CEEN 4316:
Structural Steel Design

Background Information

Fall 2023

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Presentation Overview

- What is the role of codes, such as the AISC code, in structural design?
- How is design affected by external loads?
- How is design affected by internal forces?
- How are external loads and internal forces connected?
- What design approach will we use in this course?

Role of Codes

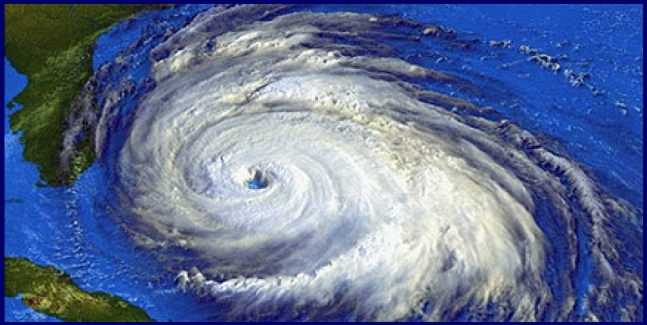
- Various codes are applied during the design and construction of a building or other large-scale infrastructure project.
- Structural engineers have a responsibility to the public to abide by code provisions.
- When structures fail during service or construction, the codes provide protection to the engineer. You must be able to prove that you met or exceeded code specifications in your design.

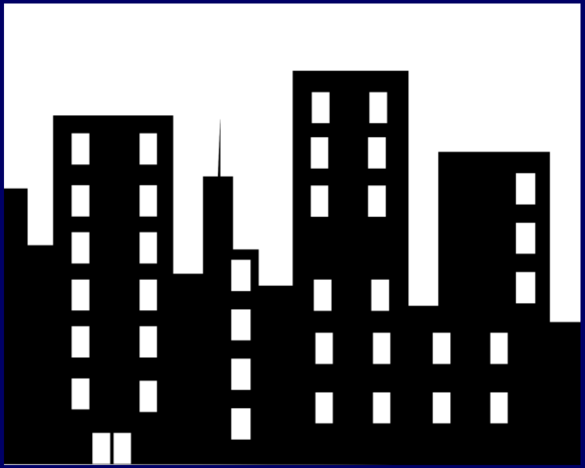
Role of Codes

- Building Codes: (Ex. International Building Code, IBC)
  - Adopted by government entities (cities, states, etc.) or specified in contract documennts.
  - Describe minimum requirements for construction – from plumbing to structural safety.
- Loading Standards: (Ex. ASCE 7)
  - ASCE 7 is included in or referenced by many building codes.
  - Describes minimum external loads a building must withstand.
- Design Specifications: (Ex. AISC manual or ACI code)
  - Industry standards of "good practice" in structural design.
  - Explains how to design individual structural members to withstand external loads calculated with ASCE 7.

Role of Codes

ASCE 7 to calculate loads.



