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# DESIGN AND ANALYSIS OF TRACTOR TROLLEY AXLE USING FEA

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## ABSTRACT

In India, various small scale industries are 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 methods or thumb rule methods of manufacturing, which leads to unwanted extra weight of components. 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. In the present market scenario, cost reduction technique is playing signified role to meet the competition in the market. 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.

## 1. INTRODUCTION

In the present market scenario, cost reduction technique is playing signified role to meet the competition in the market. Tractor trolley or trailers are very popular and cheaper mode of goods transport in rural as well as urban area. 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. Trolley axle under consideration is a supporting shaft on which a wheel revolves. The axle is fixed to the wheels, fixed to its surroundings & a bearing sits inside the hub with which a wheel revolves around the axle. A trolley axle is also called as beam axle which is typically suspended by leaf springs. 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.

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***Fig. 1 Dummy Tractor Model***

## 2. 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.

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**Material Property**

***Table: - Material Properties***

| 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 |

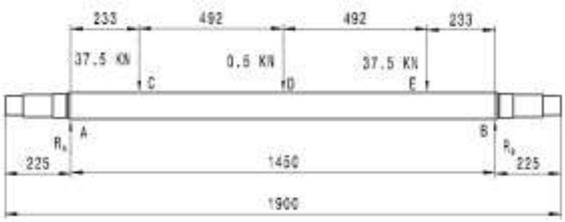


***Fig 2. Load Distribution Diagram***

**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.

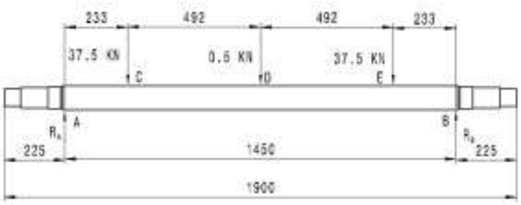


***Fig. Load Distribution Diagram***

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

Taking moments about A, we get

$R_B \times 1450 = 233 \times 37.5 + 0.5 \times 725 + 37.5 \times 1217 = 54737.5$ KN mm

$R_B = 37.75$ KN

Therefore, $R_A = 37.75$ KN

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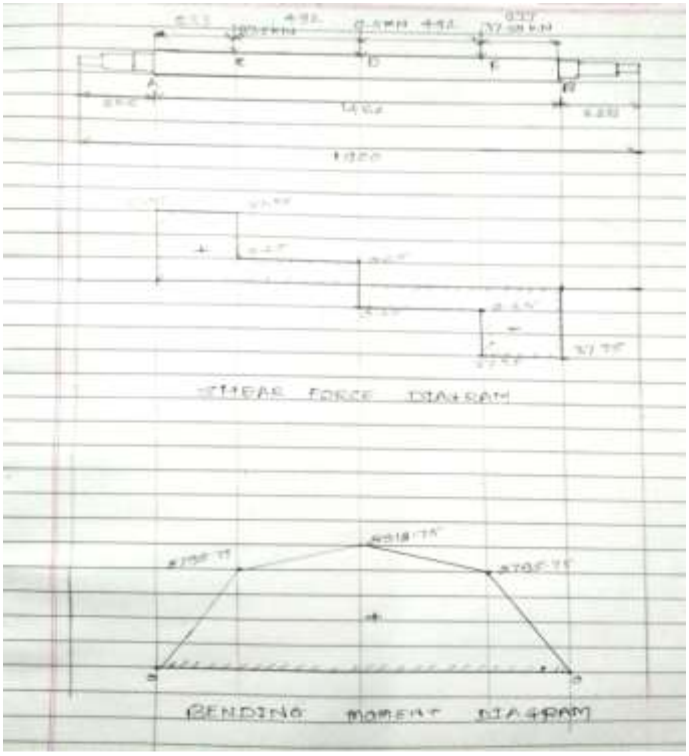
***Table: - Shear Force and Bending Moment on Axle***

| LOAD POINT | SHEAR FORCE KN | BENDING MOMENT KNmm |
|---|---|---|
| B | $F_B$ =-37.75 KN | $M_B$= 0 |
| E | $F_{ER}$ =-37.75 KN | $M_E$= 8795.75 |
| E | $F_{EL}$ =-0.25 KN | $M_D$= 8918.75 |
| D | $F_{DR}$ = -0.25 KN | $M_C$= 8795.75 |
| D | $F_{DL}$ =+0.25 KN | $M_A$= 0 |
| C | $F_{CR}$ =+0.25KN | |
| C | $F_{CL}$ =+37.75 KN | |
| A | $F_A$ =+37.75 KN | |




## 3. 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.

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**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.

