Analytical Optimization of Chassis Frame for 40ft Dual-Axle Flatbed Trailer Design

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Abstract: This article will review a design and analysis study that reduces trailer chassis mass while minimizing the total cost impact. Design approaches, material selections and proposed section were reviewed. The Trailer chassis main member were quantified and summarized to create an overall mass and weighted cost estimate for a low mass Trailer.

Keywords: Optimization, Chassis frame, Flat bed trailer, Shear stress

I. INTRODUCTION

India Truck Industry, also known as Road Goods Transport Industry (RGTI) or Indian trucking industry, has played a major role in the Indian trade and commerce for the decades. Along with railways, Indian truck industry has also played an instrumental role in moving goods form one part of the country to another.

From 1950-51 to 1990-91, the truck industry in India has seen a growth rate of 7.2%. Currently, there are more than 1300 trucks per million population, whereas the utilization of trucks is more than 70,000 kms per annum.

The reason behind the success of India truck industry is the added advantage of road transport over the railways. Trucks can accept goods in small quantities, can reach rural and hill areas, and also require less time than the rail for loading and unloading of goods. As a result, India truck industry cemented its place in goods transportation. With passage of time, truck industry in India has involved a good number of Indian automobile giants including Tata Motors, Hindustan Motors, Ashok Leyland, Mahindra and Mahindra, Force Motors, Swaraj Maza, Eicher etc.

Due to increase in the fuel prices and all it is now necessary to make the trucking less costly. By making the trailers economic is one way of doing it. This project is the effort to do the same. By reducing the dimensions of the trailer parts such as beam the reduction of weight is possible which will consequently cause the reduction in the cost of trailer.

The trailer given is 40 ft dual axle semi trailer. The objective is to reduce the weight of the trailer by 10 %. By selecting appropriate size of beams the objective is completed.

II. OBJECTIVE / PROBLEM STATEMENT

The objectives of this paper are:

i) To reduce the weight of the trailer by 10 %. By selecting appropriate size of main member beams the objective is completed.

iii) The Trailer chassis main member and cross member were quantified and summarized to create an overall mass and weighted cost estimate for a low mass Trailer.

iv) To develop a new trailer chassis.

III. ANALYTICAL APPROACH FOR OPTIMIZATION

The first paragraph under each heading or subheading should be flush left, and subsequent paragraphs should have a five-space indentation.

3.1. Design Input: 40ft Dual-Axle Flatbed Trailer Design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load coming on each twist lock</td>
<td>4500 kg</td>
</tr>
<tr>
<td>Payload</td>
<td>4500 x 8</td>
</tr>
<tr>
<td>Gross vehicle weight of trailer</td>
<td>36,000 kg</td>
</tr>
<tr>
<td>Overall vehicle weight of trailer</td>
<td>40,000 kg</td>
</tr>
<tr>
<td>Overall length of trailer</td>
<td>12,135 mm</td>
</tr>
<tr>
<td>Overall width of trailer</td>
<td>2550 mm</td>
</tr>
</tbody>
</table>
3.2 Load Distribution On Kingpin And Rear Axle Centerline Chart

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Title</th>
<th>Weight (kg)</th>
<th>Load on Kingpin (Rk) kg</th>
<th>Load on rear axle centre line (Rc) kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Load on rear side (4.5T x 2) (Right side)</td>
<td>9000</td>
<td>-</td>
<td>9000</td>
</tr>
<tr>
<td>2</td>
<td>Load on front side (4.5T x 2) (Right side)</td>
<td>9000</td>
<td>9000</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Load on centre left (case1)</td>
<td>9000</td>
<td>3520</td>
<td>5480</td>
</tr>
<tr>
<td>4</td>
<td>Load on centre right (case2)</td>
<td>9000</td>
<td>3227</td>
<td>5773</td>
</tr>
<tr>
<td>5</td>
<td>Self weight of chassis frame</td>
<td>4000</td>
<td>1643</td>
<td>2357</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40000</td>
<td>17,390</td>
<td>22,610</td>
</tr>
</tbody>
</table>

Table 1 – load distribution chart on kingpin and rear axle

Fig.1. Trailer front and top view

Fig.2: Main member design

3.3 STUDY OF DIFFERENT PROPOSED SECTIONS OF COMPANIES WORLD OVER

<table>
<thead>
<tr>
<th>Subject</th>
<th>Existing Section</th>
<th>Proposed Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Width (mm)</td>
<td>152.9</td>
<td>I 150</td>
</tr>
<tr>
<td>Top Thickness (mm)</td>
<td>13.3</td>
<td>12</td>
</tr>
<tr>
<td>Web Thickness mm)</td>
<td>8.1</td>
<td>6</td>
</tr>
<tr>
<td>Bottom Width (mm)</td>
<td>152.9</td>
<td>I 150</td>
</tr>
<tr>
<td>Bottom Thickness (mm)</td>
<td>13.3</td>
<td>12</td>
</tr>
<tr>
<td>Total Height (mm)</td>
<td>434.6</td>
<td>500</td>
</tr>
<tr>
<td>Area(cm²)</td>
<td>76.23</td>
<td>64.56</td>
</tr>
</tbody>
</table>