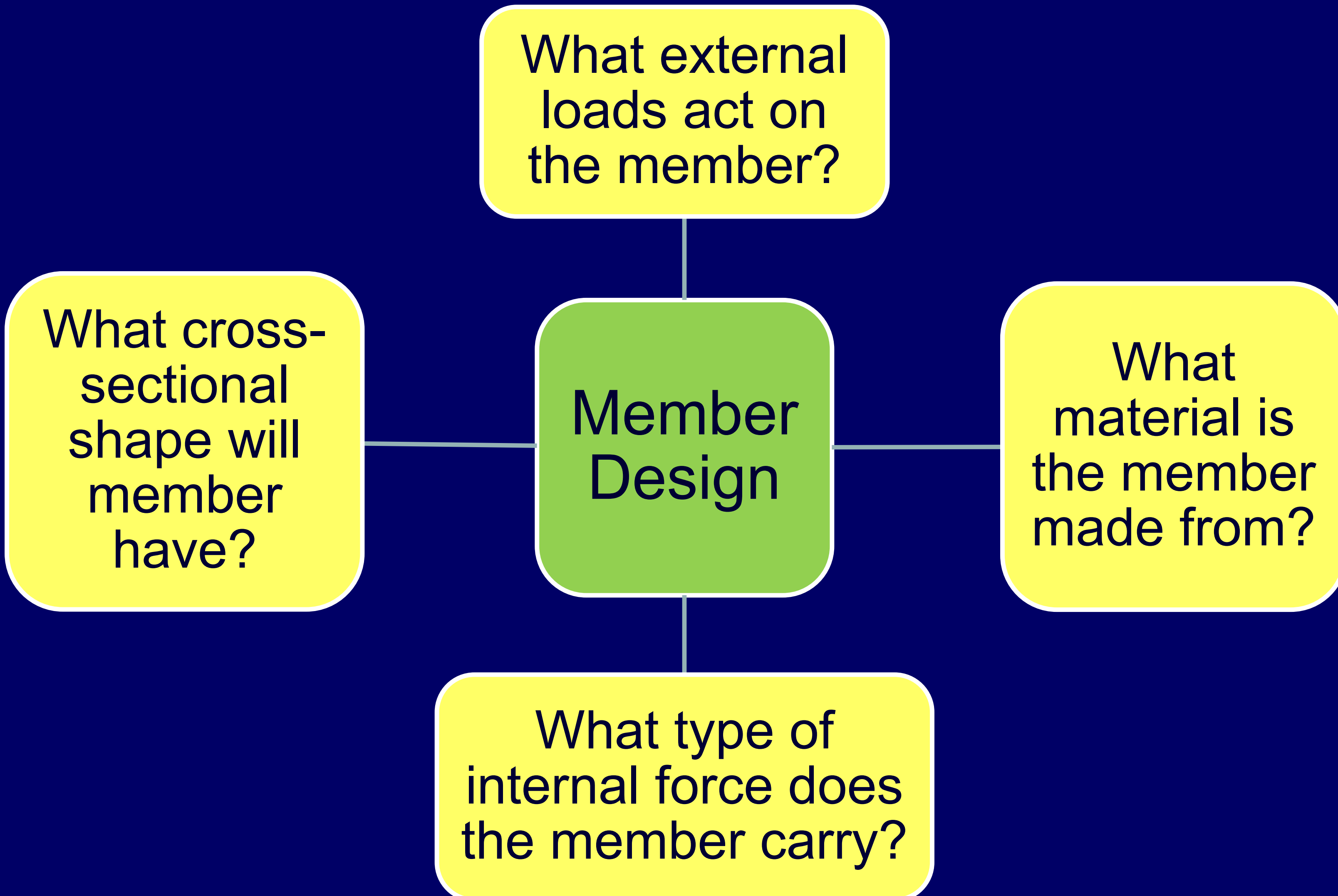


City adopts IBC 2015.

New steel building.

AISC to design members.

