MOS (CIL2030) Course Project Group- 1

Team Members

1. Pranathi (B22CI024)
2. Shubham Kumar (B22CI038)
3. Swasti Bahetee (B22CI042)
4. Tranum Kamra (B22CI043)

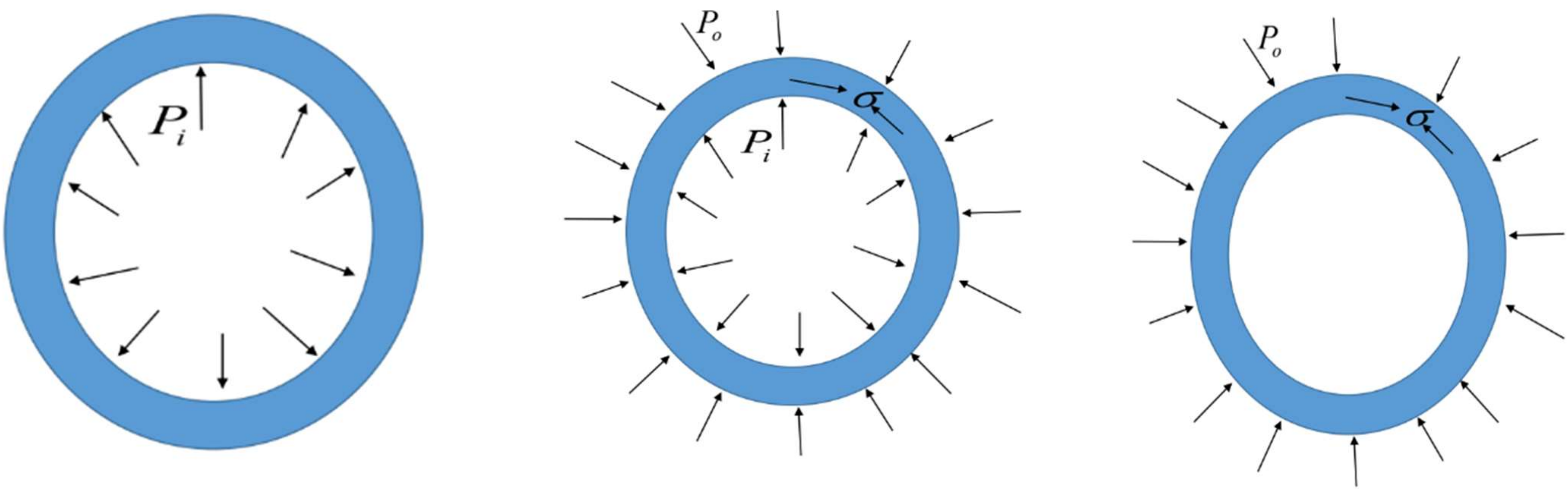
Individual Contribution :

Shubham : Mathematical formulation and calculation. Wrote the code for solution.
Pranathi : Mathematical formulation and calculation. Found th Pc formula.
Swasti : Mathematical formulation and calculation. made the PPT.
Tranum : Mathematical formulation and calculation. Made the PPT.

(Everyone contributed in mathematical formulation and calculation)

Question 1.

Designing a closed cylindrical container that can traverse the sea in the vertical direction.



Understanding :

Stress analysis is like checking how much pressure a steel container can handle before it gets stressed out. We use this info to make sure the container stays safe underwater. With our program, we figure out the stresses inside the cylinder, both radial and circumferential. We look at the maximum and minimum stresses to know where the container might struggle. Plus, we create pressure control charts to keep the internal pressure just right, making sure the container won't yield or break, even when it's deep in the sea. It's like giving the container a stress-free trip through the ocean!

Formula for radial and circumferential stress :

$$\sigma_r = \frac{\left(P_i r_i^2 - P_o r_o^2\right)}{r_o^2 - r_i^2} - \frac{(P_i - P_o) r_o^2 r_i^2}{(r_o^2 - r_i^2) r^2}$$

$$\sigma_\theta = \frac{\left(P_i r_i^2 - P_o r_o^2\right)}{r_o^2 - r_i^2} + \frac{(P_i - P_o) r_o^2 r_i^2}{(r_o^2 - r_i^2) r^2}$$

Code Implementation

Input Parameters :

:

- The program allows the user to enter several input parameters:

  - Internal Pressure (Ip): The internal pressure in the cylindrical container, in MegaPascals (MPa).
  - External Pressure (Ep): The external pressure acting on the cylindrical container, in MegaPascals (MPa).
  - Thickness (x): The thickness of the cylindrical container, in meters.

Constraints :

- If the internal pressure (Ip) is greater than 30, the program prints "Invalid pressure" and terminates.

Functions :

- radial_stress(Ip, Ep, x, r):
  - calculates the radial stress at a given radial position (r) within the cylindrical container. It takes parameters such as internal pressure (Ip), external pressure (Ep), thickness (x), and radial position (r).
- circumferential_stress(Ip, Ep, x, r):
  - Similar to the radial stress function, this calculates the circumferential stress at a given radial position (r) within the cylindrical container.
- find_max_stress(stress_values, r_values):
  - This function finds the maximum stress value and its corresponding radial position from a list of stress values and radial positions.
- Longitudinal_stress(radial_stress, circumferential_stress, v):
  - This function calculates the longitudinal stress in the container based on the radial and circumferential stresses and the Poisson's ratio (v).

