hwang, H. S. Yoon

5. FE-based Vehicle Analysis of Heavy Trucks Part I: Methods and Models I JOHANSSON, M.M GUSTAVSSON, M.Sc.

6. FE -based Vehicle Analysis of Heavy Trucks; Prediction of Force Histories for Fatigue Life Analysis

7. Stress Analysis of a Truck Chassis with Riveted Joints Cicek Karaoglu, Sefa Kuralay N

8. Dynamic Vehicle Element Method for Transient Response of Coupled Vehicle-Structure Systems Tso-Chien Pan

9. Application of the pothole DAF method to vehicles traversing periodic roadway irregularities V.Pestereva, A.Bergman, B.Yangd