Overview of Design Process

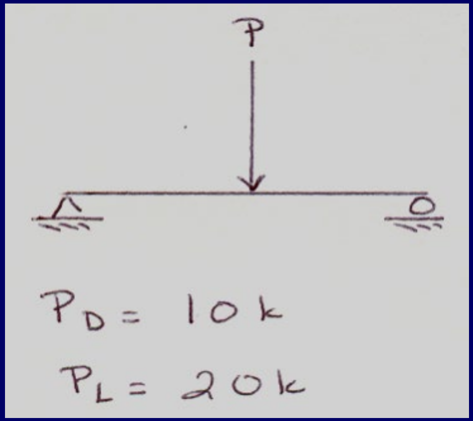


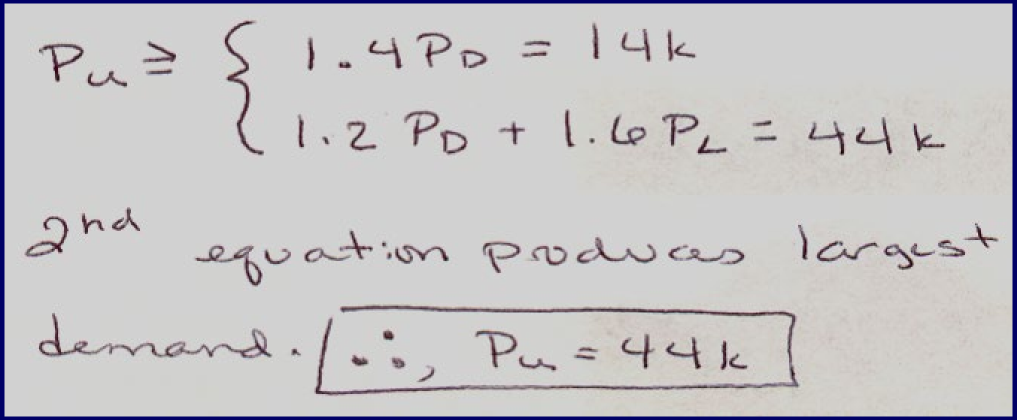
External Loads

- Environmental Loads:
  - Snow, wind, earthquake, rain.
  - Magnitudes are determined by geographic location.
- Live Loads:
  - Weight of building contents and occupants.
  - Magnitude and location vary over time.
  - Gravity-induced.
- Dead Loads:
  - Weight of the structure and its permanent components.
  - Constant magnitude and location.
  - Gravity-induced.

External Loads

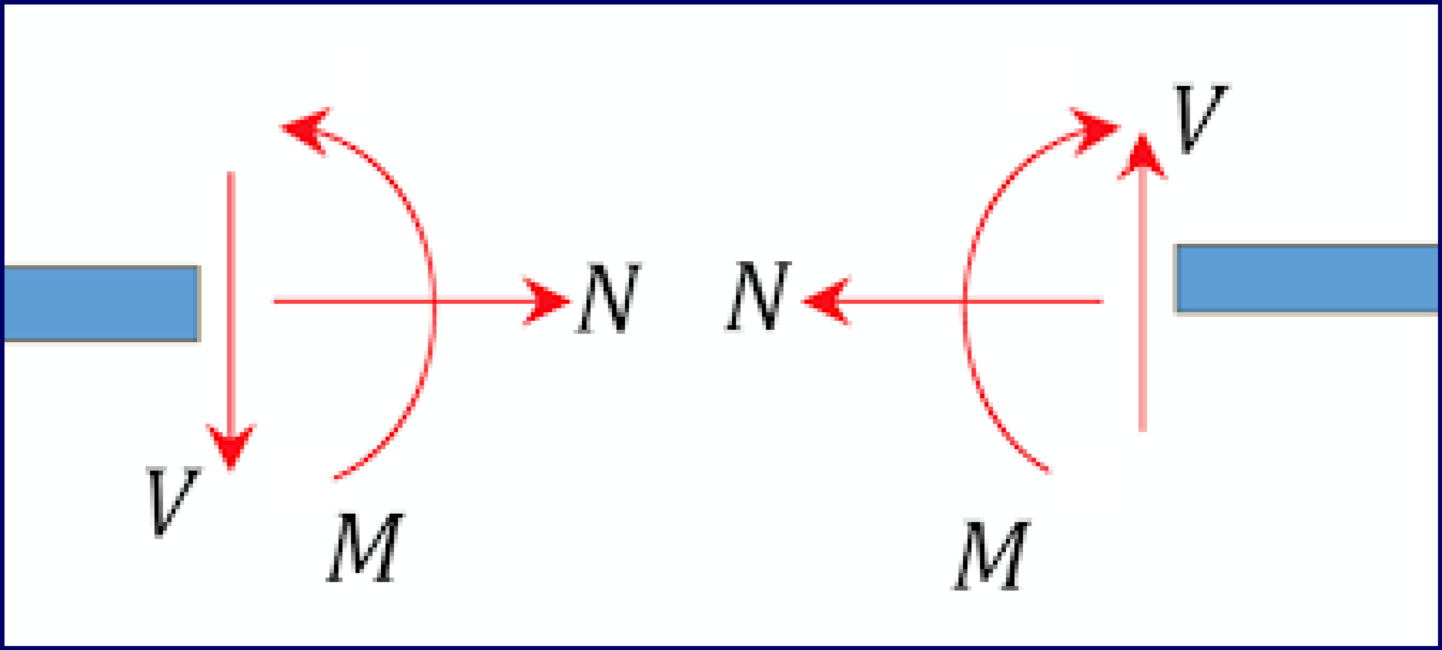
- ASCE 7 load combinations are used to determine the governing load effect on a member– i.e., the most load a member is likely to experience in its lifetime.





- As structures grow more complex, so do the loads applied to them. Multiple load combinations may need to be considered for a structure.

Internal Forces



https://pressbooks.library.upei.ca/statics/chapter/3-types-of-internal-forces/

Internal Forces

Pics from Google images, January 2017.

