Design Modification of Ladder Chassis Frame Based on Dynamic Analysis

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Abstract - *Automotive chassis is a skeletal frame on which various mechanical parts like engine, tires, axle assemblies, brakes, steering etc. are bolted. 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. Automobile chassis is usually made of light sheet metal or composite plastics. Automotive chassis helps to keep an automobile rigid, stiff and unbending.*

In this Paper, modal analysis of the chassis was done using three different materials namely structural steel, Aluminium alloy and carbon/epoxy (UD 395 GPa) composite. The first six non-zero natural frequencies and their corresponding mode shapes were extracted. Thus, in the next part, some modifications were made in the chassis design so as to study their effect on the natural frequencies and push the frequencies away from the critical range, so as to avoid resonance. Finally, harmonic response analysis was carried out on original and modified chassis to check the response under a harmonic force

Key Words: Vibration; Resonance; Chassis; Dynamic Analysis; FEA

1. INTRODUCTION

Vibration problem occurs where there are rotating or moving parts in machinery. The effects of vibration are excessive stresses, undesirable noise, looseness of parts and partial or complete failure of parts. The structures designed to support heavy machines are also subjected to vibrations. The structure or machine component subjected to vibration can fail because of material fatigue resulting from cyclic variation of the induced stress.

Chassis frame is the basic frame work of the automobile. All the automobile systems like transmission, steering, suspension, braking system etc. are attached to and supported by the chassis frame. The frames provide strength as well as flexibility to the automobile. When the vehicle travels along the road, the chassis is subjected to excitations from the engine and transmission system as well as due to the road profile. Due to these excitations, the chassis begins to vibrate. If the Natural frequency of vibration coincides with the frequency of external excitation, resonance occurs, which leads to excessive deflections and failure.

Simulation results indicate that the chassis weight optimization and cross-section have considerable effect on ride comfort, handling, stability and prevention of vehicle rollover through quick speed manoeuvres. Optimized chassis, the structural natural frequency can be moved out of this critical range.

In the current paper, dynamic analysis of a ladder chassis frame has been done using Ansys software. Modal analysis of the chassis was done using three materials and their performance was compared. The structural steel chassis was chosen for further consideration and modifications were tried out to push the natural frequencies beyond the critical range. Harmonic analysis was done on original and modified chassis to check the response to harmonic force.

The ladder chassis frame consists of two symmetrical long members and a number of connecting cross members. This type of chassis is commonly found in busses, trucks, SUV's and pick-up vans.

1.1 Modal Analysis

It is used to determine the mode shapes and natural frequencies of a machine or a structure. It is the most basic form of dynamic analysis .The output of modal analysis can further be used to carry out a more detailed dynamic analysis like harmonic response analysis, transient analysis etc.

1.2 Harmonic Analysis

From the natural frequencies obtained by modal analysis, the harmonic analysis determines which vibration modes contribute more significantly to the dynamic response of the structure through frequency response curves.

2. Modal Analysis of Chassis Frame Using Three Different Materials and their Comparison

A ladder chassis frame has been chosen for analysis. The chassis frame consists of long members and cross members as Shown in Fig. 1. The FE model of chassis is shown in Fig. 2. Modal analysis of chassis frame has been carried out in Ansys in the free-free condition. Analysis is done using three different materials namely structural steel, Aluminium alloy and carbon/epoxy composite. Since free-free condition has been used, the first six natural frequencies are either zero or very close to zero. They correspond to rigid body motion and have been neglected. The first six non-zero natural frequencies and their corresponding mode shapes have been extracted and the results have been compared.

