Structural Analysis of Six Axle Trailer Frame Design and Modification for Weight Reduction

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Abstract—Automobile chassis usually refers to the lower body of the vehicle. The frame provides necessary support to the vehicle components placed on it. The frame should be strong enough to withstand shocks, twist, vibrations and other stresses. The chassis frame consists of side members attached with a series of cross members. This paper focuses on review of work carried out by researchers in the field of static & dynamic analysis of six axle trailer frame design. Static & dynamic analysis is helpful to understand and improve the quality of design for six axle trailer frame design by using CATIA, ANSYS software.

Keywords—Trailer frame, Static analysis, weight reduction CATIA, ANSYS

I. INTRODUCTION

A frame is the main structure for the chassis of a motor vehicle. All other components are fastened to it; a term for this design is body-on-frame construction. Every motor vehicle had a frame. Since then, nearly all cars have shifted to unit-body construction, while trucks and buses are still using frames. Frame rails design can be classified into three categories; their cross-sections include:

1. C-shaped
2. Boxed
3. Hat
4. I-shaped

1. C-shape: By far the most common, the C-rail has been used on nearly every type of vehicle at one time or another. It is made by taking a flat piece of steel and rolling both sides over to form a C-shaped beam running over the length of the vehicle.
2. Boxed: Originally, boxed frames were made by welding two matching c-rails together to form a rectangular tube. Modern techniques, however, use a process similar to making C-rails in that a piece of steel is bent into four sides and then welded where both ends meet.
3. Hat: Hat frames resemble a "U" and may be either right-side-up or inverted with the open area facing down. Not commonly used due to weakness and a propensity to rust.
4. I-shaped: The most common, the I-rail has been used on every types of truck at cross members in structures.

II. CALCULATION

To find the loading area of frame, widths of all the members are assumed to be 150 mm.

Total loading area, \( A = 6.7 \times 10^6 \) mm\(^2\)

Permissible axle weight is 18 Ton per axle.

Gross laden weight for trailer having six axles is \( F = 108 \) ton = 1059480 N.

Load intensity, \( p = \frac{Gross\ laden\ Weight}{Surface\ Area} = \frac{F}{A} = 0.1575 \) N/mm\(^2\)

UDL acting on beam: \( w = \frac{p \times 4}{L} = \frac{p \times (B \times L)}{L} = 23.625 \) N/mm

Design for Main/Side Cross Member

\( P_1 = \) Equivalent point load due to UDL on main long member = \( \frac{23.625 \times 1500}{4} = 8859.375 \) N

Design for bending stress

Maximum bending moment which occurs at end of the span, \( M_c = (P_1 \times l_1) + \left( \frac{w x L^2}{2} \right) = 20671875 \) Nmm

Allowable bending stress, \( \sigma_{bt} = \frac{\sigma_y}{Factor\ of\ safety} = \frac{250}{2.5} = 100 \) N/mm\(^2\)

Modulus of section required is, \( Z_{required} = \frac{M_c}{\sigma_{bt}} = 20671875 \) mm\(^3\)

\( I = 92123442.58 \) mm\(^4\), \( B = 150 \) mm, \( T = 15 \) mm,

\( D = 103.8 \) mm \( \equiv 110 \) mm
Check for shear stress,

Effective area of web, 

\[ A_w = d \times t_w = (D - 2 \times t_w) \times t_w = 1200 \text{ mm}^2 \]

Average shear stress, 

\[ \tau_\theta = \frac{V}{2 \times A_w} = 12.76 \text{ N/mm}^2 \]

Allowable shear stress, 

\[ \tau_{av} = 0.5777 \times \sigma_{bt} = 57.7 \text{ N/mm}^2 \]

\[ \tau_\theta \leq \tau_{av}, \text{ Design is safe in shear.} \]

Check for deflection,

Allowable deflection is, 

\[ \delta_{allowable} = \frac{1}{180} \times 3.076 \text{ mm} \]

Maximum deflection occurs at free end, 

\[ \delta = \left( \frac{wL^3}{6EI} \right) + \left( \frac{P_1L^3}{3EI} \right) = 160.42 \text{ mm} \]

\[ \delta > \delta_{allowable}, \text{ Design fails in Deflection.} \]

Design is found satisfactory with following section property: 

\[ B = 150 \text{ mm}, \quad t = 15 \text{ mm}, \quad D = 1200 \text{ mm}, \]

\[ I = 528523625 \text{ mm}^4, \quad \delta = 2.7 \text{ mm} \]

\[ \delta < \delta_{allowable}, \text{ Design is safe in Deflection.} \]

Design for Side Long Member:

\[ w = \text{UDL on main cross member} = 23.625 \text{ N/mm} \]

\[ P_1 = \text{Equivalent point load due to UDL on main long member} = 35437.5 \text{ N} \]

\[ l_1 = 1800 \text{ mm}, \quad l_2 = 600 \text{ mm} \]

Design for bending stress:

Maximum bending moment which occurs at end of the span, 

\[ M_c = \left( R_1 \times l_1 \right) + \left( \frac{wL^2}{2} \right) = 33222656.25 \text{ Nmm} \]