Working

The program performs the following steps:

- The user inputs the internal pressure (Ip) of the cylindrical container. If Ip exceeds the maximum allowable value (30 MPa), an error message is displayed.
- Program computes radial and circumferential stresses at different radial positions.
- Program finds max radial/circumferential stresses and their positions.
- The program visualizes stress profiles by plotting radial and circumferential stresses against radial positions.
- The program prints out the maximum stresses and their locations within the container.
- The code allows for iterating over different thicknesses to assess their impact on stress distributions.

```python
def radial_stress(Ip, Ep, x, r):
    ri = 1500
    ro = ri + x
    A = (Ip * ri**2 - Ep * ro**2) / (ro**2 - ri**2)
    B = ((Ip - Ep) * (ri**2 * ro**2)) / (ro**2 - ri**2)
    return abs(A - (B / (r**2)))
```

1. This function calculates the radial stress at a given radial position ‘r’

```python
def circumferential_stress(Ip, Ep, x, r):
    ri = 1500
    ro = ri + x
    A = (Ip * ri**2 - Ep * ro**2) / (ro**2 - ri**2)
    B = ((Ip - Ep) * (ri**2 * ro**2)) / (ro**2 - ri**2)
    return abs(A + (B / (r**2)))
```

2. Calculates the circumferential stress at a given radial position ‘r’

```python
def find_max_stress(stress_values, r_values):
    max_stress = max(stress_values)
    max_index = stress_values.index(max_stress)
    return max_stress, r_values[max_index]
```

3. This function finds the maximum stress value and its corresponding radial position .

4. Next part calculates the longitudinal stress based on the radial and circumferential stresses, and Poisson's ratio .

5.Then, it loops over the specified thicknesses, computing stresses and their maxima for each. It visualizes stress components and prints stress values for various radial positions, aiding in understanding stress distribution across the cylinder's thickness.

Output graphs :

