Front, rear and side impact analysis of backbone chassis of a compact sports car

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Abstract. The automotive chassis is the main load carrier and energy absorbing component in all crash events namely, frontal impacts, rear impacts, side impacts and roll over. It is important to have a strong and light weight material for the chassis. The purpose of this paper is to observe how a backbone chassis behaves during collision. This work involves static, dynamic and modal analysis of a backbone chassis of Lotus Europa, a compact sports car. Deformation, stress and strain distribution are evaluated and factor of safety is calculated using static structural analysis. In modal analysis mode shapes for different natural frequencies of the system are presented. Further, impact analysis performed using explicit dynamic analysis compares the deformation and stress distribution for front, rear and side impact for different impact velocities. Two materials namely mild steel and aluminium are compared for impact analysis.

1. Introduction

An automotive chassis also known as a vehicle frame is the skeleton system of a vehicle which holds all the components of a vehicle intact ranging from powertrain to vehicle controls. It is the primary structural component where all automotive components are attached either by welding or by bolted joints. An automotive chassis not only acts as a carrying unit but also provides protection to passengers during impacts or collisions. The three major types of impacts experienced by an automobile are frontal impacts, rear impacts and the deadliest - side impacts. An ideal automotive chassis has the perfect characteristics and is most suited for an automobile. It is light weight and at the same time strong, easy and less expensive to manufacture, provides good ventilation and space to passengers. Most importantly it has the ability to withstand static, dynamic loads and provides protection from impacts. The automotive chassis is basically of two types conventional and non-conventional. The backbone chassis is a type of conventional chassis and has a tubular backbone which helps connect the front and rear suspensions attachment areas. It has a very compact design hence can be used for small sports cars. Ananda et. al., [1] designed a front car bumper to withstand frontal impacts. Static analysis was performed to get maximum stress and deformation for different shell thicknesses, to check if design is safe based on strength criteria. Dynamic analysis was performed to check maximum amplitude and dynamic conditions for safe design. Tyagi [2] designed a chrome alloy steel space frame tubular chassis for a Formula 1 student car and analysed it for maximum stress and deformation. Boundary conditions for the analysis were loads acting on the chassis under stationary condition. Finally, the design was proven safe for manufacturing. Arshad [3] studied the dynamic response of a frame structure subjected to point loads by performing vibration analysis using finite element and numerical time integration methods. The effect of speed of moving load was investigated along with the spring stiffness effect attached to the frame. Chandan et. al., [4] had made an approach to design a space frame formulae student car. Analysis was performed to evaluate stresses during front, rear and side impacts. Modal analysis was also performed to get displacement at different modes. Dasaradh et. al., [5] had designed a heavy vehicle ladder chassis using SolidWorks and performed static, dynamic and modal analysis.
using ANSYS to get stress distributions and deformations for different materials and three different thickness of crossbar. Chinnamaddaiaah et al., [6] designed a go-kart chassis using Catia V5 and analysed it for front, rear and side impacts to find stress concentrations and weak points of the chassis. Someswara et al., [7] had designed a standard ladder chassis and analyzed it for maximum shear stress, Von-Mises stress and deformation by assigning different materials such as aluminum and steel alloys under static loading. The design was based on the least weight and highest strength. Veerawamy and Sudheer [8] designed a side door composite beam to replace existing steel beam to minimize weight and improve resistance against side impact. They performed static analysis to compare the total energy absorptions of the beams. Carbon/epoxy was used as replacement for steel. Manpreet et al., [9] designed a ladder chassis and performed static structural analysis to find the maximum stress acting and the hotspots where design modifications would be required. Further, verified the results with theoretical results and found good agreement. Monika and Razik [10] reviewed various analysis techniques used to analyze a ladder chassis by referring the literature available. Ravi et al., [11] designed and performed structural analysis on heavy vehicle ladder chassis made of steel and different polymer composites having C-section, I-section and box channel cross-sections. Further, various studies such as deformation versus load and stress versus load graphs, a comparison of stiffness, strength and weight were presented. Finally, chassis design with least weight and highest strength and stiffness was chosen. Piyush and Akshay [12] designed a space frame chassis for a formula student car and then calculated stress and deformations based on front, rear, side impact, torsional and rollover using finite element analysis. Baskara et al., [13] made a 3-dimensional computer aided design (CAD) model of a space frame chassis and analyzed it for front and side impacts using ANSYS software. Further, torsional stiffness was also evaluated for the chassis. Prajwal et al., [14] first modelled a space frame tubular chassis and analysed it for stress and deformation using static analysis and then manufactured the chassis and performed actual testing on it for verification. Sairam and Gopinath [15] performed static and dynamic analysis on Tatra chassis which is of backbone type to calculate maximum stress acting. Limited modifications were carried out by adding stiffeners of various thicknesses to the C-channel to enhance the load carrying capacity. Chandrakant and Prashant [16] designed a door intrusion member for side impact protection of Hyundai Verna car and analyzed it for deformation and stress distribution during side impact loading. The results were verified by Universal Testing Machine (UTM) testing results of the intrusion member. By observing the above literature it is evident that static structural, modal analysis and impact analysis on the backbone chassis is not presented.

