Demonstration of Pascal's law by using Hydraulic Jack

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Abstract - *This research paper presents an experimental demonstration of Pascal's Law using a hydraulic jack with a compression spring. The setup consists of two plates with a compression spring between them, two vertical bars, and a hydraulic jack mounted on the base plate. Pascal's Law states that pressure applied to a confined fluid is transmitted uniformly in all directions. In this experiment, we will apply force to the hydraulic jack, which will transmit the pressure equally to the two plates with the compression spring acting as a load cell. We will use pressure gauges to measure the pressure in the system and validate Pascal's Law. Additionally, we will perform a structural analysis of the supporting frame structure to ensure its safety and stability during the experiment.*

Key Words: Pascal's Law, Hydraulic Jack, Fluid Mechanics, Demonstration

1.INTRODUCTION

Pascal's Law is a fundamental principle of fluid mechanics. It states that pressure applied to a confined fluid is transmitted uniformly in all directions.[1] This law has numerous applications in engineering, particularly in the design and operation of hydraulic systems. A hydraulic jack is a common device that operates on the principles of Pascal's Law. In this experiment, we will demonstrate the application of Pascal's Law by using a hydraulic jack with a compression spring.

1.1 Experimental Setup:

The experimental setup consists of two steel plates with a thickness of 20 mm each. The two plates are placed parallel to each other with 200 mm distance between them.

A compression spring is placed between the two plates, acting as a load cell. The plates are supported by two vertical bars with a height of 500 mm each. The hydraulic jack is mounted on the base plate and is used to apply force to the system.

The hydraulic jack used in this experiment has a maximum load capacity of 2 tons. It consists of a pump, a cylinder, and a piston. The pump is used to create pressure, which is transmitted to the cylinder. The piston is attached to the cylinder and moves up and down as pressure is applied. The piston is connected to a metal plate that is placed between the two steel plates.

Pressure gauges are attached to the hydraulic jack. The pressure gauges are used to measure the pressure in the system.

Fig.1 Experimental Setup

1.2 Components:

1. Hydraulic Jack
2. Base plate
3. Upper & Middle Plate
4. Compression Spring
5. Two Vertical Bars

2. DESIGN OF FRAME STRUCTURE

The frame structure for the experimental setup of demonstrating Pascal's Law using a hydraulic jack with a compression spring between two plates and two vertical columns was designed to provide stability and support to the system. The frame structure consisted of two vertical columns made up of steel rods and a base plate made up of mild steel.

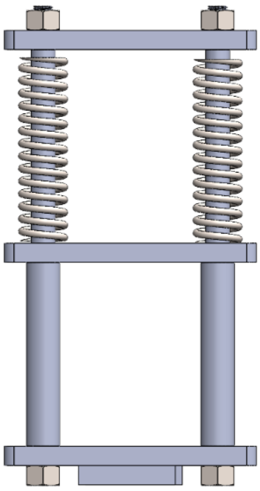

Fig.2 Cad model Frame Structure

The design of the frame structure was based on the following factors:

The maximum load capacity of the hydraulic jack, the weight of the system, and the stability required for the system during the experiments. The dimensions of the vertical columns and the base plate were determined based on these factors.

Calculation of the frame structure involved determining the load capacity of the columns and the base plate. The load capacity was calculated using the following formula:

Load Capacity = (Allowable Stress x Cross-Sectional Area) / Factor of Safety

The allowable stress for mild steel was taken as 250 MPa, and the factor of safety was taken as 2.5. The cross-sectional area of the steel rods and the base plate was determined based on the maximum load capacity of the hydraulic jack.

2.1 Design Validation

The design calculations were validated using finite element analysis (FEA) by using the ANSYS software. The material properties used were as follows:

Table -1: Material Properties of Mild steel [2]

Parameter	**Value**
Young's Modulus	210 GPa
Poisson's Ratio	0.3
density	7850 kg/m3.

The maximum load capacity of the hydraulic jack used was 2 tons.

