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Design and Buckling Analysis of Connecting Rod

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***Abstract*—Connecting rod plays a crucial role in the working of an IC Engine, whose key role is to transmit power from the piston pin to the crankpin. It basically acts as a rigid link and transmits the reciprocating motion of the piston to the rotational motion of the crankshaft. It is a slender part with its length considerably greater than its width. It is mainly subjected to axial compressive stress. In this paper, we have considered a 4-stroke single cylinder IC Engine of 66 mm bore diameter and 99 mm stroke length, and calculated the required dimensions. We have modelled the Connecting rod using SOLIDWORKS software, and carried out Static and Buckling Analysis in ANSYS software.**

Keywords— Connecting Rod, IC Engine, Finite Element Analysis, Static Structural, Buckling Analysis, ANSYS.

I. INTRODUCTION

Connecting Rod is vital component for the basic working of IC Engines. It connects the piston and the crankshaft together and helps to convert the reciprocating motion of the piston into rotational motion of the crankshaft. It also transfers oil from crankpin to piston pin for lubrication. Its key is that it should have the capability to withstand the compressive stresses from the maximum gas pressure on the piston crown and the inertia force of the reciprocating parts as well as buckling and fatigue stresses. [3, 4, 5]

The connecting rod is generally made from materials like medium carbon steels or alloy steels. The carbon content varies from 0.35 to 0.45 percent in medium carbon steels.

Typically, nickel chromium or chromium molybdenum steels are used as alloy steels. The connecting rod is usually manufactured by the drop forging process, casting process and powdered metallurgy. [1]

The performance and lifespan of connecting rod is affected by numerous factors and design parameters. These factors include the type of engine to be used, maximum speed and torque that the engine can generate, shank cross-section like I-section and H-section. Design parameters include thickness of shank, radius of fillet, criteria for material selection, manufacturing processes used etc. By improving these aspects, we can increase the performance of connecting rods. [6, 7]

Connecting rods are widely employed in range of engines such as Single Cylinder engines, Multi Cylinder- In-line engines, V-engine, Radial engine, Opposed-Cylinder engine and Opposed-Piston engines. A connecting rod has three parts - a small end, a shank section, and a big end. They can be produced as single piece or two-piece components. To ensure that the bearings would fit properly, the piston pin end and crankpin end pinholes are machined as parallel holes. The piston and the connecting rod are coupled at the small end by the piston pin. The small end of the connecting rod will have a solid bushing of Phosphor Bronze or an analogous material. As the big end revolves with the crankshaft, the small end is forced to swivel on the piston pin. The bushing is necessary due to the high pressure and temperatures, in spite of only a slight movement relative to the piston pin. A two-piece conn. rod is made up of two parts to enable it to be clamped around the crankpin. The bottom part, or rod cap, is made of identical material as the rod and is fastened to the conn. rod by two bolts. The surface that is in contact with the crankpin is generally a split shell bearing. The two parts of the bearing are positioned in between the small end and crankpin by dowel pins. From the perspective of functionality, connecting rods must have the required rigidity at the lowest possible weight. [8]

II. ANALYTICAL DESIGN

For the CAD model, the calculations have been done as per the procedure mentioned in [1, 2].

Sr. No.	Parameter	Value
1.	Angle of inclination of connecting rod with line of stroke. (ϕ°)	3.3
2.	Yield Stress of Connecting Rod (σ_c in MPa)	330
3.	Constant 'a' for steel	7500
4.	Factor of Safety (F.S.)	3
5.	Bore Diameter (D in mm)	66
6.	Stroke Length (l in mm)	99
7.	Maximum Pressure (P_{max} in MPa)	5
8.	Thickness of the bush (t_b in mm)	2
9.	Marginal Thickness (t_m in mm)	5

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 05, May-2021

10.	Allowable bearing pressure for small end (P_{b1} in MPa)	12.5
11.	Allowable bearing pressure for small end (P_{b2} in MPa)	6
12.	Let the thickness of the connecting rod be 't'	