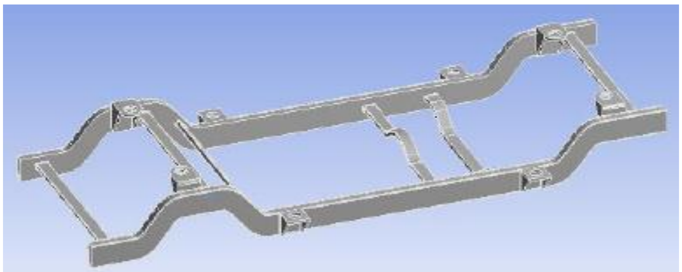


Fig. 1. 3D model of chassis frame

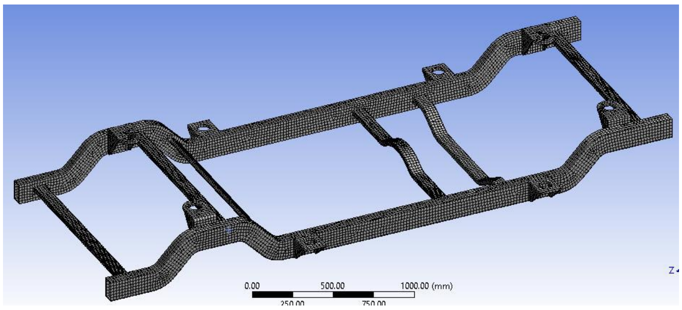


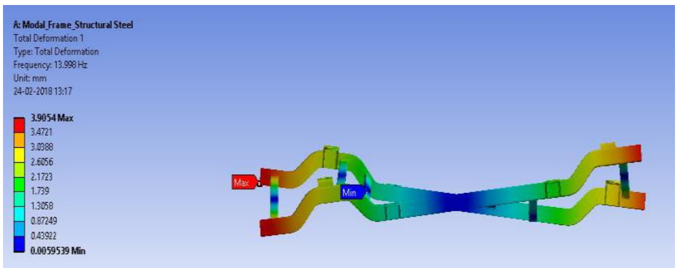
Fig. 2. FE model of chassis frame

Material 1: Structural Steel. Material properties: Density=7850kg/m^3, Young's Modulus=200 GPa, Poisson's Ratio=0.3.

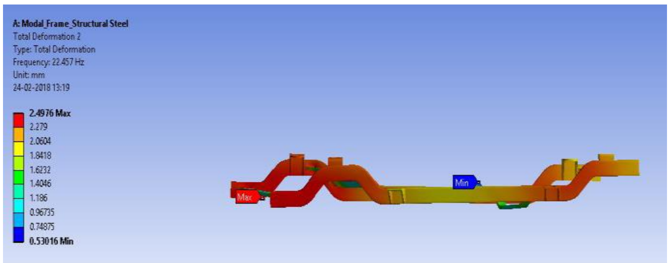
Table 1.Natural frequencies and deformations for structural steel.

Mode	frequency	Max. deformation
1	13.998	3.9054
2	22.457	2.4976
3	37.975	3.976
4	39.246	4.7399
5	49.24	4.8121
6	58.837	6.07155

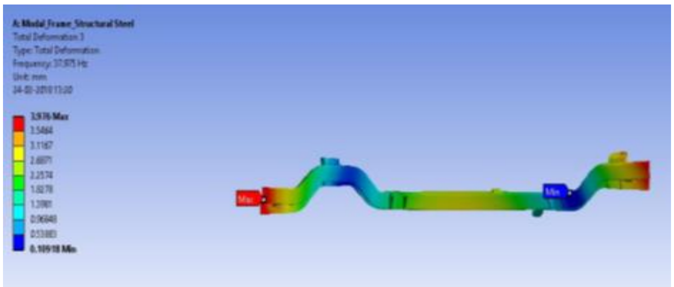
The first six mode shapes for the structural steel chassis are shown in the figure below.



