CHAPTER

Structural Steel Design
LRFD Method

Third Edition

SPECIFICATIONS, LOADS, AND METHODS OF DESIGN

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Part II – Structural Steel Design and Analysis

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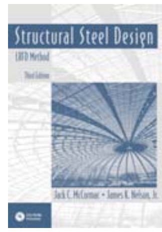

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ENCE 355 - Introduction to Structural Design

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Specifications and Building Codes

- The design of structural steel in the United States is controlled and governed by building codes.
- These codes provide general guidelines of the minimum requirements for the design of a structural component or a system.
- These codes, which are actually laws or ordinances, specify minimum:

Specifications and Building Codes

- Design loads
- Design stresses
- Construction types
- Material quality
- Other factors.

■ Some of these codes are written specifically for certain areas and disciplines of an engineering practice.

Specifications and Building Codes

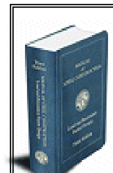
■ Examples:
- The design of steel bridges is generally in accordance with specifications of the **A**merican **A**ssociation of **S**tate **H**ighway and **T**ransportation **O**fficials (**AASHTO**).
- Railroad bridges are designed in accordance with specifications provided by the **A**merican **R**ailway **E**ngineering **A**ssociation (**AREA**).

Specifications and Building Codes

- The design or analysis of offshore structures is usually governed by the specifications adopted by the **A**merican **P**etroleum **I**nstitute (**API**).
- Commercial ship design is generally controlled by the specifications furnished by the **A**merican **B**ureau of **S**hipping (**ABS**).
- Reinforced concrete structures are generally designed according to the **A**merican **C**oncrete **I**nstitute (**ACI**).

Specifications and Building Codes

- Structural Steel Design
  - Structural steel design of buildings in the United States is principally based on the specifications of the **A**merican **I**nstitute of **S**teel **C**onstruction (**AISC**).



"LRFD Manual of Steel Construction," 3rd Edition

ASIC American Institute of Steel Construction

Specifications and Building Codes

- Structural Steel Design
  - The AISC is comprised of steel fabricator and manufacturing companies, as well as individuals interested in steel design and research.
  - The AISC Specifications are the result of the combined judgment of researchers and practicing engineers.
  - The research efforts have been synthesized into practical design procedures to provide a safe, economical structure.

Specifications and Building Codes

- Building Codes
  - The term *building code* is sometimes used synonymously with specifications.
  - More correctly, a building code is a broadly based document, either a legal document such as a state or local building code, or a document widely recognized even though not legal which covers the same wide range of topics as the state or local building code.

Specifications and Building Codes

- Building Codes
  - Building codes generally treat all issues relating to
    - Safety
    - Architectural details
    - Fire protection
    - Heating and air conditioning
    - Plumbing and sanitation, and
    - Lighting
  - Building codes also prescribe standard loads for which the structure is to be designed.

Specifications and Building Codes

The important thing to remember about specifications and building codes is that they are written, not for the purpose of restricting engineers, but for the purpose of protecting the public. No matter which building code or specification is or is not being used, the ultimate responsibility for the design of safe structure lies with the structural design engineer.

Dead, Live, and Environmental Loads

- Loads
  - The accurate determination of the loads to which a structure or structural element will be subjected is not always predictable.
  - Even if the loads are well known at one location in a structure, the distribution of load from element to element throughout the structure usually requires assumptions and approximations.

Dead, Live, and Environmental Loads

- 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 can be classified into three broad categories: (1) Dead Loads, (2) Live Loads, and (3) Environmental Loads.

Dead, Live, and Environmental Loads

- Types of Loads
  - Dead Loads
  - Live Loads
  - Environmental Loads
    - Impact
    - Rain loads
    - Wind loads
    - Snow loads
    - Earthquake loads
    - Hydrostatic and soil pressure
    - Thermal and other effects

Dead, Live, and Environmental Loads

- Dead Loads
  - Dead load is a fixed position gravity service load.
  - It is called dead load because it acts continuously toward the earth when the structure is in service.
  - The weight of the structure is considered dead load, as well as attachments to structure such as pipes, electrical conduit, air-conditioning and heating ducts, lighting fixtures, and roof and floor covering, etc.

Dead, Live, and Environmental Loads

- Dead Loads (cont'd)
  - Dead loads are usually known accurately but not until the design has been completed.
  - Reasonable estimates of structure weights may be obtained by referring to similar types of structures or to various formulas and tables.
  - Approximate weights of some common building materials for roofs, walls, floors, and so on are provided in Table 1.

