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Weight Optimization and Fatigue life estimation of Heavy Vehicle Chassis under service loading conditions

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Abstract - *Chassis Frame is one of the main components in automotive which accounts for about 70% of whole load bearing of the vehicle. Failure of Chassis Frame component during heavy loading condition use is unacceptable. Heavy commercial vehicles are designed to have higher loading capacity so they need to be properly designed and have longer life to sustain the stress during its service loadings.*

The main objective of this paper is to optimise the weight of the chassis and predicting its strength and fatigue life. This paper represents the static, modal and the fatigue analysis of the baseline model with different material configuration along with modified model. The CAD model of the heavy vehicle chassis frame is prepared in Solidworks and meshing and proper material properties and boundary conditions are assigned using Hypermesh V14. Based on the result of the FE analysis, fatigue life of the chassis is calculated by employing MSC Fatigue.

Key Words: **Chassis, Fatigue analysis, Weight optimisation, Hypermesh, Fatigue life**

1. INTRODUCTION

The greatest competition at present at any ground automobile plant is to overcome the demand for greater performance, long life cycles and less weight of the parts of an automobile. The truck chassis for e.g. integrates many of the main components of the truck such as front and rear axles, engine mountings, suspension system, power train, cabin, trailer etc. and is considered to be the backbone of the vehicle.

Chassis forms the fundamental support of the structure of a commercial automobile. Body on frame type of design was present basically in every automobile design which was considered to be separated from entire vehicle body. Fig 1 shows the Heavy vehicle chassis frame.

Fig-1: Heavy Vehicle Chassis Frame

1.1 Problem Statement

Chassis Frame moves up and down along with the wheels as they move over uneven profiled roads. Corrosion, wear and fatigue are the main causes of failure of automotive chassis frames parts. Main failure form of chassis frame is fatigue damage, as shown in Figure 2.

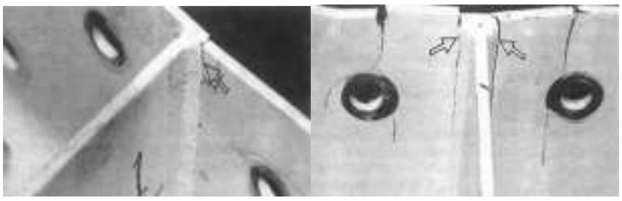

Fig-2: Chassis frame failure data

Hence it is very important that the chassis have to withstand against the failure caused due to fatigue.
Some of the major problems listed below have to overcome development stage before manufacturing the component.

- To evaluate the design strength of Chassis frame for Tata Motors LPT 2518 Model.
- To estimate the life of the Chassis frame component in design phase itself thereby reducing the experimental cost.
- Design improvement to enhance the fatigue strength of the chassis for uneven road conditions.
- Weight optimization of baseline designs for reducing the cost during batch production.

1.2 Chassis Material

Materials such as steel are typically used for building the chassis. However Aluminium alloys are nowadays preferred as they have the light weight characteristics which is essential for mass reduction property.

Why Al A201.0 T7 and A356 LM-25M Material

As compared to the other ANSI/AA Aluminium in the database, Al T7 has the high tensile strength. Al A201 material in terms of chemical composition comes with considerably large amount of Copper. Under this composition, it offers properties such as less corrosion resistance and weldability. Heat treatment is also possible for this low weight and less cost metal and loaded to relatively high level of stresses. Fatigue strength is high in T7 alloy.

Aluminum casting alloy LM25M is a common general purpose alloy of Aluminum. It is extensively used in the automotive sector. Corrosion resistant characteristics are offered by the material.

1.3 Objective of the paper

The objectives are as follows:

- Assessment and understanding the causes of failure for the chassis frames.
- To determine strength of the existing baseline model with existing material as well as for different material configuration.
- Determination of the modal frequency and mode shapes of the chassis by using modal analysis
- Reduce the mass of existing baseline model by varying the wall thickness, determine its dangerous area and improve the design.
- To evaluate the fatigue strength and fatigue life prediction of the newly modified chassis frame assembly with respect to baseline chassis design.

