# BUCKLING ANALYSIS AND MODAL ANALYSIS OF CONNECTING ROD USED IN I.C ENGINE

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*Abstract*— **Every vehicle that uses an internal combustion engine requires at least one connecting rod depending upon the number ovf cylinders in the engine. It undergoes high cyclic loads of the order of 108 to109 cycles, which range from high compressive loads due to combustion, to high tensile loads due to inertia. Therefore, durability of the component is of critical importance. Due to these factors the connecting rod has been the topic of research for different aspects such as production, materials, performance simulation, etc. When designing a connecting rod, one needs to pay attention to the buckling strength of the rod. The buckling strength is heavily affected by the beam section, and Johnson's buckling equation is used to estimate the buckling strength of a given beam section. Finite Element Analysis (FEA) is often used to evaluate the buckling strength of a rod that has complex changes in beam section. we will also reinforce 2 mm layer of carbon fiber on shank length of connecting rod. Again, we will perform Finite Element Analysis on carbon fiber reinforce connecting rod for finding buckling strength.**

*Keywords*— **Connecting Rod, Buckling, Stress, ANSYS, Catia, FEA**

## I.    INTRODUCTION

Due to the demand for downsized engines, greater specific power and increased mechanical efficiency, reciprocating power cylinder components are expected to exert less force on the cylinder walls to more efficiently transfer the combustion force in the cylinder to a reciprocating motion by the crankshaft, mainly by means of lighter weight. At the same time, these lighter cylinder components are expected to maintain sufficient strength and safety even as internal combustion engines have significantly increased both specific power and maximum speed during the last decade. One critical cylinder component is the connecting rod, which transfers the oscillating movement of the piston into the rotating movement of the crankshaft. The connecting rod must not only provide the stiffness and the strength to withstand the cylinder pressure and inertia forces of the engine, but must also be of minimal mass. Additionally, the hydrodynamic performance of the small end and big end must be considered and optimized in order to improve wear and friction properties and to meet tougher NVH requirements. This included Visual observation, metallurgical testing, magnetic testing, fractography analysis by stereo and scanning electron microscopy, residual stress imensional inspection, chemical analysis, Brinell hardness testing, tensile testing, inclusion microstructure analysis and grain flow Connecting Rod is one of the most important components of reciprocating internal combustion engine. It acts as a link between piston and crankshaft to convert the traverse motion of the piston to rotational motion of the crankshaft. It consists of small end (piston side), big end (Crank side) and I-section. Small end and big end are machined to ensure proper fitting of bush (at small end) and Bearings (at Big end). The small end is connected to piston through piston pin. The small end exhibits reciprocating motion while the Big end which is split in two parts for clamping it on the crankshaft exhibits rotational motion. Due to its operational nature, complex state of stresses which includes compression stresses associated to the pressure exerted by the combustion gases, and tensile stresses related to the inertia of the components in motion, either alternative or rotational. Increasing trend of higher power density engine and

harsh emission regulation tends to increase the mean effective pressure and the peak firing pressure. There are all four critical areas of the connecting rod the small end or pin end, the shank or I-beam, the crankshaft or big end and the bolted joint. A solution for an optimized component layout will be provided that combines excellent strength and improved durability with reduced mass. This optimized solution will enable automakers to design engines with higher fuel efficiency and greater reliability in order to meet the challenges of the future. The connecting rod can be designed and optimized under a load range comprising tensile load, maximum engine speed as one extreme load, and compressive load corresponding to the peak gas pressure as the other extreme load. Furthermore, the existing connecting rod can be replaced with a new connecting rod made of better that is lighter and less expensive due to the steel's fracture crack ability. Yet, the same performance can be expected in terms of component durability. Buckling strength is highly influenced by the yield stress of the connecting rod material.

