Introduction

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Structural Design and Analysis, and Code Specifications

A. J. Clark School of Engineering •Department of Civil and Environmental Engineering

FALL 2002

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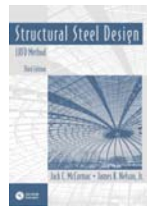

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ENCE 355 - Introduction to Structural Design

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Structural Design

"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

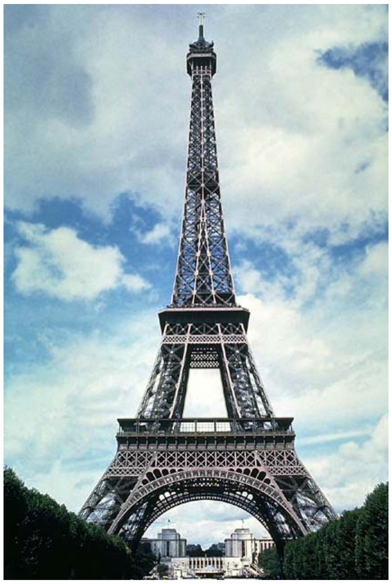
- Civil Engineering Structures
  - Among the structures that are design by civil engineers are
    - Buildings
    - Bridges
    - Transmission Towers
    - Dams
    - Highway Pavements
    - Aircraft Landing Runways (strips)
    - Retaining Walls

Engineering Systems

Eiffel Tower

Paris – 1899

984 ft. high



Engineering Systems

Sears Tower
Chicago - 1974
1450 ft.high

Engineering Systems

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

INTRODUCTION b. Structural Design & Analysis, & Code Specifications

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Engineering Systems

Engineering Systems

Hoover Dam

Arizona-Nevada Border
Near Las Vegas

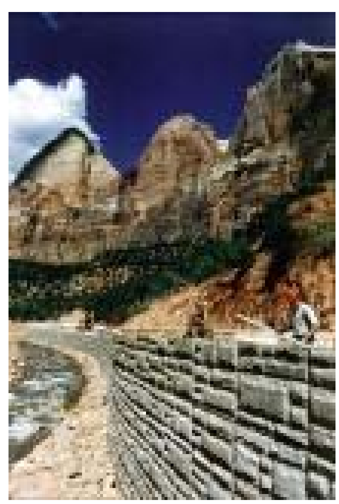
Engineering Systems

Transmission Towers

Engineering Systems

Highway & Aircraft Landing Strip

Engineering Systems



Retaining Walls

Engineering Systems

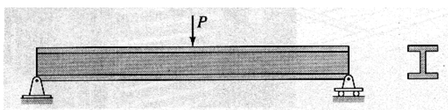
- The design of the previous groups of structures require the coordination of various disciplines in engineering, and is too large for convenient study as a unit.
- In this course, we will focus on the design of the individual structural elements or members that make up the whole structural system.

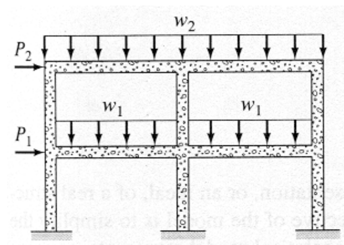
Engineering Systems

- Such members or elements include the following:
  - Beams
  - Columns
  - Trusses
  - Shear Structural Elements
  - Steel Rods
  - Connection Elements

Engineering Systems

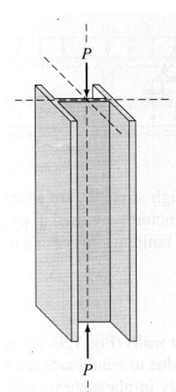
- Structural Elements
  - Bending Structures

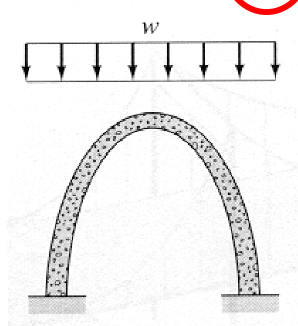




Engineering Systems

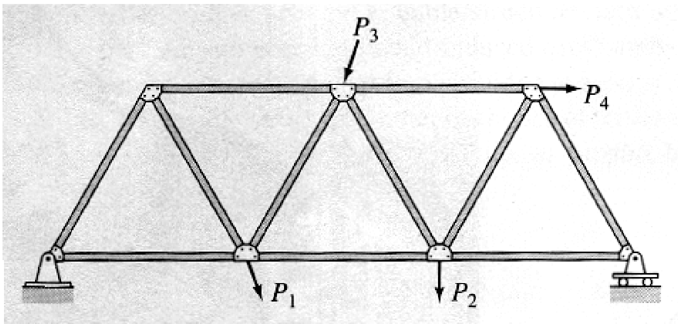
- Structural Elements
  - Compression Structures