2. Geometric Modelling and solver deck preparation

To carry out CAE analysis of any component, the solid model of the same is essential. A Three-dimensional model of Heavy vehicle chassis frame is modelled with the help of modelling software Solid works. Firstly the dimensional data of the chassis frame is collected. Each part is modelled separately and then assembled to form a complete chassis structure.

2.1 Heavy Vehicle Ladder chassis frame

The structural foundation of a commercial vehicle lies in its chassis frame and is often referred to as a ladder frame. The CAD model is shown in fig-3.

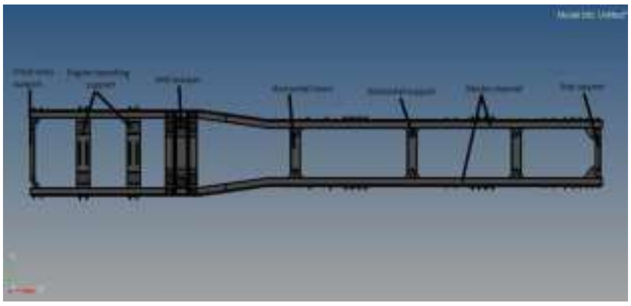

Fig-3: Ladder chassis frame

All the part components are assembled using assembly option in CAD software and the assembled CAD model is shown in fig-4.

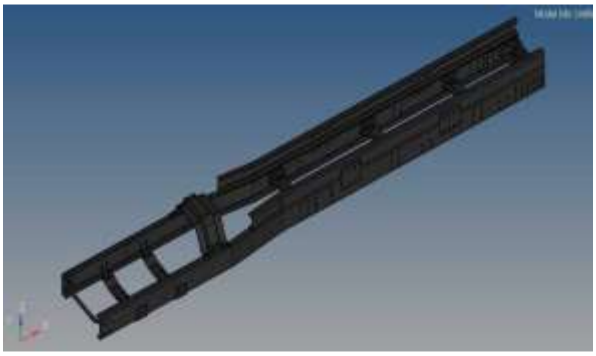

Fig-4: Assembly of the frame

2.2 Finite Element Modelling

Finite element model development initiates by importing the CAD file of the chassis frame model i.e. from Solidworks to Hypermesh software. Meshing of CAD model is carried out using shell and solid elements. Side members, cross members, end support, engine mounting support, bracket and horizontal supports are meshed using shell element quad4 with an average element size of 12mm. Fig. 5 shows the complete meshed model of chassis frame.

Fig-5: Meshed chassis frame

The component of chassis frame is a simple combination of different cross sections, properties and material.

2.3 Boundary Conditions

2.3.1 Static analysis inputs

Table-1 shows the specification of the existing heavy vehicle chassis taken for consideration

Table-1 Specification of the Heavy vehicle chassis

S.No.	Parameters	Value
1	Total length of chassis	9010 mm
2	Width of the chassis	2440mm
3	Wheel base	4880mm
4	Front overhang	1260mm
5	Rear overhang	2155mm
6	Ground clearance	250mm
7	Capacity (GVW)	25 ton
8	Kerb weight	5750 Kgs
9	Payload	19250 Kgs

The existing chassis frame have side bars of C channel with dimensions 285x65x7 mm
Truck Capacity or Gross Vehicle Weight = 25 tonnes
= 25000 x 9.81 = 245250 N
Considering 1.25% margin, total capacity of the truck
= 245250 x 1.25 N = 306562 N
Hence overall load which is acting is 306562 N.

Chassis is fixed at front axle as well as rear axles. There are two boundary conditons for the model; First one is applied at the front axle and the other one at the rear end of the axle.

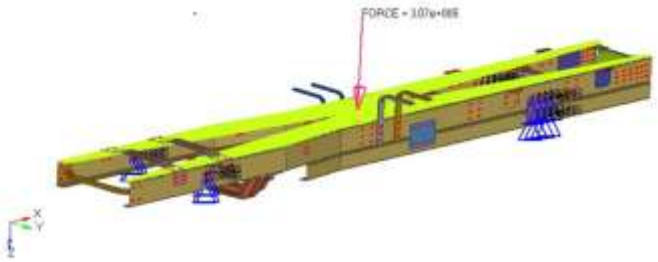

Fig-6: Boundary conditions

2.3.2 Fatigue analysis inputs

Loading history is the service environment that the chassis is subjected to its duty cycle. The loading histories are shown in the fig. 7