## II. PROCESS

◆ Modeling four-wheeler connecting rod in CATIA V5 software.
◆ To perform static analysis of existing 4-wheeler connecting rod and composite reinforcement to determine the enhancement in mechanical properties under buckling analysis in ANSYS 19/22 software.
◆ To carbon reinforced the I section of connecting rod.
◆ To perform the Modal analysis using ansysis software.
◆ To check the difference between existing connecting rod and reinforced connecting rod.

**i. Material – CS70**

| Material | C70S6 |
|---|---|
| Hardness | 266-310 BHN |
| Tensile strength | 900-1050 N/mm$^2$ |
| Yield Strength | 550 N/mm$^2$ |
| Elongation | 10%, Min |
| Process | Hot Forget & Heat treated |

Fig. 1.    Mechanical Properties

**ii. Engine Specifications**

| Engine Capacity, litre | 105 |
|---|---|
| No. of Cylinder | 3 |
| Bore X Stoke, mm | 83 X 92 |
| Compression ratio | 16.5 |
| Peaking Firing Pressure, Bar | 160 |
| Application | Passenger Car |

Fig. 2.    Engine Specifications

## III. CALCULATIONS

**Given**
1)Angle of inclination of connecting rod with line of stroke= 3.3 degree
2)Yield stress of connecting rod=550 MPA
3)Constant a of steel =7500
4)Bore diameter= 63.30 mm
5)Stroke length = 126 mm
6)Maximum Pressure = 5 Mpa
7)Thickness of Bush = 2 mm
Marginal Thickness = 5 mm
8)Allowable Bearing Pressure for small end (pb1)= 2
10)Allowable Bearing Pressure (pb2) = 0.41
11) Euler's Critical Load =1171.71 N

**Solution**
i) Cos (θ) = 0.98748
ii) Forces acting on connecting rod = PC
=(πd/4)2 Pmax/cos PC = [π×63.30/4]2X4/0.9847
PC = 1000 N
iii) Total length of connecting rod
L = 1.5 ×126
L= 189 mm
iv) Applying Rankine's Formula Pcr = ∂cA/1+1/a (L/KXX)2
= 550×11t2 / 1+1/a (189/1.78t)2 t = 2.81 ≈ 3 mm
v) Width of cross section= B = 4 × t
= 4 × 3
= 12 mm
vi) Height of cross section
B = 5 × t
= 15 mm
vii) Inner diameter of small end
= √Pc/Pb1 ×1.5
= √1000 / 2 × 1.5
= 18.70 mm
viii) Outer diameter of small end
= di + 2 t b + 2 tm
= 18.7 + 1 × 2 + 5 ×2
= 31 mm
ix) Inner diameter of big end
= √1000 / 0.4 ×1
= 49.2 mm
x) Outer diameter of big end
= Di + 2 tb + 2 + m
= Di + 2 ×2 ×2 + 5
= 57.34 mm
xi) Critical Buckling Load= Pc× Euler's Critical Load

$=1000 \times 1171.71$
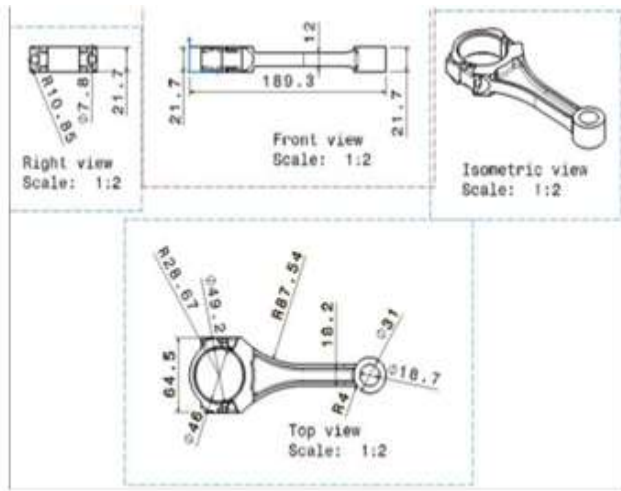$= 1171.71 \times 10^3$ N