Dead, Live, and Environmental Loads

Table 1. Typical Dead Loads for Some Common Building Materials

Reinforced concrete	150 lb/ft^3
Structural steel	490 lb/ft^3
Movable steel partitions	4 psf
Plaster and concrete	5 psf
Suspended ceilings	2 psf
3-ply ready roofing	1 psf
Hardwood flooring (7/8 in.)	4 psf
2 ´ 12 ´ 16 in. double wood floors	7 psf
Wood studs with ½ in gypsum	8 psf
Clay brick wythes (4 in.)	39 psf

Dead, Live, and Environmental Loads

- Live Loads
  - Gravity loads acting when the structure is in service, but varying in magnitude and location, are termed *live loads*.
  - Example of live loads are
    - Human occupants
    - Furniture
    - Movable equipment
    - Vehicles
    - Stored goods

Dead, Live, and Environmental Loads

- Live Loads (cont'd)
  - A great deal of information on the magnitudes of these various loads, along with specified minimum values, are presented in ASCE 7-98:
    - Floor loads:
      - Typical values for floor loading are listed in Table 2
    - Traffic loads:
      - Bridges are subjected to series of concentrated loads of varying magnitude caused by groups of truck or train wheels.

Dead, Live, and Environmental Loads

Table 2. Typical Minimum Uniform Live Loads for Design of Building

Type of Building		LL (psf)
Apartment houses	Apartments	40
	Public rooms	100
Dining rooms and restaurants		100
Garages (passenger cars only)		50
Gymnasiums, main floors, and balconies		100
Office buildings	Lobbies	100
	Offices	50
Schools	Classrooms	40
	Corridors first floor	100
	Corridors above first flo	80
Storage warehouses	Light	125
	Heavy	250
Stores (retail)	First floor	100
	Other floors	75

Dead, Live, and Environmental Loads

Table 3. Typical Concentrated Live Loads for Buildings

Hospitals - operating rooms, private rooms, and wards	1000 lb
Manufacturing building (light)	2000 lb
Manufacturing building (heavy)	3000 lb
Office floors	2000 lb
Retail stores (first floors)	1000 lb
Retail stores (upper floors)	1000 lb
School classrooms	1000 lb
School corridors	1000 lb

Dead, Live, and Environmental Loads

- Impact loads:
  - Impact loads are caused by the vibration of moving or movable loads. The ASCE Specification requires that when structures are supporting live loads that tend to cause impact, it is necessary for those loads to be increased by the percentages given in Table 4.
- Longitudinal loads
  - Longitudinal loads are another type of load that needs to be considered in designing some structures. Stopping a train on a railroad bridge or a truck on a highway bridge causes longitudinal forces to be applied. Imagine the tremendous longitudinal force developed when the driver of a 40-ton truck traveling at 60 mph has to stop suddenly.

Dead, Live, and Environmental Loads

- Table 4. Live Load Impact Factors

Elevator machinery	100%
Motor driven machinery	20%
Reciprocating machinery	50%
Hangers for floors or balconies	33%

Dead, Live, and Environmental Loads

- Environmental Loads
  - Snow loads
    - On inch of snow load is equivalent to a load of approximately 0.5 psf.
    - For roof design, snow loads vary from 10 to 40 psf.
  - Rain loads
    - Although snow load are a more severe problem than rain loads for the usual roof. The situation can be reversed for flat roofs with poor drainage systems.

Dead, Live, and Environmental Loads

- Environmental Loads (cont'd)
  - Wind loads
    - Wind loads can be severe. Numerous structural failures by wind were reported. Perhaps the most infamous of these are the failure of

      Tay Bridge in Scotland in 1979, which caused the deaths of 75 people,

      Tacoma Narrow Bridge in Tacoma, Washington, in 1940,

      Union Carbide Building in Toronto in 1958.

Dead, Live, and Environmental Loads

- Wind loads (cont'd)
  - In accordance with Bernoulli's theorem for ideal fluid striking an object, the increase in static pressure equals the decrease in dynamic pressure, or

$$q = \frac{1}{2}\rho V^2 \qquad (1)$$

  - Where q is the dynamic pressure on the object, ρ is the mass density of air (specific weight w = 0.07651 pcf at sea level and 15^0 C), and V is the wind velocity.

Dead, Live, and Environmental Loads

- Wind loads (cont'd)
  - In terms of velocity V in miles per hour, the dynamic pressure q (psf) would be given by

$$q = \frac{1}{2}\rho V^2 = \frac{1}{2}\left(\frac{0.07651}{32.2}\right)\left(\frac{5280}{2600}\right) = 0.0026V^2 \qquad (2)$$

  - In design of usual types of buildings, the dynamic pressure q is commonly converted into equivalent static pressure p, which may be expressed as

$$p = qC_eC_gC_p \qquad (3)$$

Dead, Live, and Environmental Loads

Where

C_e = exposure factor that varies from 1.0 (for 0-40-ft height) to 2.0 (for 740-1200-ft height).

