“Structural design can be defined as a mixture of art and Science, combining the engineer's feeling for the behavior of a structure with a sound knowledge of the principles of statics, dynamics, mechanics of materials, and structural analysis, to produce a safe economical structure that will serve its intended purpose.” (Salmon and Johnson 1990)
Engineering Systems

- Engineering structural systems are of variety that they defy any attempt to enumerate them.
- The many problems which arise in their design have prompted engineers to specialize in the design of particular structure or groups of related structures.
- A complete design requires the coordinated efforts of several branches of engineering.

Engineering Systems

- Civil Engineering Structures
  - Among the structures that are design by civil engineers are
    - Buildings
    - Bridges
    - Transmission Towers
    - Dams
    - Highway Pavements
    - Aircraft Landing Runways (strips)
    - Retaining Walls
Engineering Systems

Eiffel Tower
Paris – 1899
984 ft. high

Sears Tower
Chicago - 1974
1450 ft. high
Engineering Systems

RHINE BRIDGE, COLOGNE-RODENKIRCHEN, (1946-47), SPAN 94.5-378-94.5 m
Engineering Systems

Hoover Dam
Arizona-Nevada Border
Near Las Vegas

Transmission Towers
Engineering Systems

Highway & Aircraft Landing Strip

Retaining Walls
The design of the previous groups of structures require the coordination of various disciplines in engineering, and is too large for convenient study as a unit.

In this course, we will focus on the design of the individual structural elements or members that make up the whole structural system.

Such members or elements include the following:

- Beams
- Columns
- Trusses
- Shear Structural Elements
- Steel Rods
- Connection Elements
Engineering Systems

- Structural Elements
  - Bending Structures

Engineering Systems

- Structural Elements
  - Compression Structures
Engineering Systems

- Structural Elements
  - Trusses

  ![Truss Diagram]

- Structural Elements
  - Tension Structures

  ![Tension Structures Diagram]
Engineering Systems

- Structural Elements
  - Shear Structures
Analysis Versus Design

- **Structural Analysis:**
  - Structural Analysis is the prediction of the performance of a given structure under prescribed loads and/or other effects, such as support movements and temperature change.

- **Structural Design:**
  - Structural design is the art of utilizing principles of statics, dynamics, and mechanics of materials to determine the size and arrangement of structural elements under prescribed loads and/or other effects.
Design Procedure

- Design procedure consists of two parts:
  - Functional Design
  - Structural Framework Design

- Functional design ensures that intended results are achieved such as adequate working area, elevators, stairways, etc.

- Structural framework design is the selection of the arrangement and sizes of structural elements so that service loads may be carried.

Analysis Versus Design

Flowchart:

1. Planning phase
2. Preliminary structural design
3. Estimation of loads
4. Structural analysis
   - Are the safety and serviceability requirements satisfied?
     - Yes
     - Revised structural design
     - No

5. Construction phase
Analysis Versus Design

■ Example 1: Analysis

– Determine the maximum flexural stress produced by a resisting moment $M_r$ of +5000 ft·lb if the beam has the cross section shown in the figure.

```
Example 1: Analysis (cont'd)

First, we need to locate the neutral axis from the bottom edge:

$y_C = \frac{(1)(2 \times 6) + (2 + 3)(2 \times 6)}{2 \times 6 + 2 \times 6} = \frac{72}{24} = 3''$

$y_{cen} = 3'' \quad y_{com} = 6 + 2 - 3 = 5'' = y_{max}$

Max. Stress $= \frac{M_r y_{max}}{I_x}$
```
Example 1: Analysis (cont’d)

Find the moment of inertia $I_x$ with respect to the $x$ axis using parallel axis-theorem:

$$I_x = \frac{6(2)^3}{12} + (6 \times 2)(2)^2 + \frac{2(6)^3}{12} + (2 \times 6)(3-1)^2$$

$$= 4 + 48 + 36 + 48 = 136 \text{ in}^4$$

Max. Stress (com) = $\frac{(5 \times 12)(5)}{136} = 2.21 \text{ ksi}$

---

Example 1: Analysis (cont’d)

An alternative way for finding the moment of inertia $I_x$ with respect to the $x$ axis is as follows:

$$I_x = \frac{6(3)^3}{3} + \frac{2(5)^3}{3} - 2 \left[ \frac{2(1)^3}{3} \right] = 136$$
Example 2: Design

A pair of channels fastened back-to-back will be used as a beam to resist a bending moment $M_r$ of 60 kN · m. If the maximum flexural stress must not exceed 120 MPa, select the most economical channel section listed in Appendix B of the textbook.

Example 2: Design (cont’d)

\[
\sigma = \frac{M}{S}, \text{ However, we have two channels, hence}
\]

\[
\sigma = \frac{M}{2S} \Rightarrow S = \frac{M}{2\sigma}
\]

\[
S = \frac{60 \times 10^3}{2(120 \times 10^6)} = \frac{250 \times 10^{-6}}{250} \text{ m}^3 = 250 \times 10^{-3} \text{ mm}^3
\]

From a design table:
Select C254 × 30 channel
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Example 2 (cont’d)

Select

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Loads

The objective of a structural engineer is to design a structure that will be able to withstand all the loads to which it is subjected while serving its intended purpose throughout its intended life span.
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Loads

- Types of Loads
  1. Dead loads
  2. Live loads
  3. Impact
  4. Wind loads
  5. Snow loads
  6. Earthquake loads
  7. Hydrostatic and soil pressure
  8. Thermal and other effects