Input

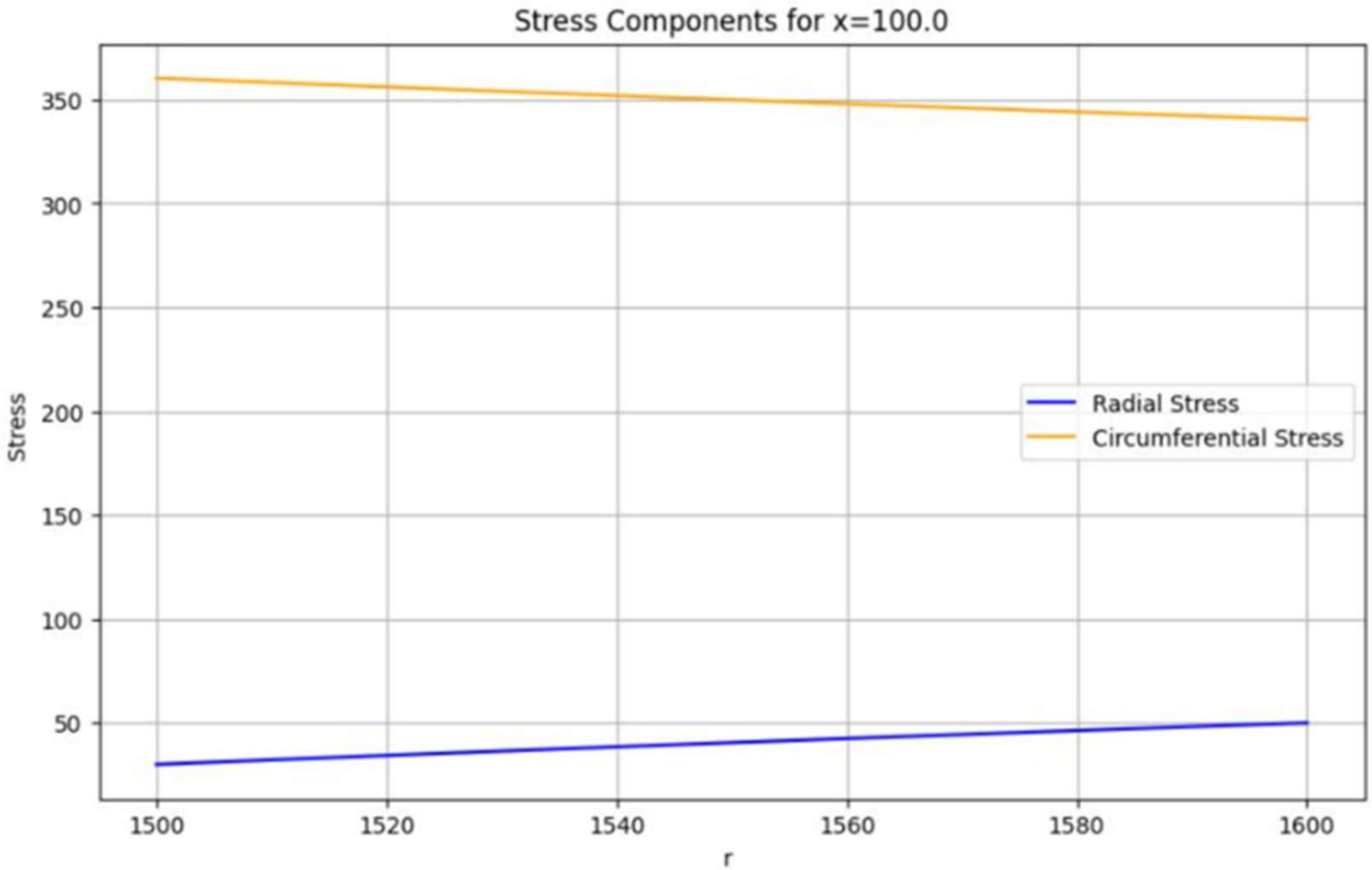
Ip = 30

Ep = 50

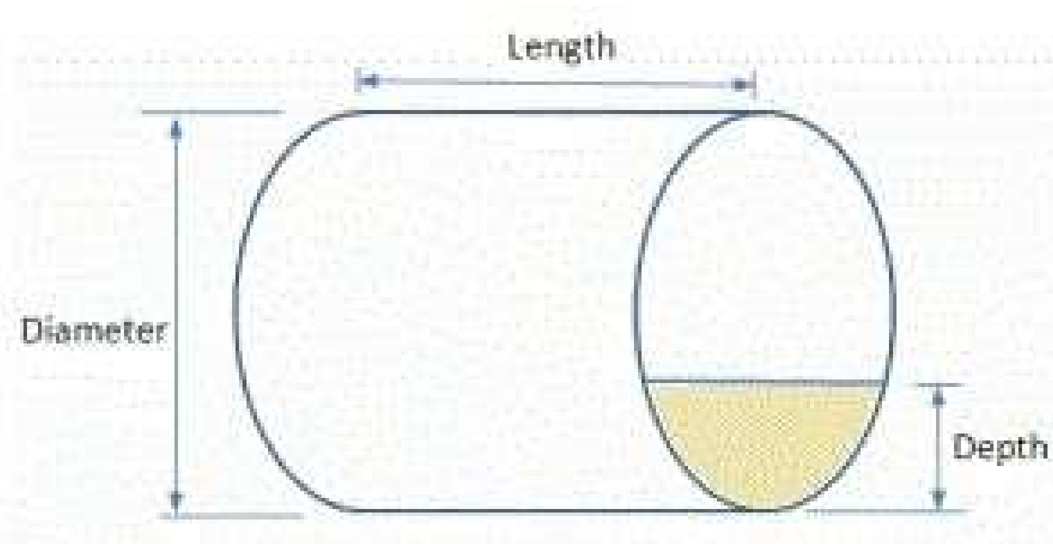
x = 100

```
Enter Ip: 30
Enter Ep: 50
Enter x: 100
Maximum Radial Stress=50.0 at r=1600.0
Maximum Circumferential Stress=360.32258064516134 at r=1500.0
Maximum Longitudinal Stress=117.0967741935484 at r=1500.0
```

```
Maximum Longitudinal Stress=117.0967741935484 at r=1500.0
```



Formula for vertical depth of cylinder:



$$A = \frac{P_i r_i^2 - P_o r_o^2}{r_o^2 - r_i^2} \quad ; \quad B = \frac{(P_i - P_o)\, r_i^2 r_o^2}{(r_o^2 - r_i^2)\, r^2}$$

$$\sigma_r = A - B \quad ; \quad \sigma_\theta = A + B$$

$$\frac{\sigma_r + \sigma_\theta}{2} = \frac{A - B + A + B}{2} = A$$

and $P_o = \rho g h$

$h \rightarrow$ vertical depth

$$\frac{\sigma_r + \sigma_\theta}{2} = \frac{P_i r_i^2 - P_o r_o^2}{r_o^2 - r_i^2}$$

$$\left(\frac{\sigma_r + \sigma_\theta}{2}\right)[r_o^2 - r_i^2] - P_i r_i^2 = -P_o r_o^2$$

$$P_o = \frac{P_i r_i^2 - \left[\left(\frac{\sigma_r + \sigma_\theta}{2}\right)[r_o^2 - r_i^2)\right]}{r_o^2}$$

$$h = \frac{P_i r_i^2 - \left[\left(\frac{\sigma_r + \sigma_\theta}{2}\right)(r_o^2 - r_i^2)\right]}{\rho g r_o^2}$$

Input Parameters :

The function takes two parameters:

- ‘Ip’: Internal pressure in MPa.

- ‘x’: Thickness of the cylindrical container in millimeters.

