Design and Analysis of Tractor Trolley Axle

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Abstract— In India, Tractor trolley plays an important role in agriculture and construction field for the transportation. Many small industries are involved in the manufacturing of the Tractor trolley. Due to lack of the advance technologies, this product may not properly design. The tractor trolley is designed as per the requirement or by trial and error method of manufacturing. Many times it may be designed without considering the actual loading condition. There are some rules and regulations for the tractor trolley or trailer. The tractor trolley should be as per the Indian Standard specification IS 8213:2000. Many small industries not follow the Indian Standards Specifications Central Motor Vehicles Act, 1988 and safety standard (SS-15) of Automotive Research Association of India. Many road accidents and breakdown or failures occurs due to poor design of the tractor trolley, In present work analytical and finite element analysis approach is used to design the tractor trolley for safe working condition. Need to consider the stress concentration, weight and cost reduction of existing trolley axle. 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.

Key words: CATIA V5 R24, ANSYS 15.0, Weight Reduction, Cost Reduction, Trolley axle

I. Introduction

Nowadays, quality of the product within the lowest cost plays an important role in the product manufacturing industries. Weight reduction and optimized design are the application of industrial engineering. Tractor trolleys are mostly manufactured in small scale industries such as farming machinery, thrashers, tractor trolleys etc.

Building construction material, Industrial equipment and agriculture product transporting are done by tractor trolleys. Robust construction, longer working life and easy maintain and high performance are the main criteria of trolley manufacturing. Tractor trolleys are available in single axle and double axle. Single axle trolleys are available in 3 ton and 5-ton capacity. Above 5-ton capacity double axle trolleys are suitable. The figure below shows the dummy model of existing tractor Trolley. A trolley is one of the standard sizes of the trolley which is generally designed for 8 tons capacity. The aim of this project is to design and analysis this standard a size of trolley for the critical loading condition i.e. for 15 tons and at critical road condition. Trolley has been designed for high load carrying capacity. While designing trolley main focus was on the weight of the trolley because for robust design if weight will be increased cost will increase for the trolley.

Fig. 1: Dummy Tractor Model

A. *Objectives*

- Getting the benchmark data of Trolleys available in the market and design the Tractor Trolley for the 15 tons capacity.
- Designing of Axle and Chassis of the trolley such that it will be strong enough to sustain the maximum loading conditions on the Indian roads.
- Cost Reduction and Weight Reduction of the Tractor Trolley, by changing the shape and material of the Axle and Chassis.
- To develop a new tractor trolley axle and chassis.

So, we need to develop the trolley parts so that quality of the parts should be good considering the cost and weight of the complete assembly. Some points are highlighted as below.

1) Strength analysis of trolley assembly will be carried out at different load conditions considering critical load conditions.
2) Design optimization study will be carried out by studying highly stress concentrated area.
3) Weight and Cost optimization will be done on trolley parts.

II. Design and Development of Tractor Trolley Axle

A. *Types of Tractor Trolley:-*

The agricultural trailers shall be of following two types:

a) Balanced trailer (double axel) and
b) Semi-trailer (single axle).

Both the types of trailers may be fitted with fixed or tipping platform.

B. *Capacity:-*

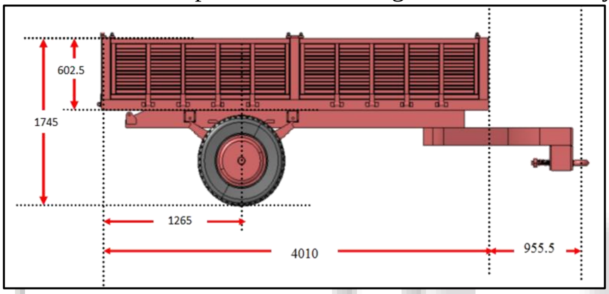
1) The capacity of a trailer shall be its gross load and shall be 2, 3, 4, 5, 6, 8 and 10 tons. The gross load along with the payload shall be declared by the manufacturer. The declared capacity shall not vary by + or - 5 percent.
2) The capacity of the single-axle trailers shall be not more than 5 tons.