**Design with different cross-section:-**

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

**Design with different cross-section:-**

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.

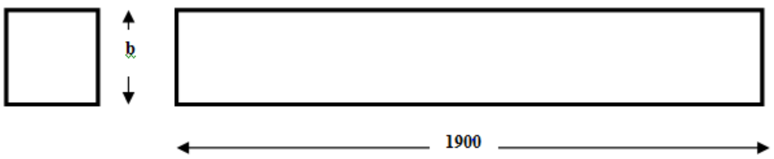


*Fig. Square Cross Section Axle*

*Table: Design of square axle for different material*

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

**Circular axle:-**

Design of circular axle for different material.

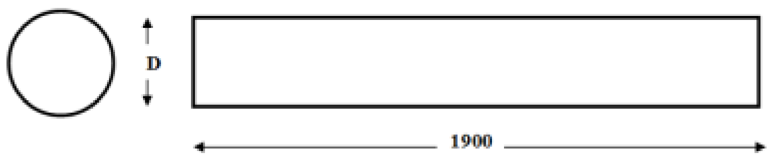


*Fig. Circular Cross Section Axle*

*Table: Design of Circular axle for different material*

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

| D = 90 mm | D = 82 mm | D = 90 mm |
|---|---|---|

**I section axle:-**
Design of I section axle for different material.

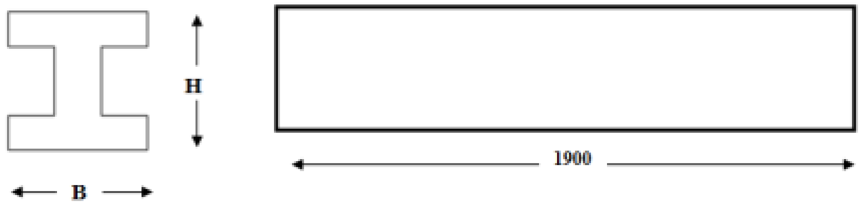


***Fig. I Cross Section Axle***

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

| SAE 1020 | SAE 1040 | Ductile Cast Iron |
|---|---|---|
| Section Modulus (z) = M/fb<br>= 8918750/185<br>(z) = 48209.45 mm3<br>(z) = $\frac{BH^3 - bh^3}{6H}$<br>B = 59.8 B<br>H = 71.80 mm<br>b = 29.92 mm,<br>h = 35.90 mm. | Section Modulus (z) = M/fb<br>= 8918750/257.5<br>(z) = 34635.922 mm3<br>(z) = $\frac{BH^3 - bh^3}{6H}$<br>B = 53.59 mm,<br>H = 64.312 mm,<br>b = 26.795 mm,<br>h = 32.156 mm. | Section Modulus (z) = M/fb<br>= 8918750/185<br>(z) = 48209.45 mm3<br>(z) = $\frac{BH^3 - bh^3}{6H}$<br>B = 59.84 mm,<br>H = 71.80 mm,<br>b = 29.92 mm,<br>h = 35.90 mm. |

***Table: Design of I Section axle for different material***

**Round up the Values**

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

## 4. 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.

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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 l

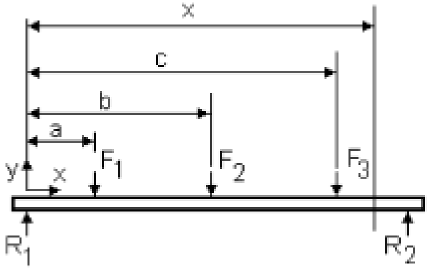


***Fig. 4. Loading Condition***

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.

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

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

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

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.