Output Parameters :

These are the output parameters:

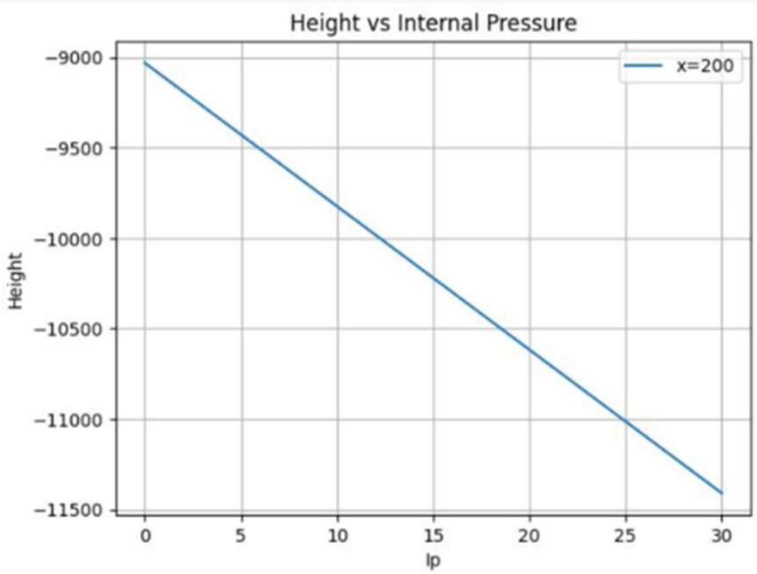
- **Maximum Absolute Height :** The highest point the cylindrical container can reach underwater without yielding.
- Internal Pressure (Ip): The internal pressure at which the maximum absolute height is achieved.
- Outer Radius (ro): The outer radius of the cylindrical container at the point where the maximum absolute height is reached.

Working

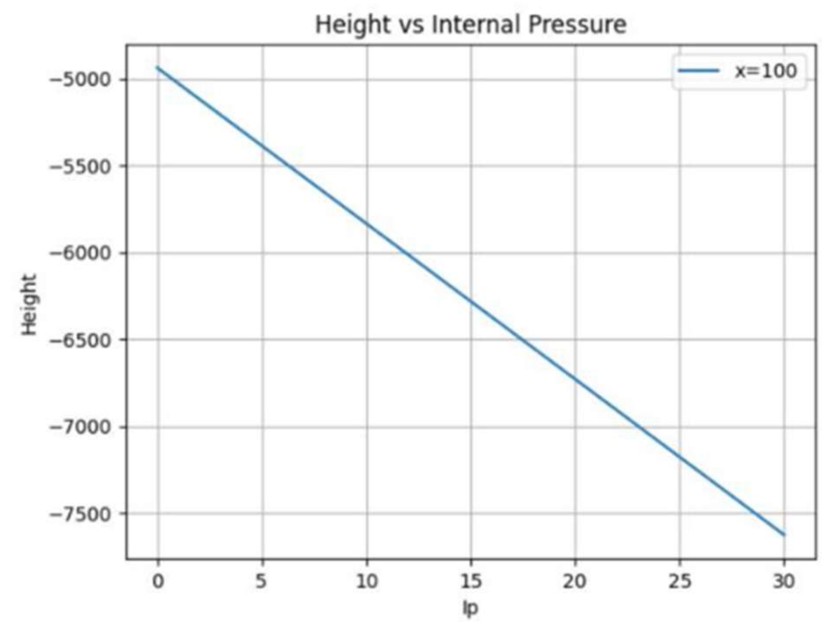
The program performs the following steps:

- The code imports necessary libraries: `numpy` for numerical operations and `matplotlib.pyplot` for plotting graphs.
- The height function determines submerged depth using fluid mechanics, accounting for internal pressure and cylinder thickness.
- Creates arrays for internal pressure (0-30) and thicknesses to compute height.
- The code loops through thickness values in x_values, computing heights based on internal pressures using the height function.
- Plots height against internal pressure for each thickness, labeling each line plot accordingly.
- Identifies maximum height, along with corresponding internal pressure and outer radius, crucial for safe underwater traversal.
- Graphs show height variations with internal pressure across different thicknesses, guiding design and operational control underwater.

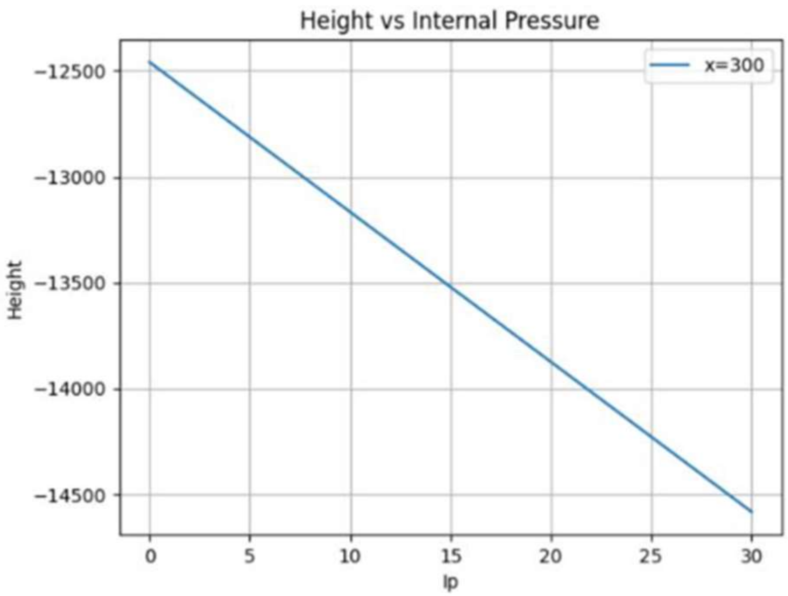
Output graphs :