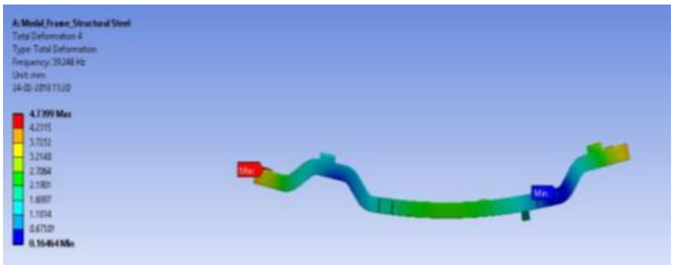
Mode 1



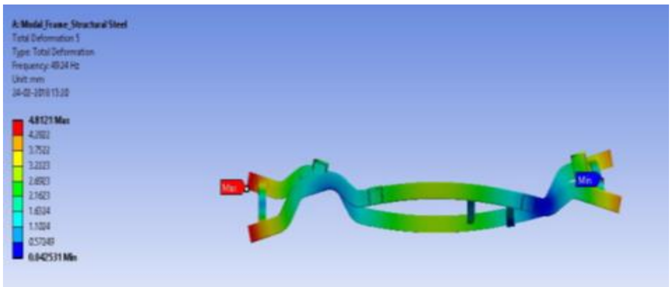
Mode2



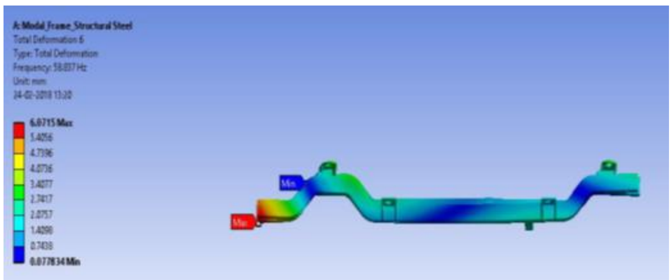
Mode 3



Mode 4



Mode 5



Mode 6

Fig. 3. Mode shapes for structural steel chassis.

It can be seen from Fig. 3 that the first mode shape is the first twisting mode of the chassis which occurs at a frequency of 13.998 Hz. The fourth mode is the vertical bending mode and occurs at 39.246 Hz frequency. The fifth mode occurs at a frequency of 49.24 Hz and is the second twisting mode of the chassis.

Material 2: Aluminium Alloy. Material properties: Density=2770 kg/m^3, Young's Modulus=71 GPa, Poisson's Ratio=0.33.

Table 2. Natural frequencies and deformations for Aluminium alloy.

Mode	Frequency (Hz)	Max. deformation (mm)
1	13.993	6.5807
2	22.68	4.1971
3	38.177	6.688
4	39.377	7.992
5	49.366	8.098
6	59.271	10.215

The mode shapes for Aluminium alloy chassis are same as that for the structural steel chassis. The only difference is in the values of relative deformations.

Material 3: Carbon/epoxy. Material properties: ρ=1540 kg/m^3, Ex=209 GPa, Ey=9450 MPa, Ez=9450 MPa, νxy=0.27, νyz=0.4, νxz=0.27, Gxy=5500 MPa, Gyz=3900 MPa, Gxz=5500 MPa. Where, ρ=Density, E= Young's modulus, ν= Poisson's ratio, G=Shear modulus.

Table 3. Natural frequencies and deformations for carbon-epoxy.

Mode	Frequency (Hz)	Max. deformation (mm)
1	9.2347	9.4605
2	16.48	5.812
3	19.375	9.5806
4	25.391	10.23
5	27.842	10.011
6	40.467	13.248

For composite material chassis, the first mode is the first twisting mode, the Third mode is the vertical bending mode, while the fourth and fifth modes are again twisting modes.

Comparison of results: The natural frequencies, maximum relative deformation per mode and weight of chassis have been compared for the three materials used in the following figures.

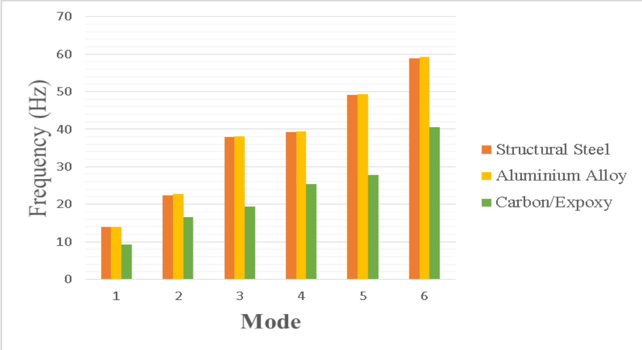


Fig. 4. Natural frequency Vs. mode number.

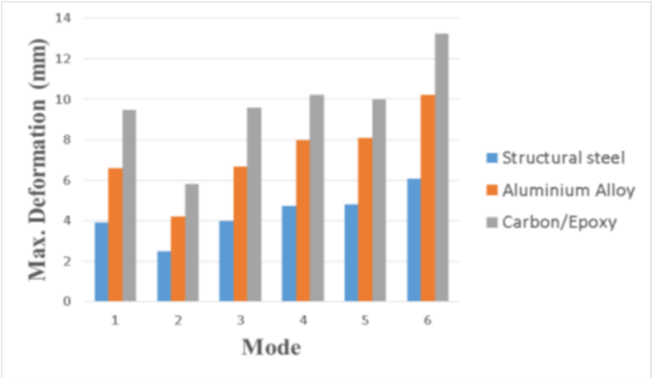


Fig. 5. Max. deformation Vs. mode number.

