ESI ENGINEERING, INC
7831 Glenroy Road/Suite 340
Minneapolis, Minnesota 55439
Tel: (952) 831-4646
Fax: (952) 831-6897
Internet: www.esi-engineering.com

STRUCTURAL DESIGN CONSIDERATIONS

BUCKLING AND ELASTIC STABILITY

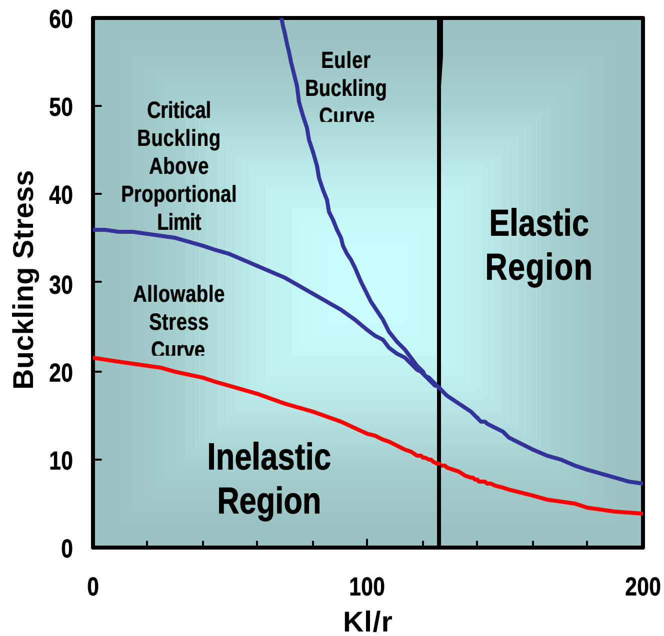
Some of us recall watching Charlie Anderson's structural model when it collapsed in the testing lab at the University. Charlie was a graduate student working on his thesis. He gradually loaded the model with weights for over an hour. Everything looked fine; then, suddenly it seemed to explode!

Buckling failures can be like an explosion, sudden and catastrophic. When the critical load is reached in compression of a slender member, something has to give and often does without many warning signs.

Structural parts that can become unstable are

- columns and struts in compression
- compression flanges of beams
- parts with unbraced flanges or lips
- thin, unstiffened panels or shells

As the dimensions (span) of an element become larger, there is a greater tendency for instability to occur. However, failure is sometimes just related to inadequate bracing or poor connection details.



Critical Buckling Stress for Steel
(Code requirements for buckling are based on these curves)

THE BUCKLING PHENOMENON

There is always some eccentricity in the applied loading of a member due to initial imperfections in the section or in its boundary conditions. When a compressive load is increased, eccentricity sets up bending in the member causing it to deflect.

In turn, the deflection increases the eccentricity, which increases the bending. This may progress to where the bending increases at a greater rate than the compressive loading and the member becomes unstable. This phenomenon can occur in columns, flanges, plates and shells subject to compression.

CRITICAL STRESS

The stress at failure is called the critical buckling stress. The Euler buckling stress equation is shown graphically above and given below as

$$\sigma_{cr} = \pi^2 E / (Kl/r)^2$$

Where E = Modulus of Elasticity
Kl/r = Slenderness Ratio

When the computed Euler stress exceeds the proportional limit of the material, the tangent modulus is often used in place of Young's modulus.

(Continued)

The proportional limit theoretically separates the elastic buckling from inelastic buckling since the strain is no longer elastic above this limit.

Various theories have been developed to represent inelastic buckling as a function of the yield stress and the slenderness ratio. As a consequence of the yield stress, high strength materials have a higher critical stress in the inelastic region.

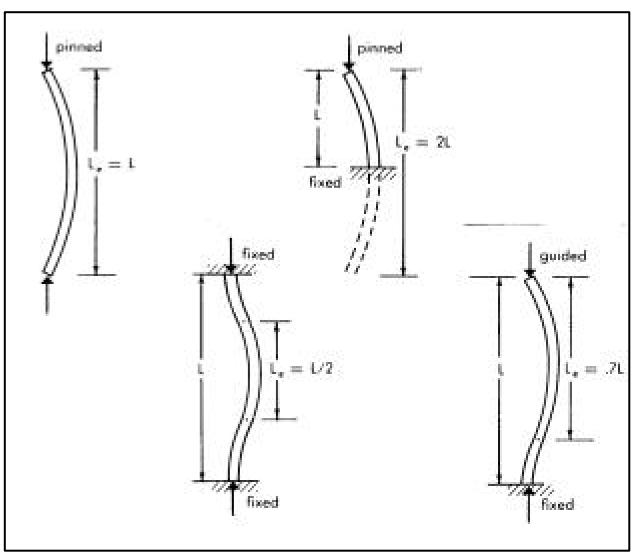
This implies there is less of an advantage to using higher strength materials in compression when the parts are slender, especially in the elastic range.

Critical stress levels are reduced by a factor of safety to create an allowable stress to be used in design. Factors of safety usually vary between 1.67 - 1.92 for metals and higher for other materials such as plastics. The bottom curve in the figure (in red) shows allowable stress levels for A36 steel.

Many of the same concepts of stability apply to plates as well as column. However, plate buckling parameters are usually expressed in width and thickness terms rather than in slenderness ratios.

SLENDERNESS IS A KEY FACTOR

As members become more slender or thinner, there is a greater possibility for failure to occur. The slenderness of a column or compression flange in a beam is a function of effective length and the least radius of gyration. The effective length of compression members is shown below for various boundary conditions. For flat plates, stability is more a function of width and thickness dimensions unless the length to width ratio is large.



Effective Length of Columns
(From Blodgett, 1976)

CONNECTION DETAILS ARE IMPORTANT

Proper sizing of the members to resist buckling is compromised if connection and bracing details are inadequately designed.

Some important details to consider are design of connections, stiffeners and spacing of fasteners. For example, if the connection is assumed to be moment-resistant, then it should be designed with full penetration welds or with bolted flanges, etc.

In the building industry there have been several tragic failures of columns supporting deep, slender roof beams where the effective column length was much greater than assumed and failure occurred.

FAILURE CAN BE CATASTROPHIC

Members in compression can become unstable at stresses well below the yield point. Failures can occur during assembly or erection before bracing members have been installed, as well as later in service when subjected to normal design loads.

Because collapse is unexpected and there are few warning signs, failure can be sudden and catastrophic. In some cases there has been loss of life because of the sudden collapse.

Safety is essential. Structures must provide service under expected loads without any injury to people or damage to property.

IN SUMMARY

When designing for stability:

- Slenderness is a key-determining factor
- Connection details are very important
- Bracing must be considered during erection
- Buckling can produce catastrophic failure
- Safety for life and property is essential

These are some of the important points realized from Charlie's model.

ESI ENGINNERING, INC.

ESI Engineering, Inc. (ESI) offers services as a consultant in analysis and design of structural systems for manufactured products and equipment. We also offer services in vibration analysis of floors, buildings and equipment for many clients.

We would like to serve you. Please call us at:
(952) 831-4646