## IV. CAD DESIGN
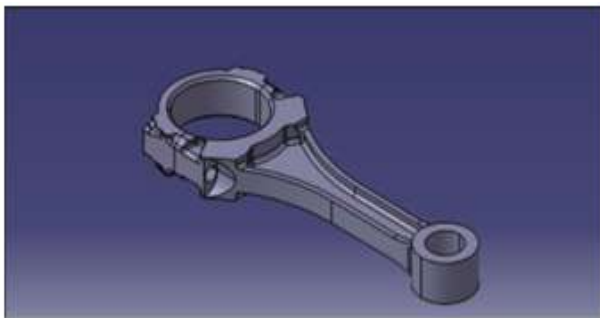


Fig. 3.    Dimensions of  Connecting Rod



Fig. 4.    3D view of connecting rod

## V. FINITE ELEMENT ANALYSIS

In present research for analysis ANSYS (Analysis System) software is used. Basically, its present FEM method to solve any problem. Following are steps in detail
1.Geometry
2.Discretization (Meshing)
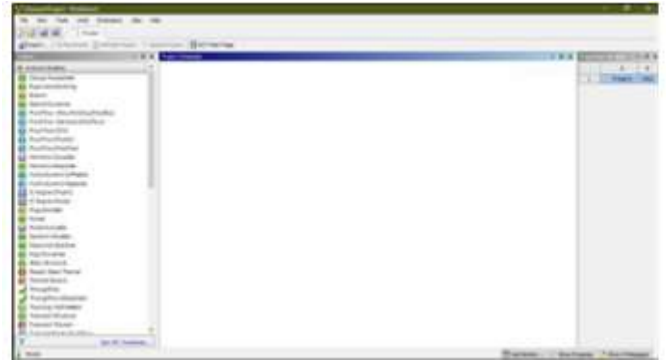3.Boundary condition
4.Solve (Solution)
5. Interpretation of results



Fig. 5.    ANSYS Overview

Workbench contain analysis of different types namely static, modal, harmonic, explicit dynamics, CFD, ACP tool post, CFX, topology optimization etc. as per problem defined.
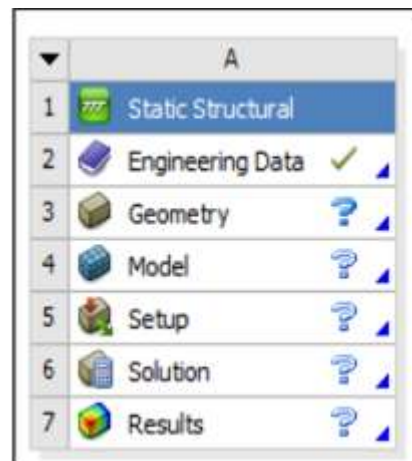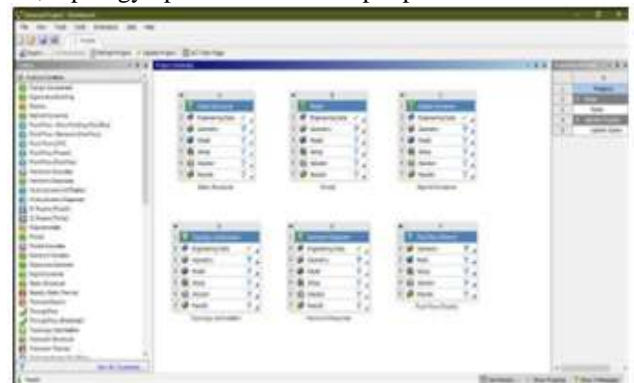




Fig. 6.    Selecting Static structural

Step 1: Details of material namely copper, steel, grey cast iron, composite material, fluid domain material is defined in engineering data. i.e. ANSYS default material is structural steel.
Step 2: Import of geometry created in any CAD software namely CATIA, PRO E, SOLIDWORK, INVENTOR etc.in geometry section. If any correction is to be made it can be created in geometry section in Design modeller or space claim.