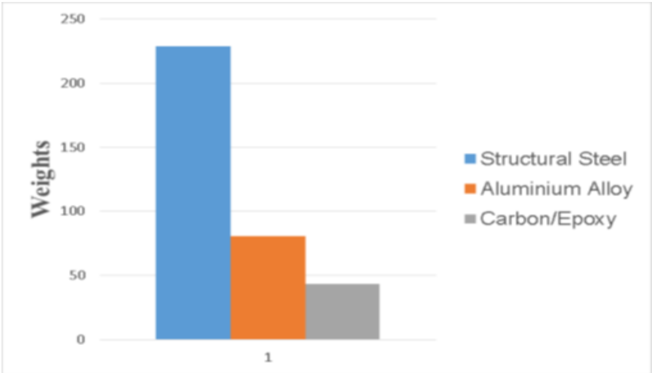


Fig. 6. Comparison of weights.

Material 4: Stainless steel. (Cross member).Material properties: Density=7750kg/m^3, Young's Modulus=193 GPa, Poisson's Ratio=0.31.

From the above comparisons, we can say that the frequency values for Structural steel and Aluminium alloy chassis are nearly the same, while those for carbon-epoxy composite material chassis are on the lower side. However, the maximum relative deformation per mode is the lowest for structural steel chassis. As compared to the steel chassis, the weight of the composite material chassis is 80% less. The structural steel chassis was selected for further analysis.

2.1 Chassis Modifications to Avoid Resonance

As can be seen from the previous discussion, the first six natural frequencies for the structural steel chassis lie in the range from 13-60 Hz. In practice, the road excitation has typical values varying from 0-100 Hz. At high speed cruising, the excitation is about 3000 rpm or 50 Hz. Diesel engine is known to have operating speed varying from 8-33 rps. In low speed idling condition, the speed range is about 8-10 rps. This translates into excitation frequencies varying from 24-30 Hz. From modal analysis results of structural steel chassis, we can see that the second natural frequency lies in the 24-30 Hz range, while the fifth frequency is close to 50 Hz. Thus the chassis may experience structural resonance at idling and high speed cruising condition. We will try to modify the chassis and try to push the natural frequencies away from the critical range. The modifications will lead to either change in mass or change in stiffness or both. An increase in mass will reduce the natural frequency, while an increase in the stiffness will increase the natural frequency.

The original chassis is as shown in Fig. 1 and consists of six cross members. The long members are of hollow rectangular box-section with 5 mm thickness. The weight of original chassis considering structural steel material is 236.68 kg. The overall length is 3825 mm.

Modification 1: In this iteration, two changes have been made to the original chassis. The Overall Length of the chassis is reduced from 3825mm to 3675mm and an additional Stainless steel cross member has been added. Material of chassis is structural steel. The modified chassis 1 is shown in Fig. 7 below.

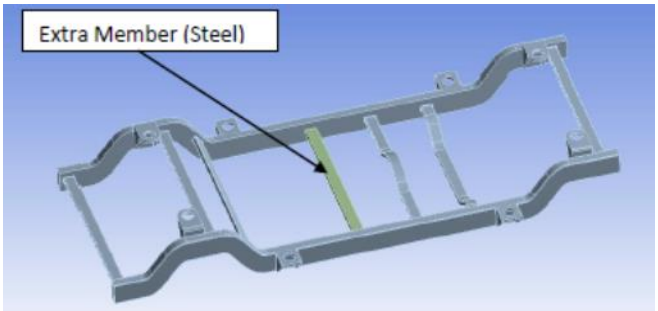


Fig. 7. Modified chassis 1.

The natural frequencies obtained are compared with the original case as follows:

Table 4. Comparison of natural frequencies for original chassis and modified chassis 1

Mode	Frequency (original) (Hz)	Frequency (modification 1) (Hz)
1	13.998	14.753
2	22.457	24.213
3	37.975	37.765
4	39.246	36.559
5	49.24	49.727
6	58.837	56.596

It can be seen from the above comparison that due to the modification, fourth and Sixth natural frequencies have reduced. Also, this modification Increases the weight of chassis to 247.8 kg. Thus, the effect of this modification is to reduce or increase the natural frequencies.