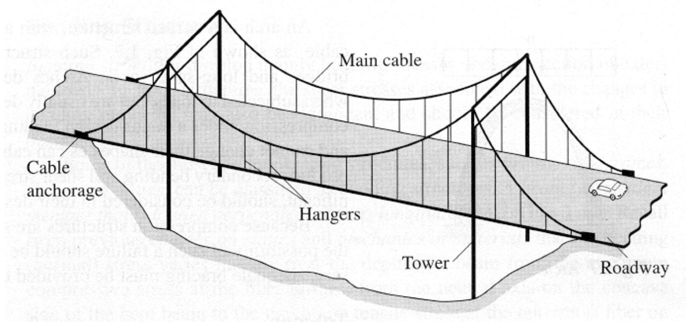
Engineering Systems

- Structural Elements
  - Trusses



Engineering Systems

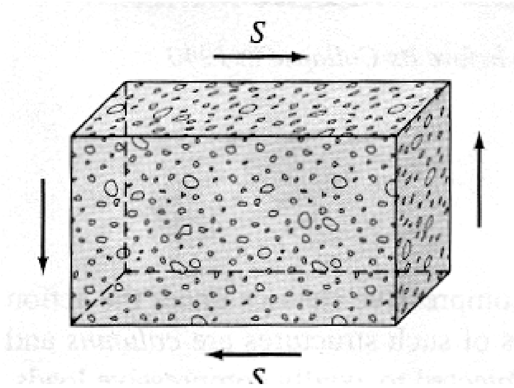
- Structural Elements
  - Tension Structures



Engineering Systems

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.

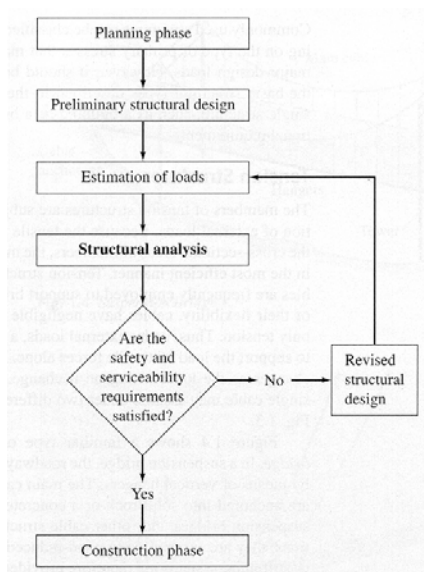
Analysis Versus Design

- 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.

Analysis Versus Design

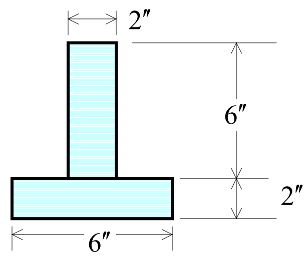
- Design Procedure
  - Design procedure consists of two parts:
    - Functional Design
    - Structural Framework Design
  - Functional design ensures that intended results are achieved such as adequate working area, elevators, stairways, etc.
  - Structural framework design is the selection of the arrangement and sizes of structural elements so that service loads may be carried.

Analysis Versus Design



Analysis Versus Design

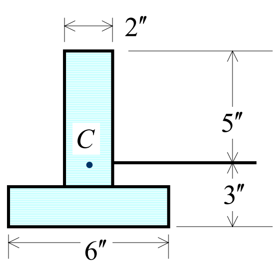
- Example 1: Analysis
  - Determine the maximum flexural stress produced by a resisting moment M_r of +5000 ft·lb if the beam has the cross section shown in the figure.