Step 3: In model section after import of component Material is assigned to component as per existing material. Connection is checked in contact region i.e. bonded, frictionless, frictional, no separation etc. for multi body components. Meshing or discretization is performed i.e. to break components in small pieces (elements) as per size i.e. preferably tetra mesh and hexahedral mesh for 3D geometry and for 2 D quad or tri are generally preferred.

Step 4: Boundary condition are applied as per analysis namely in fixed support, pressure, force, displacement, velocity as per condition. Step 5: Now problem is well defined and solve option is selected to obtain the solution in the form of equivalent stress, strain, energy, reaction force etc.

| | A | B | C |
|---|---|---|---|
| 1 | Property | Value | Unit |
| 2 | Material Field Variables | Table | |
| 3 | Density | 7850 | kg m^-3 |
| 4 | Isotropic Secant Coefficient of Thermal Expansion | | |
| 6 | Isotropic Elasticity | | |
| 7 | Derive from | Young's Modulus and Pois... | |
| 8 | Young's Modulus | 2E+11 | Pa |
| 9 | Poisson's Ratio | 0.3 | |
| 10 | Bulk Modulus | 1.6667E+11 | Pa |
| 11 | Shear Modulus | 7.6923E+10 | Pa |

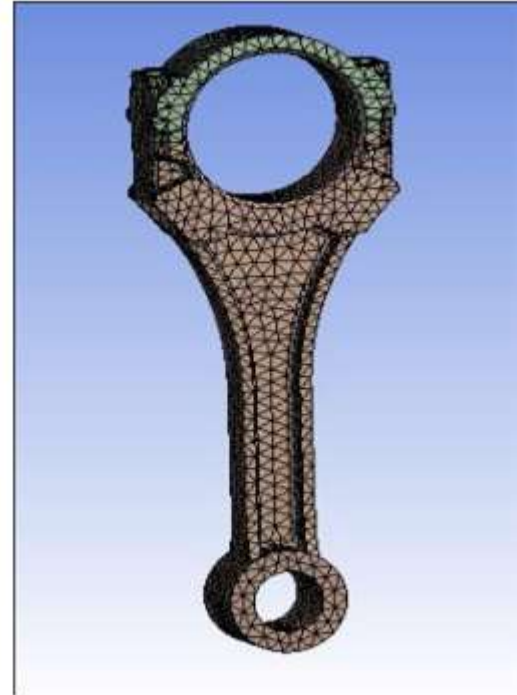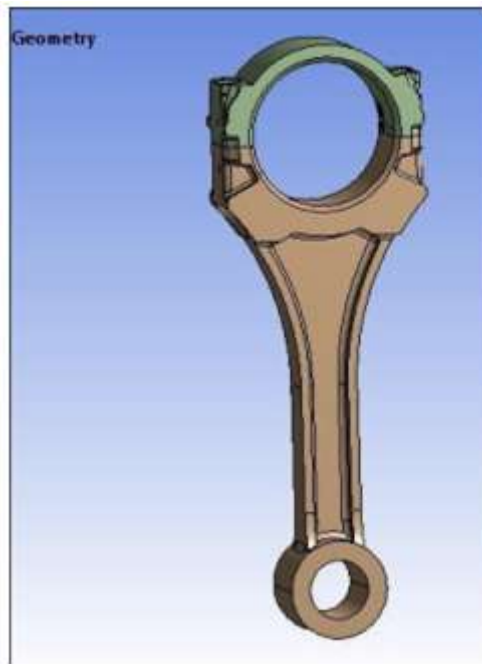Fig. 7. Properties Of Steel