Table 1. Data & Assumptions

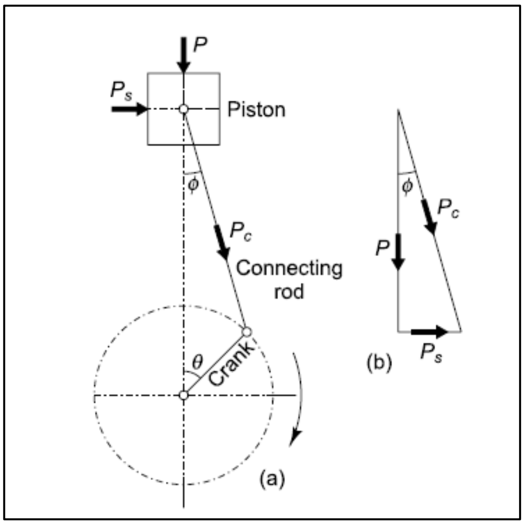

Figure 1. Schematic of forces acting on Connecting Rod. [1]

i. cos(ϕ) = 0.98748

ii. Force acting on connecting rod = $P_c = \left(\frac{\pi D^2}{4}\right)\frac{P_{max}}{\cos(\emptyset)}$

=> 17113 N

iii. Critical Buckling Load = $P_{CR} = P_c\ x\ F.S.$
=> 51338.6 N

iv. Total Length = $L = 1.5\ x\ Stroke\ Length$
=> 148.5 mm

v. Applying Rankine's Formula to find thickness 't'

$$P_{CR} = \frac{\sigma_c A}{1 + \frac{1}{a}\left(\frac{L}{K_{xx}}\right)^2} = \frac{330\ x\ 11t^2}{1 + \frac{1}{7500}\left(\frac{148.5}{1.78t}\right)^2}$$

t = 3.875 mm ≈ 4 mm

vi. Height at Middle Section = $H_o = 5t$
=> 20 mm

vii. Height at Small end = $H_s = \frac{0.75H_o + 0.9H_o}{2}$
=> 16 mm

viii. Height at Big end = $H_1 = \frac{1.1\ H_o + 1.25H_o}{2}$
=> 23 mm

ix. Width for cross-section = B = 4t
=> 16 mm

x. Height for cross-section = H = 5t
=> 20 mm

xi. Inner Diameter of Small End = $d_i = \sqrt{\frac{P_C}{P_{b1}\ x\ 1.5}}$
=> 31 mm

xii. Outer Diameter of Small End =
$d_o = d_i + 2t_b + 2t_m$
=> 45 mm

xiii. Inner Diameter of Big End = $D_i = \sqrt{\frac{P_C}{P_{b2}\ x\ 1}}$
=> 47 mm

xiv. Outer Diameter of Big End =
$D_o = D_i + 2t_b + 2t_m$
=> 61 mm

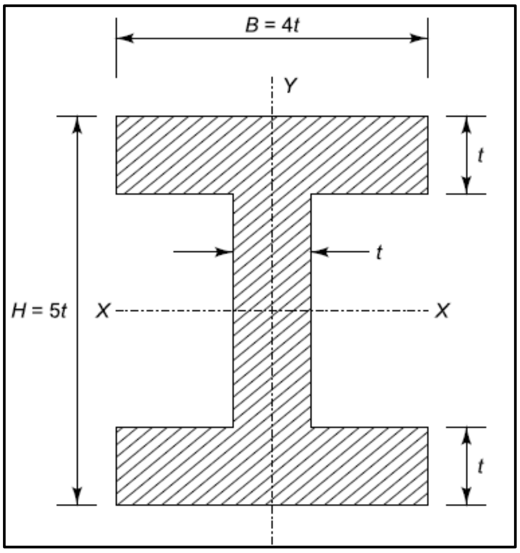

Figure 2. Typical cross-sectional view of Connecting Rod. [1]

III. CAD MODELLING

The Connecting Rod was designed in the CAD software SOLIDWORKS, using the dimensions calculated above. All the units are in mm. The main design parameters are as given in Table 2.