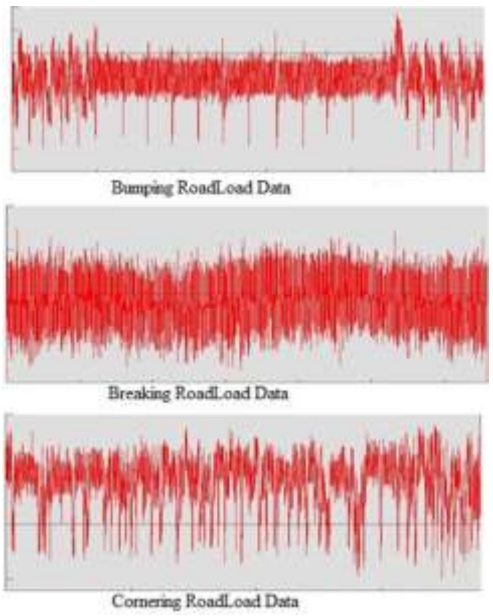

Fig-7: loading history

The maximum stress obtained from the finite element analysis is utilized and the fatigue life is then estimated using above road load histories, material properties and the mean stress correction.

3. Results and Discussion

Simulation is the processes of product validation were the product is tested with defined boundary conditions and assumed parameters.

3.1 Modal and static analysis results

For the modal analysis of the frame the boundary conditions are given as fixed support only i.e. for constrained analysis and for free-free analysis model is kept in free space. For static analysis, fixed support, loading condition and acceleration due to gravity are given as boundary conditions. The analysis is carried out on existing material i.e. low alloy steel AISI 4135 as well as on Al 201 T7 and Al A356 LM.

3.1.1 Low alloy steel 4135

For free-free modal analysis frequency is 5.57 Hz and for constrained frame frequency is 10.63 Hz. The result images are shown in fig-8 and fig-9.

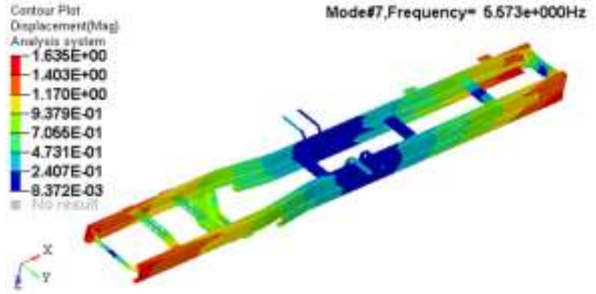

Fig-8: Free free modal analysis Low Alloy Steel AISI 4135

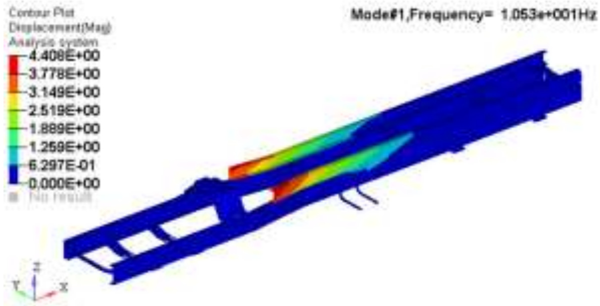

Fig-9: Constrained modal analysis Low Alloy Steel AISI 4135

For Low alloy steel AISI 4135, maximum displacement is 8.55 mm and maximum von-misses stress is 216 Mpa.

Fig-10: Von-Misses Stress plot for Low Alloy Steel AISI 4135

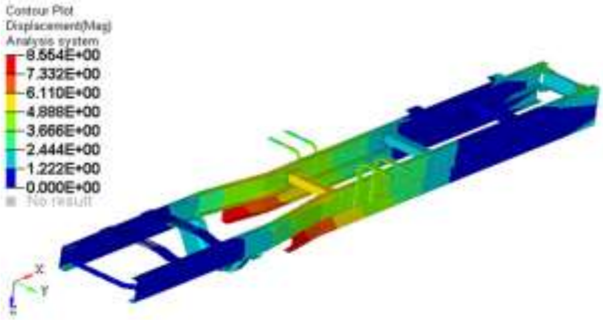

Fig-11: Displacement plot for Low Alloy Steel AISI 4135

3.1.2 Aluminum A201.0, T7

For free-free modal analysis frequency is 5.553 Hz and for constrained frame frequency is 10.5 Hz.