Fig. 9. Meshing



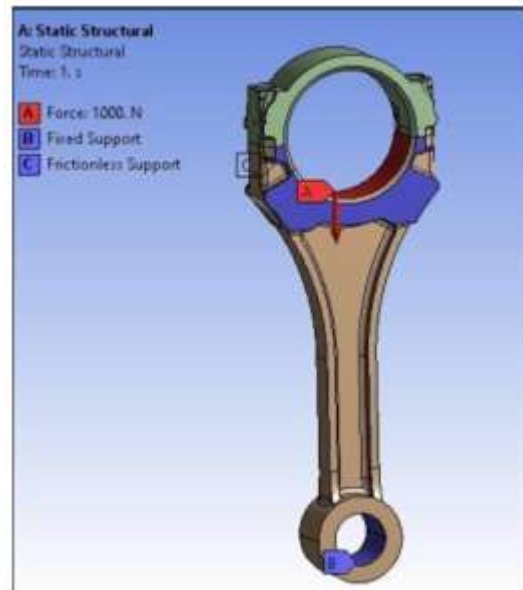Fig. 8. Geometry imported in Ansys



Fig. 10. Boundary Conditions

**Results**
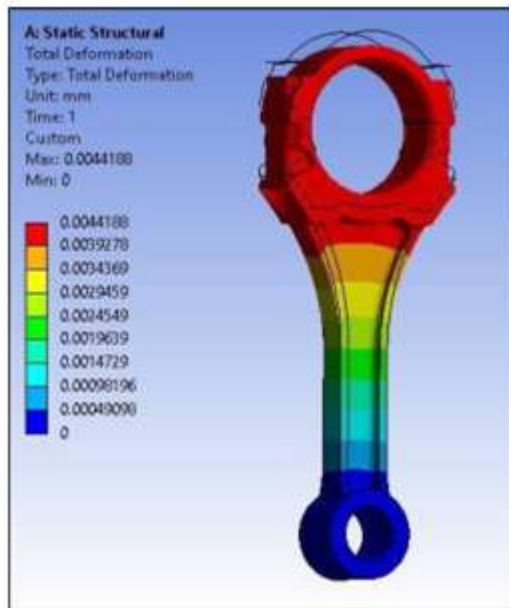
Fig. 11. Total Deformation Result



Fig. 13. Buckling Result


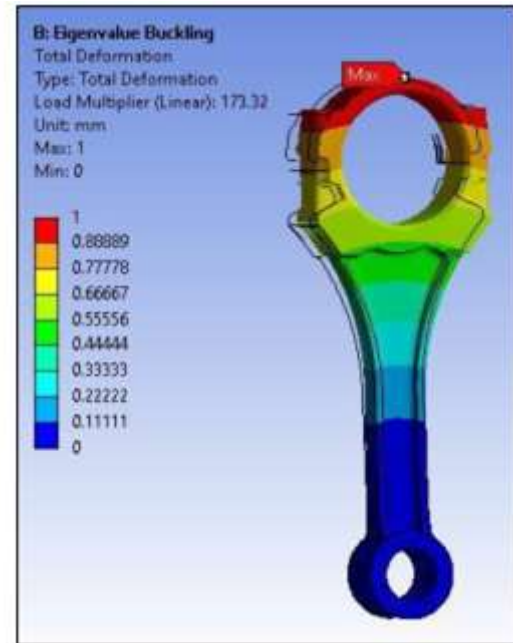
Fig. 12. Equivalent stress result



i. FOR MODE 1: Buckling load – load multiplier x force acting on rod = 173.32 x 1000 = 173320 N
ii. FOR MODE 2: buckling load – load multiplier x force acting on rod= 642.46 x 1000 = 642460 N