Trusses:

- Members arranged in triangular patterns.
- Members act in tension or compression (axial load only).
- Structure acts like a beam with sections of web missing, so that it is lighter than an equivalently sized beam.
- Used most often for roofs and bridges.

Internal Forces

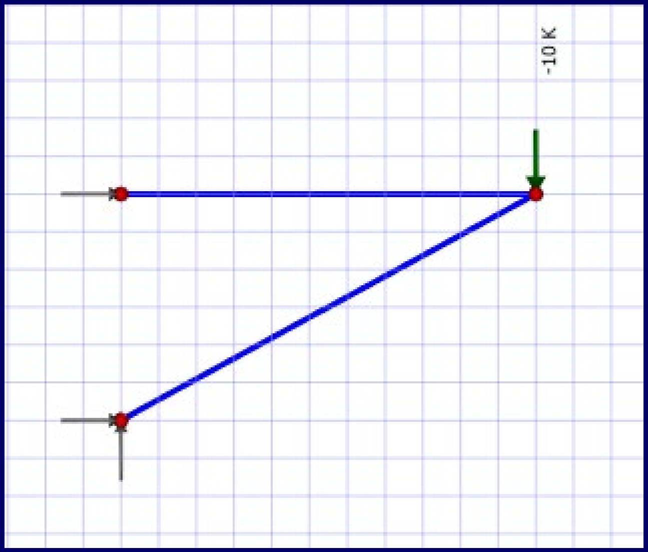
Frames

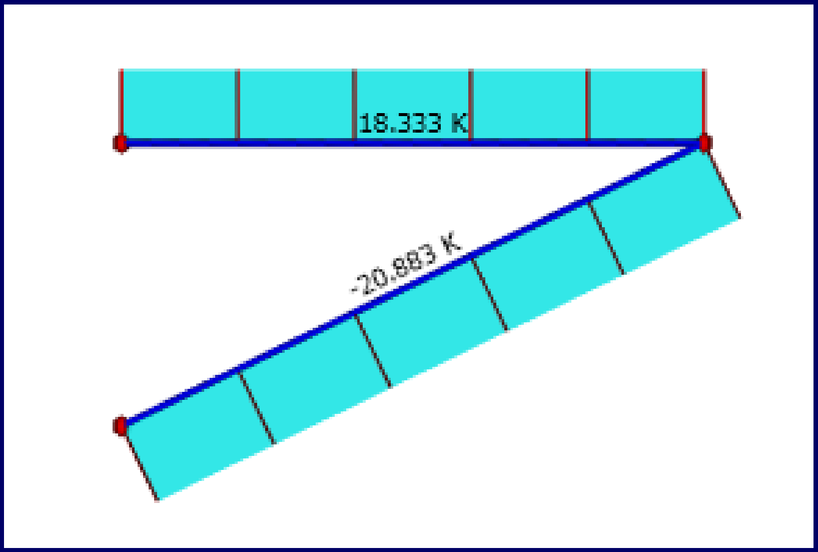
- Beams and columns arranged (usually on a rectangular grid) to carry bending loads.
- Connections may be rigid (carry moment) or pinned (carry only shear and axial forces).
- Used in most buildings.

Pics from Google images, January 2017.

Internal Forces

Different members within a structure will react differently to the same applied load:





Internal Forces

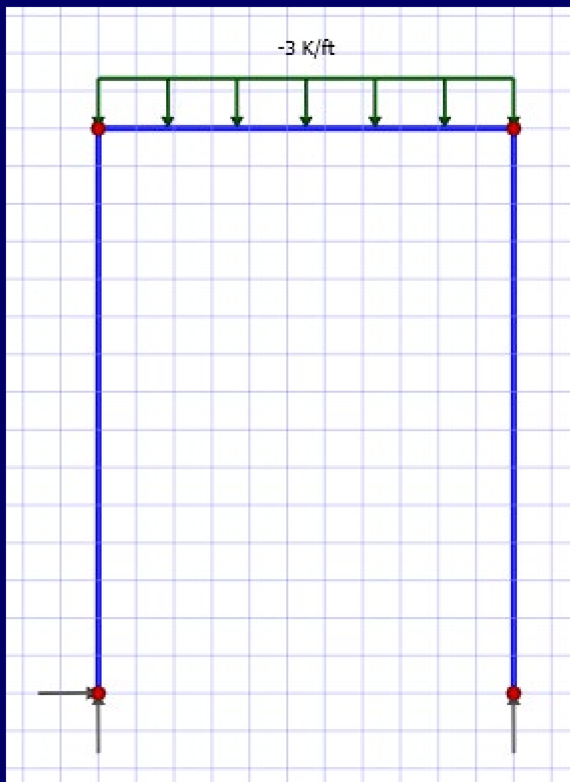
- Horizontal truss member is in TENSION. It will fracture or yield.
- Diagonal truss member is in COMPRESSION. It will buckle.
- When selecting steel cross-sections for these members, we must consider the expected failure modes.