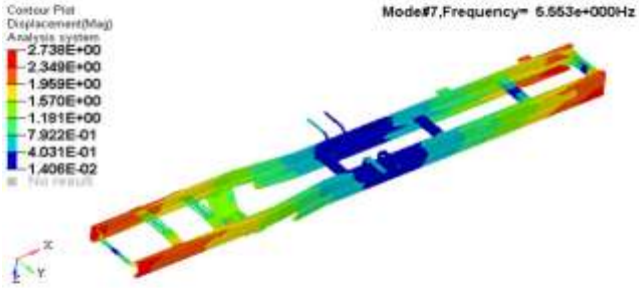

Fig-12: Free-Free Modal Analysis for Aluminium A201.0, T7

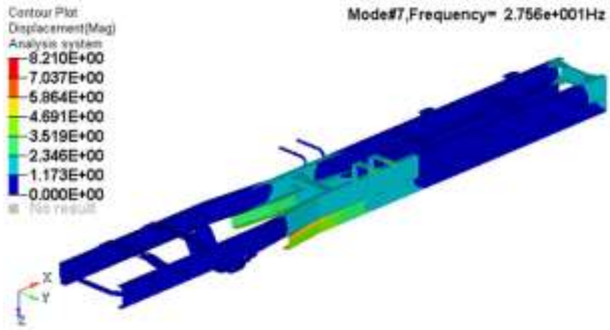

Fig-13: Constrained Modal Analysis for Aluminium A201.0, T7

For Aluminum A201.0 T7, maximum displacement is 19.65mm and maximum von-misses stress is 294 MPa.

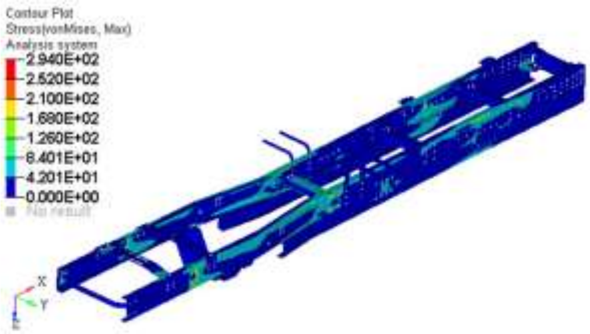

Fig-14: Von-Misses Stress plot for Aluminium A201.0, T7

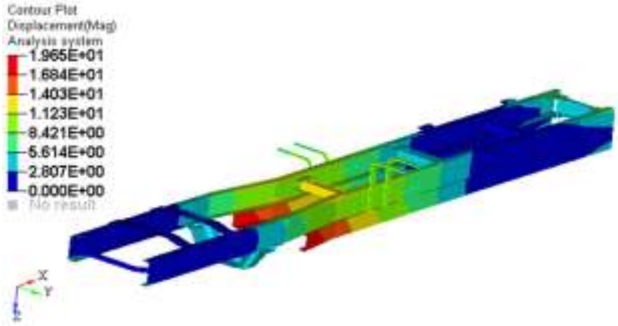

Fig-15: Displacement plot for Aluminium A201.0, T7

3.1.3 Aluminium A356.0 LM25-M

For free-free modal analysis frequency is 5.69 Hz and for constrained frame frequency is 10.53Hz.