3) Tractor operated trailers are used for transport of farm produce. This standard has been prepared for the guidance of manufacturers and purchasers in the production and selection of trailers of proper quality.

Considering the 8 tons trolley we need to design the double axel tractor trolley.

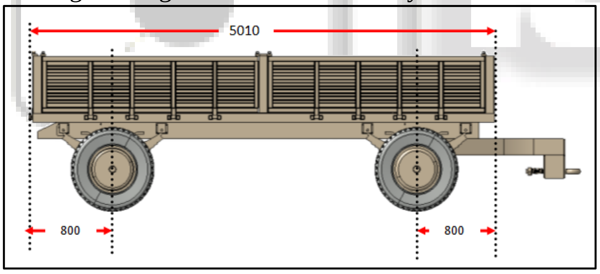
	Double Axle, 4-wheeler box type trolley	
Overall Dimensions	Overall Length	5010 mm (Trolley Box) 6050 mm (Chassis)
	Overall Width	1955 mm (Trolley Box)
	Overall Height	1745 mm above ground
Load Capacity	Pay Load	8000 kg
	Unloaded Weight	2000 kg
	Gross load Weight	10000 kg
Axle	Two square axle are used presently 80×80 mm square of length 1900 m.	

Table 1: General Specification of Original Tractor Trolley



All dimensions are in mm.

Fig. 2: Single Axle Tractor Trolley Dimensions



All dimensions are in mm.

Fig. 3: Double Axle Tractor Trolley Dimensions

C. *Materials and Methods:-*

In our project work, finite element analysis approach will be used (by considering change in materials and change in existing shape and size). A CAD model of existing trolley axle is prepared by using CATIA V5 software then the analysis is done with the help of ANSYS.

D. *Material Selection:-*

So for better design and reduce the cost of material we compare the three materials

- SAE-1020,
- SAE 1040,
- Ductile Cast Iron 80-55-06.

Material	S. A. E. 1020	S. A. E. 1040	D.C.I. 80-55-06
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 2: Material Properties

E. *Design of Existing Axle:-*

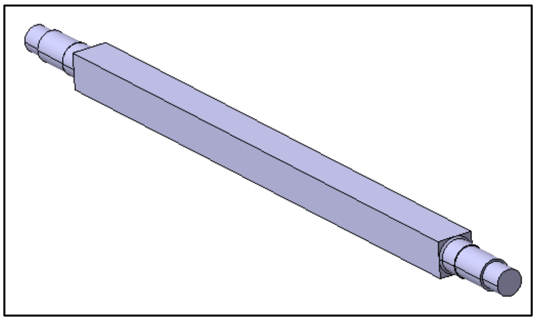


Fig. 4: Existing Axle

In our project work, analytical analysis approach is used, (By considering the change in materials and change in existing shape and size). An existing trolley axle is redesigned for the given load condition, then check the actual deflection occurred in existing axle, also, different material and different shape axle get the design, Select the best axle according to the condition. The main purpose of the project is to make a safer working condition of trolley axle as well as for stress concentration, weight and cost reduction.

F. *Load Conditions:-*

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.

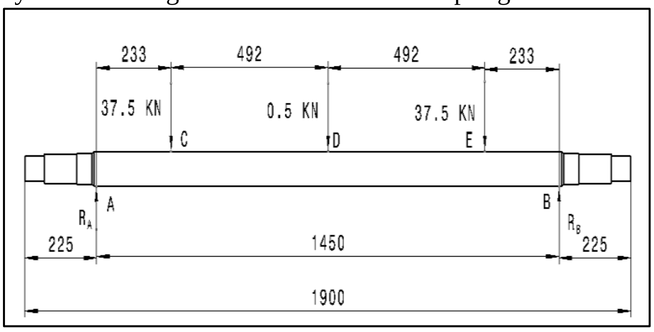


Fig. 5: Load Distribution Diagram

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

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 3: Shear Force and Bending Moment on Axle

7. 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 = b³/6
48209.45 = b³/6
b = 66.13 mm,
b = 80 mm

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

G. Design with Different Cross-Section:-

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

H. Square Axle:-

Design of square axle for different material.