Analysis Versus Design

- Example 1: Analysis (cont'd)

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



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

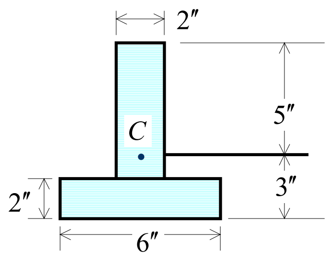
$$y_{\text{ten}} = 3'' \quad y_{\text{com}} = 6+2-3 = 5'' = y_{\max}$$

$$\text{Max. Stress} = \frac{M_r y_{\max}}{I_x}$$

Analysis Versus Design

- Example 1: Analysis (cont'd)

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

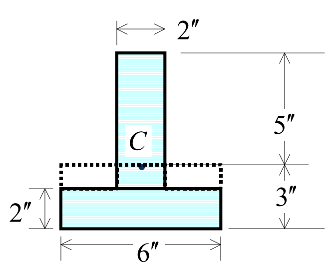


$$I_x = \frac{6(2)^3}{12} + (6\times 2)(2)^2 + \frac{2(6)^3}{12} + (2\times 6)(3-1)^2$$
$$= 4 + 48 + 36 + 48 = 136\ \text{in}^4$$

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

Analysis Versus Design

- 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:



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

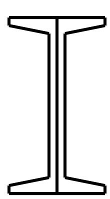
Analysis Versus Design

- 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.

Analysis Versus Design

- Example 2: Design (cont'd)



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

$$\sigma = \frac{M}{2S} \Rightarrow S = \frac{M}{2\sigma}$$

$$S = \frac{60 \times 10^3}{2\left(120 \times 10^6\right)} = 250 \times 10^{-6}\,\text{m}^3 = 250 \times 10^3\,\text{mm}^3$$

From a design table:

Select C254 × 30 channel

Example 2 (cont'd)

Select

TABLE B-6 Standard Channels (SI Units)

Designation*	Area (mm^2)	Depth (mm)	FLANGE Width (mm)	FLANGE Thickness (mm)	Web Thickness (mm)	AXIS X–X I (10^6 mm^4)	AXIS X–X S (10^3 mm^3)	AXIS X–X r (mm)	AXIS Y–Y I (10^6 mm^4)	AXIS Y–Y S (10^3 mm^3)	AXIS Y–Y r (mm)	x_C (mm)
C457 × 86	11030	457.2	106.7	15.9	17.8	281	1230	160	7.41	87.2	25.9	21.9
× 77	9870	457.2	104.1	15.9	15.2	261	1140	163	6.83	83.1	26.4	21.8
× 68	8710	457.2	101.6	15.9	12.7	241	1055	167	6.29	79.0	26.9	22.0
× 64	8130	457.2	100.3	15.9	11.4	231	1010	169	5.99	76.9	27.2	22.3
C381 × 74	9465	381.0	94.4	16.5	18.2	168	882	133	4.58	61.9	22.0	20.3
× 60	7615	381.0	89.4	16.5	13.2	145	762	138	3.84	55.2	22.5	19.7
× 50	6425	381.0	86.4	16.5	10.2	131	688	143	3.38	51.0	23.0	20.0
C305 × 45	5690	304.8	80.5	12.7	13.0	67.4	442	109	2.14	33.8	19.4	17.1
× 37	4740	304.8	77.4	12.7	9.8	59.9	395	113	1.86	30.8	19.8	17.1
× 31	3930	304.8	74.7	12.7	7.2	53.7	352	117	1.61	28.3	20.3	17.7
C254 × 45	5690	254.0	77.0	11.1	17.1	42.9	339	86.9	1.64	27.0	17.0	16.5
× 37	4740	254.0	73.3	11.1	13.4	38.0	298	89.4	1.40	24.3	17.2	15.7
× 30	3795	254.0	69.6	11.1	9.6	32.8	259	93.0	1.17	21.6	17.6	15.4
× 23	2895	254.0	66.0	11.1	6.1	28.1	221	98.3	0.949	19.0	18.1	16.1
C229 × 30	3795	228.6	67.3	10.5	11.4	25.3	221	81.8	1.01	19.2	16.3	14.8
× 22	2845	228.6	63.1	10.5	7.2	21.2	185	86.4	0.803	16.6	16.8	14.9
× 20	2540	228.6	61.8	10.5	5.9	19.9	174	88.4	0.733	15.7	17.0	15.3
C203 × 28	3555	203.2	64.2	9.9	12.4	18.3	180	71.6	0.824	16.6	15.2	14.4
× 20	2605	203.2	59.5	9.9	7.7	15.0	148	75.9	0.637	14.0	15.6	14.0
× 17	2180	203.2	57.4	9.9	5.6	13.6	133	79.0	0.549	12.8	15.9	14.5
C178 × 22	2795	177.8	58.4	9.3	10.6	11.3	127	63.8	0.574	12.8	14.3	13.5
× 18	2320	177.8	55.7	9.3	8.0	10.1	114	66.0	0.487	11.5	14.5	13.3
× 15	1850	177.8	53.1	9.3	5.3	8.87	99.6	69.1	0.403	10.2	14.8	13.7
C152 × 19	2470	152.4	54.8	8.7	11.1	7.24	95.0	54.1	0.437	10.5	13.3	13.1
× 16	1995	152.4	51.7	8.7	8.0	6.33	82.9	56.4	0.360	9.24	13.4	12.7
× 12	1550	152.4	48.8	8.7	5.1	5.45	71.8	59.4	0.288	8.06	13.6	13.0
C127 × 13	1705	127.0	47.9	8.1	8.3	3.70	58.3	46.5	0.263	7.37	12.4	12.1
× 10	1270	127.0	44.5	8.1	4.8	3.12	49.2	49.5	0.199	6.19	12.5	12.3
C102 × 11	1375	101.6	43.7	7.5	8.2	1.91	37.5	37.3	0.180	5.62	11.4	11.7
× 8	1025	101.6	40.2	7.5	4.7	1.60	31.6	39.6	0.133	4.64	11.4	11.6
C76 × 9	1135	76.2	40.5	6.9	9.0	0.862	22.6	27.4	0.127	4.39	10.6	11.6
× 7	948	76.2	38.0	6.9	6.6	0.770	20.3	28.4	0.103	3.82	10.4	11.1
× 6	781	76.2	35.8	6.9	4.6	0.691	18.0	29.7	0.082	3.31	10.3	11.1