## 6. COMPARISON OF STRESSES AND PRICE

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

| MATERIAL | SHAPE | MAXIMUM STRESSES (N/mm²) | DEFLECTION (mm) | MASS OF AXLE(Kg) | PRICE/PIECE (Rs.) |
|---|---|---|---|---|---|
| **SAE 1020** | SQUARE | 43.99 | 1.31650 | 130.26 | 5308.10 |

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| | | | | | |
|---|---|---|---|---|---|
| | (Existing Axle) | | | | |
| **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 |

**For Material SAE 1020:-**
**For Existing Square Axle (100×100)**

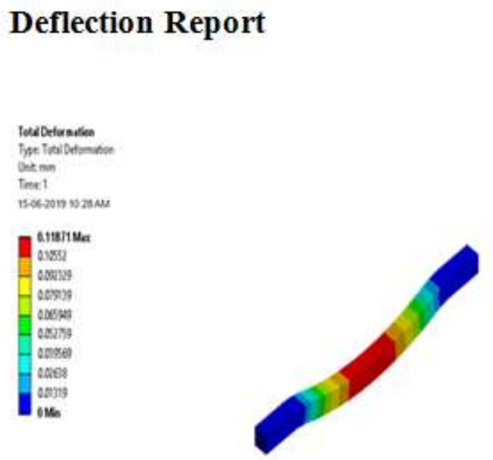


*Fig. 4.1 Deflection Report for Existing Square Axle*

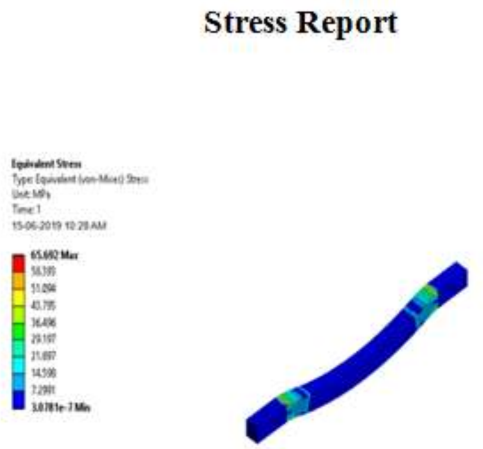


*Fig. 4.2 Stress Report for Existing Square Axle*

**For Material SAE 1020:-**
**For Square Axle (80×80)**

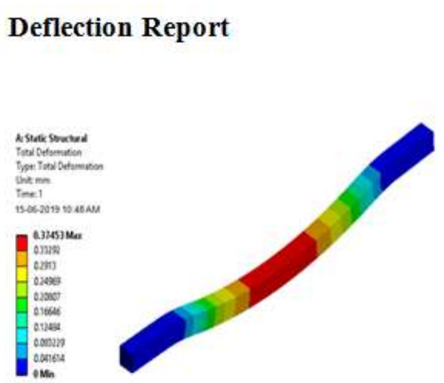


*Fig. 4.3 Deflection Report for Square Axle (80 * 80)*


*Fig. 4.4 Stress Report for Square Axle (80 * 80)*

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**For Material SAE 1020:-**
**For Circular Axle Dia. 80**