Modification 2. In this iteration, two changes have been made to the original chassis. Firstly, the overall length has been reduced from 3825 mm to 3675 mm. Also, two extra cross members made of stainless steel have been added. Material of chassis is structural steel. The modified chassis 2 is shown in Fig.8.

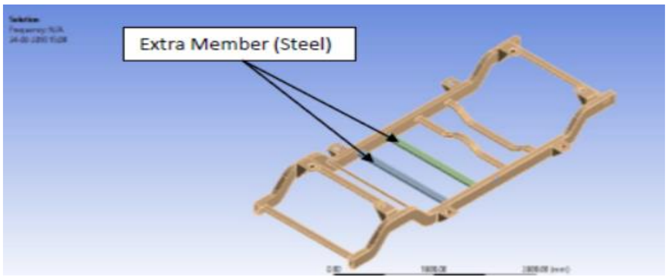


Fig. 8.Modified chassis 2.

The results as compared to the original chassis are given below:

Table 5. Comparison of natural frequencies for original chassis and modified chassis 2.

Mode	Frequency (original) (Hz)	Frequency (modification 2)
1	13.998	15.228
2	22.457	26.173
3	37.975	34.975
4	39.246	35.231
5	49.24	49.087
6	58.837	56.126

It can be seen from the above comparison that due to the Modification, third, fourth, Sixth natural frequencies have reduced. Also, this modification Increases the weight of Chassis to 271.24 kg. Thus, the effect of this modification is to Reduce or increase the natural frequencies.

Modification 3. In this iteration, the length of chassis has been reduced from 3825 mm to 3675 mm and two extra cross members made of carbon-epoxy composite material have been added. The remaining body of chassis is made of structural steel. The modified chassis 3 is shown in Fig. 9 below.

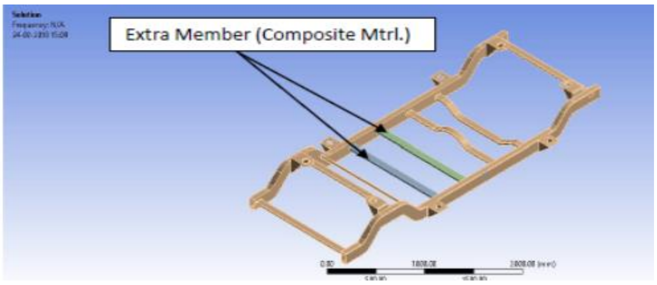


Fig. 9. Modified chassis 3.

The comparison of frequencies is given in the table below:

Table 6. Comparison of natural frequencies for original chassis and modified chassis 3.

Mode	Frequency (original) (Hz)	Frequency (modification 3) (Hz)
1	13.998	14.401
2	22.457	25.93
3	37.975	38.112
4	39.246	39.491
5	49.24	50.965
6	58.837	62.4

From the above table, we can say that this modification also results in an increase in the natural frequency values for all modes. Also, the weight of chassis has reduced from 236.38 kg to 233.38 kg due to this modification. Thus, the effect of this modification is to increase the natural frequencies.

3. Harmonic Response Analysis of Original and Modified Chassis

In this part, a harmonic force having magnitude equal to engine weight (1000 N) is applied to one of the cross member and the average response of the entire chassis to this harmonic force at different frequencies is recorded. The output is the frequency response curve, where the peaks correspond to the natural frequencies corresponding to the vertical bending modes of the chassis.

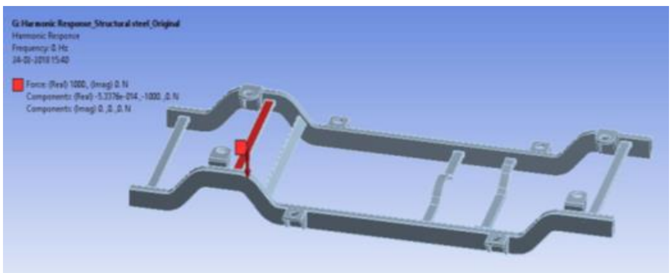


Fig. 10. Harmonic force applied to chassis.

The frequency response curves for the original chassis and the three modified chassis are shown in the figures below.

