# Static, Quasistatic and Buckling Analysis of 600 HP Engine Connecting Rod

**S.A. Muhammed Abraar, M. Rameeza, B. Ramesh**

***Abstract:** We have involved in the design & development of 600 hp indigenous engine with an aim to suit the power-pack requirements of our vehicle. In view of the above, it is planned to analyze the crank train components viz., Piston, Connecting rod, Crankshaft etc., for their structural strength for the given load condition. Hence it is proposed to carry out a detailed static, quasistatic and buckling analysis of connecting rod. The objective of this study is to analyse the connecting rod of the 600 hp diesel engine for the induced stresses due to static, quasistatic and buckling load. The net force acting due to the gas pressure and the inertia, is applied on the top of the piston. The reaction forces produced at each end of the connecting rod were predicted and given as input load for this analysis from the data generated through simulation. This report predicts the induced stresses and the buckling load estimation by the connecting rod of 600 hp engine.*

***Keywords :** Connecting rod, static, quasistatic and buckling analysis*

## I. INTRODUCTION

Development and application of buckling estimation method in engine connecting rod, by Heewook Moon, Sungwon Shin, Kyungwoo Lee, Hoon Chang and DaejoonYeom [1] tells about the buckling estimation method in engine connecting rod. Introduction to FEA, preprocessing, Altair Engineering [2], Altair Hypermesh gives the method to do buckling analysis. ABAQUS theory manual [3] (on-line) Ver.6.5, 2005 gives the method to do buckling analysis.

Design and analysis of connecting rod using forged steel, by Leela Krishna Vegi, Venu Gopal Vegi [4] gives the method to do buckling analysis. Structural and fatigue numerical analysis for connecting rods development, by Haroldo Chacon,Thyssen Krupp Metalurgica Campo Limpo [5] gives the method to do the numerical calculations for connecting rods. Design and analysis of connecting rod using ABAQUS by Rohit B. Bhandwale [6] gives the method to do buckling analysis.

### A. Engine Loads

The structural components of an internal combustion engine are subjected to complex field of strain and stresses created by temperature distribution related to heat transfer, gas pressures developed during the thermal cycle and the inertia forces due to moving parts. Thus the main forces acting on an engine are due to

- Inertia forces due to reciprocating masses (piston, piston pin & connecting rod)and
- Gas pressure due to forces of combustion.

### B. Engine Specifications

The specifications of the engine analyzed are given in the Table 1.

Table- I: Engine specification

| | |
|---|---|
| Description | Diesel engine, 60° V- Direct ignition, 4 stroke water cooled, Turbocharged |
| Max. Power | 600 hp |
| Max. Torque | 2700 N-m |
| Max. Speed | 4500 rpm |
| Peak fire pressure | 190 bar |
| Bore/Stroke | 137 mm / 169 mm |
| Starting System | Electric |

In any high power engine, the engine components are subjected to enhanced structural loadings. Mechanical loading is due to the inertia forces of reciprocating members and gas pressure in terms of peak pressure.

### C. Solid Modeling

The solid model of the entire assembly of the 600 hp engine connecting rod components is done in Creo. Figure1shows the solid model of the connecting rod
assembly.

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**Fig. 1 Solid model of 600 hp engine connecting rod assembly**

Initially it is planned to carry out the structural analysis of connecting rod alone against the forces developed by piston thrust, gas pressure and other inertia forces.

## II. MATERIAL PROPERTIES OF CONNECTING ROD

The connecting rod are made from the steel material. The material properties considered for steel are given below in the Table-II.

**Table-II: Material properties of connecting rod**

| Material | Young's modulus (E) MPa | Density (ρ) kg/m$^3$ | Poisson's ratio (ν) |
|---|---|---|---|
| Steel | $2.1 \times 10^5$ | 7,850 | 0.3 |

**Material**: 42CrMo4

UTS : 1200-1350, MPa
Tensile stress : 850-1000, MPa
Yield stress : 650, MPa
Fatigue limit : 450-600, MPa

## III. FINITE ELEMENT MODELLING FOR STRUCTURAL ANALYSIS

### A. Static Analysis

The Connecting rod is modeled with quadratic tetrahedral solid finite elements (C3D10). The finite element model of connecting rod is shown in Figure 2.