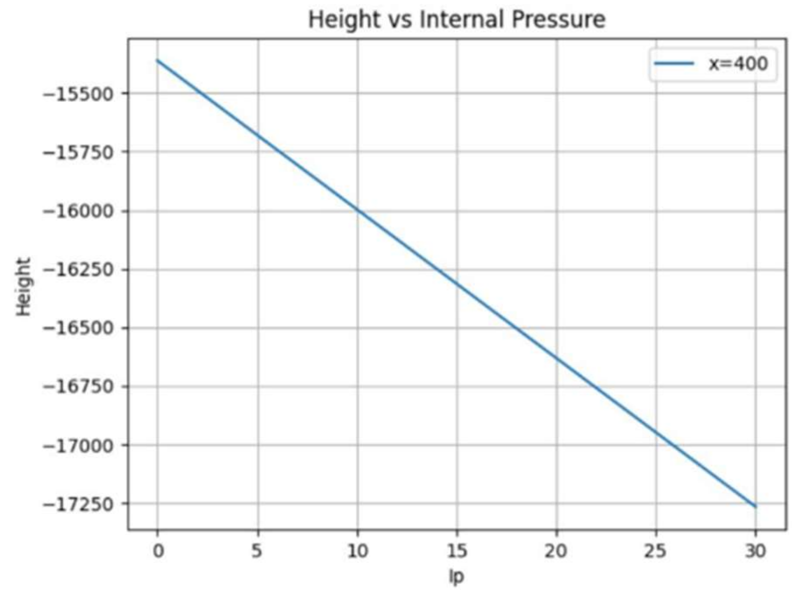
For x=200, the maximum absolute height value is 11410.57250387113 at Ip=30.0 and ro=1700



For x=100, the maximum absolute height value is 7625.350407747196 at Ip=30.0 and ro=1600



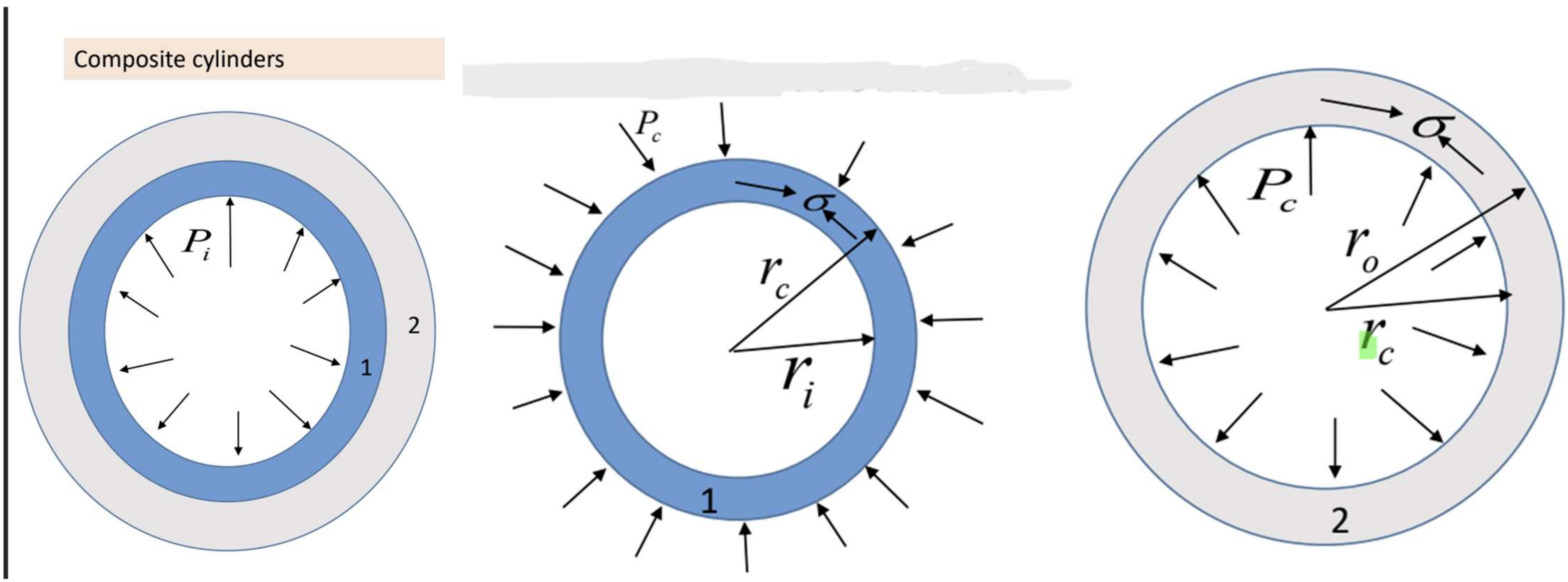
For x=300, the maximum absolute height value is 14582.625438894553 at Ip=30.0 and ro=1800



For x=400, the maximum absolute height value is 17267.133712278443 at Ip=30.0 and ro=1900

Question 2.