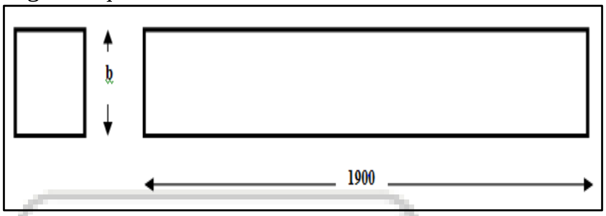


Fig. 6: Square Cross Section Axle

SAE 1020	SAE 1040	Ductile Cast Iron
Section Modulus (z) = M/fb = 8918750/185 (z) =48209.45 mm³ (z) = b³/6 b = 66.13 mm b = 80 mm	Section Modulus (z) = M/fb = 8918750/257.5 (z) = 34635.92 mm³ (z) = b³/6 b = 59.232 mm b = 75 mm	Section Modulus (z) = M/fb = 8918750/185 (z)= 48209.45 mm³ (z) = b³/6 b = 66.13 mm b = 80 mm

Table 4: Design of square axle for different material

I. Circular Axle:-

Design of circular axle for different material.

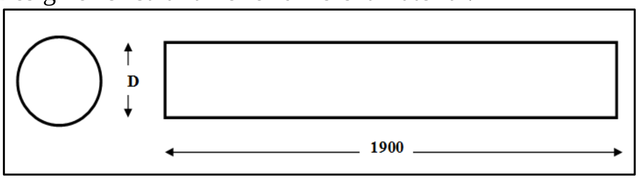


Fig. 7: Circular Cross Section Axle

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

Table 5: Design of Circular axle for different material

J. Section Axle:-

Design of I section axle for different material.

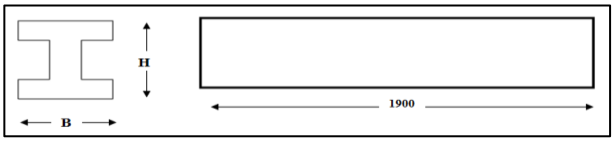


Fig. 8: I Cross Section Axle

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

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

Table 6: Design of I Section axle for different material

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

Table 7: Round up the Values

III. ANALYTICAL METHOD OF ANALYSIS

A. Deflection of Beams:-

It is observed that when a beam or a cantilever is subjected to some type of loading it deflects from its initial/original position. The amount of deflection depends on its cross section and bending moment. Strength and stiffness are the two main criteria for a beam or a cantilever. 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 the permissible limit.

B. Slope and Deflection at a Section

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.

1) 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 the 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.

When the load on a beam does not conform to standard cases, the solution for slope and deflection must be found from first principles. Macaulay developed a method for making the integration simpler.

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. During the evaluation, any bracket with a negative value is ignored because a negative value means that the load it refers to is not within the limit of x. the general method of solution is conducted as follows. Refer to figure given below. In the real example, the loads and reactions would have numerical values numerical values but for the sake of demonstrating the general method, we will use algebraic symbols. This example has only point loads.

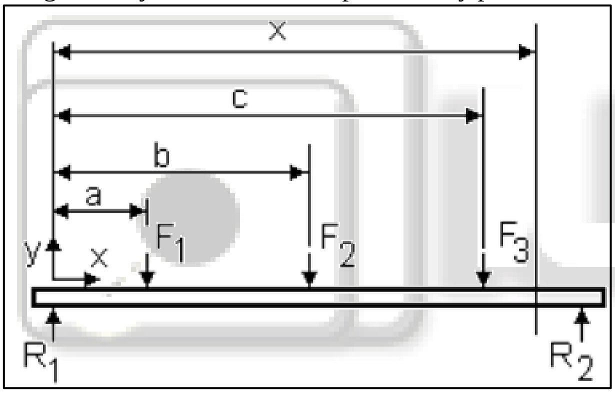


Fig. 9: Loading Condition

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.