Modulus of section required is, 

\[ Z_{required} = \frac{M_c}{\sigma_{bt}} = 332226.5625 \text{ mm}^3 \]

\[ Z_{required} = \frac{I}{B/2} = 29069824.88 \text{ mm}^4 \]

\[ I = 1.192 \times 10^8 \text{ mm}^4, \quad B=150 \text{ mm}, \quad T = 15 \text{ mm}, \]

\[ D= 340.64 \text{ mm} \pm 340 \text{ mm} \]

Check for shear stress:

Effective area of web, 

\[ A_w = d \times t_w = 4200 \text{ mm}^2 \]

Average shear stress, 

\[ \tau_\theta = \frac{V}{2 \times A_w} = 4.37 \text{ N/mm}^2 \]

Allowable shear stress, 

\[ \tau_{av} = 0.5777 \times \sigma_{bt} = 57.7 \text{ N/mm}^2 \]

\[ \tau_\theta < \tau_{av}, \text{ Design is safe in shear.} \]

Check for deflection:

Allowable deflection is, 

\[ \delta_{allowable} = \frac{1}{325} \times 5.54 \text{ mm} \]

\[ \delta = \left( \frac{wL^3}{6EI} \right) + \left( \frac{P_1L^3}{3EI} \right) = 85.74 \text{ mm} \]

\[ \delta < \delta_{allowable}, \text{ Design is safe in Deflection.} \]

Design for End Cross Member:

\[ w = \text{UDL on main cross member} = 23.625 \text{ N/mm} \]

\[ P_1 = \text{Equivalent point load due to UDL on main long member} = 17718.75 \text{ N} \]

\[ l_1 = 1800 \text{ mm}, \quad l_2 = 600 \text{ mm} \]

Design for bending stress:

Maximum bending moment which occurs at end of the span, 

\[ M_c = \left( P_1 \times l_1 \right) + \left( \frac{wL^2}{2} \right) = 70164900 \text{ N-mm} \]

Modulus of section required is, 

\[ Z_{required} = \frac{M_c}{\sigma_{bt}} = 701649 \text{ mm}^3 \]

\[ I = 1.192 \times 10^8 \text{ mm}^4, B=150 \text{ mm}, \quad T = 15 \text{ mm}, \]

\[ D= 340.64 \text{ mm} \pm 340 \text{ mm} \]

Check for shear stress:

Effective area of web, 

\[ A_w = d \times t_w = 2175 \text{ mm}^2 \]

Average shear stress, 

\[ \tau_\theta = \frac{V}{2 \times A_w} = 12.514 \text{ N/mm}^2 \]

Allowable shear stress, 

\[ \tau_{av} = 0.5777 \times \sigma_{bt} = 57.7 \text{ N/mm}^2 \]

\[ \tau_\theta < \tau_{av}, \text{ Design is safe in shear.} \]

Check for deflection:

Allowable deflection is, 

\[ \delta_{allowable} = \frac{1}{325} \times 3.077 \text{ mm} \]

\[ \delta = \left( \frac{wL^3}{6EI} \right) + \left( \frac{P_1L^3}{3EI} \right) = 85.74 \text{ mm} \]

\[ \delta < \delta_{allowable}, \text{ Design is safe in Deflection.} \]
Design is found satisfactory with following section property: B = 150 mm, t = 15 mm, D = 700 mm, I = 2.48X10^9 mm4, Ø = 4.013 mm

Design for Main Long Member:
w = UDL on main cross member = 23.625 N/mm

Design for bending stress:
Modulus of section required is, Z_{required} = \frac{Mc}{\sigma_{be}} = 5647187.5 mm^3

I = 7.059 x 10^10 mm4, B = 150 mm, T = 15 mm, D = 2500 mm

Check for shear stress:
Effective area of web, A_w = d \times t_w = 37050 mm^2

Average shear stress, \tau_{eq} = \frac{V}{2 \times A_w} = 1.5N/mm^2

Allowable shear stress, \tau_{ad} = 0.577 \times \sigma_{bt} = 57.7 N/mm^2

Check for deflection:
Allowable deflection is, \delta_{allowable} = \frac{f_k}{325} = 4.61 mm

Maximum deflection, \delta = 0.12 < \delta_{allowable}

Design is safe in deflection.

Design is found satisfactory with following section property: B = 150 mm, t = 15 mm, D = 1500 mm

II. ANALYSIS OF CHASSIS FRAME

The finite element method is based on the idea of building a complicated object with simple blocks or complicated object into small and manageable pieces. The finite element method is a powerful technique to solve a wide range of engineering problems. In FEM behavior of the structure is obtained by analyzing the collective behavior of the elements.

A. Loading and Boundary condition on I-Section frame

The model of truck chassis is loaded by static forces from the truck body and load. For this model, the maximum loaded weight of truck plus body is 18kg per axle. The load is assumed as a uniformly distributed obtained from the maximum loaded weight divided by the total length of chassis frame.
Fig. 4: Von-mises stress on the frame

The location of maximum von mises stress and maximum shear stress are at corner of side bar which in figure 4. The von mises stress magnitude of critical point is 4.2352 MPa and the minimum is 0.00051277 MPa.