- Total number of nodes: 214227
- Total number of elements: 143959

### B. Quasistatic Analysis

- It is a series of static analysis
- Quasistatic load means the load is applied so slowly that the structure deforms also very slowly (very low strain rate) and therefore the inertia force is very small and can be ignored.
- A dynamic load, on the other hand, causes a structure to vibrate and the inertia force is big enough and must be considered.
  - These reaction forces were predicted and given as input for this analysis

### C. Buckling Analysis

Buckling analysis is carried out to find out the critical buckling load and the buckling factor of safety.

**Fig. 2. Finite element model of connecting rod**

## IV. STRUCTURAL LOADING

The net force acting due to the gas pressure and the inertia, is applied on the top of the piston in the crank train mechanism developed in Creo. Also, for particular speed of engine, the reaction forces produced at each eye of the connecting rod is found and plotted for the two revolutions i.e., for 720$^o$. For the rated speed of 2340 rpm, the reaction forces produced at each eye of the main connecting rod is found.

### I. Load case 1: Max. inertia load @ 4500 rpm

(a) Load applied at small end
- Axial load = 36922.4 N

### II. Load case 2: Max. Gas pressure @ 2340 rpm

(a) Max load considered at 13 degree crank angle
(b) Load applied at small end
- Axial load = 184370.13 N
- Perpendicular load = 255.56 N

The kinematic couplings with boundary condition and the load are shown in Figure 3(a).

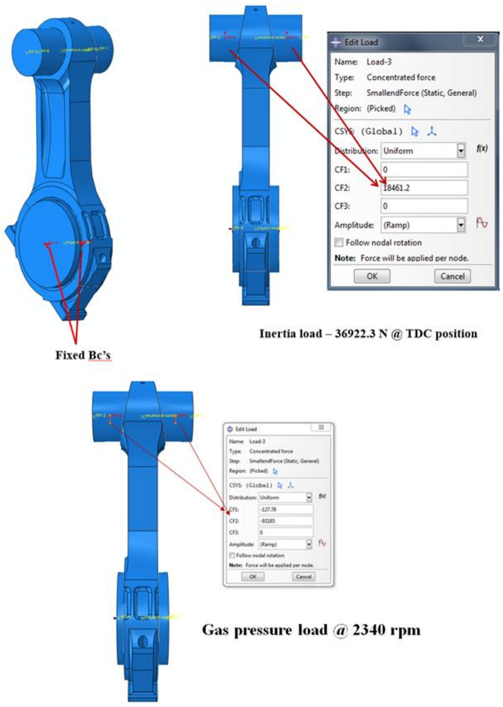



**Fig. 3.(a). BC and Loads**

Figure 3(b), shows the proper surface contacts provided between the inner surface of the connecting rod small end and outer surface of the gudgeon pin and inner surface of the bush at connecting rod big end and outer surface of the crank pin of crank shaft.

Fig. 3.(b) Surface contact between connecting rod small end with Gudgeon pin and connecting rod big end with crank pin

Figure 3(c), shows the tie constraint between the surfaces in contact at connecting rod big end which is split into two pieces.

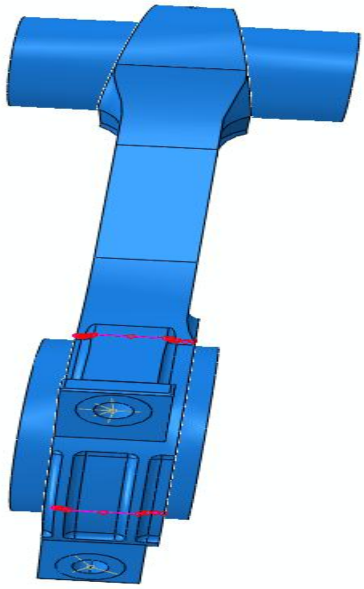


Fig. 3.(c) Tie constraint between the contact surfaces of split part & the main connecting rod at connecting rod big end

Figure 3(d), shows the,

- Pretension load of 36363.64 N due to tightening the bolts are applied on the coupling center point provided at bolt location on the connecting rod big end.

