Design, Analysis and Optimization of Axle and Chassis of Tractor Trolley Using FEA and Experimentation

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Abstract- *In India, various small scale industries is adopting the crude methodologies for designing and manufacturing the machine components. One such industry producing tractor trolleys for agricultural use has been identified for this study. In the present market condition, various instruments or products used in agricultural areas are mostly manufactured in small scale industries such as farming machinery, thrashers, tractor trolleys etc.*

These products are manufactured as per requirement, by trial and error or thumb rule methods of manufacturing. Reputed Farm Equipment manufacturing companies have not yet entered in manufacturing of these products; hence no proper development in design of agricultural product has been done so far. So, it is important to design these components with considering all factors of safety. For this it requires proper analysis and validation before going in the market. There is major issue in this process; we have to keep the good quality of the product in very low price. From this point we have two main objectives 1. Cost Reduction 2.Weight Reduction. Both the factors are related to each other. In this project, we will do the design related work in CATIA V5 R24 and the analysis work in the ANSYS 15.0 Software. Static analysis i.e. analytical method required for this to compare the ANSYS results. From the comparison reports we will suggest the best possible solution for the Tractor Trolley.

Keywords- CATIA V5 R24, ANSYS 15.0 Trolley axle, Safety working condition, Cost reduction.

I. INTRODUCTION

In the present market scenario, cost reduction technique is playing signified role to meet the competition in the market. Weight reduction and simplicity in design are application of industrial engineering etc., various components or products used in rural areas are mostly manufactured in small scale industries such as farming machinery, thrashers, tractor trolleys etc. It has been observed that these rural products are not properly designed. These products are manufactured as per need, by trial and error methods of manufacturing.

Trolleys are widely used for transporting agriculture product, building construction material, and industrial equipment. The main requirements of trolley manufacturing are high performance, easy to maintain, longer working life and robust construction. In this work, tractor trolley which is used for the agriculture work and sometimes used for transporting building construction material is considered. These trolleys are divided into two types as two wheeler and four wheeler. The tractor trolleys are available in various capacities like 3 ton, 5 ton, 8 ton. Figure below shows the dummy model of existing tractor trolley.

Fig. 1 Dummy Tractor Model

II. MATERIALS AND METHODS

Methodology

The experimental analysis of trolley axle is done with the help of new technology of CAD/CAE.

For Designing: CAD software like CATIA V5. For FE Analysis: ANSYS WORKBENCH. Tractor Trolley Axle The axle of a tractor trolley is one of the major and very important components and needs to be designed carefully, since this part also experiences the worst load condition such as static and dynamic loads due to irregularities of road, mostly during its travel on off road. Therefore it must be resistant to tolerate additional stress and loads. Trolley axle under consideration is a supporting shaft on which a wheel revolves. The axle is fixed to the wheels, fixed to its surroundings and a bearing sits inside the hub with which a wheel revolves around the axle. A trolley axle is also called as beam axle.

Material Selection

Materials science and engineering plays a vital role in this modern age of science and technology. Various kinds of materials are used in industry, housing, agriculture, transportation, etc. to meet the plant and individual requirements. The rapid developments in the field of quantum theory of solids have opened vast opportunities for better understanding and utilization of various materials.

So for better design and reduce the cost of material we compare the three materials: (a) SAE-1020, (b) SAE 1040, (c) Ductile Cast Iron 80-55-06. SAE-1020: The SAE-1020 grade steel material is existing material used for the axle which having carbon percentage up to 0.17- 0.23 and percentage of silicon 0.15-0.35, also the density of material is 7870 (Kg/m3) and its ultimate strength is 420 MPa. This material is generally used for making the farming equipments and industrial purpose. SAE 1040: The SAE-1040 grade steel material is proposed material for the axle of tractor trolley, this material have the good properties than the SAE 1020 steel grade, its having the carbon percentage up to 0.37- 0.44 and percentage of silicon 0.35,the percentage of carbon is higher than the SAE 1020 steel grade material. Also it's having density up to 7845 (Kg/m3) and its ultimate strength is 595 MPa. Ductile Cast Iron 80-55-06: Ductile iron is competitive with steel in strength for a given level of ductility and 8-10% lower in specific gravity than wrought steel. Ductile cast iron round bars were prepared using alloys with Carbon Equivalent percentage (CE) ranging between 4.50% and 4.76%. Different measurements were carried out on as—cast and heat-treated specimens. Ductile cast iron is essentially a family of materials with a wide verity of properties which are satisfactory for different engineering requirements. The soft ferrite grades are available to use when toughness and ductility are needed, while the harder pearlitic grades are used when higher strength is required. Grades with mixture of pearlite and ferrite in the matrix are also available.