**Result**

VI.. CARBON REINFORCEMENT



| | | A | B | C |
|---|---|---|---|---|
| | | Property | Value | Unit |
| 1 | | | | |
| 2 | | Density | 1.49E-09 | mm^-3 t |
| 3 | | Orthotropic Secant Coefficient of Thermal Expansion | | |
| 8 | | Orthotropic Elasticity | | |
| 9 | | Young's Modulus X direction | 1.21E+05 | MPa |
| 10 | | Young's Modulus Y direction | 8600 | MPa |
| 11 | | Young's Modulus Z direction | 8600 | MPa |
| 12 | | Poisson's Ratio XY | 0.27 | |
| 13 | | Poisson's Ratio YZ | 0.4 | |
| 14 | | Poisson's Ratio XZ | 0.27 | |
| 15 | | Shear Modulus XY | 4700 | MPa |
| 16 | | Shear Modulus YZ | 3100 | MPa |
| 17 | | Shear Modulus XZ | 4700 | MPa |
| 18 | | Orthotropic Stress Limits | | |
| 19 | | Tensile X direction | 2231 | MPa |
| 20 | | Tensile Y direction | 29 | MPa |
| 21 | | Tensile Z direction | 29 | MPa |
| 22 | | Compressive X direction | -1082 | MPa |
| 23 | | Compressive Y direction | -100 | MPa |
| 24 | | Compressive Z direction | -100 | MPa |
| 25 | | Shear XY | 60 | MPa |
| 26 | | Shear YZ | 32 | MPa |
| 27 | | Shear XZ | 60 | MPa |

Fig. 14. Equivalent stress result
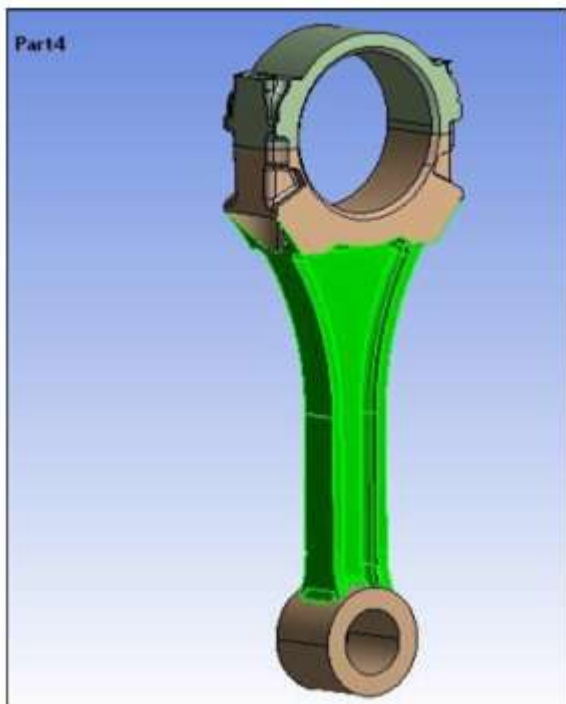


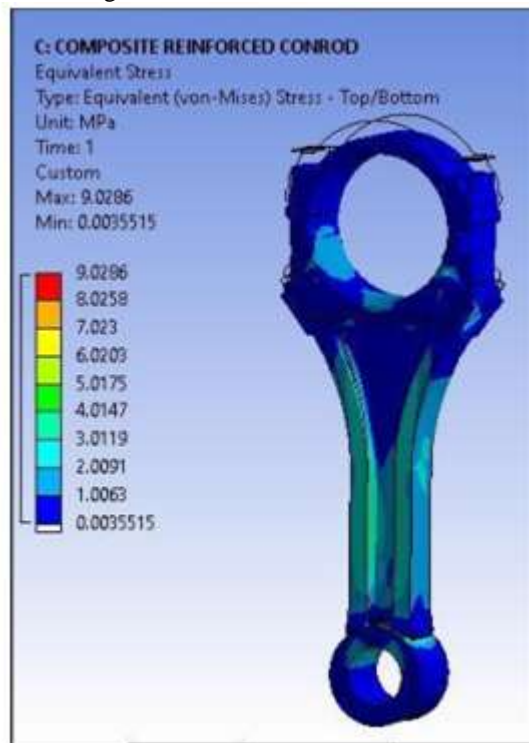Fig. 15. Reinforcement on I section
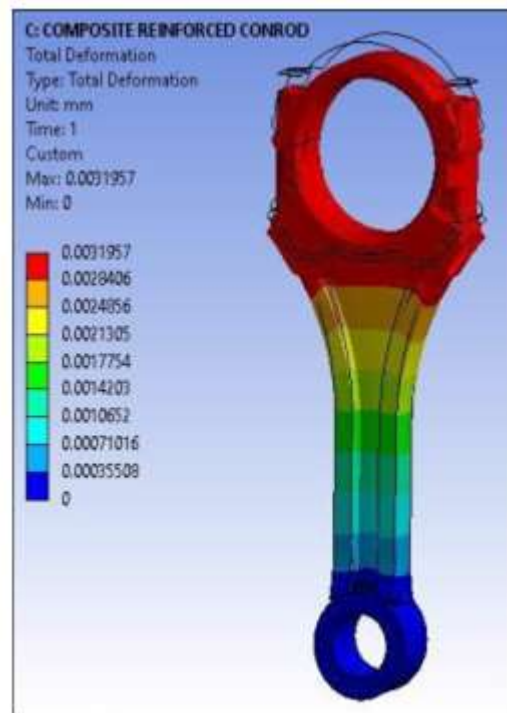