Fig. 5: Displacement for I-section frame

The displacement of chassis and location of maximum displacement is shown in figure 5. The magnitude of maximum displacement is 0.013349 mm.

B. Loading and Boundary condition for Hollow-Section

Fig. 6: 3D model of 6 axle hollow-section frame

Fig. 7: Meshing of model

Fig. 8: Load acting on the frame
Fig. 9: Von-misses stress on the frame

The maximum von mises and shear stresses are located at corners of side bar shown in Figure 9. The magnitude of von Mises stress at critical point is 2.517 MPa.

Fig. 10: Displacement for hollow-section frame

The displacement of chassis and location of maximum displacement is shown in figure 10. The magnitude of maximum displacement is 0.010522 mm.

| TABLE I |
|-----------------|------------------|
| **Section**     | **Max. Stress**  | **Max. Deflection** |
| I               | 4.2352           | 0.013349             |
| Hollow Rectangular | 2.5170           | 0.010522             |

C. Design Modification for Weight Reduction

Optimization is defined as the process of finding the conditions that would yield the minimum or maximum value of a function, where the function represents the effort required or the desired output. Optimization is the act of obtaining the best results under the given circumstances. It is useful for design, construction and maintenance of engineering systems involving decision making at both the managerial and the technological level. Successful optimization requires availability of appropriate analysis models and knowledge of the capabilities and limitations of the mathematical optimization techniques.

Case 1(A): Changing width and height of I-Section chassis frame.

| Table II TABLE FOR I-SECTION CHANGE IN HEIGHT & WIDTH |
|-----------------|------------------|
| **MEMBER**      | **CASE 1(A)**    |
|                 | **W** | **H**   |
| Main cross      | 100   | 600     |
| Side long       | 100   | 700     |
| End cross       | 100   | 400     |
| Main long       | 100   | 900     |

Fig. 11: 3D model of 6 axle I-section frame
The location of maximum von-mises stress and maximum shear stresses are at the corner of side bar shown in figure 13. The magnitude of von mises stress at critical point is 3.1199MPa while the minimum is 0.0016454MPa.

The displacement of chassis and location of maximum displacement is shown in figure 14. The magnitude of maximum displacement is 0.0072668 mm.

**Case 1(B):** Changing width and height of I-Section chassis frame.

<table>
<thead>
<tr>
<th>TABLE III</th>
<th>TABLE FOR I-SECTION CHANGE IN HEIGHT &amp; WIDTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEMBER</td>
<td>CASE 1(B)</td>
</tr>
<tr>
<td></td>
<td>W</td>
</tr>
<tr>
<td>Main cross</td>
<td>200</td>
</tr>
<tr>
<td>Side long</td>
<td>200</td>
</tr>
<tr>
<td>End cross</td>
<td>200</td>
</tr>
<tr>
<td>Main long</td>
<td>200</td>
</tr>
</tbody>
</table>
The location of maximum von-mises stress and maximum shear stress are at corners of the side bar shown in figure 17. The magnitude von-mises stress at critical point is 7.1701 MPa and the minimum is 0.00051759 MPa.
The displacement of chassis and location of maximum displacement is shown in figure 18. The magnitude of maximum displacement is 0.064924 mm.

Case 1(C): Changing width and height of I-section chassis frame.

### TABLE IV
**TABLE FOR I-SECTION CHANGE IN HEIGHT & WIDTH**

<table>
<thead>
<tr>
<th>MEMBER</th>
<th>CASE1(C)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>Main cross</td>
<td>180</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>Side long</td>
<td>180</td>
<td>850</td>
<td></td>
</tr>
<tr>
<td>End cross</td>
<td>180</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>Main long</td>
<td>180</td>
<td>1200</td>
<td></td>
</tr>
</tbody>
</table>

The location of maximum von mises stress and maximum shear stress are at corner of side bar which in figure 21. The von misses stress magnitude of critical point is 4.2306 MPa and the minimum is 0.00057531 MPa.
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Fig. 22: Displacement for I-section frame

The displacement of chassis and location of maximum displacement is shown in figure 22. The magnitude of maximum displacement is 0.015596 mm.

Conclusion: Comparison of the result is shown in the table for case 1.

<table>
<thead>
<tr>
<th>Cases</th>
<th>Stress (N/mm) (maximum)</th>
<th>Deformation (mm) (maximum)</th>
<th>Weight (Kg) (analysis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1(A)</td>
<td>3.1199</td>
<td>0.0072668</td>
<td>4544.5</td>
</tr>
<tr>
<td>Case 1(B)</td>
<td>7.1701</td>
<td>0.064924</td>
<td>8769.6</td>
</tr>
<tr>
<td>Case 1(C)</td>
<td>4.2306</td>
<td>0.015596</td>
<td>6403</td>
</tr>
</tbody>
</table>

From the above result it is evident that the weight of chassis frame is reduced by approximately 37%. So it may be concluded that by using finite element techniques weight of chassis frame can be optimized and it is feasible to analyse the modified chassis frame before manufacturing.

REFERENCES