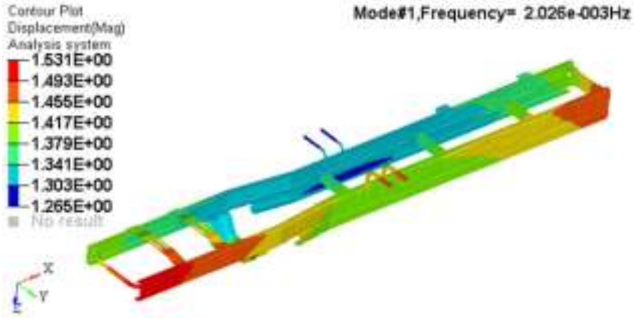

Fig-16: Free-Free Modal Analysis for Aluminium, A356.0 LM25-M

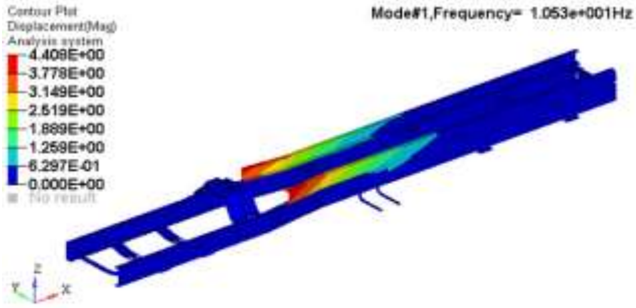

Fig-17: Constrained Modal Analysis for Aluminium, A356.0 LM25-M

For Aluminum, A356.0 LM25-M static analysis results are maximum displacement is 13.75mm and maximum von-misses stress is 292.3Mpa.

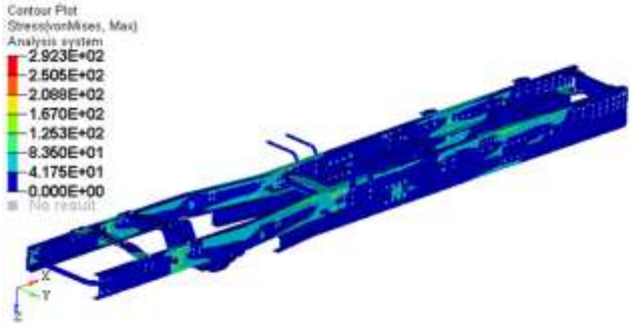

Fig-18: Von-Misses Stress for Aluminium, A356.0 LM25

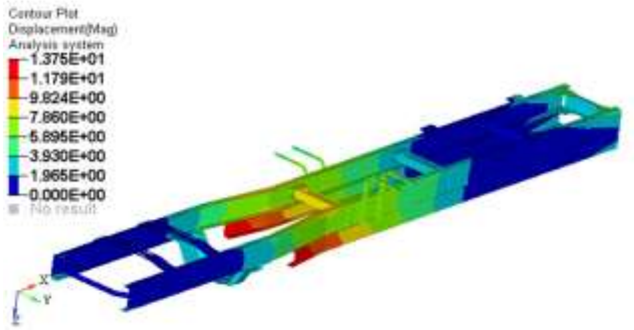

Fig-19: Displacement plot for Aluminium A356.0 LM25

3.2 Summary of Static and Modal analysis results

The table-2 shows the comparison between the simulation results of ladder chassis frame with different materials

Table-2: Summary of Results

Materials	Static Analysis		Modal Analysis		Weight	Price
	Displacement (mm)	Stress (MPa)	Free-free frequency	Constrained frequency	(kg)	(INR/Kg)
Low Alloy Steel AISI 4135	8.55	216	5.57	10.63	1470	60-95
Aluminium A201.0 T7	19.6	294	5.553	10.5	524.7	116-128
Aluminium A356.0 LM25-M	13.75	292.3	5.69	10.53	500.2	105-116

The displacement is less i.e. 8.55 mm in Low Alloy Steel AISI 4145 compared to other metal alloys.

The ladder chassis made of Aluminum A356.0 LM25-M has less weight of 500.2 kg compared to other materials analyzed. So we brief that it is better to use Aluminium A201.0 or Aluminium A356.0 LM25-M, cast as material for frames of heavy vehicle chassis. As we have seen max displacement is 13.75 mm as well as we have decreased the weight of the chassis by considerably 50-60 %.

3.3 Fatigue analysis results

The fatigue life contours for the baseline model and the modified model are shown in fig-20 to fig-23

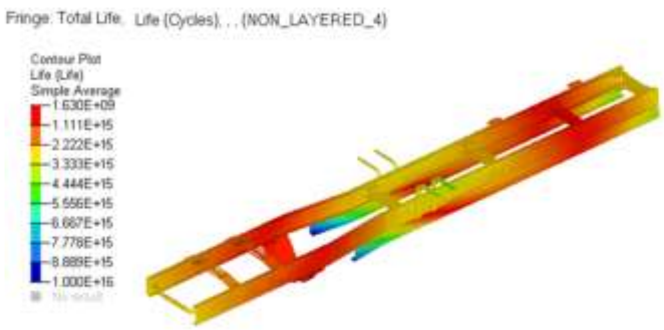

Fig-20 : Fatigue life counter plot of chassis (Low alloy steel AISI 4135)