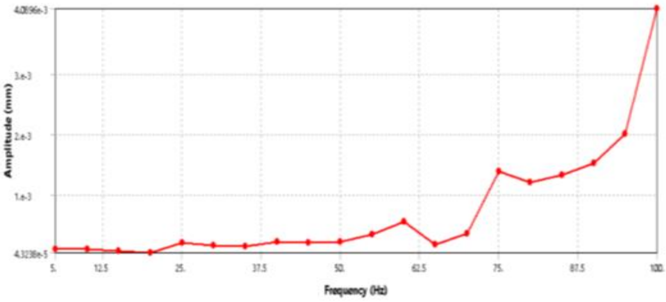


Fig. 11. Frequency response curve- original chassis.

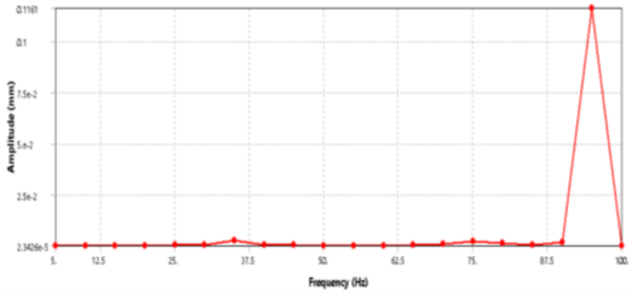


Fig. 12. Frequency response curve-modified chassis 1.

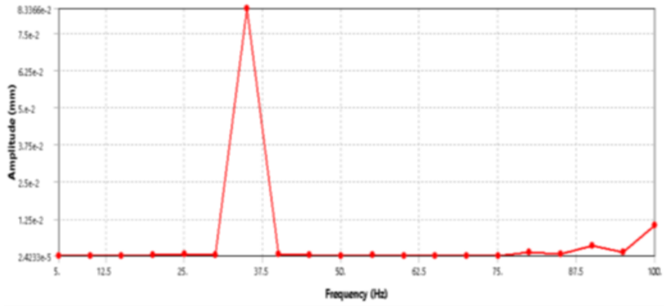


Fig. 13. Frequency response curve-modified chassis 2.

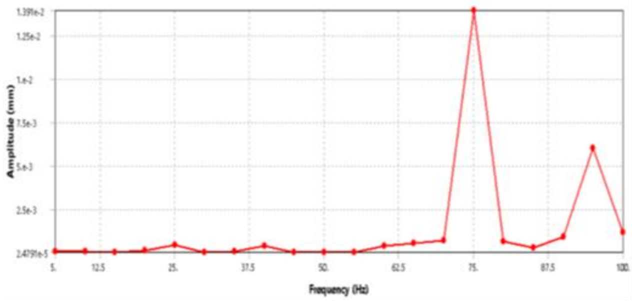


Fig. 14. Frequency response curve-modified chassis 3.

From the above four frequency response curves, we can see that the maximum amplitude of vibration is 4.0896e-3 mm At 100 Hz for the original chassis, 0.1161 mm at 95 Hz for Modification 1, 8.34e-2 mm at 35 Hz for modification 2and 1.391e-2 mm at 75 Hz for modification 3. Thus, out of the three modifications, the amplitude of vibration is Minimum for modification 3.

4. CONCLUSIONS

In this paper, dynamic analysis of a ladder chassis frame is Discussed and based on the results, some modifications were made to the chassis to study their effect on the natural frequencies. The modifications included reduction in overall length of chassis, addition of extra cross members and use of alternate materials for cross members. These modifications helped in pushing the frequencies away from the critical range. The following results can be drawn from this work:
The frequency values for Structural steel and Aluminium alloy chassis are nearly the same and lie in the range 13-60 Hz, while those for carbon-epoxy composite material chassis are on the lower side (9-45 Hz). However, the maximum relative deformation per mode is the lowest for structural steel chassis. By using composite material for the chassis, there is a reduction in weight by 80 % over steel chassis.

These frequencies lie in the range of excitation frequencies due to engine vibrations and road profile excitations.

Reducing the length of chassis increases its stiffness and hence increases its natural frequencies.

Extra cross members added to chassis mainly affect its natural frequency and increase or decrease it significantly.
Using these methods, we can alter the natural frequencies of the chassis and place them in the natural range and hence prevent resonance and unusual chassis vibrations.

Out of the three modifications made, harmonic analysis showed that for the given inputs, the amplitude of vibration is minimum for modification 3. It also reduced the weight of chassis by 3 kg.

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