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

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

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

3) Integrate again using the same rules.

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

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.

1. In the case of a fixed beam, there are four unknowns: R_A, R_B, M_A and M_B. Thus, the two statics equations must be supplemented by two additional equations arising from deformations.

For the same spans and loads, the fixed beams claim the following advantages over simply supported beams.

1. These have lesser values for maximum bending moments.
2. These have lesser values for maximum deflection.

IV. Finite Element Analysis

The finite element method is a numerical method for solving problems of engineering and mathematical physics. Typical problem areas of interest in engineering and mathematical physics that are solvable by use of the finite element method include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. For problems involving complicated geometries, loadings, and material properties, it is generally not possible to obtain analytical mathematical solutions. Analytical solutions are those given by a mathematical expression that yields the values of the desired unknown quantities at any location in a body (here total structure or physical system of interest) and is thus valid for an infinite number of locations in the body. These analytical solutions generally require the solution of ordinary or partial differential equations, which, because of the complicated geometries, loadings, and material properties, are not usually obtainable. Hence, we need to rely on numerical methods, such as the finite element method, for acceptable solutions. The finite element formulation of the problem results in a system of simultaneous algebraic equations for the solution, rather than requiring the solution of differential equations. These numerical methods yield approximate values of the unknowns at discrete numbers of points in the continuum. Hence, this process of modeling a body by dividing it into an equivalent system of smaller bodies or units (finite elements) interconnected at points common to two or more elements (nodal points or nodes) and/or boundary lines and/or surfaces is called discretization. In the finite element method, instead of solving the problem for the entire body in one operation, we formulate the equations for each finite element and combine them to obtain the solution of the whole body.

A. For Material SAE 1020:-

For Existing Square Axle (100×100)

1) Deflection Report

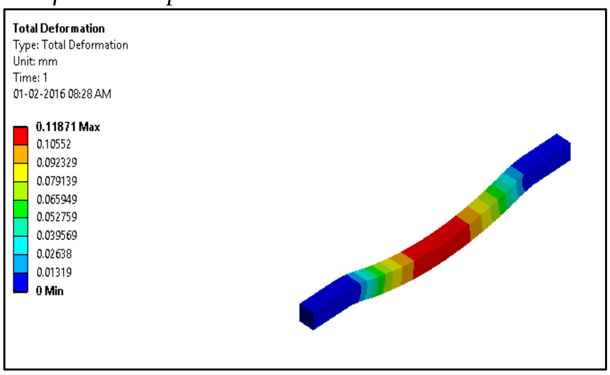


Fig. 10: Deflection Report for Existing Square Axle

2) Stress Report

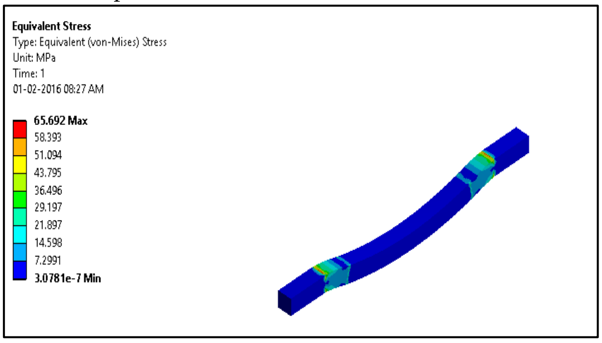


Fig. 11: Stress Report for Existing Square Axle

B. For Material SAE 1020:-

For Square Axle (80×80)