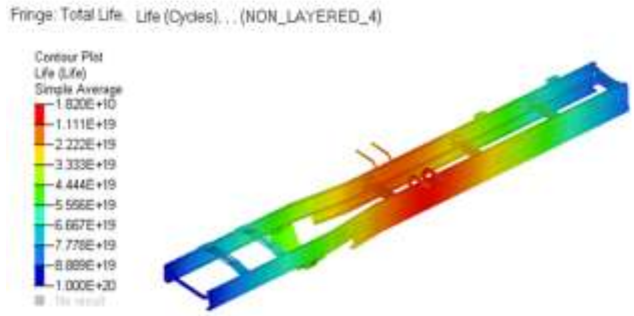

Fig-21 : Fatigue life contour plot of chassis (Aluminium, A356.0 LM25-M)

Modifications for the baseline geometry of the chassis has been done considering Al A356 material. These modifications include increase in weld thickness by 5mm, adding corrosion resistance parameter to the material property and increasing the thickness by 3mm near bolt connection region. These are performed on all the clamping component of the chassis. Figure shows the modified fillet region for the clamping support of the model.

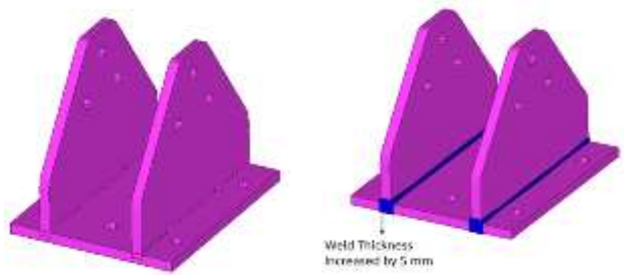

Fig-22 : Modified fillet region for clamping support

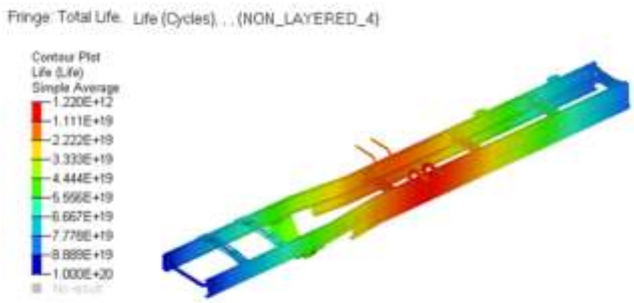

Fig-23: Fatigue life counter plot of chassis with increased fillet radius (Aluminium, A356.0 LM25-M)

3.4 Summary of fatigue analysis

Table-3 below summarizes the fatigue analysis results of the chassis with different models.

The fatigue analysis results showed that weakest spot in the baseline model is near mounting of Rear axle and engine mounting has 1.60 e+09 life cycles (> 10^6 cycles). For Modified baseline model with Aluminium A356 LM-25M has 1.82 e+10 life cycles.

Table-3: Summary of fatigue results

Model Description	Fatigue Life
Existing baseline model (Low Alloy Steel AISI 4135)	1.60 e+09
Modified baseline model (Aluminium, A356.0 LM25-M)	1.82 e+10
Modified baseline model + Increased fillet (Aluminium, A356.0 LM25-M)	1.22 e+12

As the fillet radius is increased by 5mm in weld and joint connections, we found increase in fatigue life of the model. Increase in fillet radius by 3mm near bolt connection showed up increase in fatigue life. For modified baseline model with increased fillet radius for the material Al A356 has life of 1.22 e+12 cycles.

4 Validation of the results

Theoretical calculations have been done for the validation of finite element model results. Stress acting at critical region have been obtained from finite element analysis and compared with theoretical design calculations.

4.1 Design calculations for Static Analysis

The chassis which we have considered is having C cross section with dimensions 285mm x65mm x7mm. Loading condition over the beam is shown in the fig 24.