Designing Composite Cylinders with Lack of Fit



Approach :

Goal # 1

Understanding th
question.

Goal # 2

Deriving requires formula
and performing manual
calculations.

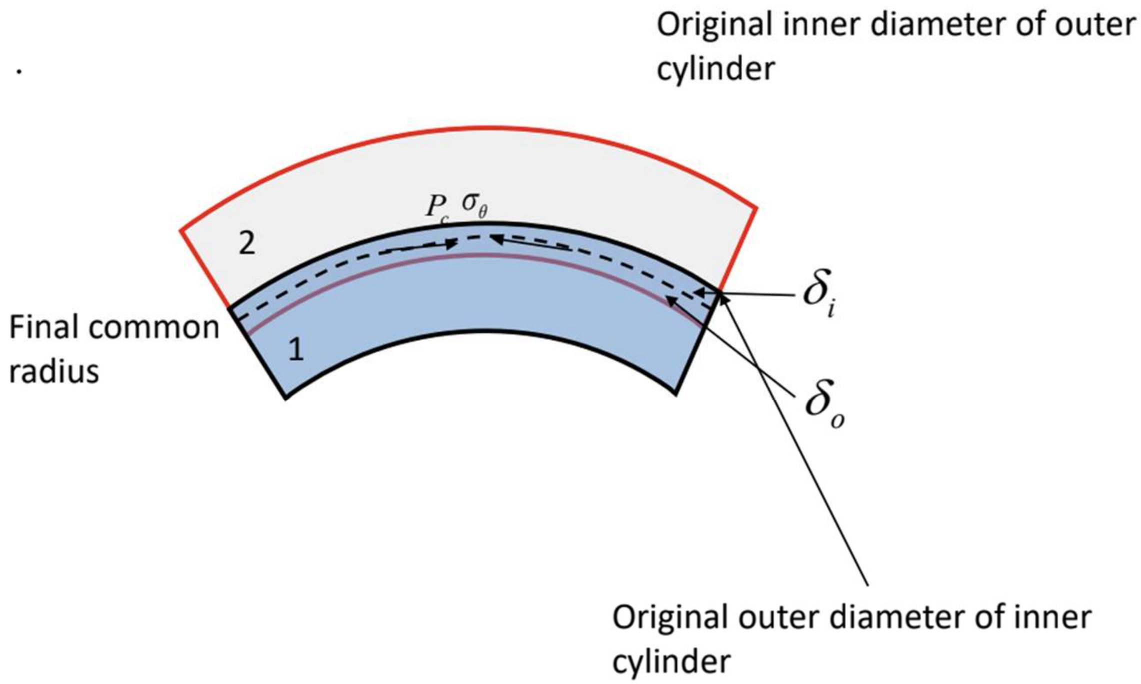
Goal # 3

Code implementation and
drawing conclusions from
the plot.

Understanding :

We designed a composite cylinder subjected to both internal and external pressure. The cylinder consists of an outer and inner layer of the same material and thickness. The design criterion is based on yielding we developed internal pressure control charts for different thicknesses and levels of lack of fit.

Deriving Formula for Pc :



$$\sigma_{\theta i} = \frac{(P_i r_i^2 - P_c r_c^2)}{r_c^2 - r_i^2} + \frac{(P_i - P_c)\, r_c^2 r_i^2}{(r_c^2 - r_i^2)\, r^2}$$

$$\sigma_{\theta i} = \frac{(P_i r_i^2 - P_c r_c^2)}{r_c^2 - r_i^2} + \frac{(P_i - P_c)\, r_i^2}{r_c^2 - r_i^2}$$

$$\sigma_{\theta o} = \frac{(P_c r_c^2 - P_o r_o^2)}{r_o^2 - r_c^2} + \frac{(P_c - P_o)\, r_o^2}{r_o^2 - r_c^2}$$

$$\sigma_{\theta o} - \sigma_{\theta i} = \frac{P_c r_c^2}{r_o^2 - r_c^2} + \frac{P_c r_c^2}{r_c^2 - r_i^2} + \frac{P_c r_o^2}{r_o^2 - r_c^2} + \frac{P_c r_i^2}{r_c^2 - r_o^2}$$

$$\delta = \frac{r}{E}(\sigma_{\theta o} - \sigma_{\theta i})$$

$$\frac{\delta E}{r} = \frac{P_c r_c^2 + P_c r_o^2}{r_o^2 - r_c^2} + \frac{P_c r_c^2 + P_c r_i^2}{r_c^2 - r_i^2}$$

$$\therefore\ P_c = \frac{\delta E}{r\left[\frac{r_c^2 + r_o^2}{r_o^2 - r_c^2} + \frac{r_c^2 + r_i^2}{r_c^2 - r_i^2}\right]}$$

$$P_c = \frac{\delta E}{r} + \frac{2 P_o r_o^2}{r_o^2 - r_c^2} + \frac{2 P_i r_i^2}{r_c^2 - r_i^2}$$

$$P_c = \frac{\frac{\delta E}{r}(r_o^2 - r_c^2)(r_c^2 - r_i^2) + 2 P_o r_o^2 (r_c^2 - r_i^2) + 2 P_i r_i^2 (r_o^2 - r_c^2)}{(r_c^2 + r_o^2)(r_c^2 - r_i^2) + (r_c^2 + r_i^2)(r_o^2 - r_c^2)}$$

$$\boxed{P_c = \frac{\frac{\delta E}{R}(r_o^2 - r_c^2)(r_c^2 - r_i^2) + 2 P_o r_o^2 (r_c^2 - r_i^2) + 2 P_i r_i^2 (r_o^2 - r_c^2)}{2 r_c^2 (r_o^2 - r_i^2)}}$$