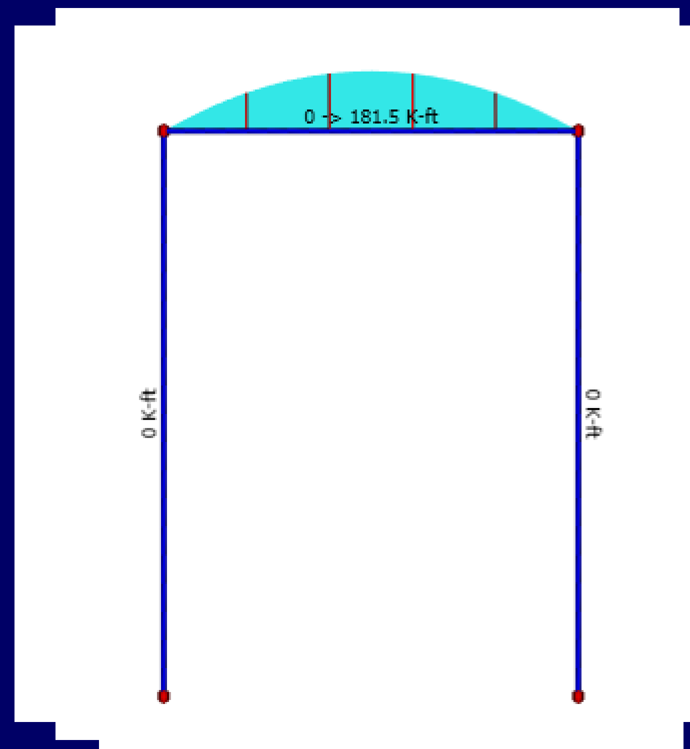
External Loads + Internal Forces

- External loads are factored to determine largest amount of load on a member at a given time.
- External loads create internal loads depending on how load is distributed to individual members within the structure.
- HOWEVER, structures are complex systems, and load changes over time.

External Loads + Internal Forces

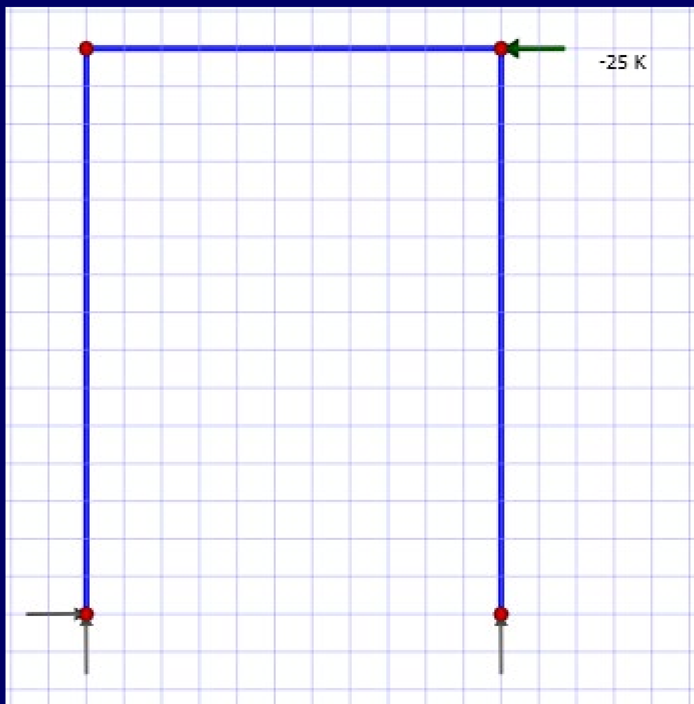
Frame with moment bearing joints subject to gravity load.

