Structural Stability
– Introduction –

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Outline

• Concept of structural failures

• Structural failures due to instability

• Types of instability

• Approaches in structural stability

• Classical beam-column problem

• Examples

• Design philosophies
Concept

- Material failures:
  - Brittle failure
  - Ductile failure
  - Fatigue failure

- Structural failures:
  - Local material failure (e.g., cracking, yielding, imperfection)
  - Global material failure (e.g., aging)
  - Local system failure (e.g., buckling, manufacturing errors)
  - Global system failure (e.g., buckling, excessive loading)
Structural Failures

- Global buckling of a wind turbine tower

(Note: Temperature = -54°F)
Structural Failures

- Global buckling of a wind turbine tower

(Source: Unknown)
Structural Failures

- Global buckling of a wind turbine blade

Sigel, Michigan (02/24/16)  
(Source: NSE Composites)
Structural Failures

- Torsional buckling of an I-beam member
- Local buckling of the compression flange
Structural Failures

- Global buckling of a truss system

Hartford Civic Center Stadium, CN (01/18/78)
Structural Failures

- Global buckling of a truss system

University of Washington, Husky Stadium, Seattle, WA (02/25/87)
(Source: John Stamets)
Structural Failures

- Global buckling of a truss system

University of Washington, Husky Stadium, Seattle, WA (02/25/87)
(Source: John Stamets)
Structural Failures

• Global buckling of a truss system
Structural Failures

- Global buckling of a truss system

Malaysia (2009)
Structural Failures

- Combined buckling of rails

Washington, D.C. (06/23/09)

South Korea
Structural Failures

- Combined buckling of rails

(Source: Iowa DOT, Oct. 2013)
Structural Failures

• Buckling of bridge girders during construction
Structural Failures

- Buckling of bridge girders during construction
Structural Failures

- Buckling of steel towers

South Australia (10/05/16)
Structural Failures

- Buckling of reinforced concrete columns

2010 Canterbury earthquake, Christchurch, New Zealand

(Source: Hyland Consultants, Ltd.)
Structural Failures

- Buckling of reinforced concrete columns

1995 Kobe earthquake, Japan
Structural Failures

- Failures of reinforced concrete columns in an expressway

1995 Kobe earthquake, Japan
Types of Instability

- Classical/bifurcation instability (buckling)
  - Symmetric bifurcation
    - Stable and unstable
  - Asymmetric bifurcation
    - Stable and unstable

- Limit-load/snap through instability (buckling)

- Finite-disturbance instability (buckling)
Types of Instability

• Examples of classical/bifurcation instability
  – Buckling of long straight columns loaded axially
  – Buckling of thin plate loaded by in-plane loads
  – Buckling of rings
Types of Instability

• Examples of limit-load/snap through instability (buckling)
  – Snapping of a low pinned arch under lateral loads

  – Snapping of clamped shallow spherical caps under uniform lateral pressure
Types of Instability

• Examples of finite-disturbance instability (buckling)
  – Buckling of thin cylindrical shells under axial compression
  – Buckling of complete, spherical, thin shells under external pressure
Approaches in Structural Stability

- The Force/Bifurcation Approach
  - Static equilibrium
  - Eigenvalue analysis

- The Energy Approach
  - Principle of virtual work / Hamilton’s principle
  - Elastic strain energy, internal work, external work, potential energy

- The Dynamic Approach

- Small deflection analysis vs. large deflection analysis
Classical Beam-Column Problem

- Timoshenko beam-column with a concentrated lateral load
Examples

• Spring-bar system subjected to axial loading – \textbf{Small} deflection
  – The force approach

  – The energy approach
Examples

• Spring-bar system subjected to axial loading – **Large** deflection
  – The force approach

  – The energy approach
Design Philosophies

• Allowable Stress Design (ASD)

• Plastic Design (PD)

• Load and Resistance Factor Design (LRFD)
Summary

- Structures can fail due to instability/buckling which occurs below the elastic, plastic, or fatigue limit and the fracture strength, in addition to plastic yielding and brittle fracture.

- Structural instability can be local, global, or the combination of both.

- Stability analysis of structural problems means i) finding the minimum buckling load and its mode, ii) determining the post-buckling behavior, and iii) developing strategies for stabilization.

- Three approaches to find the buckling load of a structure; the force/bifurcation, energy, and dynamic approaches.