ESTIMATION OF CRITICAL BUCKLING LOAD USING SOUTHWELL'S PLOT

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1 Introduction

Structural stability of the system is a crucial factor which has to be taken into account during the design of a component. Buckling is one such mode of failure where the system loses its stability and its designated shape/design. Hence, evaluating the critical load for a system to avoid buckling becomes an important task.
More often than not, this has to be done non-destructively as the material becomes inefficient once it surpasses the buckling stage. Southwell's plot is one such technique where the critical load can be estimated without actually reaching the critical load and buckling the member.

2 THEORY/CONCEPT

2.1 Critical Load

Critical load is defined as the compressive load at which the structure buckles. This often occurs due to already existing imperfections in the structural member. The structure properties such as the Young's modulus(E), Moment of cross-sectional area (I), length of the member affect the critical load. The boundary conditions too affect this value which is incorporated using an effective length factor. :

$$P_{\text{cr}} = \frac{\pi^2 EI}{(KL)^2}; K = 1$$

where:

- P_{cr} is the Euler critical load,
- E is the modulus of elasticity of the material,
- I is the moment of cross-sectional area,
- L is the actual length of the column,
- K is the effective length factor (for pinned-pinned ends, $K = 1$).

2.2 Equations for Southwell's plot

2.2.1 Deflection based

The slope of the δ vs $\frac{\delta}{p}$ plot gives the critical load.

$$\delta = P_{\text{cr}} \frac{\delta}{P} - C$$

- δ is the lateral deflection,
- P is the applied load,
- P_{cr} is the critical buckling load,

2.2.2 Strain based

The slope of the ϵ vs $\frac{\epsilon}{p}$ plot gives the critical load.

$$\epsilon = P_{\text{cr}} \frac{\epsilon}{P} - C$$

where ϵ is the strain measurement of the strain gauge placed at the deformation location.

3 Apparatus and Experimental setup

- Three Aluminium specimens

  Dimensions:(70cm X 2cm X 1mm), (70cm X 2cm X 0.5mm) and one with the same length, 2mm thickness, and the breadth varying from 1.8cm-2.5cm.

- Loading mechanism(Southwell's plot apparatus)
- Strain gauges and Dial gauge for deflection measurement.
- Digital strain indicator

Figure 1: Dial Gauge setup

Figure 2: Strain gauge setup

Experimental Procedure

- The specimen was secured in a pinned-pinned or clamped-clamped configurations.
- A strain gauge was attached to the specimen roughly at its center and is connected to digital strain indicator.
- A compressive load was applied. The load was gradually increased in small steps while simultaneously measuring the deflection of the column at the center of the specimen.
- The applied load and corresponding deflection/strain recorded were used for plotting the Southwell graph.

4 Analysis and Results

Deflection and strain readings obtained from the experiment.

Load (N)	Strain ($\mu\epsilon$)
0	0
1	22
2	35
3	104
4	188
5	372
6	710

Table 1: Strain vs Load 1mm

Load (N)	Deflection (mm)
0	0
1	1.15
2	2.12
3	3.9
4	4.5
5	5.8

Table 2: Load vs Deflection 2mm

5 Plots

5.1 ϵ vs $\frac{\epsilon}{p}$ for 1mm thickness and δ vs $\frac{\delta}{p}$ for 2mm thickness

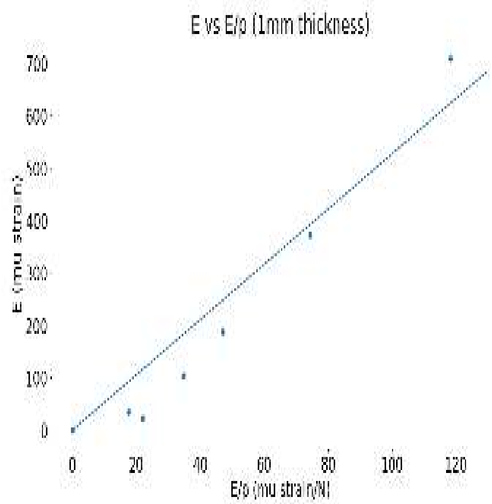

Figure 3: Strain variation w.r.t. the load

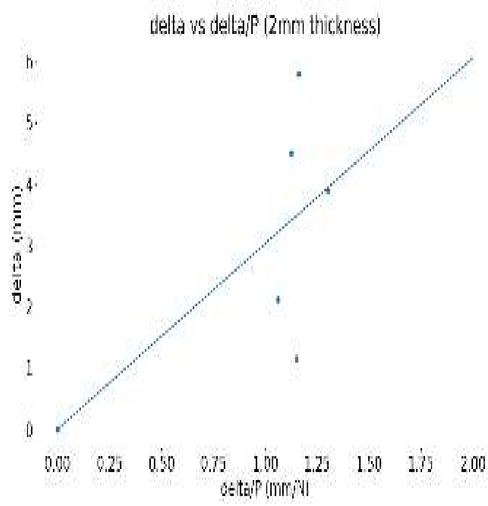

Figure 4: Deflection variation w.r.t. the load

6 Observations

The following images show the buckled columns after the experiment was performed.

1. For the beam with dimensions 70cm x 2cm x 1mm, the buckling test was performed under clamped-clamped conditions. Theoretically, the critical load turns out to be 9.39N, whereas the experiment suggests a critical load of 5.27N.

2. The beam with varying breadth doesn't show a good trend. The best fit linear plot predicts a buckling load of 3.02N. The breadth varies from 1.8cm to 2.5cm. So assuming an average width of 2.15cm, the theoretical load turns out to be 20.2 N which is much higher in comparison to the prediction.

3. The chosen specimen was 70cm in length which wasn't sufficient to apply large compressive loads as shifting the setup wasn't an easy task.

4. The specimen with 0.5mm thickness was difficult to mount on the setup as the beam buckled even before placing it with the knife edge on the setup.

Figure 5: Buckling of 1mm specimen

Figure 6: Buckling of 0.5mm specimen

5. The force due to the spring in the dial gauge is large enough to control the buckling of beams with 0.5mm, 1mm thickness and hence, the dial gauge measurements were not reliable. This forced us to consider a beam with a thickness of 2mm.
6. Another buckling test was performed on a 0.5 mm thickness where a strain gauge was attached to the beam using a tape. The strain gauge readings were not pretty useful as the applied load couldn't cross 3N. The buckling though did not occur at the center of the beam where the strain gauge was pasted. It was produced to the right of the strain gauge. The reason for this might be the adhesive forces of the tape. They were probably strong enough to avoid buckling in that region.

7 Conclusion

Southwell's plot is an extremely useful experiment in non-destructively predicting the critical buckling load. But, from this experiment, we learnt that establishing the theoretical boundary conditions is not a walk in the park. Huge care has to be taken in designing the specimens. As mentioned, constraints like the least count of the load cell, forces due to the spring in the dial gauge etc have to be taken into account before deciding the dimensions of the specimen in order to achieve better results from the experiment.

8 Contributions

1. Adinarayan Agaram - Fabrication, experimentation, and report writing
2. Kishore Kumar - Fabrication, simulation, and slides
3. Dhanush Pagadala - Experimentation and slides
4. Laxmi Sai Pedaboina - Experimentation and report writing
5. Meda Vamsi - Report writing

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