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Decision Making in Engineering

- Best Decision
  - Full understanding of alternative solution procedures
    - Unbiased Solution
    - Highly precise
    - Cost effective
    - Have minimal environmental consequences
Decision Making in Engineering

- Typical Approach to an Engineering Solution
  - Identify the problem
  - State the objective
  - Develop alternative solutions
  - Evaluate the alternatives, and
  - Use the best alternative

Engineering Design

- Design of Engineering Systems
  - Design of engineering systems is usually a trade-off between maximizing safety and minimizing cost.
  - A design procedure that can accomplish both of these objectives is highly desirable, but also difficult.
Engineering Design

- Deterministic design procedures (i.e., ASD or WSD) do not provide adequate information to achieve the optimal use of the available resources to maximize safety and minimize cost.
- On the other hand, probabilistic-based design can provide the required information for optimum design.
- Probability, statistics, and reliability tools can help achieving the optimal design.

Need for Reliability Evaluation

- The presence of uncertainty in engineering design and analysis has always been recognized.
- Traditional approaches simplify the problem by considering the uncertain parameters to be deterministic.
- Traditional approaches account for the uncertainty through the use of empirical safety factor.
- This factor is based on past experience but does not absolutely guarantee safety or performance.
Probability-based Design and Analysis of Engineering Systems

- Reliability-Based Design (RBD)
  - RBD requires the consideration of:
    - Loads
    - Structural Strength
    - Methods of Reliability Analysis (i.e., FORM)
  - Two primary approaches for RBD:
    - Direct Reliability-based Design
    - Load and Resistance Factor Design (LRFD)

Probability-based Design Approach Versus Deterministic Approach

$$\frac{R_n}{FS} \geq \sum_{i=1}^{m} L_i$$  \hspace{1cm}  $$\phi R_n \geq \sum_{i=1}^{m} \gamma_i L_i$$

ASD  \hspace{1cm}  LRFD

- According to ASD, one factor of safety (FS) is used that accounts for the entire uncertainty in loads and strength.
- According to LRFD (probability-based), different partial safety factors for the different load and strength types are used.
**Probability-based Design and Analysis of Engineering Systems**

- **Load and Resistance Factor Design (LRFD)**
  - General Form

\[
\phi R_n \geq \sum_{i=1}^{m} \gamma_i L_{ni}
\]

Where

- \( \phi \) = strength reduction factor
- \( \gamma_i \) = load factor for the \( i \)th load component out of \( n \) components
- \( R_n \) = nominal or design strength (stress, moment, force, etc.)
- \( L_{ni} \) = nominal (or design) value for the \( i \)th load component out of \( m \) components

---

**Partial Safety Factors**

- Different building codes use different partial safety factors for both the strength and the load effects.

- For example the ACI building code uses the following dead and live load factors

\[
\phi R_n = U = 1.4D + 1.7L
\]

and the following strength factors:

- 0.90 for bending
- 0.85 for shear & torsion
- 0.7 bearing on concrete.
Probability-based Design and Analysis of Engineering Systems

- **Partial Safety Factors**
  - On the other hand, the AISC LRFD Manual of steel construction uses the following dead and live load factors:
    \[ \phi R_n = U = 1.2D + 1.6L \]
  - and the following strength factors:
    - 0.90 for bending
    - 0.85 for columns
    - 0.75 bolts in tension

Probability-based Design and Analysis of Engineering Systems

- **Calculation of Partial Safety Factors**
  \[ \phi R \geq \gamma_1 L_1 + \gamma_2 L_2 \]

Given Information

<table>
<thead>
<tr>
<th>( \frac{R}{R_n} )</th>
<th>COV (R)</th>
<th>Dist. (R)</th>
<th>COV (L₁)</th>
<th>Dist. (L₁)</th>
<th>COV (L₂)</th>
<th>Dist. (L₂)</th>
</tr>
</thead>
</table>

Selected Values

| β | \( \frac{L_2}{L_1} \) |

Output Values

| \( \frac{R}{L_1} \) | \( \phi \) | \( \gamma_1 \) | \( \gamma_2 \) |
Probability-based Design and Analysis of Engineering Systems

- LRFD Advantages
  - Provides a more rational approach for new designs and configurations.
  - Provides consistency in reliability.
  - Provides potentially a more economical use of materials.
  - Allows for future changes as a result of gained information in prediction models, and material and load characterization.
  - Code Calibration.

Several design codes have recently been revised to incorporate probabilistic design and analysis

- AISC LRFD (1994)
- ACI (318-02)
- AASHTO
- API
- ABS
- Other structural and marine codes
Probability-based Design and Analysis of Engineering Systems

LRFD-based Partial Safety Factors

Design Specifications and Building Codes

ASIC  American Institute of Steel Construction
ACI   American Concrete Institute
NFPA  National Forest Products Association
AASHTO American Association of State Highway Officials

For the purpose of this course, the following two codes will be used:

1. "Building Code Requirements for Structural Concrete (318-02) and Commentary (318-02),”
   ACI  American Concrete Institute

   ASIC American Institute of Steel Construction
Building Codes

- Building codes are usually revised, updated, and reissued periodically.
- The codes themselves have no legal status.
- They have been incorporated into the building codes of almost all states throughout the United States.
- However, when so incorporated, they have official sanctions, become legal documents, and considered part of the law controlling design and construction in a particular area.