## III. Bolt Preload

$P_i = T/(K D)$

Where $P_i$ = bolt preload

T = bolt installation torque (T = 80 Nm)

K = torque coefficient (K = 0.22)

D = bolt nominal shank diameter (D = 10 mm)

$P_i = 80000/(0.22*10)$

$\mathbf{P_i = 36363.64\ N}$

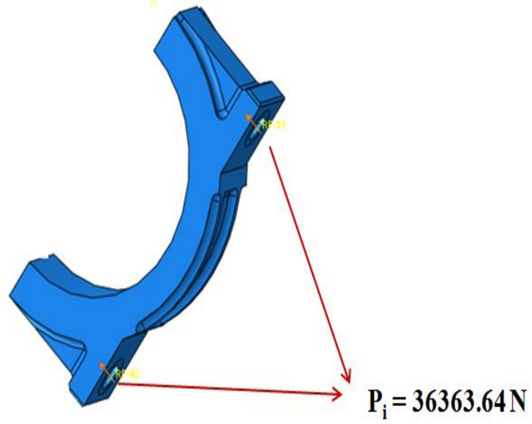



**Fig. 3.(d): Pretension load of 36363.64 N**

The forces are taken at the worst condition, i.e. during the power stroke for the rated speed, at small end of connecting rod. The resultant inertia force vs time used in q uasistatic analysis are shown in Figures 4 (a), 4 (b), 4(c) & 4(d).

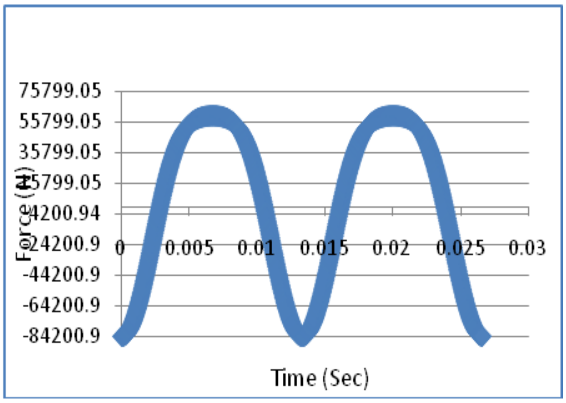



**Fig. 4. (a). Inertia force acting at big end along the axis of the connecting rod**

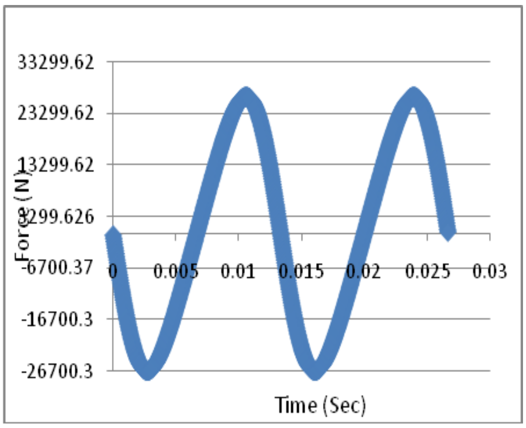



**Fig. 4 .(b) Inertia force acting at big end perpendicular to connecting rod**

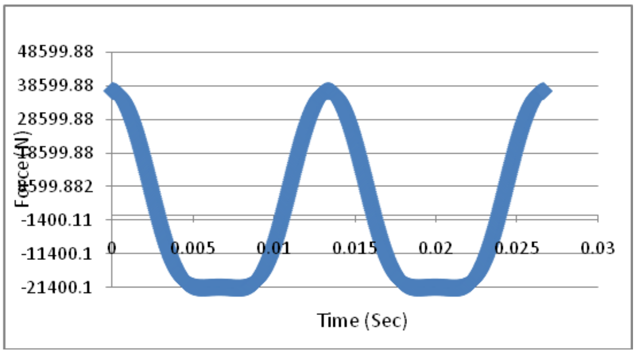



**Fig. 4. (c). Inertia force acting at small end along the axis of the connecting rod**

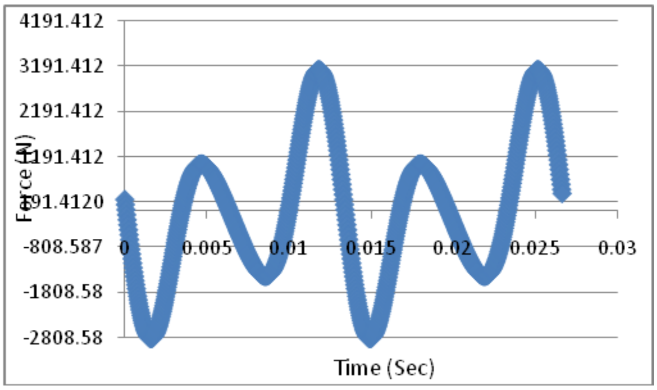



**Fig. 4. (d). Inertia force acting at small end** perpendicular to connecting rod

The resultant gas pressure force vs time are shown in Figures 5 (a) , 5 (b), 5(c) & 5(d).