Sr. No.	Parameter	Value
1.	Length	148.5 mm
2.	ID of Small End	30 mm
3.	OD of Small End	44 mm
4.	ID of Big End	40 mm
5.	OD of Big End	54 mm
6.	Height at Middle Section	20 mm
7.	Height at Small End	16.5 mm
8.	Height at Big End	23.5 mm
9.	Width for cross-section	16 mm
10.	Height for cross-section	20 mm

Table 2. Design Parameters for Connecting Rod

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 05, May-2021

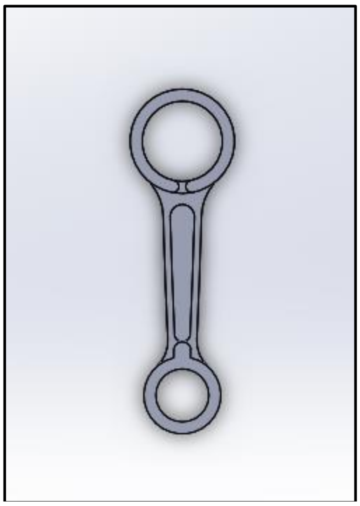

Figure 3. Top View of Conn. rod

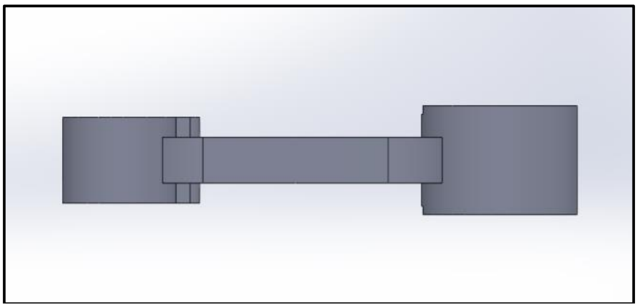

Figure 4. Side View of Conn rod

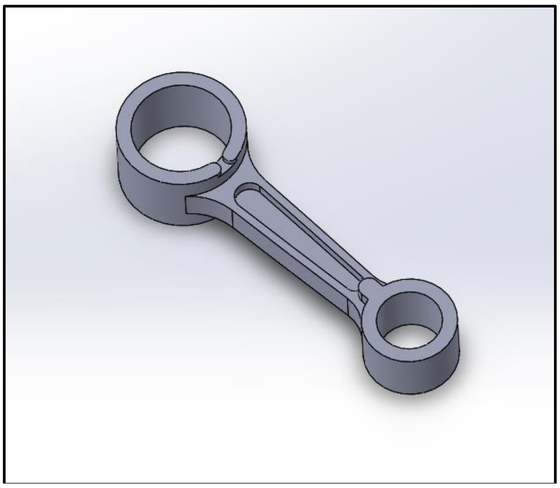

Figure 5. Isometric View of Conn. Rod

IV. FINITE ELEMENT ANALYSIS OF CONNECTING ROD

Using Ansys Geometry Design Modeler, the small end was sliced into two equal parts. This was done so that the force would be applied only to the lower half of the small end, similar to actual conditions. It can be seen in Fig 6. below.

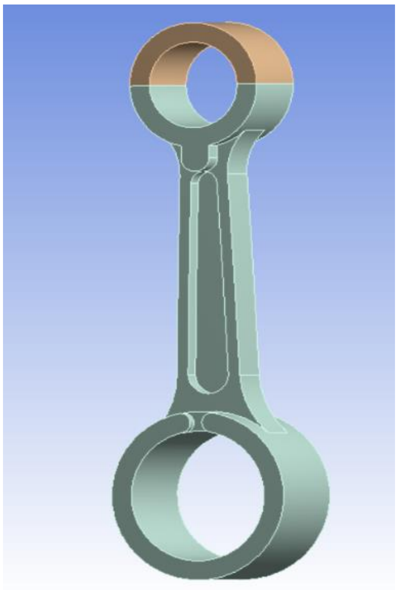

Figure 6. Conn. Rod Model

i. MESHING

Tetrahedron geometry was used for the meshing. The element type was Tet10 – 10 noded Tetrahedron. Mesh refinement was carried out at the locations as per the Structural Error Plot was showing significant error.