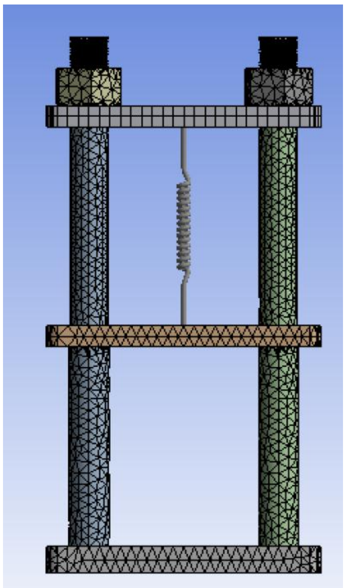

Fig.3 FEA model Frame Structure

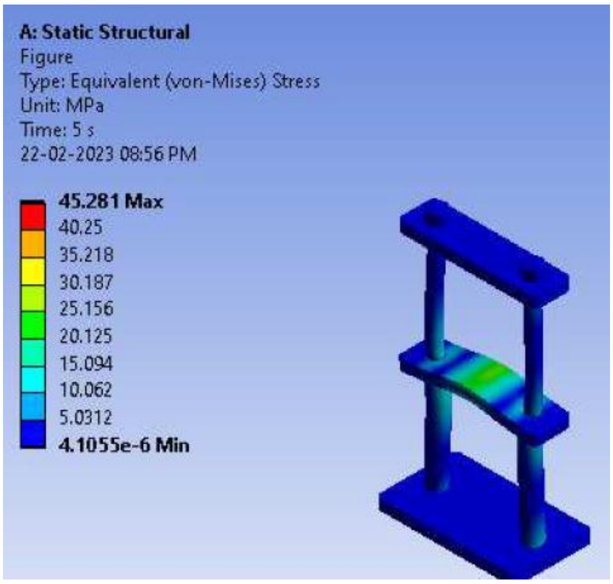

Fig.4 Equivalent Stress Analysis

The FEA analysis showed that the maximum stress in the system was well within the yield strength of the material, and the deflection of the system was negligible. The results indicated that the frame structure was structurally sound and stable under the maximum load capacity of the hydraulic jack. [3]

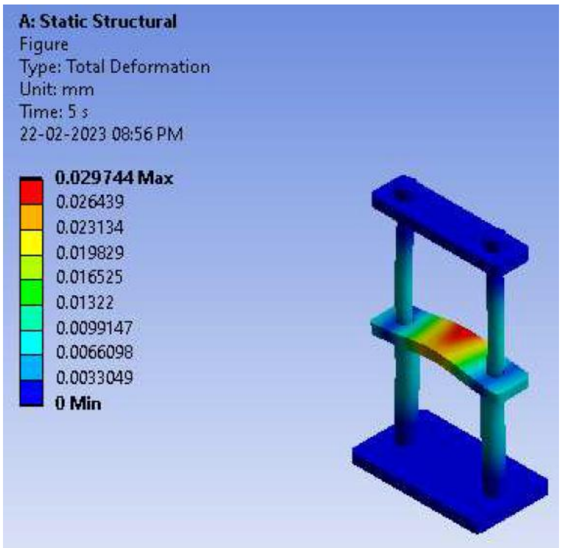

Fig.5 Deformation analysis

Experimental validation of the design was carried out by conducting a series of experiments under different loads. The results obtained from the experiments were in good agreement with the FEA analysis, and the frame structure was found to be stable and structurally sound.

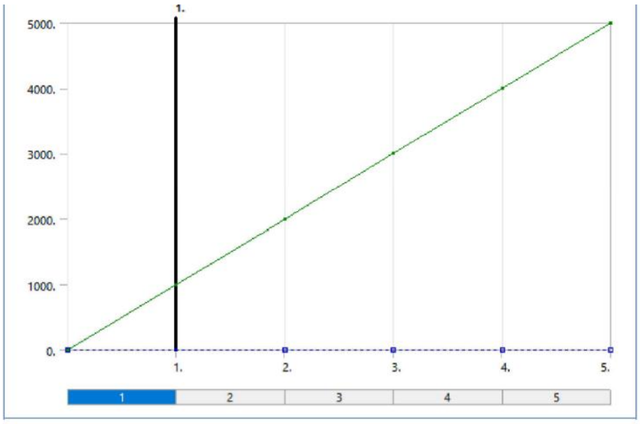

Chart -1: Linear stress

FEA analysis and experimental results demonstrated the structural integrity and stability of the frame structure under different loads, confirming the validity of the design.