In the present paper, static structural analysis, modal analysis and impact analysis of the backbone chassis is presented. The main aim of this paper is to observe how a backbone chassis Lotus Europa behaves during collision. Deformation, stress and strain distribution are evaluated and factor of safety is calculated using static structural analysis. In modal analysis mode shapes for different natural frequencies of the system are presented. Further, impact analysis performed using explicit dynamic analysis compares the deformation and stress distribution for front, rear and side impact for different impact velocities. Two materials namely mild steel and aluminium are compared for impact analysis.

2. Modelling

A 3D model of a backbone chassis frame is designed using SolidWorks software as shown in figure 1. Chassis dimensions are from the Lotus Europa backbone chassis referred from a manufacturing manual of Lotus Europa chassis. The static structural analysis, modal analysis and impact analysis is performed by using ANSYS 16. For impact analysis, a separate impact wall is modelled and considered for front, side and rear impacts. Boundary conditions for front impacts with wall at front end of the chassis is shown in figure 2. Two different velocities of approaches such as 50 kilometer per hour (kmph) and 100 kmph of the chassis for front and rear impact are set in a single direction, impact wall approaches the chassis with same velocities for side impact.
3. Results and Discussion

3.1. Static Structural Analysis

Static structural analysis is performed to get total deformation as shown in figure 3, stress as shown in figure 4 and strain. Factor of safety is calculated to check the design safety. The material used for analysis is mild steel.

Since only body forces are acting and no particular external forces are applied, hence the deformation is negligible so is the strain. The maximum induced stress is only 15.27 MPa as shown in table 1. Hence, the factor of safety which is the ratio yield strength and induced stress is 16.06. The design is thereby safe.

![Figure 3. Total deformation – static structural](image)

![Figure 4. Von-Mises stress – static structural](image)

| Title       | Deformation (mm) | Stress (MPa) | Strain (mm/mm) |
|-------------|------------------|--------------|----------------|
| Maximum     | 0.022            | 15.278       | 6.72 x 10^{-5} |
| Minimum     | 0                | 0.004        | 2.63 x 10^{-8} |

4. Modal Analysis

Analysis is run and five different mode shapes at particular natural frequencies are obtained. Figure 5 shows the mode shape and Von-Mises at fifth natural frequency. Deformation and stress for these five mode shapes are noted. Mild steel is the material assigned. Induced stresses get amplified at specific
natural frequencies for different mode shapes. The deformations at these frequencies are also at peak. Following table 2 describes the deformations and stress values of first five mode shapes.