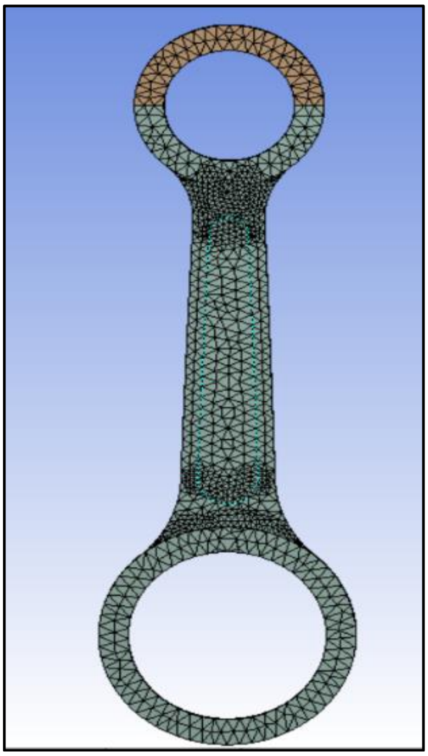

Figure 7. Meshing

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 05, May-2021

ii. BOUNDARY CONDITIONS

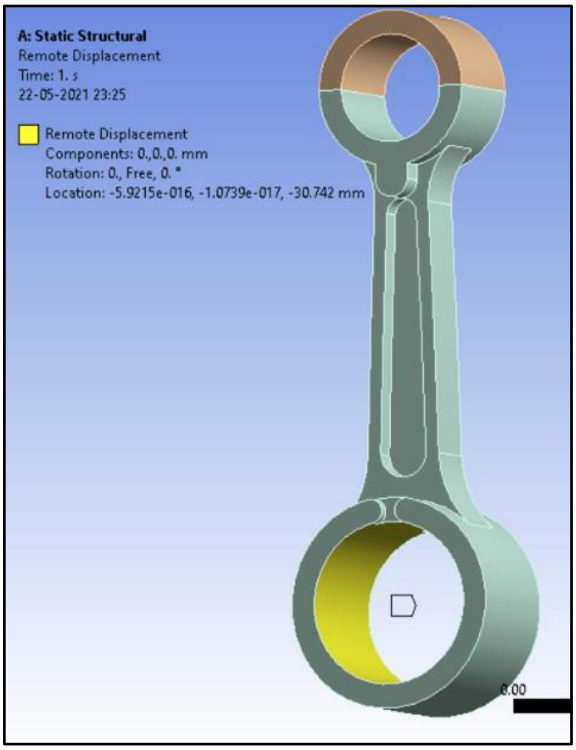

Figure 8. Boundary Condition 1

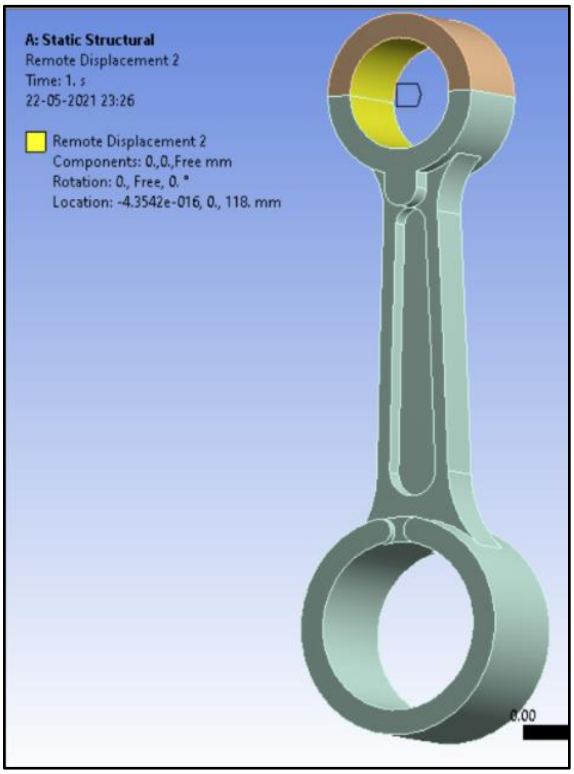

Figure 9. Boundary Condition 2

Dynamic behavior is observed for both, the small end and big end of the connecting rod. The small end moves along with the piston pin, whereas the big end moves with the crankpin. Hence, Remote Displacement has been applied to both the ends. Condition given to the big end is free rotation about Y-axis as it rotates with the crankpin. Condition given to small end is free translation along Z – axis and free rotation about Y – axis. Therefore, the connecting rod behaves as if the small end and the big end are hinged at the piston pin and crankpin respectively.