Fig. 16. Total deformation Result



Fig. 17. Equivalent Stress Result

Fig. 18. Buckling Result

BUCKLING LOAD – LOAD MULTIPLIER X FORCE ACTING ON ROD = 1184.9 X 1000 = 1184900 N

| Tabular Data | | |
|---|---|---|
| | Mode | ✔ Load Multiplier |
| 1 | 1. | 283.99 |
| 2 | 2. | 1184.9 |

### VIII. MODAL ANALYSIS

Connecting rod is an important component of the automobile engine dynamic system, it is not only a transmission component but also moving part, at the same time it must withstand variable load such as tensile, compressive force and bending in the working process. Therefore, dynamic characteristics study on the connecting rod has become an important part of design. Modal analysis is an effective method to determine vibration mode shapes and weak parts of the complex mechanical system. In this study, a modal analysis was applied to a connecting rod by ANSYS software at three critical working conditions, such as maximum tensile and compressive on small end, and tensile of cap end of connecting rod, the main purpose of analysis is to identify the model parameters of connecting rod such as natural frequency, vibration mode shapes and provide a basis for structural dynamics analysis and the follow-up optimal design of connecting rod. In this study modal analysis have been done for three critical working conditions of the connecting rod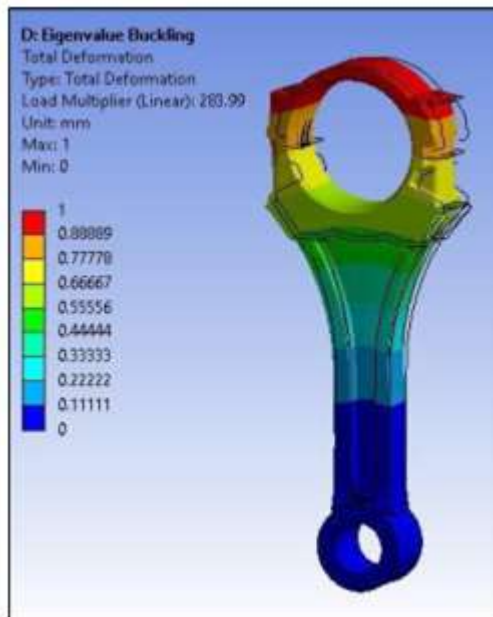. In this study, modal analysis was performed to calculate natural frequencies and mode shapes. And displacement in X and Y direction at selected node components is plotted.
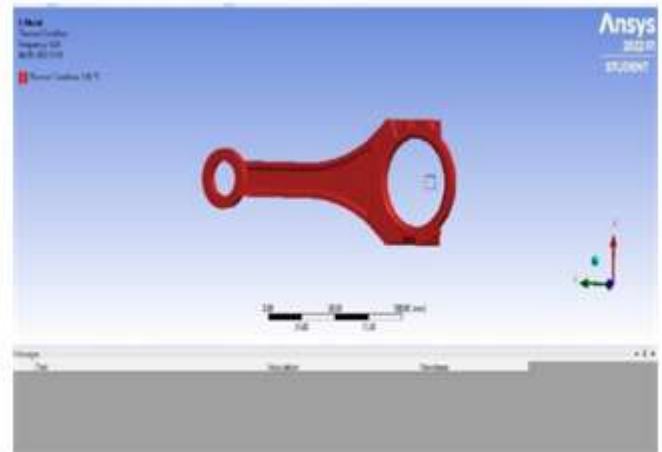
**Boundary Conditions**