Material Property:-

Material	SAE 1020	SAE 1040	DUCTILE
Ultimate Strength(N/mm^2)	420	595	559
Yield Strength (N/mm^2)	370	515	370
Density (Kg/m^3)	7870	7845	7150
E (N/mm^2)	205000	200000	168000
Poisson Ratio	0.29	0.29	0.31
Cost Per Kg (Rs)	40.75	45.75	64.5

Table: - Material Properties

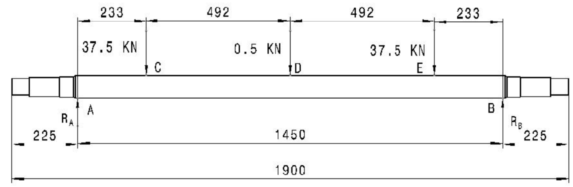

Fig 2. Load Distribution Diagram

Dynamic Load

Trolleys are used in rural areas and on rough roads at moderate speed, i.e., up to 40 km per hour. On full load conditions the speed is 20 km per hour maximum. Due to moderate speed and wavy road conditions the axle is subjected to dynamic loads which are nonlinear in nature. The load coming on the axle due to this are much larger than static loads, which makes it necessary to analyses the axle for dynamic loads.

Dynamic Load Analysis

As we know that the dynamic load is always more than static load but it is not possible to define the accurate dynamic load, so we consider as a maximum load due to dynamic loading is 37.5 KN on each leaf spring.

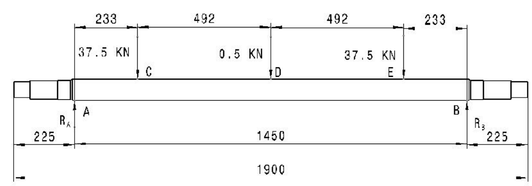

Fig. Load Distribution Diagram

Let R_A and R_B be the reactions at the supports A and B respectively.

Taking moments about A, we get

R_B×1450 = 233×37.5+0.5×725+37.5×1217

= 54737.5 KN mm

R_B = 37.75 KN

Therefore, R_A = 37.75 KN

LOAD POINT	SHEAR FORCE KN	BENDING MOMENT KNmm
A	37.75	0
C	0.25	8795.75
D	-0.25	8918.75
E	-37.75	8795.75
B	0	0

Table: - Shear Force and Bending Moment on Axle

BENDING MOMENT ON AXLE:-

Moment at B = 0 KNmm.
Moment at E = 37.75×233
= 8795.75 KNmm.
Moment at D =37.75×725-7.5×492
= 8918.75 KNmm.
Moment at C = 8795.75 KNmm.
Moment at A = 0 KNmm.

Design:-

The maximum moment (M) = 8918750 N-mm
The stress (fb) = 185 N/mm2 (SAE 1020)
Section Modulus (Z) = M / fb
= 8918750/185
Z = 48209.45 mm3.
Therefore, Z = $b^3/6$
48209.45 = $b^3/6$
b = 66.13 mm,
b = 80 mm

So by considering the dynamic load condition we obtain the cross section of axle is 80 mm.

DESIGN WITH DIFFERENT CROSS-SECTION:-

Design the axle while considering maximum bending moment 8918750 N/mm for all cross section of axle.

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Design the axle while considering maximum bending moment 8918750 N/mm for all cross section of axle.

SQUARE AXLE:-

Design of square axle for different material.

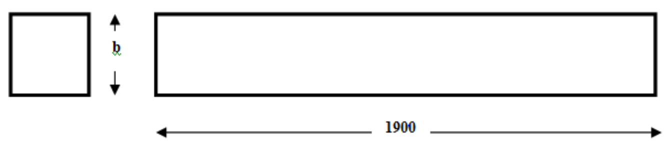


Fig. Square Cross Section Axle

Table: Design of square axle for different material

SAE 1020	SAE 1040	Ductile Cast Iron
Section Modulus (z) = M/fb	Section Modulus (z) = M/fb	Section Modulus (z) = M/fb
= 8918750/185	= 8918750/257.5	= 8918750/185
(z) = 48209.45 mm^3	(z) = 34635.92 mm^3	(z) = 48209.45 mm^3
(z) = $b^3/6$	(z) = $b^3/6$	(z) = $b^3/6$
b = 66.13 mm	b = 59.232 mm	b = 66.13 mm
b = 80 mm	b = 75 mm	b = 80 mm

CIRCULAR AXLE:-

Design of circular axle for different material.