**Deflection Report**

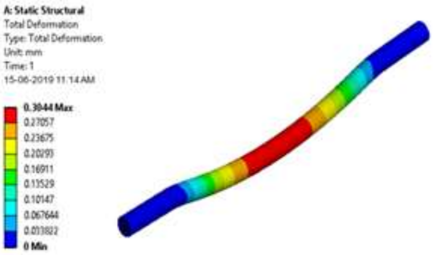


*Fig. 4.5 Deflection Report for Circular Axle Dia. 90*

**Stress report**

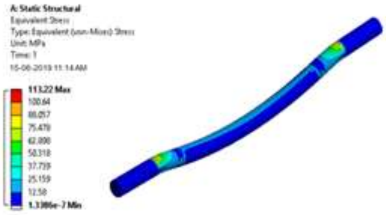


*Fig. 4.6 Stress Report for Circular Axle Dia. 90*

**For Material SAE 1020:-**
**For I Section**

**Deflection Report**

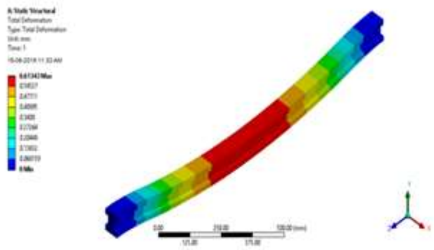

*Fig. 4.7 Deflection Report for I-Section Axle*

**Stress Report**

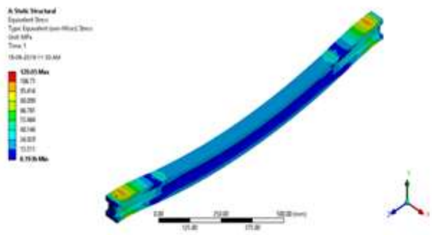

*Fig. 4.8 Stress Report for I-Section Axle*

**For Material SAE 1040:-**
**For Square Axle (75×75)**

**Deflection Report**

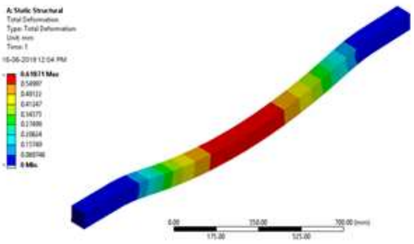

*Fig. 4.9 Deflection Report for Square Axle (75*75)*

**Stress Report**

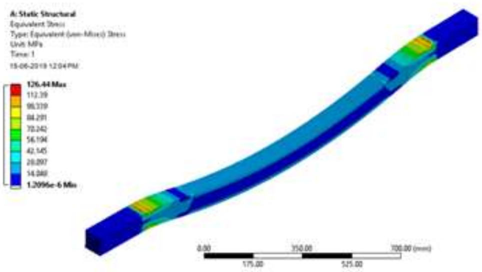

*Fig. 4.10 Stress Report for Square Axle (75*75)*

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**For Material SAE 1040:-**
**For Circular Axle Dia. 82mm**