iii. STATIC STRUCTURAL

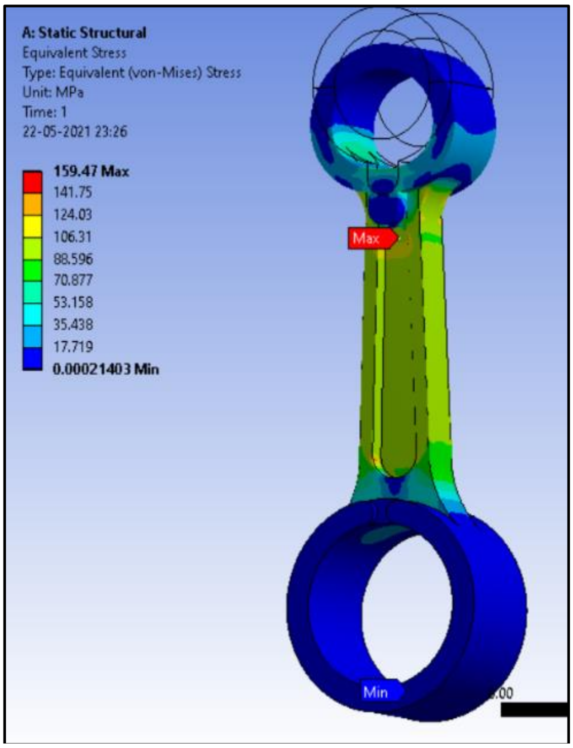

Figure 10.a. Equivalent Stress Contours

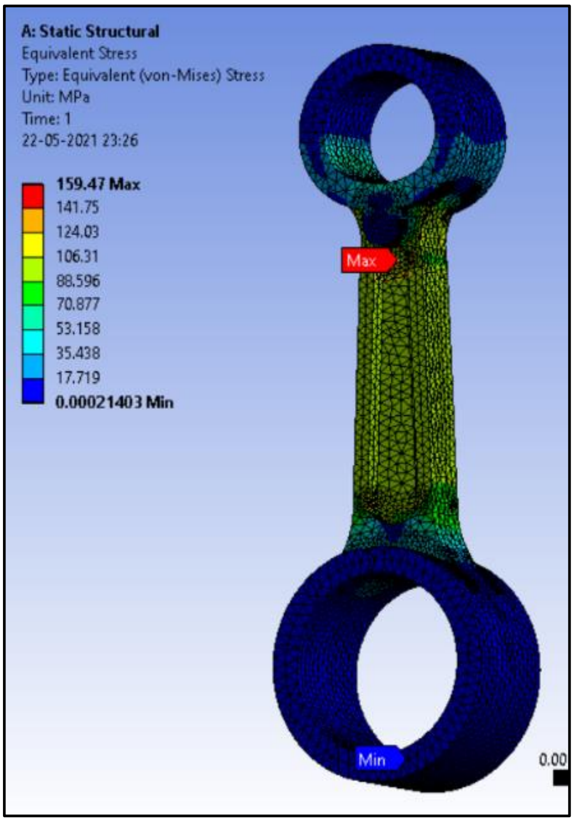

Figure 10.b. Plot for Equivalent Stress

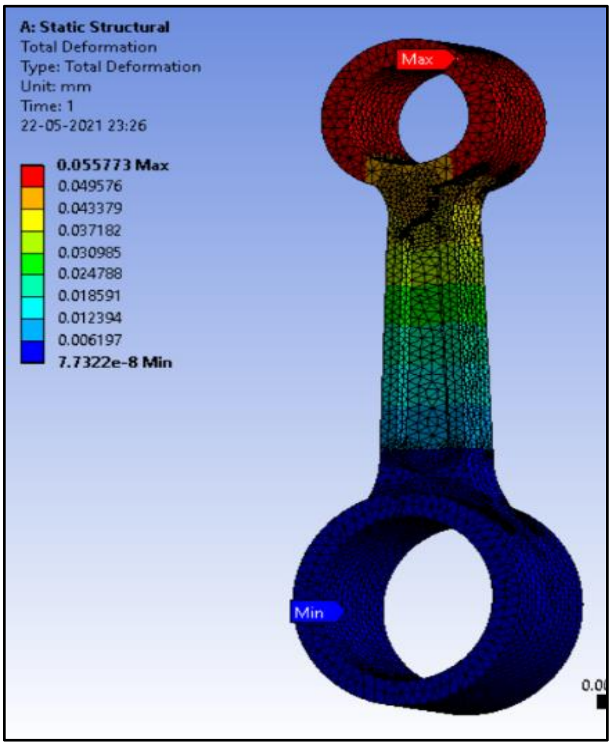

Figure 11.a. Plot for Total Deformation

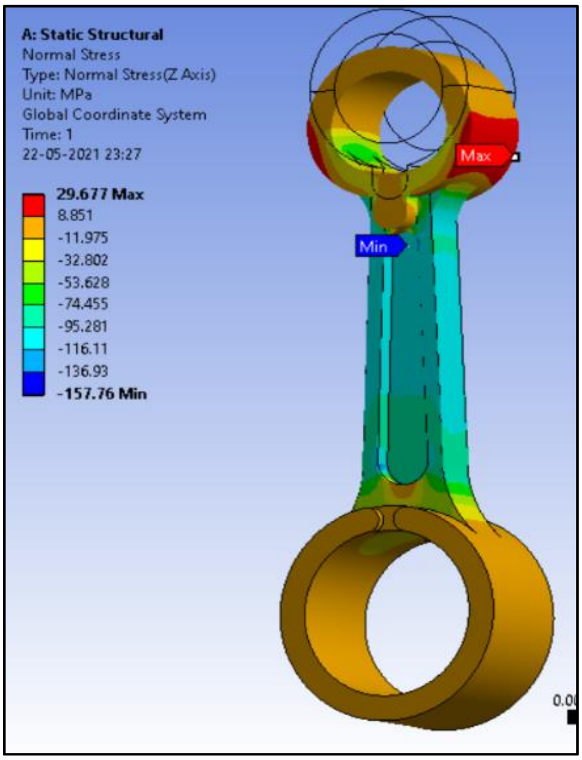

Figure 12. a. Normal Stress Contours

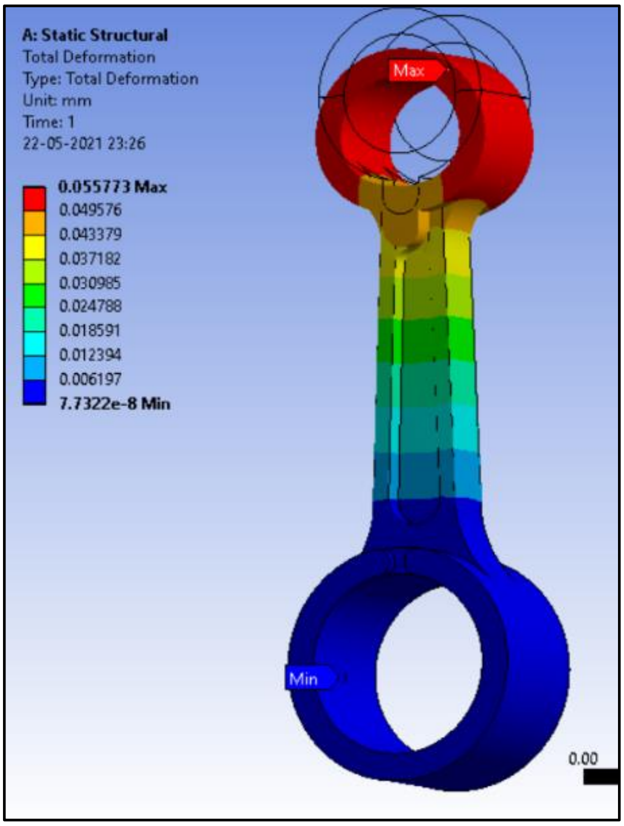

Figure 11.b. Total Deformation Contours

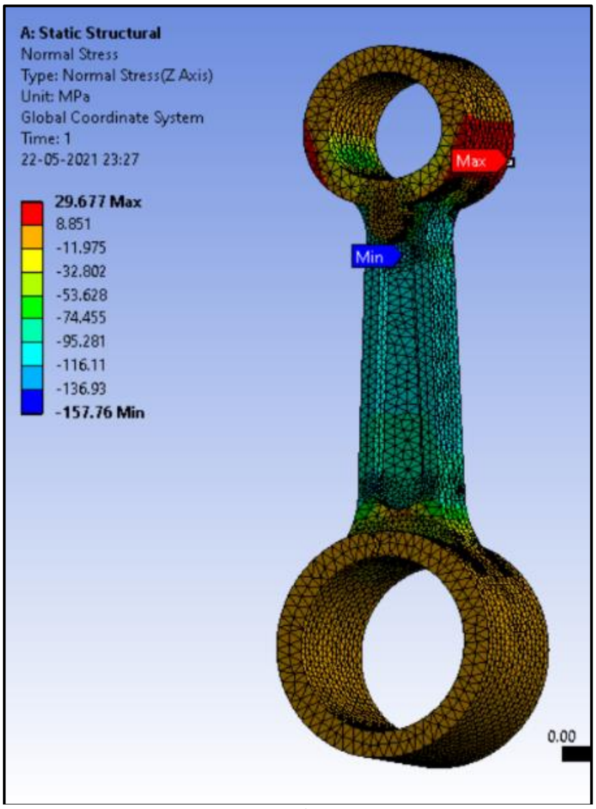

Figure 12. b. Plot for Normal Stress

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 05, May-2021

iv. BUCKLING ANALYSIS

The eigen value buckling analysis system in ANSYS was used for the estimation of buckling modes (See Fig. 13.a., 13.b., 14.a., 14.b.). It is a linear buckling analysis method. The buckling load has been evaluated by taking the product of applied load and load multiplier. The buckling analysis was done for two modes. The results generated by ANSYS for both the modes resembled the real-world scenario of failure of connecting rod, i.e., the first and second mode of buckling are exactly alike to the buckling failure of connecting rod. (See Fig. 13. a., 14. a.) [8]