1) Deflection Report

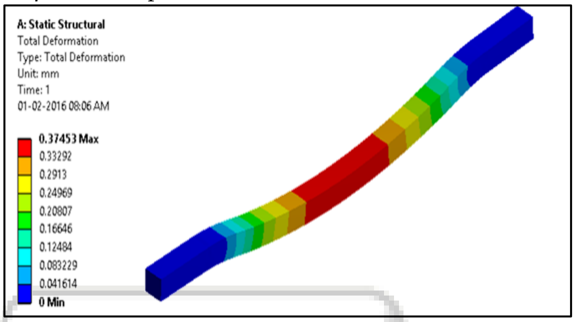


Fig. 12: Deflection Report for Square Axle (80 * 80)

2) Stress Report

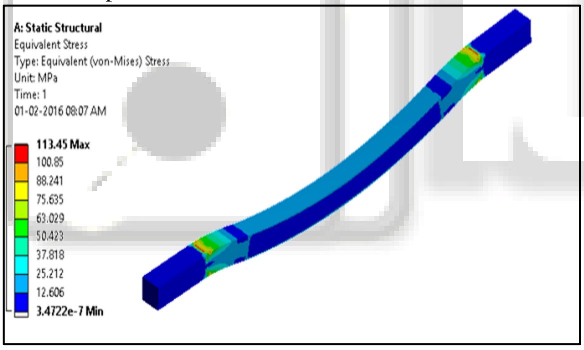


Fig. 13: Stress Report for Square Axle (80 * 80)