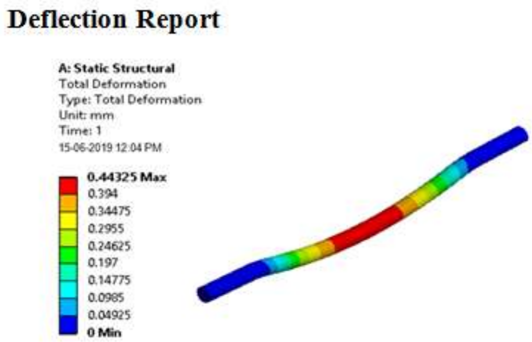


*Fig. 4.11 Deflection Report for Circular Axle (82*82)*

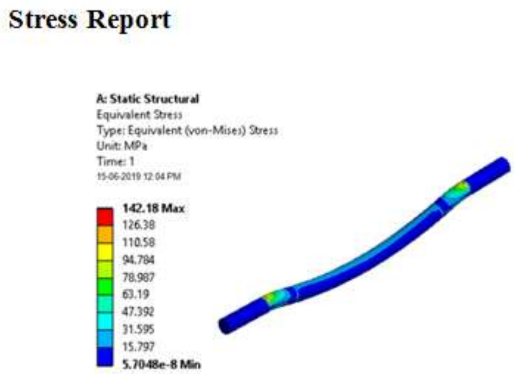


*Fig. 4.12 Stress Report for Circular Axle (82*82)*

**For Material SAE 1040:-**
**For I Section Axle**

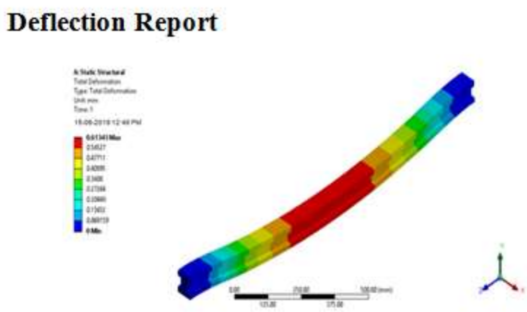


*Fig. 4.13 Deflection Report for I-Section Axle*

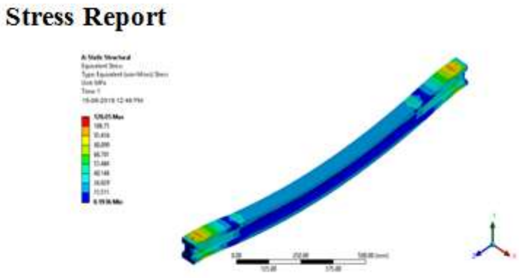


*Fig. 4.14 Stress Report for I-Section Axle*

**For Material Ductile Material:-**
**For Square Axle (80×80)**

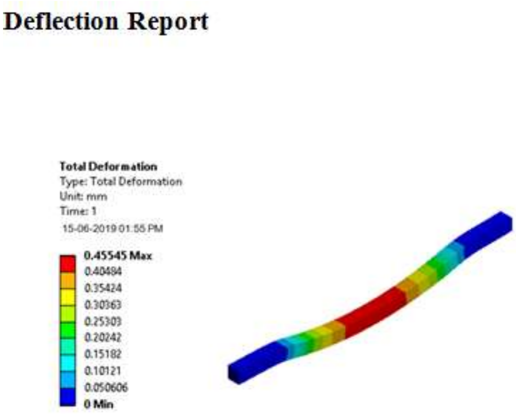


*Fig. 4.15 Deflection Report for Square Axle*

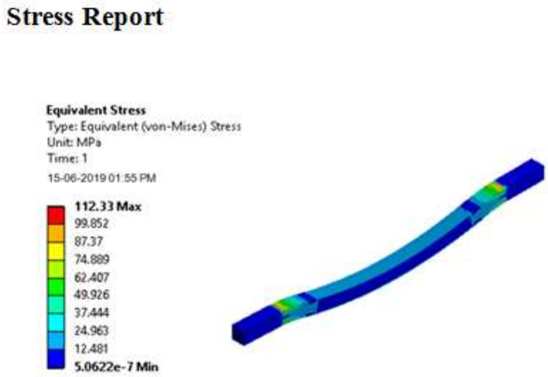


*Fig. 4.16 Stress Report for Square Axle*

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**For Material Ductile Material:-**

**For Circular Axle**

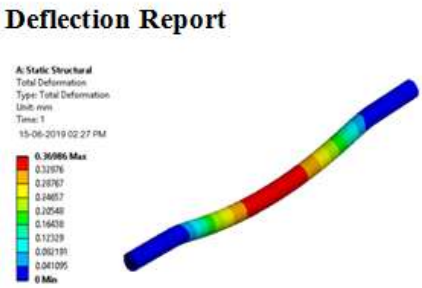


*Fig. 4.17 Deflection Report for Circular Axle*

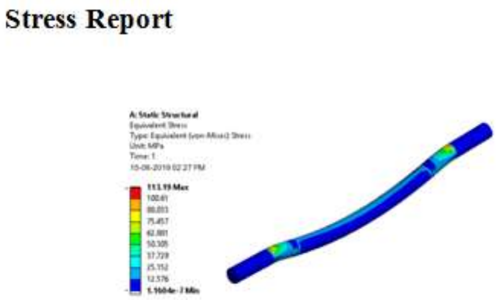


*Fig. 4.18 Stress Report for Circular Axle*

**For I Section Axle**

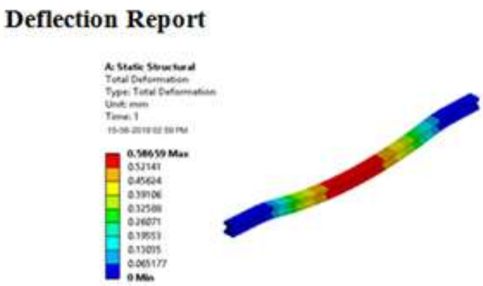


*Fig. 4.19 Deflection Report for I-Section Axle*

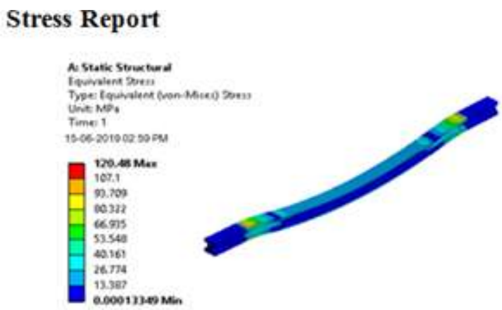


*Fig. 4.20 Stress Report for I-Section Axle*

## 7. 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.

## 8. 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-wantedly 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 shows 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 lying within limits. The amount looks very less for single axle, but if we consider huge number of axles produced in a firm then it truly being the huge amount.

## 9. ACKNOWLEDGMENT

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