Table 2. Modal Analysis Result.

| Mode shape | Natural frequency (Hz) | Maximum Stress (MPa) | Maximum Deformation (mm) |
|------------|------------------------|-----------------------|--------------------------|
| 1          | 46.21                  | 311.33                | 6.60                     |
| 2          | 81.48                  | 318.04                | 5.92                     |
| 3          | 110.87                 | 258.09                | 7.29                     |
| 4          | 141.79                 | 368.34                | 7.50                     |
| 5          | 169.78                 | 898.68                | 5.70                     |

5. Impact Analysis – Front End

It is observed that the deformations increase as the velocity of impact increases. Interestingly stress increases for mild steel and for aluminium stress decreases with increase of impact velocity. Figure 6-9 shows the total deformation and Von-Mises stress for mild steel material at 50 kmph and 100 kmph impacts. Similarly, figure 10-13 shows the results for aluminium material. Summarised results of front impact for mild steel and aluminium are presented in table 3 and table 4 respectively.
Table 3. Front Impact Analysis – Mild Steel.

| Impact Velocity (kmph) | Maximum total deformation (mm) | Maximum stress (Pa) |
|------------------------|-------------------------------|---------------------|
| 50                     | 239.66                        | $2.782 \times 10^{11}$ |
| 100                    | 284.07                        | $2.903 \times 10^{11}$ |

Table 4. Front Impact Analysis – Aluminum.

| Impact Velocity (kmph) | Maximum total deformation (mm) | Maximum stress (Pa) |
|------------------------|-------------------------------|---------------------|
| 50                     | 319.15                        | $2.906 \times 10^{11}$ |
| 100                    | 378.15                        | $2.804 \times 10^{11}$ |
Front impact leads to chassis failure as the induced stress is much higher than yield strength of both the materials. Aluminium chassis is more vulnerable to failure.

6. Impact Analysis –Rear End

For crash analysis at the rear end of the chassis, it is observed that the deformations as well as induced stresses increase with the increase of impact velocity from 50 kmph to 100 kmph. Figure 14 and 15 shows the total deformation and Von-Mises stress for mild steel at 50 kmph impact velocity from rear end respectively and similarly, figure 16 and figure 17 shows for aluminium. Summarised results of rear impact for mild steel and aluminium are presented in table 5 and table 6 respectively.

Table 5. Rear Impact Analysis – Mild Steel.

| Impact Velocity (kmph) | Maximum total deformation (mm) | Maximum stress (Pa) |
|------------------------|--------------------------------|---------------------|
| 50                     | 188.31                         | $1.51 \times 10^{11}$ |
| 100                    | 238.70                         | $1.606 \times 10^{11}$ |

Table 6. Rear Impact Analysis – Aluminum.

| Impact Velocity (kmph) | Maximum total deformation (mm) | Maximum stress (Pa) |
|------------------------|--------------------------------|---------------------|
| 50                     | 239.40                         | $1.603 \times 10^{11}$ |
| 100                    | 305.72                         | $1.757 \times 10^{11}$ |
Rear impact leads to chassis failure as the induced stress is much higher than yield strength of both the materials. Aluminium chassis is more vulnerable to failure. Moreover, deformations obtained during rear impact are lesser than front impact.

7. Impact Analysis – Side

It is observed that the deformations as well as induced stresses increase as the velocity of impact is increased. Figure 18 and 19 shows the total deformation and Von-Mises stress for mild steel at 50 kmph impact velocity from side of the chassis respectively and similarly, figure 20 and figure 21 shows for aluminium. Summarised results of side impact for mild steel and aluminium are presented in table 5 and table 6 respectively.

| Impact Velocity (kmph) | Maximum total deformation (mm) | Maximum stress (Pa) |
|------------------------|-------------------------------|---------------------|
| 50                     | 188.31                        | 1.51 x 10^{11}      |
| 100                    | 238.70                        | 1.606 x 10^{11}     |

Table 7. Side Impact Analysis – Mild Steel.

| Impact Velocity (kmph) | Maximum total deformation (mm) | Maximum stress (Pa) |
|------------------------|-------------------------------|---------------------|
| 50                     | 239.40                        | 1.603 x 10^{11}     |
| 100                    | 305.72                        | 1.757 x 10^{11}     |

Table 8. Side Impact Analysis – Aluminum.
Rear impact leads to chassis failure as the induced stress is much higher than yield strength of both the materials. Aluminium chassis is more vulnerable to failure. Moreover, deformations obtained during rear impact are lesser than front impact. It is observed that the overall deformation for all impact velocities for side impact is less compared to front and rear impact. This could be due to bending resistance is higher for this chassis. Furthermore, there is not much difference observed in the results obtained for mild steel and aluminium materials.