Fig. 19. Boundary Conditions
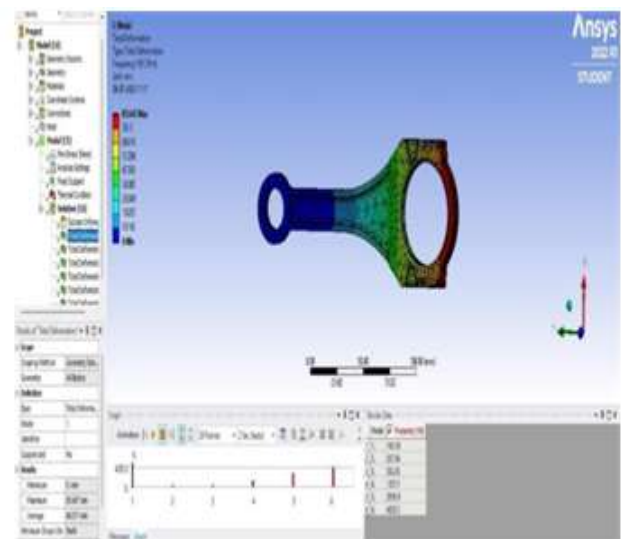


Fig. 20. Results

| Tabular Data | | |
|---|---|---|
| | Mode | ✔ Frequency [Hz] |
| 1 | 1. | 161.18 |
| 2 | 2. | 337.56 |
| 3 | 3. | 352.35 |
| 4 | 4. | 1357.1 |
| 5 | 5. | 2915.9 |

Fig. 21. Frequency Table
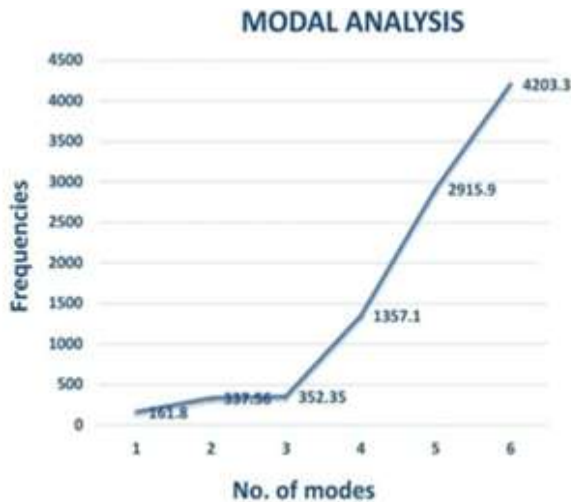
Fig. 22. Graph

| Sr. No | Parameter | Theoretical | Analytical |
|---|---|---|---|
| 1 | Total Deformation for buckling analysis (mm) | - | 1 |
| 2 | Total Deformation for static analysis | - | 0.004418 |
| 3 | Critical Bucking Load | 1171.71*10^3 | 1184.9*10^3 |
| 4 | Load multiplier difference between existing Connecting rod | 642.46*10^3 | 1184.9*10^3 |

Fig. 23. Comparison Between Theoretical & Analytical Result

## IX. CONCLUSION

- In present study 4-wheeler connecting rod is studied to determine the buckling load of existing connecting rod and reinforcement of carbon epoxy on rod to enhance its material strength properties.
- It is observed that existing connecting buckling load is lower than the composite connecting rod so, buckling load for composite rod have been improved by marginal difference.
- Buckling analysis gives buckling factor greater than one or equal to one hence connecting rod will not buckle under currently apply load.

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