Code Implementation:

Input Parameters :

- The program allows the user to enter several input parameters:
  - Lack of fit (s): Represents a geometric parameter in meters.
  - Internal Pressure (Ip): The pressure inside the cylindrical junction.
  - External Pressure (Ep): The pressure outside the cylindrical junction.
  - Thickness (x): The thickness of the cylindrical junction.

Constraints :

- If the internal pressure (Ip) is greater than 30, the program prints "Invalid pressure" and terminates.

Functions :

- Junction_radial_stress(Ip, Ep, x, s):
  - Calculates the radial stress at the junction based on input parameters and material properties.
- radial_stress(Ip, Ep, x, r):
  - Calculates the radial stress at a given radial distance from the center of the junction.
- circumferential_stress(Ip, Ep, x, r):
  - Calculates the circumferential stress at a given radial distance from the center of the junction.
- find_max_stress(stress_values, r_values):
  - Finds the maximum stress value and its corresponding radial distance.
- Longitudinal_stress(radial_stress, circumferential_stress, v): Calculates the longitudinal stress based on radial and circumferential stresses, considering Poisson's ratio (v).

Working

For each value of thickness (x), the program performs the following steps:

- Calculates radial and circumferential stresses at various radial positions within the junction.
- Determines the maximum radial stress, maximum circumferential stress, and maximum longitudinal stress.
- Plots the radial stress and circumferential stress as functions of radial position, normalized by the outer radius.
- Prints stress values at critical radial positions (ri, ro, rc, and rc+1).
- Displays the maximum stresses and their corresponding radial positions.

This code calculates the height of a fluid column in a cylindrical container under the influence of internal pressure.

1. height(Ip, x):
   - This function calculates the height of the fluid column given the internal pressure (Ip) and the thickness of the container (x)

```
def height(Ip, x):
    ri = 1500
    ro = ri + 2*x
    numerator = ((400 - Ip) * (ri**2) - 400 * (ro**2))
    denominator = (9.81 * 1000) * (ro**2)
    return ((numerator / denominator)*1000000), ro
```

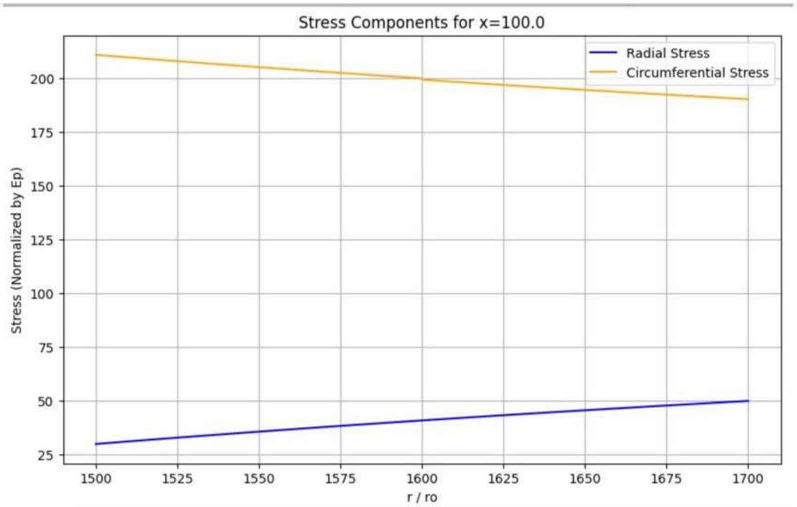
2. Ip_values and x_values:
   - Arrays defining the range of internal pressure (Ip) values and thickness (x) values to be analyzed.

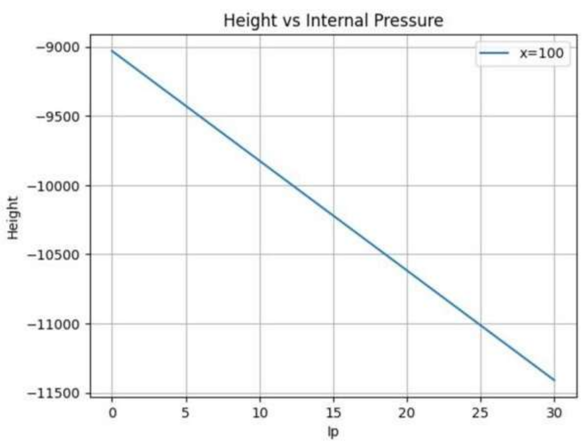
3. For Loop:
   - Iterates over each thickness value (x) in the x_values array.
   - For each x value, calculates the height values for the corresponding range of Ip values.
   - Extracts the height values and corresponding ro (outer radius) values.