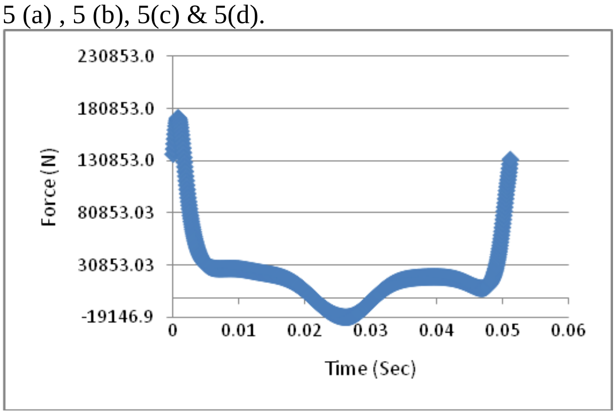



**Fig. 5. (a). Gas pressure force acting at big end along the axis of the connecting rod**

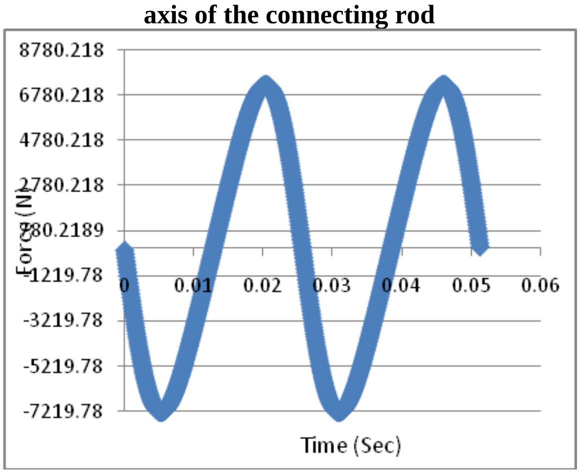



**Fig. 5. (b). Gas pressure force acting at big end perpendicular to connecting rod**

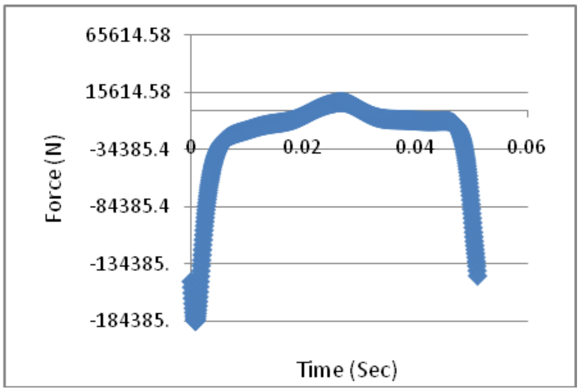



**Fig. 5. (c). Gas pressure force acting at small end along the axis of the connecting rod**

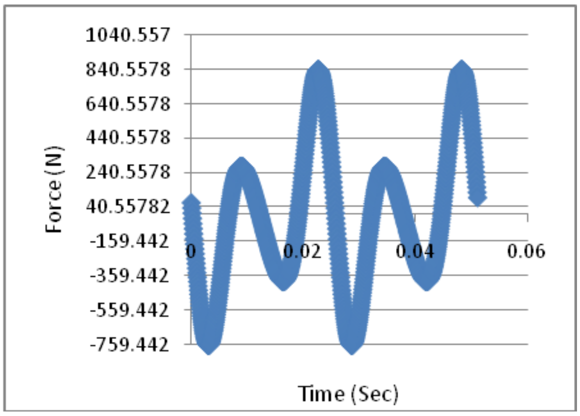



**Fig. 5. (d). Gas pressure force acting at small end perpendicular to connecting rod**

## IV. RESULTS & DISCUSSION

The static analysis has been carried out using finite element analysis tool, ABAQUS. The estimated Von-misses stresses and deformation are plotted, as shown in the Figures. The results are also shown in Table 3.

### A. Load case 1: Max. inertia load @ 4500 rpm

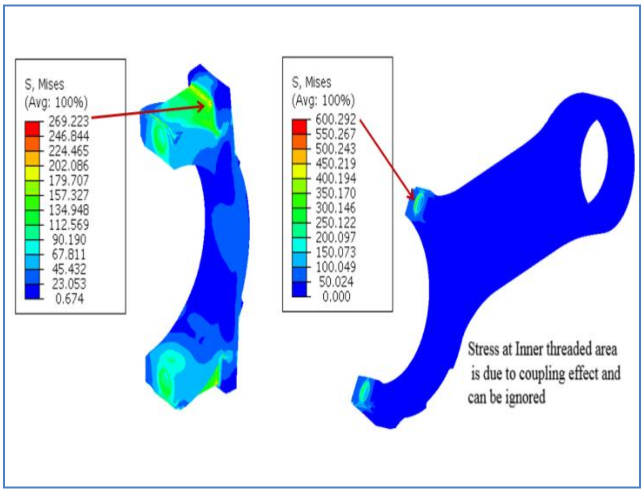



**Fig. 6. Stress due to pretension**

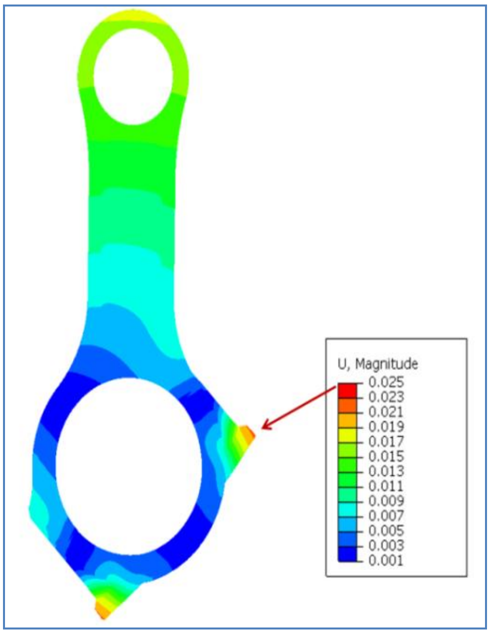



**Fig. 7. Deformation due to pretension**

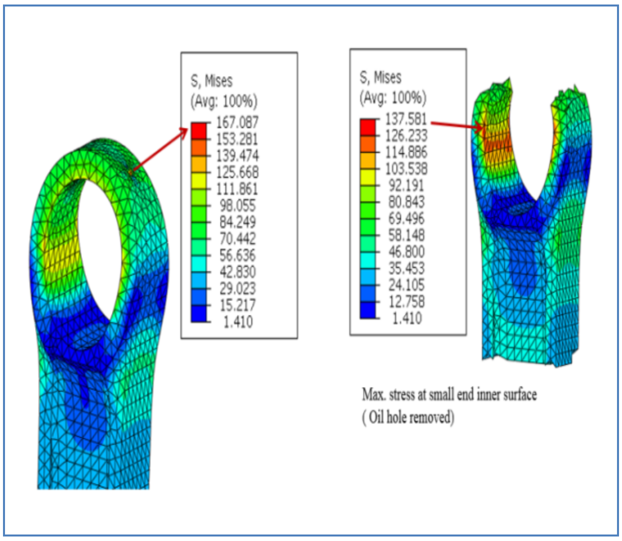



**Fig. 8. Stress in the small end due to inertia load – 4500 rpm**

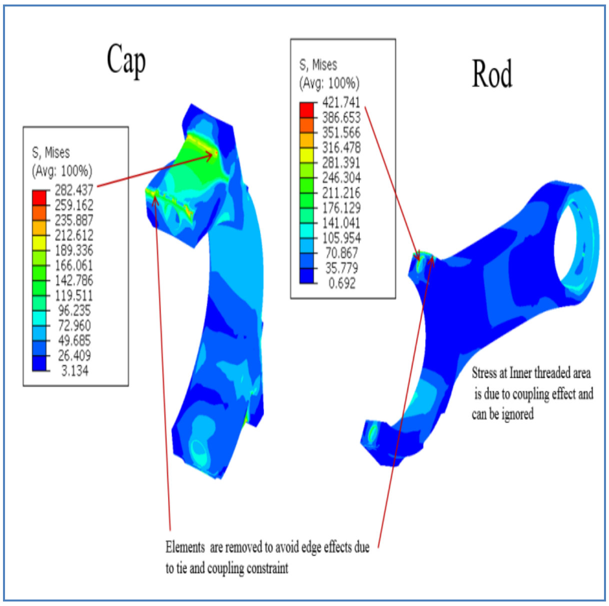



**Fig. 9. Stress in the big end due to inertia load – 4500 rpm**

## B. Load case 2: Max. gas pressure @ 2340 rpm

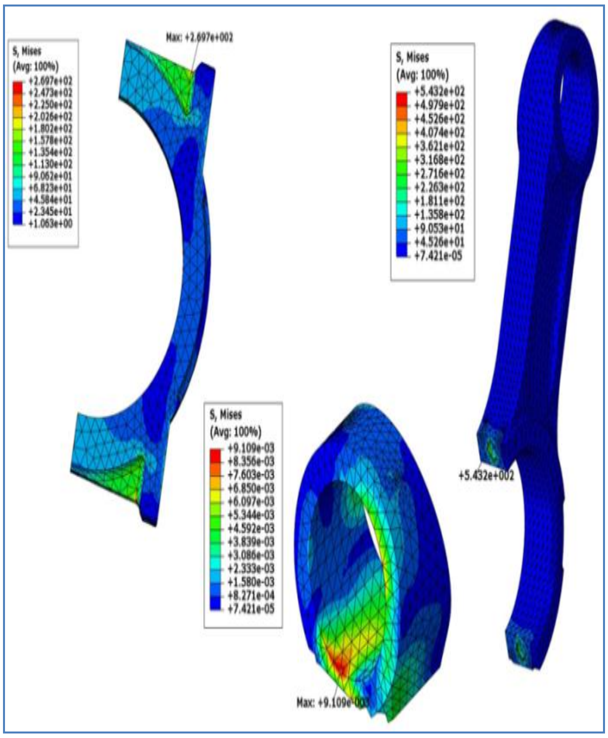