Section selected – Section I with web of 6 mm

Reference

- CNHTC Fujian special Vehicles co.Ltd. (made-in-china.com)
- Hubei Mingren Dongfang Industry co.Ltd. (www.himfr.com)
- Wall cargo semitrailer (factory.dhgate.com)
### 3.4 Section Selection

<table>
<thead>
<tr>
<th>Subject</th>
<th>Existing Section</th>
<th>Proposed Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Figure 1: Existing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Figure 2: Proposed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Selected Material**
- **St-52-3U**
- **St-52-3U**

**Ultimate Tensile Strength**
- **490 N/mm² (49.94 kg/mm²)**
- **490 N/mm² (49.94 kg/mm²)**

**Yield Strength**
- **355 N/mm² (36.18 kg/mm²)**
- **355 N/mm² (36.18 kg/mm²)**

**Area of Section**
- **76.23 cm²**
- **64.56 cm²**

**Section Modulus**
- **1122 cm³**
- **1073.2 cm³**

**Moment of Inertia**
- **25500 cm⁴**
- **26830 cm⁴**

### 3.5 Calculations Of Proposed Section:

<table>
<thead>
<tr>
<th>Formula</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>[ \text{Area} = \left( \frac{2b \times t_f}{2} + d_1 \times t_w \right) \times 2 ]</td>
</tr>
<tr>
<td>Moment Of Inertia ( (I_{xx}) )</td>
<td>[ \left( \frac{1}{12} \right) \times 150 \times 500^3 - \left( \frac{1}{12} \right) \times (150 - 6) \times 476^3 ]</td>
</tr>
<tr>
<td>Section Modulus ( (z_{xx}) )</td>
<td>[ \left( \frac{1}{6} \right) \times 150 \times 500^2 - \left( \frac{1}{6} \right) \times 144 \times (456^2/500) ]</td>
</tr>
</tbody>
</table>

### IV. Calculations Of Shear Stresses

**Maximum shear stress**

The shear stress is given by,

\[
\tau = \frac{S \times ay}{I_{xx} \times tw}
\]

Where,
- \( S \) = Maximum shear force, kg.
- \( ay \) = Moment of the area above neutral axis, about the neutral axis.
- \( I_{xx} \) = Moment of inertia, mm⁴.
- \( tw \) = Breadth of web, mm.

(Moment of the area above neutral axis = 150x12x244 + 6x238x119)

And about the neutral axis:

\[
tw = 60.91 \times 10^4 \text{ mm}^3
\]

Maximum shear stress \( \tau_{max} \) = \[
\frac{(900 \times 60.91 \times 10^4)}{(26830 \times 10^3 \times 6)}
\]

\( = 3.40 \text{ kg/mm}^2 \)
Shear stress just above the junction of the flange and web
(Shear stress in the Flange in the web at 238 mm from neutral axis)

\[ \tau = \frac{S \cdot d_y}{I_{xx} \cdot 2 \cdot b} = \frac{9000 \times (150 \times 12 \times [(12/2) + 238])}{(26830 \times 10^4 \times 150)} = 0.09 \text{ kg/mm}^2 \]

Shear stress just below the junction of the flange and web
(Shear stress in the Web at 238 mm from neutral axis)

\[ \tau = \frac{S \cdot d_y}{I_{xx} \cdot t_w} = \frac{9000 \times (150 \times 12 \times [(12/2) + 238])}{(26830 \times 10^4 \times 150)} = 2.25 \text{ kg/mm}^2 \]

%Reduction in Area
= Area of existing section – Area of proposed section / area of existing section
= \[\frac{76.23 - 64.56}{76.23} \times 100\]
= 15%

V. Weld Size Calculations At The Junction Of Flange Plate And Web Plate

4.1 Input Data:
Analytical Optimization of Chassis Frame for 40ft Dual-Axle Flatbed Trailer Design

| Maximum bending moment (M) | 148 x 10^5 kg-mm. (from fig.2) |
| Web thickness (b) | 6 mm. |
| Length of the weld (l) | 12135 mm. (from fig.1) |
| Allowable bending stress in weld (σb) | 15 kg/mm² |

Case I: Weld material of allowable bending stress 15 kg/mm²

i) Required Section Modulus:

Formula:
\[ Z_R = \frac{M_w}{\sigma b} \]  
……[Ref. Eqn. (2.5)-Strength of materials by Nirali Publication]

Where,
- \( M_w \) = Bending Moment at the welding section, kg-mm
  = Maximum Bending moment x 0.9 (from fig.5)
  = 148.26 x 10^5 x 0.9
  = 133.43 x 10^5 kg-mm

\[ Z_R = \frac{M_w}{\sigma b} \]

\[ = \frac{(133.43 \times 10^5)}{15} \]
\[ = 8.89 \times 10^5 \text{ mm}^3 \]

\[ \therefore \text{Required Section Modulus is } 8.89 \times 10^5 \text{ mm}^3 \]

ii) Available Section Modulus:

Formula:
\[ Z_A = t \times b \times l \]
\[ Z_A = t \times 6 \times 12135 \]
\[ = 72810 \times t \]

iii) Weld leg calculation:

For weld leg calculation we put following condition,
Available Section Modulus = Required Section of Modulus

\[ (Z_A) = (Z_R) \]
\[ 72810 \times t = 8.89 \times 10^5 \]
\[ t = 12.20 \text{ mm} = 13 \text{ mm} \]

\[ \therefore \text{Weld throat (t) = weld leg (s) = 13 mm } \]

The weld leg is 13 mm for allowable bending stress of 15 kg/mm² of the weld

Case II: Weld material of allowable bending stress 16 kg/mm²

i) Required Section Modulus:

Formula:
\[ Z_R = \frac{M_w}{\sigma b} \]

Where,
- \( M_w \) = Bending Moment at the welding section, kg-mm
  = Maximum Bending moment x 0.9 (from fig.5)
  = 148.26 x 10^5 x 0.9
  = 133.43 x 10^5 kg-mm

\[ Z_R = \frac{M_w}{\sigma b} \]

\[ = \frac{(133.43 \times 10^5)}{16} \]
\[ = 8.33 \times 10^5 \text{ mm}^3 \]

\[ \therefore \text{Required Section Modulus is } 8.33 \times 10^5 \text{ mm}^3 \]

ii) Available Section Modulus:

Formula:
\[ Z_A = t \times b \times l \]
iii) Weld leg calculation:

For weld leg calculation we put following condition,
Available Section Modulus = Required Section of Modulus
\[ (Z_A) = (Z_R) \]
\[ 72810 \times t = 8.33 \times 10^3 \]
\[ t = 11.45 \text{ mm} = 12 \text{ mm} \]

\[ \therefore \text{ Weld throat (} t \text{) = weld leg (} s \text{) = 12 mm} \quad \text{(From input data)} \]

The value of weld leg is 12 mm for allowable bending stress of 16 kg/mm² of the weld

4. EXISTING MIDDLE AND SIDE CROSS MEMBERS DESIGN

A) Input Data:

![Cross Member Image](image)

Section: ISMC – 75x40x4.8thk x 7.14 kg/m

- Weight per unit length = 7.14 kg/m  (IS:808)
- Moment of inertia \( (I_{xx}) \) = 78.5 cm⁴  (IS:808)
- Section of modulus \( (Z_{xx}) \) = 16.14 cm³ calculated in calculations
- Area of section = 9.1 cm²  (IS:808)
- Load on Member = 1166 kg  Given

4.1 Calculations Of Existing Middle And Side Cross Member

1) Shear stress on beam
Shear stress on beam \( (\tau) = (w \times A) / 2 \)
\[ \tau = 1166 / 2 \times 9.1 \times 100 \]
\[ = 0.64 \text{ kg/mm}^2 \]

2) Bending moment
Bending moment \( (M) = w \times l / 12 \)
\[ = 1166 \times 950 / 12 \]
= 92308.33 kg-mm
= 92.3 kg-m

3) Section of Modulus
Section of modulus \( (z_{xx}) = \frac{I_{xx}}{(H/2)} \)
\[ = \frac{78.5}{3.75} \]
\[ = 20.96 \text{ cm}^3 \]
\[ = 20966.66 \text{ mm}^3 \]

4) Bending stress
Bending stress \( \sigma_b = \frac{\text{Bending moment (M)}}{\text{Section of modulus (} z_{xx} \text{)}} \)
\[ = \frac{92308.33}{20966.66} \]
\[ = 4.4 \text{ kg/mm}^2 \]

4.2 PROPOSED MIDDLE AND SIDE CROSS MEMBER CALCULATIONS
Input data:

**Fig.9 Proposed cross member**

Section: ISMC – 75x40x5thk x 6.08 kg/m
Weight per unit length
= 6.08 kg/m ….. (calculated in calculations)
Moment of inertia \( (I_{xx}) \)
= 60.52 cm\(^4\) .....
.. (calculated in calculations)
Section of modulus \( (Z_{xx}) \)
= 16.14 cm\(^3\) ….. (calculated in calculations)
Area of section
= 7.75 cm\(^2\) ... ...(calculated in calculations