C. For Material SAE 1020:-

For Circular Axle Dia. 80

1) Deflection Report

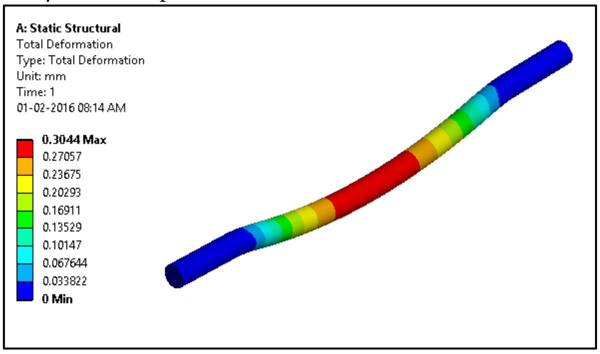


Fig. 14: Deflection Report for Circular Axle Dia. 90

2) Stress Report

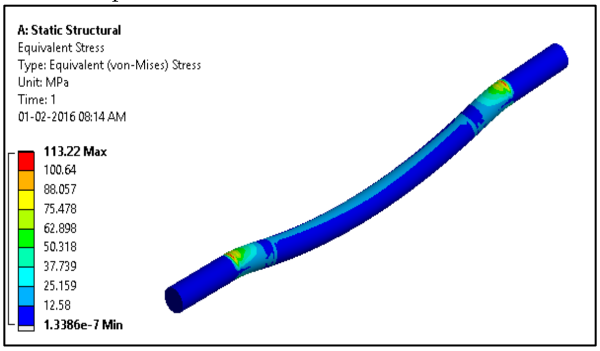


Fig. 15: Stress Report for Circular Axle Dia. 90

D. For Material SAE 1020:-

For I Section

1) Deflection Report

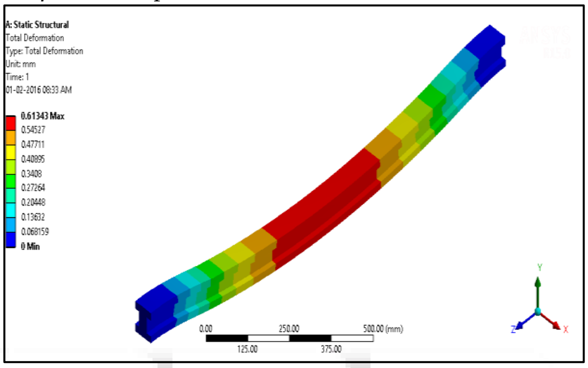


Fig. 16: Deflection Report for I-Section Axle

2) Stress Report

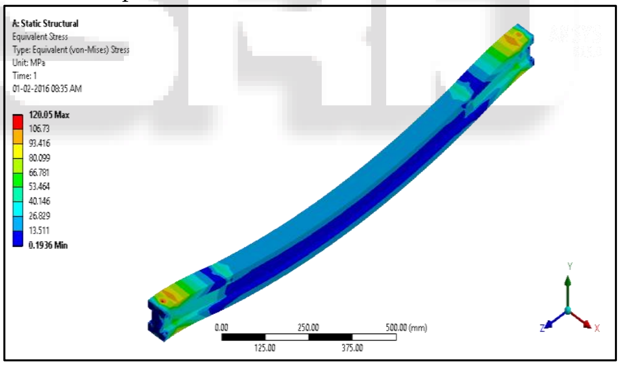


Fig. 17: Stress Report for I-Section Axle

E. For Material SAE 1040:-

For Square Axle (75×75)

1) Deflection Report

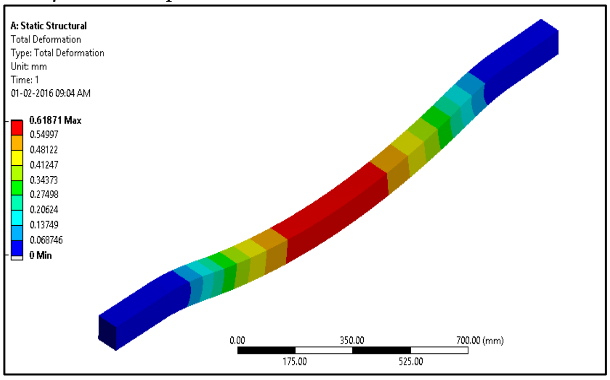


Fig. 18: Deflection Report for Square Axle (75*75)

2) *Stress Report*

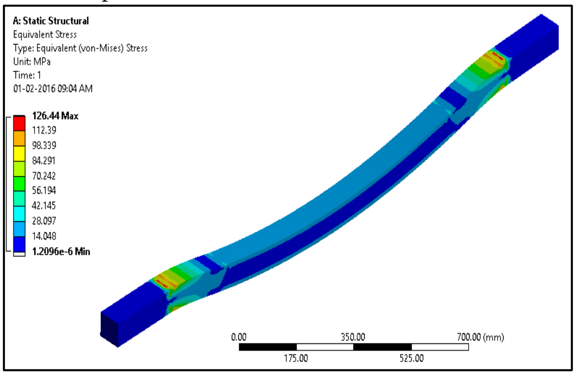


Fig. 19: Stress Report for Square Axle (75*75)

F. For Material SAE 1040:-

For Circular Axle Dia. 82mm

1) *Deflection Report*

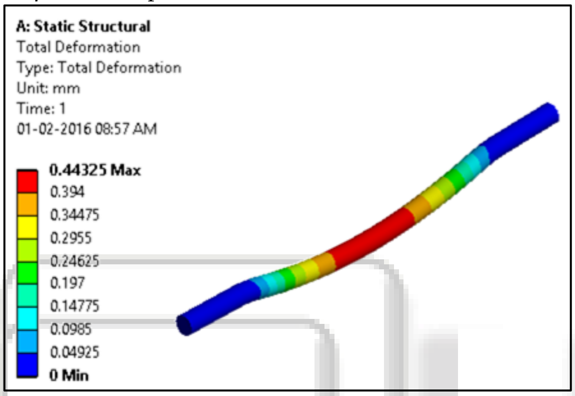


Fig. 20: Deflection Report for Circular Axle (82*82)

2) *Stress Report*

Fig. 21: Stress Report for Circular Axle (82*82)

