Buckling Laboratory Report

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Abstract

This laboratory investigates the buckling behavior of slender columns under compressive loads. Critical buckling loads are measured experimentally and compared with theoretical predictions based on Euler's buckling theory. The influence of geometry, boundary conditions, and material properties is analyzed.

1 Introduction

Buckling is a failure mode in which a structural member subjected to compressive forces suddenly deforms laterally. Euler's formula predicts the critical load at which buckling occurs:

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2}$$

where E is Young's modulus, I is the area moment of inertia, L is the column length, and K is the effective length factor depending on boundary conditions.

2 Objectives

- Measure critical buckling loads for columns of varying lengths and materials.
- Compare experimental results with theoretical predictions from Euler's formula.
- Investigate the effects of geometry and material properties on buckling behavior.

3 Experimental Setup

- Test specimens: slender rods of different lengths and cross-sections.
- Loading frame with force sensor and displacement measurement.
- Optional instrumentation: strain gauges or thermocouples.

4 Procedure

1. Measure specimen dimensions (length, diameter) and enter them in machine.
2. Mount selected specimen in the loading frame.
3. Apply compressive load gradually until buckling occurs.
4. Record critical load and displacement.
5. Repeat steps 1-3 for all available lengths for chosen material.
6. Repeat all steps for all materials.

5 Data and Analysis

- Calculate theoretical critical loads using Euler's formula.
- Compare with experimental values.
- Plot load-displacement curves.
- Discuss discrepancies and sources of error.

Variable Definitions

L Column length (mm)

D Column diameter (mm)

A Cross-sectional area (mm^2)

I Area moment of inertia (mm^4)

S Slenderness ratio (L/r)

E Young's modulus (MPa)

σ_{cr} Euler buckling stress (MPa)

P_{cr} Critical buckling load (N)

P_{peak} Peak load measured experimentally (N)

σ_{peak} Peak stress measured experimentally (MPa)

Table 1: 6061-T6 Aluminium Dimensions and Calculations

L	D	A	I	S	σ_{cr}	P_{cr}	σ_{peak}
45.5	6.38	31.969	81.330	28.527	3344.827	9704.405	303.555
140.8	6.35	31.669	79.811	88.693	346.017	9521.747	300.663
241.2	6.36	31.769	80.315	151.698	118.281	4352.159	136.994
341.2	6.37	31.869	80.822	214.254	59.295	2117.980	66.459
498.1	6.34	31.570	79.310	314.259	27.561	849.594	26.912

Table 2: A36 Steel Dimensions and Calculations

L	D	A	I	S	σ_{cr}	P_{cr}	σ_{peak}
46.3	6.28	30.975	76.350	29.490	9078.771	21884.799	706.535
141.1	6.31	31.271	77.819	89.445	986.903	17830.297	570.177
239.5	6.30	31.172	77.327	152.063	341.460	11236.102	360.450
341.8	6.29	31.074	76.837	217.361	167.119	5729.370	184.381
499.9	6.33	31.470	78.811	315.893	79.124	3089.866	98.184

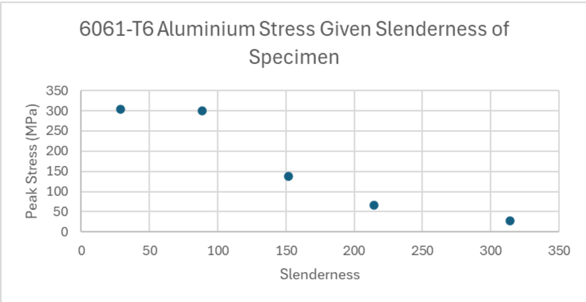


Figure 1: Aluminium Rods - Peak Stresses

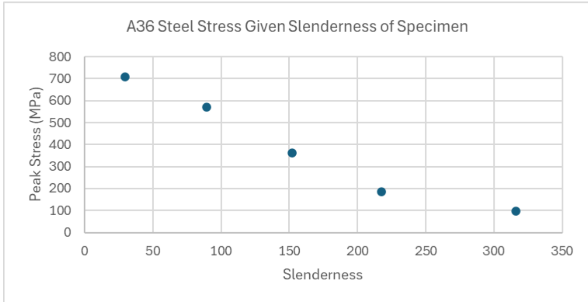
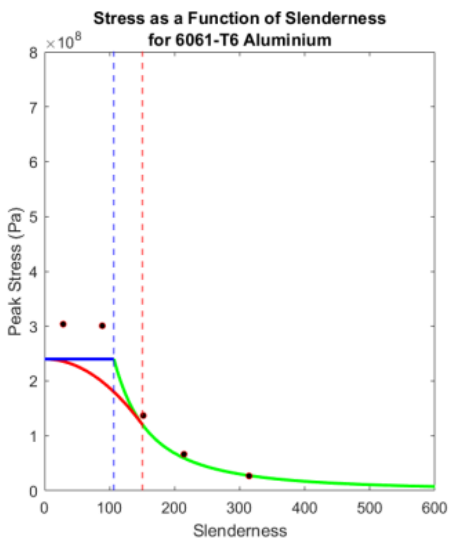


Figure 2: Steel Rods - Peak Stresses

Table 3: Summary of Strength Values

Material	S_{tr} (MPa)	$S_{tr-Johnson}$ (MPa)
Aluminum	106.496	150.608
Steel	177.715	251.327



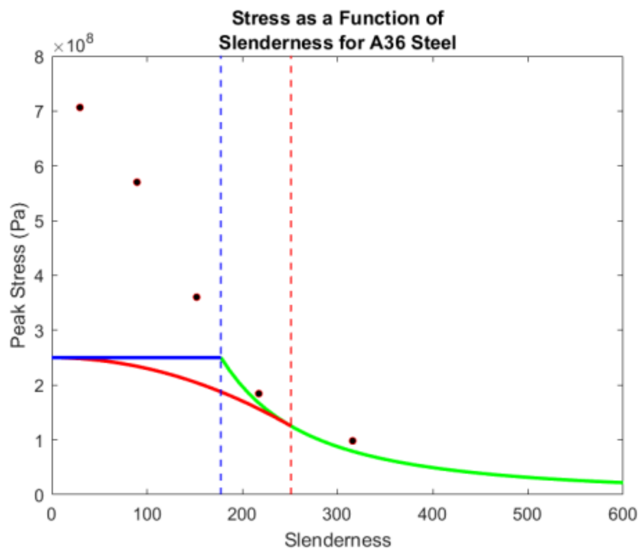


Figure 3: Peak stresses compared to theoretical parameters - yield limit, Euler buckling limit, Johnson parabola and transition points.

6 Analysis

Deformation Behavior Analysis

After reaching peak or yield strength, the specimens exhibited distinct deformation modes depending on their slenderness. The two longest (most slender) specimens for both aluminium and steel showed highly elastic buckling, characterized by lateral deflection without significant plastic compression. In contrast, the shortest specimens (least slender) underwent plastic compression yielding, expanding radially and displaying pronounced strain-hardening. The intermediate specimens (second shortest and mid-length) tended to deform through plastic buckling, remaining slightly bent even after unloading from the compression machine. These observations highlight the transition from elastic buckling in slender beams to plastic yielding and strain-hardening in stockier specimens.

Comparison with Buckling and Yielding Criteria

The experimental data for aluminium showed semi-accurate agreement with theoretical predictions. Specimens with high slenderness followed the Euler buckling criterion closely, while those with low slenderness exhibited peak stresses higher than expected, surpassing the yield strength of the material. This indicates that shorter aluminium specimens underwent plastic compression and strain-hardening, increasing their maximum achievable stress.

For steel, the agreement was less consistent. Although the slender specimens buckled as expected, the shorter specimens displayed extremely high peak stresses that did not follow a clear trend. The accepted yield strengths of both materials were used for comparison: 68.947 MPa for aluminium and 200 MPa for steel.

A likely explanation is the nature of the shorter specimens. Those that deformed plastically experienced strain hardening, which increased the effective strength of the material during loading. Additionally, data for these specimens were collected at the maximum observed stress, after yielding had already begun, which contributed to the unusually high values. To improve accuracy, peak loads should be measured at the point where the load–displacement curve plateaus rather than after significant strain hardening has occurred.

Validity of Buckling Criteria and Determination of Limit Load

The results indicate that the Euler buckling limit is highly accurate, as both aluminium and steel data points in the buckling region aligned closely with the Euler buckling stress curve. However, it is difficult to assess the validity of Johnson's parabola with the available data. The aluminium specimens showed peak loads leveling out as slenderness approached zero, but without a clear relationship. The steel specimens exhibited very high peak stresses in the shorter samples, without clearly indicating the onset of yielding or buckling.

For shorter specimens, load values should be collected after the load–displacement curve plateaus, since yielding allows the material to continue supporting additional stress.

This suggests that Johnson's parabola may also be valid, but accurate assessment would require unloading specimens earlier, before significant yielding occurs. Observations from the lab graphs indicated that smaller specimens had different stress curves but tended to plateau at similar stress values.

The best way to determine the limit load is to unload the specimen as soon as its load–slenderness curve plateaus, or when buckling begins and the curve shows a decrease in peak load.