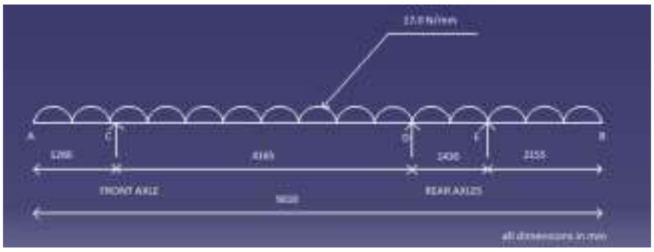

Fig-24 : Total load acting over the beam

Considering chassis member as simply supported beam with uniformly distributed load acting on the beam. So as per the boundary condition of the beam, load acting along one side of beam = 153281 N per beam
Length of the beam = 9010mm
Maximum bending moment is calculated from the loading diagram by taking moments equation
Bending stress is calculated by employing the basic bending equation.

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$$

$$\sigma = -\frac{39657411.25}{29195623.9} \times 142.5$$

Hence we get σ = -193.56 MPa

Hence we can correlate the stress value obtained theoretically by calculation and the value obtained from FE analysis which is coming around as 216 MPa.

4.2 Calculations for Modal Analysis

For Modal analysis, chassis is assumed to be a rectangular plate under fixed free condition. Under fixed- free condition, Rayleigh method can be utilised to calculate the natural frequency of the plate.

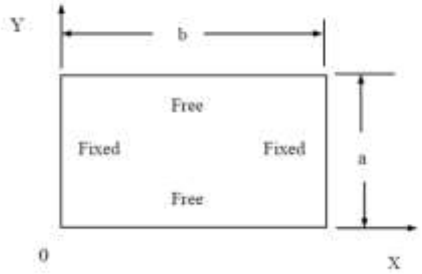

Fig-25: Rectangular plate under fixed free condition

$$f_n = \frac{3.55}{b^2}\sqrt{\frac{D}{\rho}}$$

Hence we get

$$f_n = \frac{3.55}{9^2} \times \sqrt{4.29 \times \frac{10^8}{7850}}$$

= 10.245 Hz

Hence we can correlate the above obtained frequency value with the constrained frequency obtained from FE analysis which is around 10.6 Hz.

4.3 Calculation for fatigue analysis of chassis

The maximum and minimum stress values obtained from the Static analysis for the chassis (baseline model) are 216 MPa and 30.93 MPa respectively. By applying the Goodman criteria, we can estimate the endurance strength of the material.

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}} = 1$$

Hence by substituting the values in the equation we get,
Se= 118.7 MPa
Using the S-N approach formula,

$$S_n = aN^b$$

a and b are fatigue constants and are evaluated using

$$\log a = \log S_m - 3b$$

$$b = -\frac{1}{3}\log\left(\frac{S_m}{S_e}\right)$$

Hence we get a= 2292.7
b= -0.209
Therefore by putting the values in the equation we get
N= 1.39x 10^6 cycles
Hence S-N approach used for the calculation of life satisfies the infinite life criteria (> 10^6 cycles).

5 Conclusion

The FE analysis performed on all the chassis models with different materials showed that, the most critical spot in the chassis is located at the mounting of rear and engine mounting.
The static and modal analysis showed that Aluminium A201.0 T7, Aluminium A356 LM-25M material is suitable for chassis design.
Baseline model is showing the fatigue life of 1.6 E+09, but is not meeting the actual service life in reality.
The stress life (S-N) approach is employed to evaluate the fatigue life of Chassis. The analysis results showed that modified chassis with increased radius has 1.22 E+12 fatigue life cycles.
It is observed that by increasing the weld thickness by 5 mm and increasing the material thickness by 3mm near bolt connection region will stop crack formation in real life scenario and hence there is significant improvement of fatigue life of the chassis.
By these conclusions we can say that the modified chassis is safe and satisfy the infinite life criteria. By implementing FE based fatigue analysis at development stage the cost of prototype testing and production time can be reduced.

Future Scope

The study can be further done by replacing the chassis material by composite material, increasing the strength and stiffness with low mass.
The study can be extended to investigate the crack propagation characteristics, if there is crack in chassis. The fracture mechanics criteria can be implemented to determine remaining life of chassis before fracture.

Acknowledgement

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