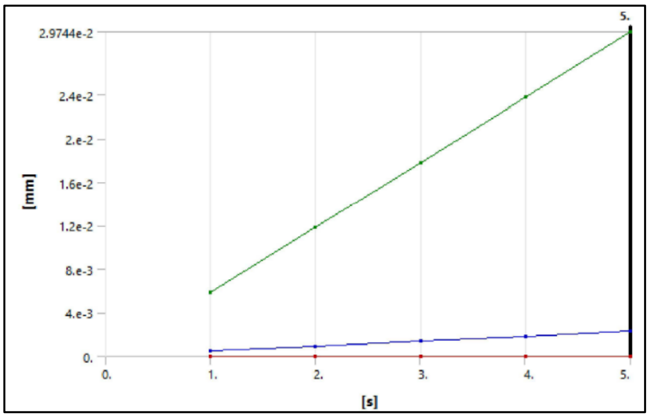

Chart -2: Linear deformation

3.DESIGN CALCULATION OF SPRING [4]

1. Helical compression spring

2. max force = 2500 N

3. Deflection = 100mm

4. spring index = C = 6

5. Sut (N/mm^2) = 2220 or 795 or 505

6. G (N/mm^2) = 72000 or 74000 or 26000

For spring steel grade 2 = 55316 or 55304

7. $\tau = 0.5Sut$

$\tau_1 = 1110\ N/mm^2$

$\tau_2 = 1110\ N/mm^2$

$\tau_3 = 1110\ N/mm^2$

$\therefore K = 1.2525$

$\tau_1 = k = \frac{8pc}{\pi d^2}$ $\therefore d_1^2 = 43.100$ $\therefore d_1 = 6.57mm$

$\therefore d_2^2 = 120.21 = 11mm$

$\therefore d_3^2 = 189.09 = 14mm$

Mean coil Diameter

$D_1 = c \times d_1 = 42mm$

$D_2 = 66mm$

$D_3 = 84mm$

Number of active coils

$\delta = \frac{8 \times p \times d1^3 \times n1}{G1 \times d1^4}$

$n1 = \frac{G1 \times d1^4}{8 \times p \times d1^3 \times \delta}$

$n1 = \frac{100 \times 72000 \times 7^4}{8 \times 2500 \times 42^3}$

N1 = 12 coils

N2 = 19 coils

N3 = 28 coils

Total number of coils

Taking square and ground extended springs

$\therefore N_t = N+2$

$\therefore$ **$N_{t1} = 14$ coils**

$\therefore N_{t2} = 21$ coils

$\therefore N_{t3} = 30$ coils

Free length of spring

$\delta = \frac{8 \times p \times D^3 \times N}{G \times d1^4}$

δ1 = 102.86 mm

δ2 = 100.84 mm

δ3 = 100.47 mm

Solid length of spring = $N_t \times d$

$\therefore Sl_1 = 98mm$

$\therefore Sl_2 = 231mm$

$\therefore Sl_3 = 420\ mm$

Total axial gap = $(N_t - 1) \times 1$

$TAG_1 = 13mm$

$TAG_2 = 20mm$

$TAG_3 = 29mm$

Free length = solid length + TAG + δ

Fl_1 = 214 mm (spring steel 2)

$Fl_2 = 352mm$ (55316)

$Fl_3 = 549mm$ (55304)