C_g = gust factor, such as 2.0 for structural members and 2.5 for small elements including cladding.

C_p = shape factor for the building as a whole.

- The commonly used wind pressure of 20 psf, as specified by many building codes, correspond to a velocity of 88 mph from Eq. 2.

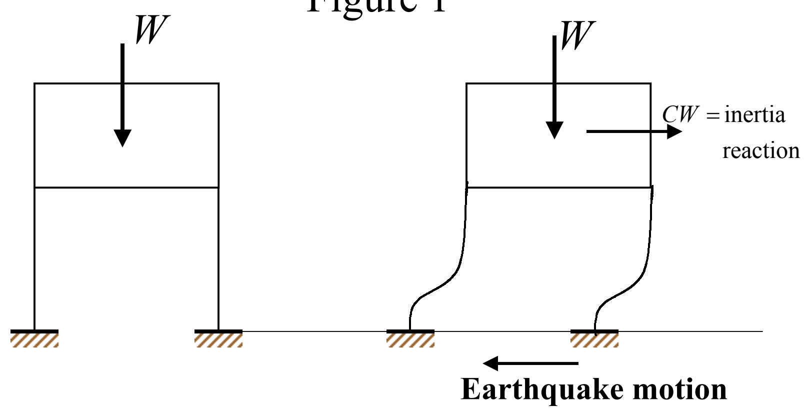
Dead, Live, and Environmental Loads

– Earthquake Loads
  - An earthquake consists of horizontal and vertical ground motions, with the vertical motion usually having much smaller magnitude.
  - Since the horizontal motion of the ground causes the most significant effect, it is that effect which usually thought of as earthquake load.
  - When the ground under a structure having a certain mass suddenly moves, the inertia of the mass tends to resist the movement (Fig. 1)

Dead, Live, and Environmental Loads

– Earthquake Loads (cont'd)

Figure 1



(a) At rest

(b) Under horizontal motion from earthquake

Dead, Live, and Environmental Loads

– Earthquake Loads (cont'd)
- In order to simplify the design process, most building codes contain an equivalent lateral force procedure for designing to resist earthquake.
- One of the most widely used design recommendations is that of the Structural Engineers Association of California (SEAOC).
- Some recent rules for equivalent lateral force procedure are those given by the ANSI Standard.

Dead, Live, and Environmental Loads

– Earthquake Loads (cont'd)

- In the ANSI, the lateral seismic forces *V*, expressed as follows, are assumed to act non-concurrently in the direction of each of the main axes of the structure:

$$V = ZIKCSW \tag{4}$$

Z = seismic zone coefficient (varies from 1/8 to 1).
I = occupancy important factor (varies from 1.5 to 1.25).
K = horizontal force factor (varies from 0.67 to 2.5).
T = fundamental natural period.
S = soil profile coefficient (varies from 1.0 to 1.5).
W = total dead load of the building.

$$C = \frac{1}{15\sqrt{T}} \leq 0.12$$

Dead, Live, and Environmental Loads

– Earthquake Loads (cont'd)

- When the natural period *T* cannot be determined by rational means from technical data, it may be obtained as follows for shear walls or exterior concrete frames using deep beams or wide piers, or both:

$$T = \frac{0.05 h_n}{\sqrt{D}} \tag{5}$$

D = dimension of the structure in the direction of the applied forces, in feet.
h_n = height of the building

Load and Resistance Factor Design (LRFD)

- The load and resistance factor design (LRFD) is a probability-based design approach.
- It has been adopted in most modern structural codes.
- The LRFD is based on a limit states philosophy, i.e., a state at which a structure ceases to perform its intended function.

Load and Resistance Factor Design (LRFD)

- 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.

Load and Resistance Factor Design (LRFD)

- 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)

Load and Resistance Factor Design (LRFD)

- Probability Based-design Approach Versus Deterministic Approach

$$\frac{R_n}{\mathrm{FS}} \geq \sum_{i=1}^{m} L_i \qquad \phi R_n \geq \sum_{i=1}^{m} \gamma_i L_i \qquad (6)$$

ASD 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.

Load and Resistance Factor Design (LRFD)

- The General From of LRFD:

$$\phi R_n \geq \sum_{i=1}^{m} \gamma_i L_{ni} \qquad (7)$$

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

Load and Resistance Factor Design (LRFD)

- Special Form for Specific Strength (moment) and Load Effects (dead and Live load):

$$\phi M_R \geq \gamma_D M_D + \gamma_L M_L$$

or

$$0.90 M_R \geq 1.2 M_D + 1.6 M_L \qquad (8)$$