VI. Calculations

1) Area
Area = \((75+40+40) \times 5\)
\[ = 775 \text{ mm}^2 \]
\[ = 7.75 \text{ cm}^2 \]

2) Weight per unit length:
For area 9.1 cm\(^2\)
weight / unit length is = 7.14 kg/m
For area 7.75 cm\(^2\)
weight / unit length =?

weight / unit length = 7.75 x 7.4 / 9.1
for selected section
= 6.08 kg/m

3) % Reduction in load:
\[ = \frac{\text{weight per unit length of (existing section} - \text{proposed section)}}{\text{Weight per unit length of existing section}} \]
\[ = 7.14 - 6.08 / 7.14 \]
\[ = 14.8 \% \]

4) Bending moment
Bending moment \( (M) = \frac{w \times l}{12} \)
\[ = \frac{1166 \times 950}{12} \]
\[ = 92308.33 \text{ kg-mm} \]
Analytical Optimization of Chassis Frame for 40ft Dual-Axle Flatbed Trailer Design

5) **Section of Modulus**
Section of modulus \( z_{xx} \) = \((BH^2/6) – (bh^3/6H)\)
\[= (40 \times 75^2 / 6) – (35 \times 65^3 / 6 \times 75)\]
= 16140 mm³

6) **Moment of Inertia**
Moment of inertia \( I_{xx} \) = Section of modulus \times H/2
\[= 16140 \times 75/2\]
= 605250 mm⁴

7) **Bending stress**
Bending stress \( \sigma_b \) = Bending moment \( M \) / Section of modulus \( z_{xx} \)
\[= 92308.33 / 16140\]
= 5.7 kg/mm²

1. **SUMMARY:**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Existing Section</th>
<th>Proposed Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure</td>
<td><img src="image.png" alt="Figure" /></td>
<td><img src="image.png" alt="Figure" /></td>
</tr>
<tr>
<td>Section</td>
<td>ISMC – 75x40x4.8thk x 7.14 kg/m</td>
<td>ISMC – 75x40x5thk x 6.08 kg/m</td>
</tr>
<tr>
<td>Weight per unit length</td>
<td>7.14 kg/m</td>
<td>6.08 kg/m</td>
</tr>
<tr>
<td>Bending Stress</td>
<td>4.4 kg/mm²</td>
<td>5.7 kg/mm²</td>
</tr>
<tr>
<td>Area of Section</td>
<td>9.1 cm²</td>
<td>7.75 cm²</td>
</tr>
<tr>
<td>Section Modulus</td>
<td>20.96 cm³</td>
<td>16.14 cm³</td>
</tr>
<tr>
<td>Moment of Inertia</td>
<td>78.5 cm⁴</td>
<td>60.52 cm⁴</td>
</tr>
<tr>
<td>% reduction in weight</td>
<td>14.8%</td>
<td></td>
</tr>
</tbody>
</table>

VII. **CONCLUSION**

1. A conclusion for main member by modifying the size of the existing section the weight is reduces up to 15%.

2. The weld leg size for main member

<table>
<thead>
<tr>
<th>Case</th>
<th>Allowable bending stress in weld (kg/mm²)</th>
<th>Required section modulus (mm³)</th>
<th>Weld leg (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>15</td>
<td>8.89 x10⁴</td>
<td>13</td>
</tr>
<tr>
<td>II</td>
<td>16</td>
<td>8.33 x10⁴</td>
<td>12</td>
</tr>
</tbody>
</table>

3. For middle and side cross members by modifying the existing section the weight is reduced by 14.8%.

4. The weight of the trailer is reduced to make it economical.

**Acknowledgements**

I would like to express my very great appreciation to Professor S.M Oak for his valuable and constructive suggestions during the planning and development of this research work. His willingness to give his time so generously has been very much appreciated.

I would also like to thank the Mr. G. Singhal, Managing Director of Pragya Technologies (India) Pvt Ltd.
Pursuing M.E. (Design Engineering) from Vishwakarma Institute of Technology, Pune, of University of Pune, having 3.10 years of industrial experience.

Assistant Professor at Vishwakarma Institute of Technology, Pune, India. Received M.E. in Mechanical Engineering with Heat Power as specialization from College of Engineering, Pune.

Pursuing M.E. (Design Engineering) from Vishwakarma Institute of Technology, Pune, of University of Pune, having 2.8 years of industrial experience.

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[12] From Design Data Book --- PSG Tech 5.130

Theses: