

Design and Structural Analysis of a Hydraulic Piston–Rod Assembly Using Finite Element Method Use in Orange Peel Grab

Sonu Rajeshvar More¹, Dr. S. K. Biradar², Vilas Bhimrao Jadhav³,
Prof. Md. Irfan⁴

¹Mechanical Engineer, MSS CET Jalna, Dr. Babasaheb Ambedkar Technological University Lonere
432103, Maharashtra

²Principal, Matsyodari Shikshan Sanstha's College of Engineering and Technology Jalna, Maharashtra
shantisagarbiradar@gmail.com

³Assistant Professor, MSS College of Engineering and Technology, Nagewadi Jalna, Maharashtra
vilasj17@gmail.com

⁴Assistant Professor, Mechanical Engineering Department, irfanmohd777@gmail.com

Abstract

Hydraulic cylinders are widely used in industrial machinery, construction systems, and material-handling equipment. The piston–rod assembly is the most critical load-bearing component, directly transmitting hydraulic force into mechanical work. This study presents the design, analytical calculations, and Finite Element Analysis (FEA) of a steel piston–rod system subjected to 25 MPa operating pressure. Three commonly used materials—EN8 & EN19 were evaluated to determine their structural suitability. Theoretical axial stress and deformation were calculated and validated through static simulation. The FEA results illustrate that EN19 provides the highest strength and lowest deformation, while EN8 demonstrates marginal safety under overload. The study concludes with material recommendations, comparative safety factors, and guidelines for future optimization. The findings serve as a reference for safe piston design in medium-pressure hydraulic applications.

Keywords: Hydraulic cylinder, piston design, piston rod, Finite Element Analysis, EN8 steel, EN19 steel, static loading, 25 MPa pressure.

1. Introduction

Hydraulic cylinders convert hydraulic energy into linear mechanical motion and form the core of a vast range of industrial systems such as cranes, presses, agricultural machinery, and construction equipment. The piston and rod assembly experiences extremely high compressive and tensile forces during operation, making durability and material selection essential for safe operation. Failure of this assembly leads to catastrophic failure of the entire system, extra downtime, extra cost, and safety hazards.

The piston–rod interface in particular is vulnerable to high stresses due to pressure fluctuations, thread engagement load, and sudden impact forces. While numerous studies exist on general hydraulic system

design, limited literature specifically addresses the structural performance of piston–rod joints under high pressures such as 25 MPa, which is common in industrial systems.

This research aims to evaluate the mechanical performance of a piston–rod assembly using both analytical and numerical methods. Three engineering steels EN8 and EN19 were studied to determine their suitability for high-pressure applications. Static FEA was performed to obtain stress contours, deformation behavior, and safety factors under the applied load.

2. Literature Review

Hydraulic cylinder design traditionally relies on empirical formulas and safety factors, but modern engineering uses simulation for robust verification. Past studies indicate that the maximum stresses occur near the piston–rod shoulder fillet and around thread engagement. Medium-carbon steels such as EN8 are economical but offer limited yield strength, making them suitable for low-pressure systems. Alloy steels such as EN19 and EN24 provide high tensile strength and improved fatigue resistance, making them ideal for heavy-duty cylinders.

Finite Element Method (FEM) has been widely adopted for evaluating stress in machine components. Researchers commonly apply axial pressure loads to pistons to determine stress distribution. Recent advancements in CAD/CAE allow designers to simulate complete assemblies with realistic contacts, improving prediction of stress concentration zones.

The reviewed literature highlights the need for an integrated analytical–numerical approach for piston design, particularly under fluctuating or high loads.

3. Objectives of the Study

- To design a hydraulic piston–rod assembly capable of safely withstanding 25 MPa pressure.
- To perform theoretical evaluations: hydraulic force, axial stress, thread shear stress, and deformation.
- To conduct extended FEM analysis with correct boundary conditions.
- To compare EN8 & EN19 materials in terms of stress, deformation, and safety factor.
- To propose the best material and design improvements.

4. Methodology

The methodology used in study of dimensional analysis, drafting, modeling, and preliminary assessment. The following steps are followed.

4.1 Cad Modeling

A parametric 3D model of the piston and rod was created using SolidWorks. Key dimensions:

Piston diameter : 69 mm

Rod diameter: 40 mm

Thread diameter: 31 mm

Thread engagement length: 30 mm

Working pressure: 25 MPa

The assembly contains piston, rod, and end cap components.

4.2 Material studied

Three materials were selected based on industrial use:

Material	Yield Strength (MPa)	Young's Modulus (GPa)
En 8	250	210
En 19	415	210

5. Detailed Theoretical Analysis

5.1. Piston Area Calculation

$$A = (\pi \times D \times D) / 4$$

$$A = (3.1416 \times 69 \times 69) / 4; A = 3738.3 \text{ mm}^2$$

5.2. Hydraulic Force Calculation

$$F = P \times A$$

Where: P = hydraulic pressure (MPa); A = piston area (mm²)

$$F = 25 \times 3738.3$$

$$F = 93,457.5 \text{ N}$$

Hence, hydraulic force acting on the piston is approximately 93.5 kN

5.3. Piston Rod Cross-Sectional Area

$$A_r = (\pi \times d \times d) / 4$$

$$A_r = (3.1416 \times 40 \times 40) / 4; A_r = 1256.6 \text{ mm}^2$$

5.4. Axial Stress in Piston Rod

$$\sigma = F / A_r$$

Where: σ = axial stress (MPa); F = applied force (N); A_r = rod area (mm²)

$$\sigma = 93,457.5 / 1256.6; \sigma = 74.4 \text{ MPa}$$

5.5. Thread Shear Area Calculation

$$A_s = \pi \times d_m \times L$$

Where: d_m = mean thread diameter (mm); L = thread engagement length (mm)

$$A_s = 3.1416 \times 31 \times 30; A_s = 2920 \text{ mm}^2$$

5.6. Thread Shear Stress

$$\tau = F / A_s$$

$$\tau = 93,457.5 / 2920; \tau = 32.0 \text{ MPa}$$

5.7. Axial Deformation of Piston Rod

$$\delta = (F \times L) / (A_r \times E)$$

Where: δ = deformation (mm); F = applied force (N); L = rod length (mm); A_r = rod area (mm²)

E = Young's modulus (MPa)

$$L = 180 \text{ mm}; E = 210,000 \text{ MPa}$$

$$\delta = (93,457.5 \times 180) / (1256.6 \times 210,000); \delta = 0.064 \text{ mm}$$

5.8. Stress Concentration Factor

Maximum stress = Nominal stress \times Stress concentration factor

Typical stress concentration factor (Kt) range:

$$K_t = 1.6 \text{ to } 2.5$$

This indicates local stress amplification due to geometry changes.

5.9. Factor of Safety Calculation

Factor of Safety (FOS) is calculated as:

FOS = Yield strength of material / Maximum induced stress - for example for EN19:

$$FOS = 415 / 128; FOS \approx 3.24$$

6. CAD Modeling and Assembly Description

6.1 3D Model Creation

The piston, rod, and end cap were modeled in SolidWorks. The design follows conventional hydraulic standards ensuring manufacturability, tolerance stack-up, and thread compatibility.

6.2 Assembly Constraints

The piston is bonded to the rod via threaded connection. The end cap provides axial support and ensures directional constraint.

A simplified model without barrel was used for clarity, focusing stress on the piston-rod junction.

7. FEM Simulation Methodology

7.1 Import and Preprocessing

The 3D model was imported into the simulation environment. All bodies were checked for integrity and interference.

7.2 Meshing Strategy

The meshing is done by using autogenrate by ansys to fine mesh

7.3 Boundary Conditions

- Rear face of piston rod: Fully fixed (first condition)
- Piston internal face: 25 MPa pressure (first condition)
- Rod face face: 93.5 KN (second condition)
- Piston internal face: Fully fixed (second condition)
- Piston-rod joint: Frictional

8. FEM Results

For first condition rod end is fixed and pressure is applied to piston face,

Material	Von Mises Stress	Total Deformation	Factor of Safety
EN 8	385.65	0.140	0.648
EN 19	385.65	0.140	1.07

Fig 1 : first condition a) equivalent stress b) total deformation c) factor of safety for EN 08 material

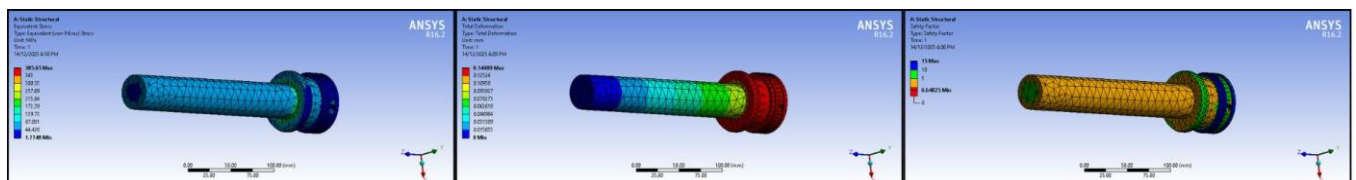
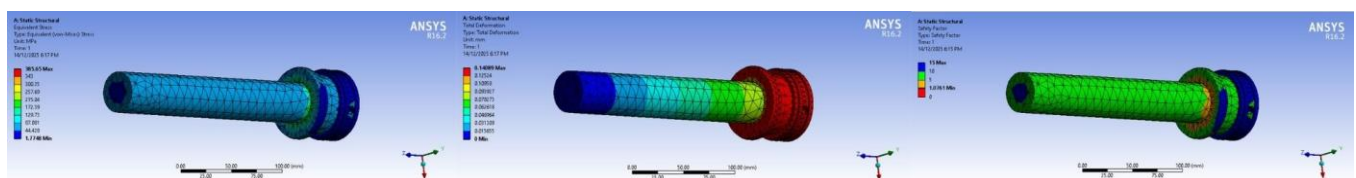


Fig 2 : first condition a) equivalent stress b) total deformation c) factor of safety for EN 19 material



For second condition piston face is fixed and force is applied to rod end ,

Material	Von Mises Stress	Total Deformation	Factor of Safety
EN 8	347.45	0.112	0.71
EN 19	347.45	0.112	1.19

Fig 3 : second condition a) equivalent stress b) total deformation c) factor of safety for EN 08 material

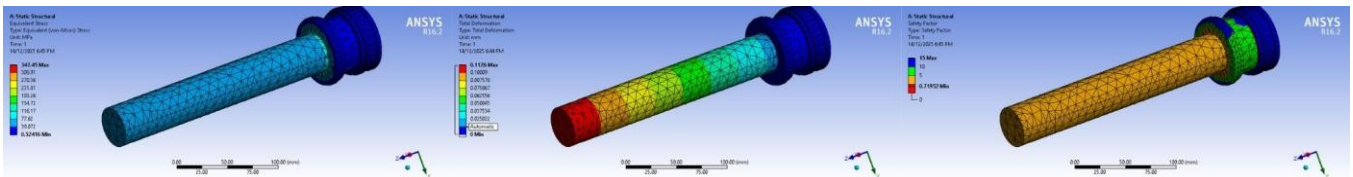
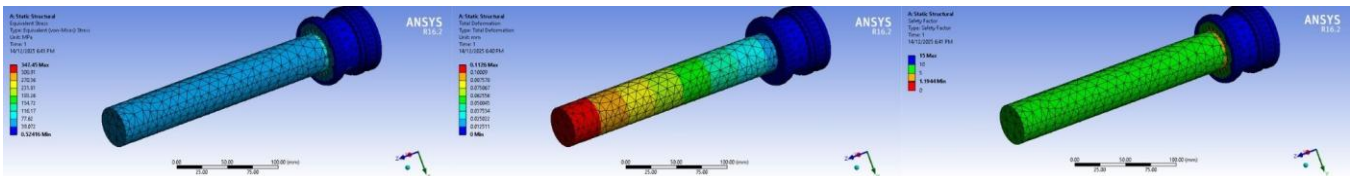


Fig 4 : second condition a) equivalent stress b) total deformation c) factor of safety for EN 19 material



9. Conclusion and Future Scope

This research provided a complete analytical and numerical evaluation of a hydraulic piston–rod assembly operating at 25 MPa. The study showed:

- The piston experiences approximately 93.5 kN hydraulic force.
- Maximum stresses concentrate at the rod–piston junction.
- EN8 operates close to yield limit not recommended at 25 MPa.
- EN19 provides good safety margin.

Therefore, EN24 is the recommended material for 25 MPa hydraulic piston applications

Future Scope

- Fatigue life estimation using cyclic loading.
- Thermal-structural coupled simulation.
- Optimization of fillet radius and thread profile.
- Experimental validation using strain gauges.
- CFD analysis of internal hydraulic flow behavior.

References

1. Shigley, J. E., Mischke, C., & Budynas, R. G. Mechanical Engineering Design. McGraw-Hill.
2. Beer, F. P., Johnston, E. R., & DeWolf, J. T. Mechanics of Materials. McGraw-Hill.
3. M. Antony Maria Thomas Benny, U.S. Chavan, Design and Analysis of Piston Rod Joint in Hydraulic Cylinder for Industrial Implements, IOSR Journal of Mechanical and Civil Engineering, Volume 14, Issue 3 Ver. VII (May - June 2017), PP 47-53.