8. Conclusion

In this paper, Backbone chassis is considered for the static, modal and impact analysis by varying materials such as mild steel and aluminium. Through static structural analysis it is found that the design is safe in terms of factor of safety. Mode shapes and their natural frequencies are found using modal analysis these are the instances where any load applied on the chassis gets amplified. Impact analysis using explicit dynamics for front, rear and side impact illustrates a comparison of stress and deformation of chassis under the action impacts at different velocities such as 50 and 100 kmph. By comparing the materials used in impact analysis it is concluded that mild steel is more preferable over aluminium since it is less vulnerable to failure. Finally, Front impact causes the highest damage to the backbone chassis and lowest damage in side impact. This article will help the researchers or industrialist who would like to work with backbone chassis.

9. Codes and Standards

The following standards have been used through the paper to conduct various analysis in ANSYS 16 Academic.

1. ASTM A36 (Mild Steel)
2. ASTM B209 – 14 (Aluminium)

10. References

[1] Ananda Babu, Vijay Praveen and Venkateswarao M Crash analysis of car chassis frame using finite element method 2012 International journal of engineering research and technology, 1 1-8
[2] Apoorva Tyagi Design and analysis of a space frame tubular chassis for a formula student car 2016 International journal of innovative research in science, engineering and technology, 5 16451-6
[3] Arshad Mehmood Using finite element method vibration analysis of frame structure subjected to moving loads 2015 International journal of mechanical engineering and robotics research, 4 50-65
[4] Chandan S N, Sandeep G M and Vinayaka N Design, analysis and optimization of race car chassis for its structural performance 2016 International journal of engineering research and technology 5 361-7
[5] Dasaradh Palagiri, Chavali Joy Davidson and Ramesh Babu Vemuluri Static, dynamic and harmonic analysis of heavy vehicle chassis system 2017 International journal of research in mechanical engineering and technology 70 44-7
[6] Chinnamaddiaiah, K, Lakshmipathi Y and Ravikanth Raju P Modelling and structural analysis of a go-kart vehicle chassis frame 2017 International journal of mechanical engineering and technology 8 305-11
[7] Someswara Rao K, Pradeep Kumar and Sai Kumar B Design and analysis of light weighted Chassis 2017 International journal of mechanical engineering and technology, 8 96-103
[8] Veeraswamy K and Venkata Sudheer Design and analysis of a composite beam for side impact protection of a car door 2016 *International research journal of engineering and technology* 3 464-9

[9] Manpreet Singh Bajwa, Yatin Raturi and Amit Joshi Static load analysis of tata super ace chassis and its verification using solid mechanics 2013 *International of mechanical and production engineering* 1 55-8

[10] Monika S Agarwal and Md Razik A review on study of analysis of chassis 2013 *International journal of modern engineering research* 3 1135-8

[11] Ravi Chandra M, Sreenivasulu S and Syed Altaf Hussain Modelling and structural analysis for heavy vehicle chassis made of polymeric composite material by three different cross sections 2012 *International journal of modern engineering research*, 2 2594-600

[12] Piyush Ram Shahade and Akshay Kumar Kaware Structural performance analysis of formulae SAE car 2014 *International journal of pure and applied research in engineering and technology* 2 46-61

[13] Baskara Sethupathi P, Chandradass J and Shubham Sharma Design and optimization of FSAE chassis using FEA 2018 *In proceedings of international conference on advances in mechanical engineering* 402 012184

[14] Prajwal Kumar, Vivek Muralidharan and Madhusudhana G Design and analysis of tubular space frame chassis of high performance race car 2014 *International journal of research in engineering and technology* 3 497-501

[15] Sairam Kotari and Gopinath V Static and dynamic analysis on tatra chassis 2015 *International journal of modern engineering research* 2 86-94

[16] Sarang C and Prashantkumar Design and experimentation of side impact beam for Hyundai Verna 2017 *International research journal of engineering and technology* 4 62-9