**Fig. 10. Stress due to pretension**

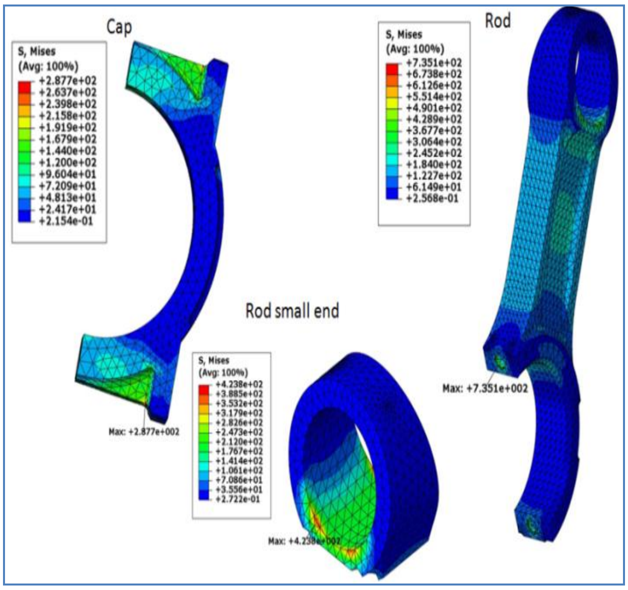



**Fig.11. Stress due to gas pressure load @ 2340 rpm**

**Table-III Maximum Von-Misses stresses in MPa at respected cases**

| Sl.No | Load condition | Stress due to Bolt Pretension, MPa | Stress due to Loads, MPa |
|---|---|---|---|
| Case 1 | Inertia load | 600. 29 | 421. 74 |
| Case 2 | Gas pressure load | 543. 2 | 735. 1 |