G. For Material SAE 1040:-

For I Section Axle

1) *Deflection Report*

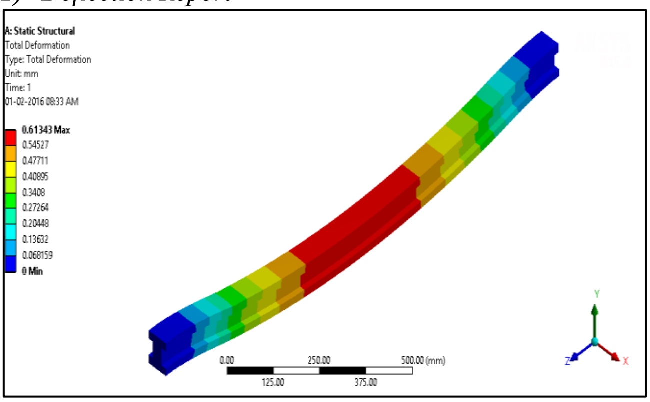


Fig. 22: Deflection Report for I-Section Axle

2) *Stress Report*

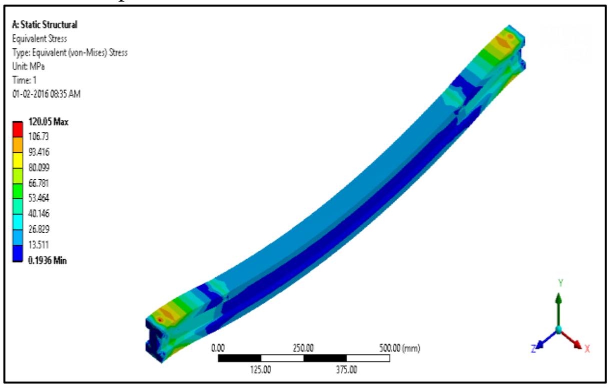


Fig. 23: Stress Report for I-Section Axle

H. For Ductile Cast Iron (80-55-06) Material:-

For Square Axle (80×80)