*C means channel, followed by the nominal depth in mm, then the mass in kg per meter of length.

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.

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

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 objective 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.

Probability-based Design and Analysis of Engineering Systems

- 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 and Analysis of Engineering Systems

- Probability Based-design Approach Versus Deterministic Approach

$$\frac{R_n}{\text{FS}} \geq \sum_{i=1}^{m} L_i$$

ASD

$$\phi R_n \geq \sum_{i=1}^{m} \gamma_i L_i$$

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
ϕ = strength reduction factor
γ_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

Probability-based Design and Analysis of Engineering Systems

- 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:

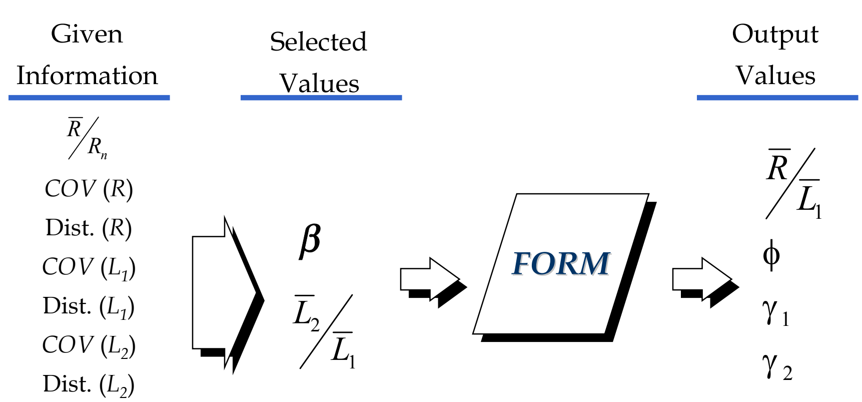
0.90 for bending   0.85 for columns

0.75 bolts in tension

Probability-based Design and Analysis of Engineering Systems

- Calculation of Partial Safety Factors

$$\phi R \geq \gamma_1 L_1 + \gamma_2 L_2$$



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.

Probability-based Design and Analysis of Engineering Systems

- 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*

Probability-based Design and Analysis of Engineering Systems

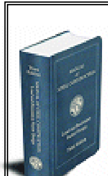
For the purpose of this course, the following two codes will be used:

1

"Building Code Requirements for Structural Concrete (318-02) and Commentary (318-02),"

ACI *American Concrete Institute*

2



"LRFD Manual of Steel Construction," 3rd Edition

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.