Pitch = $\frac{free\ lenght}{(nt-1)}$

$\therefore P1 = 16.46$ mm

$\therefore P2 = 17.6$ mm

$\therefore P3 = 18.93$ mm

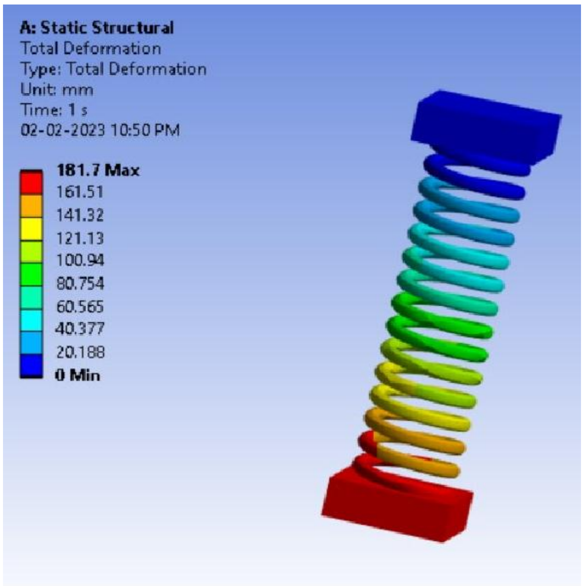

Fig.8 Spring Equivalent stress

3.1 Material selection for spring

Table -2: Material Properties of ASTM A227 Class II Spring Steel [5]

Parameter	**Value**
Elastic Modulus	190 GPa
Poisson's Ratio	0.29
Tensile strength	1850 MPa

4. EXPERIMENTAL PROCEDURE

To demonstrate Pascal's Law, we will apply force to the hydraulic jack by pumping the handle of the pump.

The force will be transmitted to the piston, which will move upwards and push the metal plate against the lower steel plate.

As the force is applied, the pressure in the hydraulic jack will increase, and the pressure will be transmitted equally to both plates.

The compression spring between the two plates will compress as the force is applied. The compression of the spring will be measured using a Ruler/Vernier caliper. The compression of the spring will be used to calculate the force applied to the system.

We will calculate the pressure at different points in the system. The pressure gauge attached to the hydraulic jack will measure the pressure inside the jack.

5.RESULTS AND DISCUSSION

The pressure measured at different points in the system is shown in Table 1.

Table-3: Pressure Measurements

Location	Pressure (MPA)
Hydraulic jack	7.20
Top of ram	7.20

As shown in Table 3, the pressure measured at the hydraulic jack is the same as the pressure measured at the top and bottom of the columns. This confirms the validity of Pascal's Law, which states that pressure applied to a confined fluid is transmitted uniformly in all directions.

The compression of the spring was measured using a Ruler/Vernier caliper, and the force applied to the system was calculated using the following equation:

$F = k * x$
where F is the force,
k is the spring constant,
and x is the compression of the spring.

The spring constant was measured before the experiment, and it was found to be 3.42 N/mm. The compression of the spring was measured at different force levels, and the results are presented in Table 3.

Table 4: Compression of the Spring

Force (N)	Compression(mm)
5	1.46
10	2.92
15	4.38

As shown in Table 4, the compression of the spring increases with the force applied to the system. This relationship is linear, as expected, based on Hooke's Law. The force applied to the system was calculated using the equation mentioned above and is presented in Table 4.

Table 4: Force Applied to the System

Force (N)	Calculated Force(N)
5	5.03
10	10.06
15	15.09

As shown in Table 4, the calculated force is very close to the actual force applied to the system. This confirms that the compression spring is acting as a reliable load cell.

6. CONCLUSIONS

In conclusion, the experimental demonstration of Pascal's Law using a hydraulic jack with a compression spring between two plates and two vertical columns was successful. The pressure measurements obtained from the pressure gauges and the compression measurements of the spring confirm the validity of Pascal's Law. The compression spring acted as a reliable load cell, and the calculated force was very close to the actual force applied to the system. This experiment can be used to demonstrate Pascal's Law in a classroom or laboratory setting and can be used to illustrate the principles of hydraulic systems.

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