4. Plotting:
   - Plots the height values against the internal pressure (Ip) for each thickness value (x).
   - Each curve represents the relationship between height and internal pressure for a specific thickness (x).

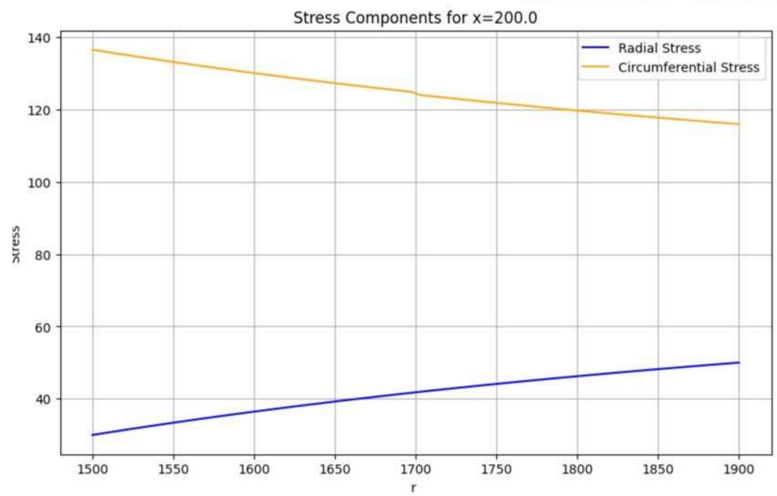
5. Max Height Calculation:
   - Finds the maximum absolute height value and its corresponding Ip and ro values for each thickness (x).
   - Prints out the maximum absolute height value, along with the corresponding Ip and ro values, for each thickness (x).

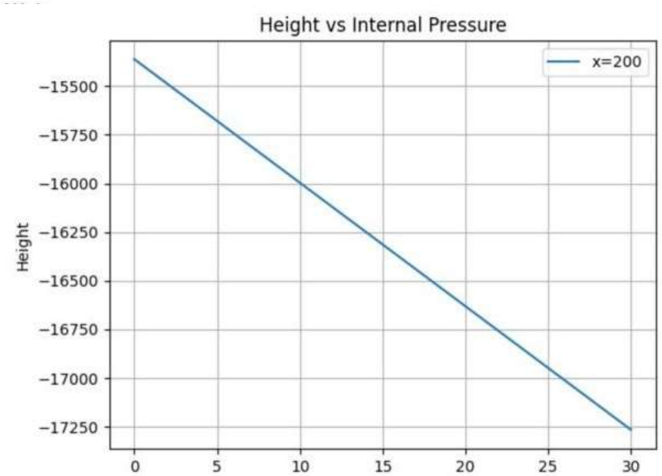
```
Enter lack of fit(in m): 0.005
Enter Ip: 30
Enter Ep: 50
Enter x: 100
Maximum Radial Stress=50.0 at r=1700.0
Maximum Circumferential Stress=210.947265625 at r=1500.0
Maximum Longitudinal Stress=-72.0966796875 at r=1601.010101010101
```






```
Enter lack of fit(in m): 0.005
Enter Ip: 30
Enter Ep: 50
Enter x: 200
Maximum Radial Stress=50.0 at r=1900.0
Maximum Circumferential Stress=136.48788927335633 at r=1500.0
Maximum Longitudinal Stress=-49.76989619377164 at r=1702.02020202020202
```





Conclusion :

- As Pi increases, the stress($\sigma\theta$) on thick-walled cylinders can exceed their yield strength(σy), even if the pressure itself isn't very high. To address this, shrinking a hollow cylinder over the main cylinder can help. This process creates compressive stresses in the cylinder, delaying or preventing yielding, especially in the outer layers.

- Utilizing a composite cylinder with lack of fit can enhance the strength and safety of the structure under high internal pressures.

- It proves especially advantageous in situations where there are no constraints on internal pressure exceeding certain limits.

- However, if specific limits on internal pressure exist, other design considerations such as optimizing wall thickness and material properties are crucial for meeting safety requirements while staying within prescribed pressure limits.

- **Pressure Resistance :** Both cylinders handle pressure well, but the composite one is a bit safer because of its extra layer.
- **Weight :** The single-walled one is lighter, which is good for submarines' movement in water.
- **Durability and Maintenance :** The composite one might last longer and need less fixing over time because it's stronger.
- **Cost :** The single-walled one is cheaper to make, but the composite one might save money in the long run because it lasts longer.

So, if weight and cost are big concerns and the submarine doesn't need extra strength, we can go with the single-walled cylinder.
But if durability and safety matter more, or if the submarine needs to be really strong, we can go with the composite double-walled cylinder.

Refrences:

Lecture Slides of Dr. P. Ravi Prakash

Assistant Professor| Department of Civil and Infrastructure Engineering
Affiliate Faculty| School of Artificial Intelligence and Data Sciences
Indian Institute of Technology Jodhpur

Thank you