1) *Deflection Report*

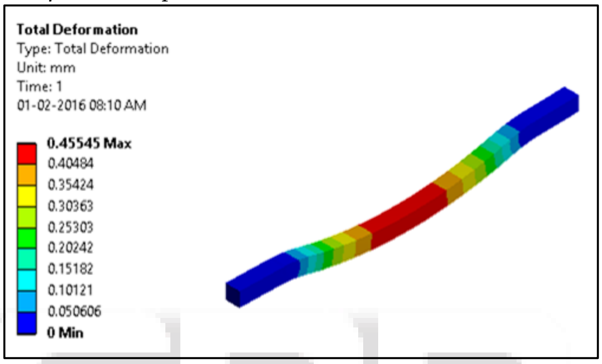


Fig. 24: Deflection Report for Square Axle

2) *Stress Report*

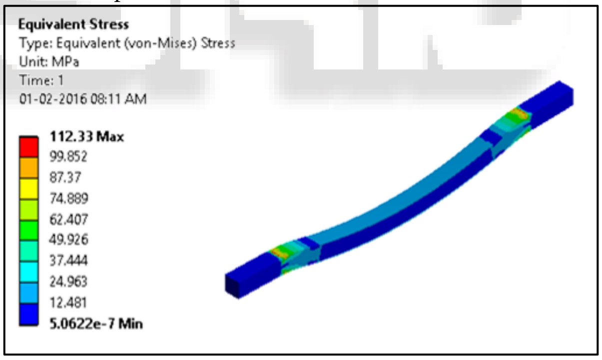


Fig. 25: Stress Report for Square Axle

I. For Ductile Cast Iron (80-55-06) Material:-

For Circular Axle

1) *Deflection Report*

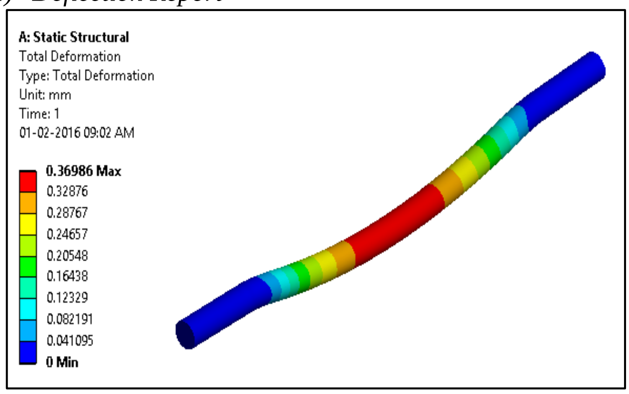


Fig. 26: Deflection Report for Circular Axle

2) Stress Report

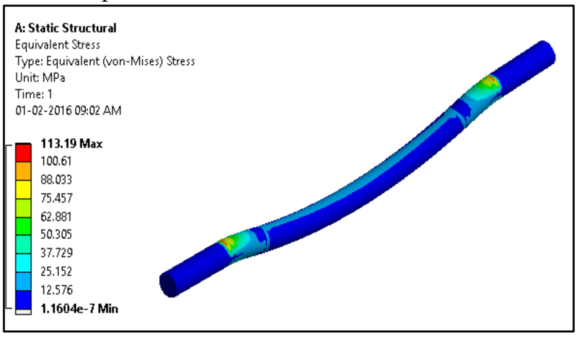


Fig. 27: Stress Report for Circular Axle

J. For Ductile Cast Iron (80-55-06) Material:-

For I Section Axle

1) Deflection Report

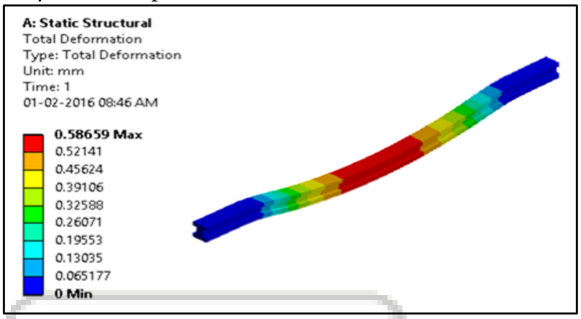


Fig. 28: Deflection Report for I-Section Axle

2) Stress Report

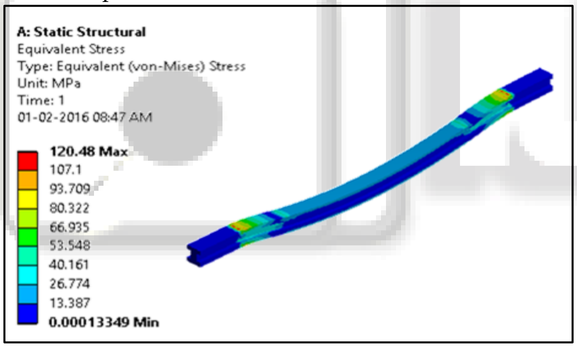


Fig. 29: Stress Report for I-Section Axle

Material	Shape	Maximum Stresses (N/mm²)	Deflection (mm)	Mass of Axle(Kg)	Price/Piece (Rs.)
SAE 1020	SQUARE (Existing Axle)	44.02	0.160	130.26	5308.10
SAE 1020	Square	85.92	0.391	88.64	3612.08
	Round	102.44	0.414	88.198	3594.06
	I-Section	90.20	0.386	67.715	2759.386
SAE 1040	Square	104.275	0.518	79.427	3633.785
	Round	134.5	0.616	75.463	3452.432
	I-Section	111.08	0.518	60.24	2755.98
Ductile Cast Iron	Square	85.92	0.477	80.531	5194.25
	Round	102.45	0.505	80.129	5168.32
	I-Section	90.20	0.471	61.52	3968.04

Table 3: Comparison of stresses and price for different cross section axle

K. Cost Reduction

When we consider the different c/s of the axle with the different material then we got minimum weight of axle 60.24 Kg. For I-section and material is SAE 1040 iron with the price of 2755.98 Rs. But I section is not uniform throughout; we need the 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.

Compare the Existing Axle Price and New Designed Axle Minimum Price

Existing axle price is 5308.10 Rs.

New designed axle minimum price is 3612.08 Rs.

So we got the price difference of 1696.02 Rs.

Means by adopting the new design of axle we can reduce the axle cost up to 1696.02 Rs.

V. 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 increases 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 reduce the 31.95 % weight as compared 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 newly designed axle are in within limits.

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