### C.Buckling Analysis Result

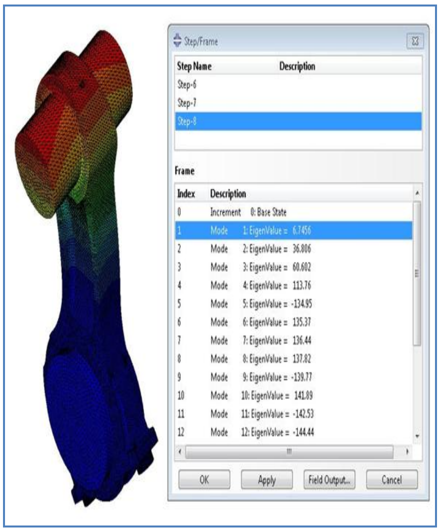



**Fig. 12. Buckling analysis result**

### D.Calculations

Merchant-Rankine formula is

$$P_{cr} = \left[ \left( \frac{\pi^2 EI}{(KL)^2} \right)^{-1} + \left( A \times \sigma_y \right)^{-1} \right]^{-1}$$

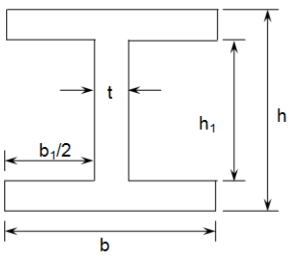
$$= \left[ \left( \frac{1}{P_{cr}|_e} \right) + \left( \frac{1}{P_{cr}|_p} \right) \right]^{-1} \quad (1)$$

The first term of Merchant-Rankine's equation the first term is the elastic term given by Euler's equation and the second term is the plastic term derived with yield strength of material and cross section area A. As the slenderness ratio decreases $P_{cr}$ of Merchant-Rankine's equation is close to the yield load, and as it increases $P_{cr}$ is close to the elastic buckling load. For connecting rod, it seems to be K = 1. In this study, the method to evaluate $P_{cr}|_e$ is developed by using FEA. The maximum compressive load of the connecting rod is **184370 N**. The commercial FEA software ABAQUS calculates the eigenvectors and eigenvalues of the structure under the given boundary conditions, $P_{cr}|_e$ is obtained as the multiplication of eigenvalue to the maximum applied compressive load.

$$P_{cr}|_e = (F_{applied} \times \lambda) \quad (2)$$

From FEA analysis we got $\lambda$ = 6.7456
Applied load = 184370.13 N
Thus elastic critical/buckling load,

$$\mathbf{P_{cr}|_e = 1243687.15\ N}$$




b = 29.2 mm
$b_1$ = 15.67 mm
t = 13.53 mm
h = 55 mm
$h_1$ = 39 mm

The shank area, A = 994.87 $mm^2$

Yield strength of connecting rod is $\sigma_y$ = 415 MPa

$$P_{cr}|_p = A \times \sigma_y \quad (3)$$

$$\mathbf{P_{cr}|_p = 412871.05\ N}$$

Finally the critical buckling load is

$$P_{cr} = \left[ \left( \frac{1}{P_{cr}|_e} \right) + \left( \frac{1}{P_{cr}|_p} \right) \right]^{-1} \quad (4)$$

$$\mathbf{P_{cr} = 310060.65\ N}$$

To evaluate the buckling possibility BSF is defined here as equation

$$BSF = \frac{P_{cr}}{P_{\max}} \quad (5)$$

**BSF = 310060.65 / 184370**
**BSF =1.68**

## V. SUMMARY & CONCLUSION

- This study has been carried out for the purpose of finding the induced mechanical stress and critical buckling load in the connecting rod of 600 hp engine.
- Proper contact surfaces are created between the connecting rod and Gudgeon pin and between connecting rod and crank shaft crank pin. BCs and compressive, tensile loads with the pretension bolt load of 36363.64 N is considered for this analysis.
- The structural analysis has been done with the reaction forces, predicted by engine group and given as input for this analysis, which are calculated based on the gas pressure produced during expansion (Power stroke).
- The maximum Von-Misses stress which was estimated from the analysis is (in case No.2) less than the yield stress 65**0** MPa.
- Critical buckling load was found out to be 310060.65 N and the buckling factor of safety BSF is calculated as 1.68.
- Quasistatic analysis result coincides with the static analysis results.
- It is further planned to carry out the dynamic analysis of connecting rod by applying P-θ diagram.

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