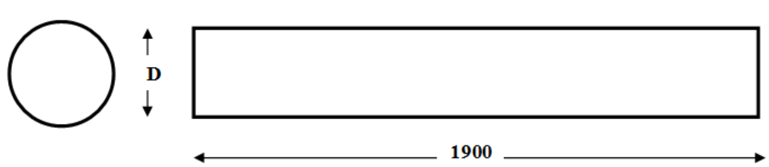


Fig. Circular Cross Section Axle

Table: Design of Circular axle for different material

SAE 1020	SAE 1040	Ductile Cast Iron
Section Modulus (z) = M/fb = 8918750/185 (z) = 48209.45 mm3 (z) = $\frac{1}{32}\pi D^3$ D = 78.89 mm D = 90 mm	Section Modulus (z) = M/fb = 8918750/257.5 (z) = 34635.92 mm3 (z) = $\frac{1}{32}\pi D^3$ D = 70.66 mm D = 82 mm	Section Modulus (z) = M/fb = 8918750/185 (z) = 48209.45 mm3 (z) = $\frac{1}{32}\pi D^3$ D = 78.89 mm D = 90 mm

I SECTION AXLE:-

Design of I section axle for different material.

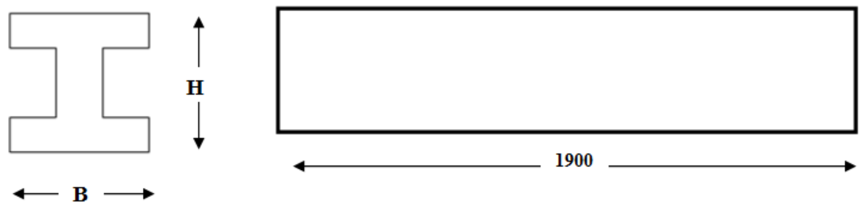


Fig. I Cross Section Axle

Assume H = 1.2 B, h = H/2, b = B/2.

Table: Design of I Section axle for different material

SAE 1020	SAE 1040	Ductile Cast Iron
Section Modulus (z) = M/fb = 8918750/185 (z) = 48209.45 mm3 (z) = $\frac{BH^3-bh^3}{6H}$ B = 59.84 mm, H = 71.80 mm b = 29.92 mm, h = 35.90 mm.	Section Modulus (z) = M/fb = 8918750/257.5 (z) = 34635.922 mm3 (z) = $\frac{BH^3-bh^3}{6H}$ B = 53.59 mm, H = 64.312 mm, b = 26.795 mm, h = 32.156 mm.	Section Modulus (z) = M/fb = 8918750/185 (z) = 48209.45 mm3 (z) = $\frac{BH^3-bh^3}{6H}$ B = 59.84 mm, H = 71.80 mm, b = 29.92 mm, h = 35.90 mm.

Round up the Values

B = 72 mm	H = 85 mm
b = 36 mm	h = 42.5 mm

III. ANALYTICAL METHOD OF ANALYSIS

Deflection of Beams

According to strength criterion of the beam design, the beam should be adequately strong to resist shear force and bending moment. In other words the beam should be able to resist shear stresses and bending stresses. But according to stiffness criterion of the beam design, which is equally important, the beam should be adequately stiff to resist deflection. In other words, the beam should be stiff enough not to deflect more than permissible limit.

The important methods used for finding out the slope and deflections at a section in a loaded beam are given below:

1. Double Integration Method.
2. Moment Area Method.
3. Macaulay's Method.

The first two methods are suitable for a single load, whereas the last one is suitable for several loads.

MACAULAY'S METHOD

In Macaulay's method a single equation if formed for all loadings on a beam, the equation is constructed in such a way that the constants of integration apply to all portions of the beam. This method is also called method of singularity functions.

This is a convenient method for determining the deflection of a beam subjected to point loads or in general discontinuous loads.

The basic equation governing the slope and deflection of beams is

$$EI\,\frac{d^2y}{dx^2} = M$$

Where, M is a function of x.

When a beam has a variety of loads it is difficult to apply this theory because some loads may be within the limits of x during the derivation but not during the solution at a particular point. Macaulay's method makes it possible to do the integration necessary by placing all the terms containing x within a square bracket and integrating the bracket, not x. This example has only point loads.