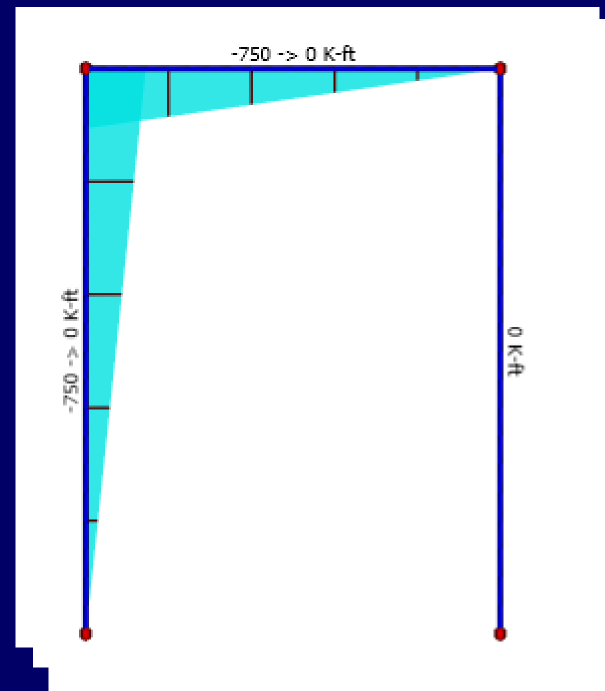




External Loads + Internal Forces

Frame with moment bearing joints subject to lateral load.





External Loads + Internal Forces

- Roller supported column always has compressive load only.
- Beam acts in bending with the gravity load, and then acts as a beam-column (compression + bending simultaneously) with the lateral load.
- Pinned column acts in compression only with the gravity load and then acts as a beam-column with the lateral load.
- Expected failure modes change as loads change.
- Different load combinations consider different load sources!

Understanding Internal Forces is Key to Structural Design

1. Individual structural members play different roles in supporting load. Therefore, we expect failure mechanisms that reflect these various roles.
2. The role of a structural component (and, therefore, it's expected failure mechanism) may change when a different loading scenario is considered.
3. We must DESIGN (i.e., select an appropriate cross-section) structural components to withstand the worst possible load(s) those components will see in the structure's lifetime.

Design Philosophies

- In structural steel, there are two governing design philosophies. Both seek to satisfy the design equation:

$$\Sigma Q_i < R$$

- Q = load effect; any load creating force or stress in a structural member.
- R = member resistance; the capacity of a structural member to resist the applied load.
- Both design methods strive to select members with enough resistance to withstand the sum of all loads acting on the member while in service (ΣQ_i).

Design Philosophies

- Allowable Stress Design (ASD):
  - Compares stresses due to applied loads to theoretical maximums.
  - Uses one factor of safety to make sure stresses stay below theoretical maximums.
- Governing ASD Equation:

$$\Sigma Q_i / \Gamma < R / FS$$

  - Γ = relevant cross-sectional property (A or I)
  - FS = factor of safety

Design Philosophies

- Load and Resistance Factor Design (LRFD):
  - Service loads (loads calculated from ASCE 7 that we would reasonably expect in the structure's lifetime) are increased to multiply their effect on the member.
  - The nominal member strength (the capacity of the member to withstand loads based upon dominate failure mechanisms) is decreased to make the member appear weaker than it is.
  - Distributes a factor of safety between loads and members.
- Factored loads are called design loads, and the factored resistance is the member's design strength.
- LRFD uses failure modes to determine a design that reflects the lowest possible design strength. This failure mode is the governing limit state for the member.

Design Philosophies

- Governing LRFD Equation:

$$\Sigma \gamma_i Q_i < \Phi R_n$$

- γ_i = magnification factor to increase load Q_i; generally > 1.0.
- R_n = nominal strength (or resistance) of the member.
- Φ = phi factor or resistance factor; used to reduce member capacity; generally < 1.0.
- Selection of γ_i and Φ factors depends on probability analysis. The goal is to reduce the region of probability where applied load will exceed member resistance. See Section 2.5 of Segui text.

Course Goal

- We will be designing structural steel components (truss members, beams, columns, etc.) according to the AISC steel manual, which sets forth minimum legal requirements.
- The AISC manual contains equations for designing according to the ASD or LRFD design philosophies.
- We will be using the LRFD provisions.
- So let's get started!