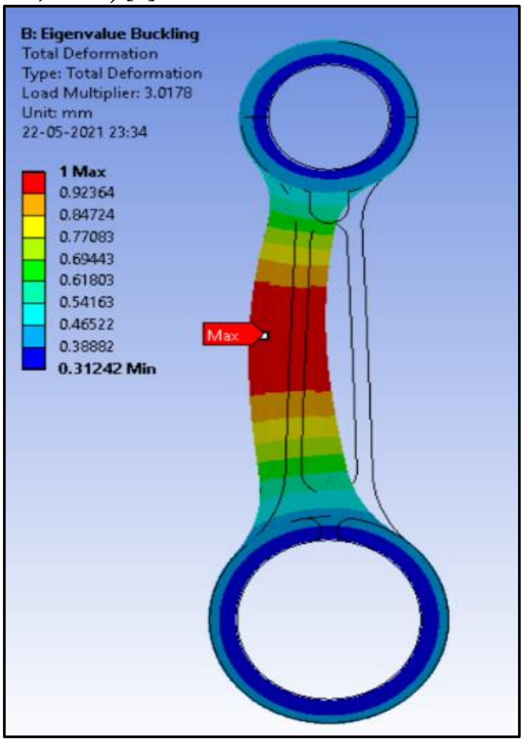

Figure 13. a. Total Deformation Contours

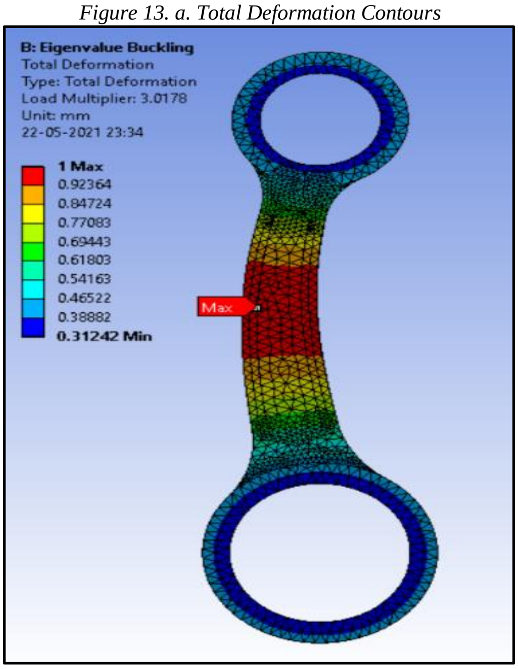

Figure 13. b. Plot for Total Deformation

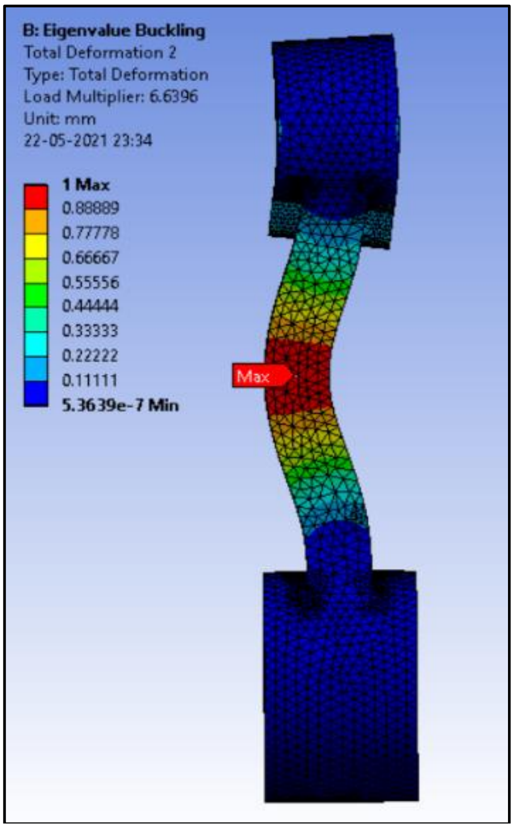

Figure 14. a. Plot for Total Deformation

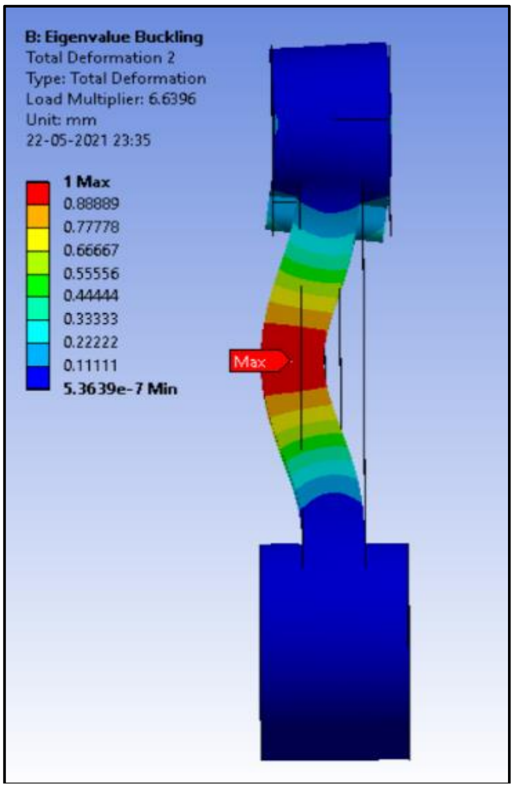

Figure 14. b. Total Deformation Contours

V. RESULTS

Sr. No.	Parameter	Results	
		Theoretical	Analytical (max)
1.	Normal Stress (σ_b in MPa)	110	157
2.	Critical Buckling Load (P_{CR} in N)	51338.6	51646.73
3.	Total Deformation for Static Analysis (in mm)	-	0.055
4.	Total Deformation for Buckling Analysis (in mm)	-	1

Table 3. Result table

For calculating the Theoretical Buckling Load, the force acting on the small end was multiplied by Factor of Safety. The load multiplier which we get from buckling analysis in ANSYS, is nothing but the Factor of Safety. So, for calculating the Analytical Buckling Load, we need to multiply the Force Applied by the load multiplier. Load multiplier was 3.0178 for mode 1 (See Fig. 13.b.) and 6.6396 for mode 2 (See Fig. 14. a.).

VI. CONCLUSIONS

In this study, we have designed the Connecting Rod, carried out Finite Element Analysis for Connecting Rod, and the results have been tabulated in the previous sections. The following inferences can be drawn from Finite Element Analysis –

- Static Analysis shows that the stress generated in the model is within acceptable limits or maximum allowable stress.
- The Displacement Plot shows very insignificant deformation, which has no consequence on the functioning of the Connecting Rod. Hence, it will not deform under the applied load.
- Buckling Analysis shows the buckling shape accurately, with the maximum deformation in the centre part of the Connecting Rod
- Buckling Analysis gives buckling factor greater than 1 and hence the Connecting Rod will not buckle under currently applied load.
- The values of Theoretical Factor of Safety and Analytical Load Multiplier are almost identical. From the load multiplier we can conclude that the Connecting rod can withstand upto three times the current load without buckling.

Thus, it can be concluded that the design and analysis of the Connecting Rod was carried out both, accurately and successfully.

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