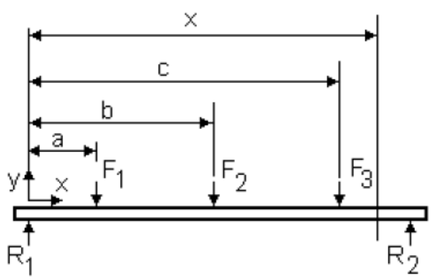


Fig. 4. Loading Condition

1. Write down the bending moment equation placing x on the extreme right hand end of the beam so that it contains all the loads. Write all terms containing x in a square bracket.

$$EI\frac{d^2y}{dx^2} = M = R_1[x] - F_1[x-a] - F_2[x-b] - F_3[x-$$

2. Integrate once treating the square bracket as the variable.

$$EI\frac{dy}{dx} = R_1\frac{[x]^2}{2} - F_1\frac{[x-a]^2}{2} - F_2\frac{[x-b]^2}{2} - F_3\frac{[x-c]^2}{2} +$$

3. Integrate again using the same rules.

$$EIy = R_1\frac{[x]^3}{6} - F_1\frac{[x-a]^3}{6} - F_2\frac{[x-b]^3}{6} - F_3\frac{[x-c]^3}{6} + Ax + B$$

4. Use boundary conditions to solve A and B.

5. Solve slope and deflection by putting in appropriate value of x. IGNORE and brackets containing negative values.

ANALYSIS

ANSYS has developed product lines that allow you to make the most of your investment and choose which product works best in your environment. ANSYS is a Finite Element Analysis (FEA) code widely used in the Computer-Aided Engineering (CAE) field. A CAD model of existing trolley axle and new designed axle is prepared using CATIA V5 R24 software then analysis is done with the help of ANSYS workbench. Below figures shows the Equivalent (von misses) stress on the axle when the load is applied. Red colour shows the maximum stress and blue colour shows minimum stress generated on the axle. For this analysis purpose following data is used.

COMPARISON OF STRESSES AND PRICE:-

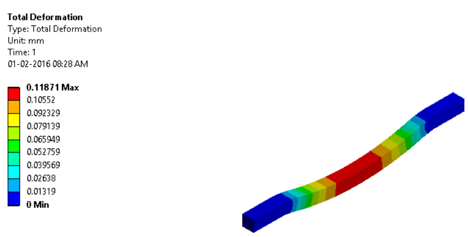
MATERIAL	SHAPE	MAXIMUM STRESSES (N/mm^2)	DEFLECTION (mm)	MASS OF AXLE(Kg)	PRICE/PIECE (Rs.)
SAE 1020	SQUARE (Existing Axle)	44.02	1.31650	130.26	5308.10
SAE 1020	Square	85.92	3.214	88.64	3612.08
	Round	102.44	3.406	88.198	3594.06
	I-Section	90.20	3.175	67.715	2759.386
SAE 1040	Square	104.275	4.265	79.427	3633.785
	Round	134.5	5.066	75.463	3452.432
	I-Section	111.08	4.259	60.24	2755.98
DUCTILE CAST IRON	Square	85.92	3.922	80.531	5194.25
	Round	102.45	4.15	80.129	5168.32
	I-Section	90.20	3.875	61.52	3968.04

Table: **-** Comparison of stresses and price for different cross section axle.

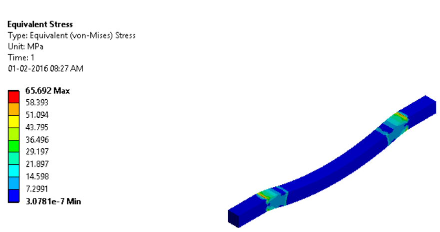
For Material SAE 1020:-

For Existing Square Axle (100×100)

Deflection Report



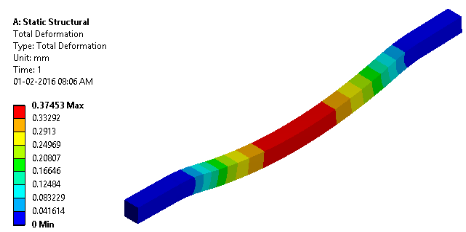
Stress Report



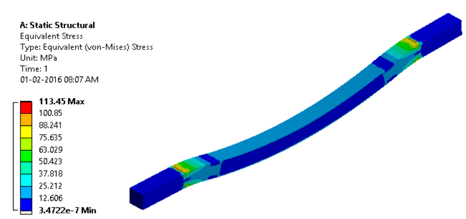
For Material SAE 1020:-

For Square Axle (80×80)

Deflection Report



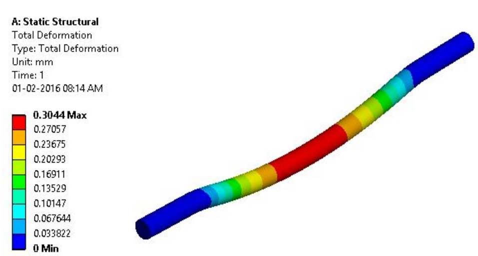
Stress Report



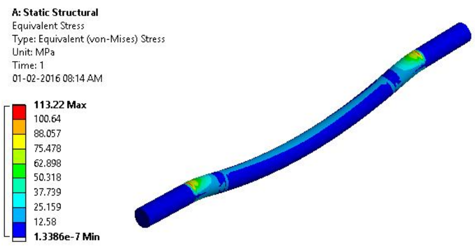
For Material SAE 1020:-

For Circular Axle Dia. 80

Deflection Report



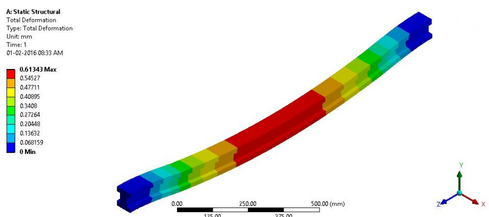
Stress Report



For Material SAE 1020:-

For I Section

Deflection Report



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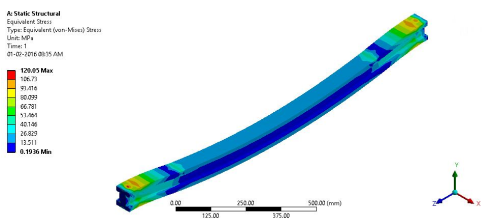
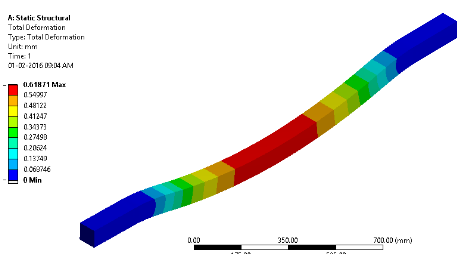


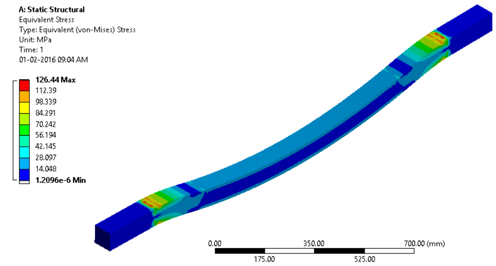
For Material SAE 1040:-

For Square Axle (75×75)

Deflection Report



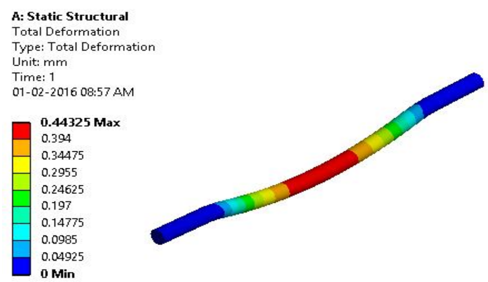
Stress Report



For Material SAE 1040:-

For Circular Axle Dia. 82mm

Deflection Report



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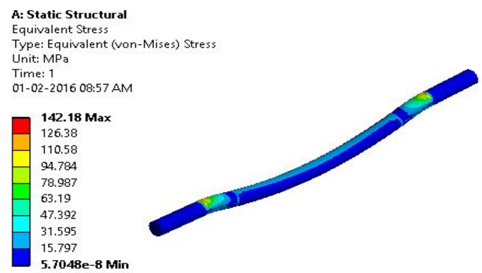
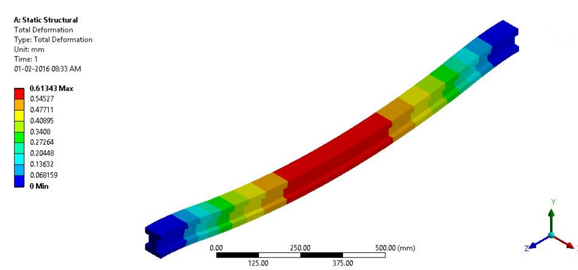


For Material SAE 1040:-

For I Section Axle

Deflection Report



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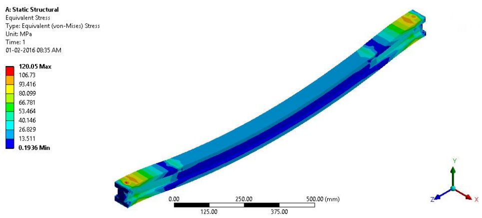
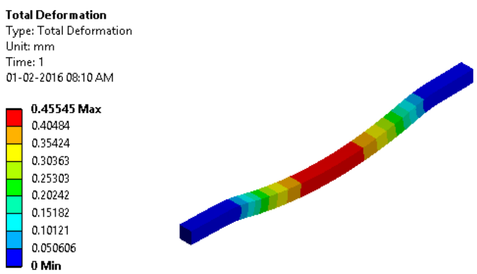


For Material Ductile Material:-

For Square Axle (80×80)

Deflection Report



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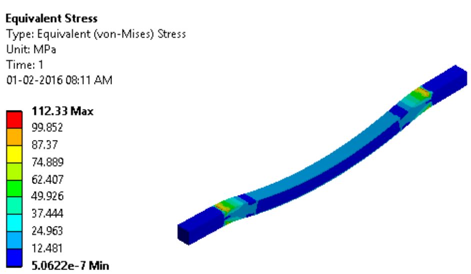
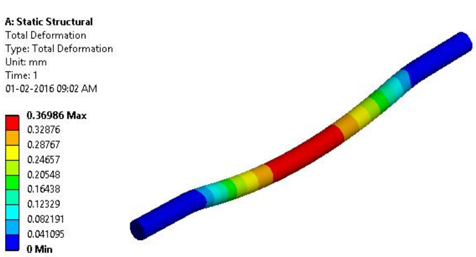


For Material Ductile Material:-

For Circular Axle

Deflection Report



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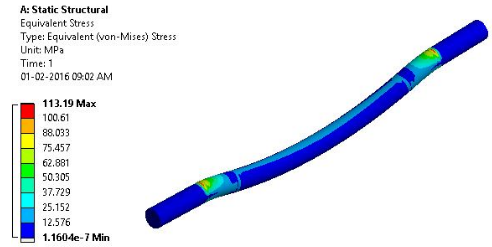
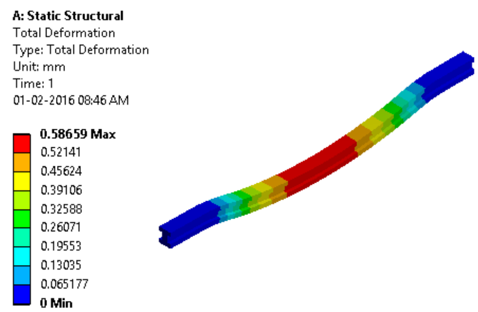


For Material Ductile Material:-

For I Section Axle

Deflection Report



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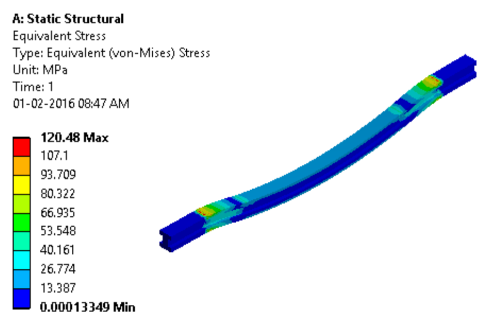


COST REDUCTION:-

When we consider the different c/s of axle with different material then we got minimum weight of axle 60.24 Kg. For I-section and material is SAE 1040 iron with price of 2755.98 Rs. But I section is not uniform throughout; we need circular section at the ends for the rim attachment. We need to weld the circular ends to the axle. Weld is not as strong as the uniform material part. So, we have to avoid the welding and I section for the axle. In this case we need to consider the deflection of the axle at the center. The minimum deflection is 0.391 mm. Also the stress is minimum 85.92 N/mm². As the material cost is less. We will go for the SAE 1020 modified square section axle. From the safety point of view we will use SAE 1020 modified square section axle.

IV. CONCLUSION

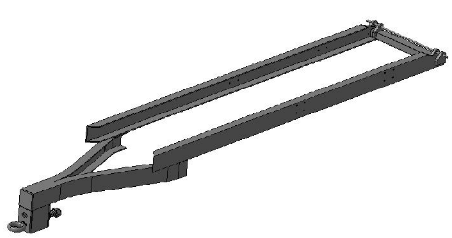
This study was conducted on an existing rear axle shaft used in tractor trolley shows that the existing axle has greater factor of safety so un-wontedly heavy axle is used for trolley in existing condition which increase the weight of axle as well as cost of axle. But the newly designed axle with different cross section and different material show that we can maximally reduces the 31.95 % weight as compare to the existing axle shown in comparison table. Also reduces the cost of trolley axle as the weight of the axle reduces. We reduce the cost of axle approximately up to 1696 Rs. per axle and the deformations as well as stresses developed in new designed axle are in within limits.

DESIGN OF EXISTING CHASSIS:-

A Chassis is one of the key components of tractor trolley. It consists of an internal framework that supports the container of tractor trolley in its construction and use. It serves as a frame work for supporting the body. It should be rigid enough to withstand the shock, twist, and other stresses & its principle function is to carry the maximum load for static and dynamic condition safely. An important consideration in chassis design is to have adequate bending stiffness along with strength for better handling characteristics. The Chassis is used to support the container on which the load is to be carried out.

Functions of Chassis:-

- To carry load of the goods carried in the body.
- To withstand the forces caused due to the sudden braking or acceleration.
- To withstand the stresses caused due to the bad road condition.



GENERAL	Double Axle, 4-wheeler box type trolley	
OVERALL DIMENSIONS	Overall length	5010 mm (Trolley Box) 6050 mm (Chassis)
	Overall width	1955 mm (Trolley Box)
	Overall height	1745 mm above ground
LOAD CAPACITY	Pay Load	8000 kg
	Unloaded weight	2000 kg
	Gross Load weight	10000 kg
AXLE	Two square axle are used presently 80×80 mm square of length 1900 mm.	
TYRES	Four number of 10”(width)×20”(radius)	

Table: **-** General Specification of original tractor trolley

STRUCTURAL ANALYSIS OF CHASSIS:-

In the present study, market available tractor trolley Chassis is selected and its dimension is noted. The Possible loads acting and the place of loads are noted. According to the dimensions, tractor trolley Chassis is modeled using CATIA V5 software. It is then imported to design modeler software ANSYS.

EXISTING MAIN CHASSIS CROSS MEMBERS DESIGN

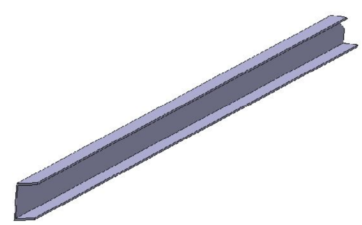


Fig. Cross Member

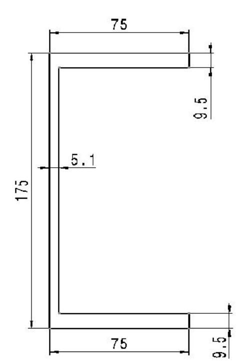


Fig. Existing section cross member

The existing section of chassis main member is taken from the BUREAU OF INDIAN STANDARDS. (IS

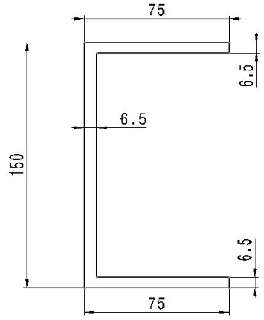
808:1989) Reaffirmed2004. Taken from the table of Dimensions for Hot Rolled Steel Beam, Column, Channel and Angle Sections. (Third Revision).

Section: ISMC – 175x75x5.1thk x 17.6 kg/m

Weight per unit length = 17.6 kg/m (IS: 808)
Moment of inertia (Ixx) = 1050 cm4 (IS: 808)
Section of modulus (Zxx) = 131 cm3 Calculated in calculations
Area of section = 22.4 cm2 (IS: 808)
Load on Member = 7500 kg Given

PROPOSED MAIN CHANNEL CROSS MEMBER CALCULATIONS

Input data:

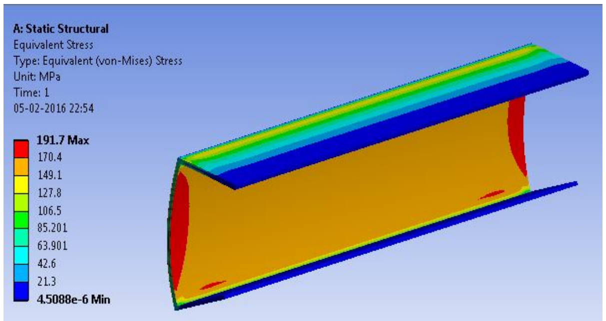


All dimensions are in mm
Fig. Proposed cross member

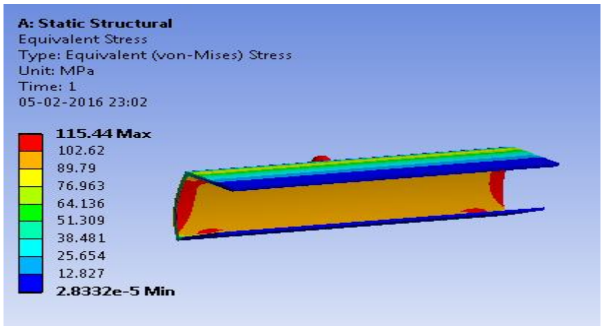
Section: **ISMC–150x75x6.5thick x 15.321 kg/m**
Weight per unit length = 15.321 kg/m (Calculated in calculations)
Moment of inertia (Ixx) = 60.52 cm^4 (Calculated in calculations)
Section of modulus (Zxx) =16.14 cm^3 (Calculated in calculations)
Area of section = 19.50 cm^2
(Calculated in calculations)

V. ANALYSIS RESULT

1) Stresses in existing C Section



2) Stresses in C Section proposed



CONCLUSION

1. A conclusion for main member by modifying the size of the existing section the weight is reduces up to 12.95%.
2. The weight of the trolley is reduced to make it economical.
3. Proposed section has minimum stresses as compared to current section.

EXPERIMENTAL STATIC STRESS ANALYSIS

Method of Testing

Initial Adjustment: - before testing adjust the pendulum with respect to capacity of the test i.e. 8 Tones; 10 Tones; 20 Tones; 40 Tones etc. For ex: - A specimen of 6 tones capacity gives more accurate result of 10 Tones capacity range instead of 20 Tones capacity range. These ranges of capacity are adjusted on the dial with the help of range selector knob. The control weights of the pendulum are adjusted correctly. The ink should be inserted in pen holder of recording paper around the drum & the testing process is started depending upon the types of test as mentioned below.

Compression Test

Compression test is just opposite in nature to tensile test. Nature of Deformation and fracture is quite different from that in tensile test. Compressive load tends to squeeze the specimen brittle material are generally week in tension but strong in compression. Hence the test is normally performed on cast iron, cement concurrent etc. but ductile material Aluminium and mild steel which are strong in tension, are also tested in compression.

Test set-up and Specification of Machine

Fix upper and lower pressure plates to the upper stationary head & lower table respectively. Place the specimen on the lower plate in order to grip. Then adjust zero by lifting the lower table. The upper head moveable while the lower head is stationary. One of the two heads is equipped with a hemispherical bearing to obtain. Uniform distribution load over the test-piece ends. A load gauge fitted for recording the applied load.

Fig. Universal Testing Machine

Steps of Experimentation

1. Dimension of test peace (C section) is measured three different places along its height /length to determine the average cross section area.
2. End of the specimen should be plane. For that the ends are tested on bearing plates.
3. The specimen(C section) placed centrally between the two compressions plates, such that the centre of moving head is vertically above the centre of specimen.
4. Load is applied the specimen by moving the movable head. (i.e. 75KN)
5. The load and corresponding contraction are measured at different intervals.
6. Load is applied until the specimen fails

The Fig. shows the validation setup of chassis for getting the deformation values at given boundary and loading conditions. For measuring the load vs. deformation on test rig one fixture need to develop. In this work, 70 mm length cross section was considered instead of whole chassis, compression test was performed on both cross sections C & proposed C section using Universal Testing Machine.

In compression test, fully automatic computerized UTM is utilized which is having capacity 80 tons. It shows that at given loads for C-section 15 KN the deformation was found 5.5 mm. But in case of I section 75.32 KN load is required for 3.3 mm deformation.

VI. RESULT, DISCUSSION & COMPARASION

Following table shows comparative result between existing C-section & suggested C-section. According to stress analysis of existing C-section & suggested C-section is carried out. As per the conditions initially stress range was fixed and then the stress analysis is performed. Stress range of suggested C-section shows a very good match with the stress range of existing C-section. As stress range of suggested C-section is within the stress range of existing C-section. Thus, the modified design proves to be safe. Safer stresses are obtained in new suggested design and increase in Factor of Safety obtained in new suggested design. Thus to improve the load carrying capacity of trolley that was reduced by heavy chassis.

VIII. CONCLUSION

1) The newly proposed designed ‘C’ section Chassis reduces deformation as compared to the existing ‘C’ section Chassis.
2) More safer stresses are obtained in new suggested design.
3) Increase in Factor of Safety obtained in new suggested design.
4) To improve the load carrying capacity of trolley that was reduced by heavy chassis.

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