CHAPTER

2b

Prentice Hall

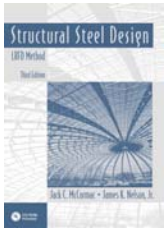
Prentice Hall Structural Steel Design
LRFD Method

Third Edition

SPECIFICATIONS, LOADS, AND METHODS OF DESIGN

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

Part II – Structural Steel Design and Analysis



FALL 2002

By
Dr. Ibrahim. Assakkaf

ENCE 355 - Introduction to Structural Design

Department of Civil and Environmental Engineering
University of Maryland, College Park

Load Factors

- The load factors are usually amplifying factors that are used in LRFD design equation to increase the loads.
- The purpose of increasing the loads is to account for the uncertainties involved in estimating the magnitudes of dead and/or live loads.

How close (%) could you estimate the worst wind or snow load that will ever be applied to a particular building?

Load Factors

- Since the dead loads can be estimated more accurately than live loads, the factor for live load is usually higher than that used for dead loads.
- Examples:
  - A load factor of 1.6 for live loads in LRFD steel manual as compared to 1.2 for dead loads.
  - A load factor of 1.7 for live loads in ACI Code as compared to 1.4 for dead loads.

Load Factors

- Loads and Load Combinations

$$1.4\,(D + F) \quad (1)$$

$$1.2\,(D + F + T) + 1.6\,(L + H) + 0.5\,(L_r \text{ or } S \text{ or } R) \quad (2)$$

$$1.2\,D + 1.6\,(L_r \text{ or } S \text{ or } R) + (0.5\,L \text{ or } 0.8\,W) \quad (3)$$

$$1.2\,D + 1.6\,W + 0.5\,L + 0.5\,(L_r \text{ or } S \text{ or } R) \quad (4)$$

$$1.2\,D + 1.0\,E + 0.5\,L + 0.2\,S \quad (5)$$

$$0.9\,D + 1.6\,W + 1.6\,H \quad (6)$$

$$0.9\,D + 1.0\,E + 1.6\,H \quad (7)$$

Load Factors

- Notations

  U = the design (ultimate) load
  D = dead load
  F = fluid load
  T = self straining force
  L = live load
  L_r = roof live load
  H = lateral earth pressure load, ground water pressure.
  S = snow load
  R = rain load
  W = wind load
  E = earthquake load

Load Factors

- Example 1

  A floor system has W24 × 55 section spaced 8 ft on-center supporting a floor dead load of 50 psf and a live load of 80 psf. Determine the governing load in lb/ft which each beam must support.

For one foot of length of the beam,

$$\text{area} = 8 \times 1 = 8 \text{ in}^2$$

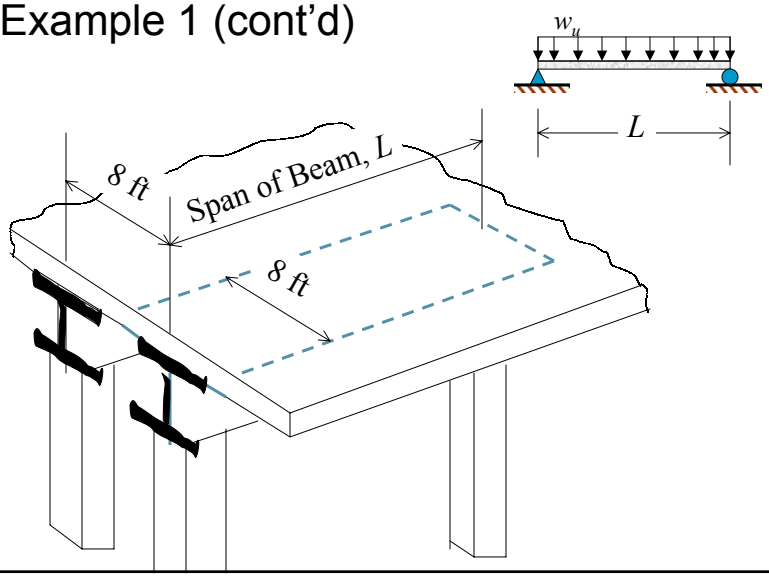
Therefore,

$$D = 55 + 8(50) = 455 \text{ lb/ft}$$

$$L = 8(80) = 640 \text{ lb/ft}$$

Load Factors

■ Example 1 (cont'd)



Load Factors

■ Example 1 (cont'd)

Computing factored loads and noting that *D* and *L* are the only loads to be supported, therefore using Eqs. 1 to 7 result in:

1. $U = 1.4(D+F) = 1.4(455+0) = 637 \text{ lb/ft}$
2. $U = 1.2(D+F+T)+1.6(L+H)+0.5(L_r \text{ or } S \text{ or } R)$
   $= 1.2(455+0+0)+1.6(640+0)+0.5(0 \text{ or } 0 \text{ or } 0)$
   $= 1570 \text{ lb/ft}$ ← Controls (largest)
3. $U = 1.2D+1.6(L_r \text{ or } S \text{ or } R)+(0.5L \text{ or } 0.8W)$
   $= 1.2(455)+1.6(0)+0.5(640) = 866 \text{ lb/ft}$

Load Factors

- Example 1 (cont'd)

4. $U = 1.2D + 1.6W + 0.5L + 0.5(L_r \text{ or } S \text{ or } R)$
$= 1.2(455) + 1.6(0) + 0.5(640) + 0.5(0) = 866 \text{ lb/ft}$

5. $U = 1.2D + 1.0E + 0.5L + 0.2S$
$= 1.2(455) + 1.0(0) + 0.5(640) + 0.2(0) = 866 \text{ lb/ft}$

6. $U = 0.9D + 1.6W + 1.6H = 0.9(455) + 1.6(0) + 1.6(0) = 409.5 \text{ lb/ft}$

7. $U = 0.9D + 1.0E + 1.6H = 0.9(455) + 1.0(0) + 1.6(0) = 409 \text{ lb/ft}$

Load Factors

- Example 2

The various axial loads for a building column have been computed according to the applicable building code with the following results: dead load = 200 k, load from roof = 50 k (roof live load), live load from floor = 250 k, compression wind = 80 k, tensile wind 65 k, compression earthquake = 60 k, and tensile earthquake = 70 k.

Determine the critical design load using the combinations provided by Eqs. 1 to 7.

Load Factors

■ Example 2 (cont'd)

1. $U = 1.4(D + F) = 1.4(200 + 0) = 280\text{ k}$
2. $U = 1.2(D + F + T) + 1.6(L + H) + 0.5(L_r \text{ or } S \text{ or } R)$
   $= 1.2(200 + 0 + 0) + 1.6(250 + 0) + 0.5(50)$
   $= 665\text{ k}$ ← Controls (largest)
3. $U = 1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (0.5L \text{ or } 0.8W)$
   a. $U = 1.2(200) + 1.6(50) + 0.5(250) = 445\text{ k}$
   b. $U = 1.2(200) + 1.6(50) + 0.8(80) = 384\text{ k}$
   c. $U = 1.2(200) + 1.6(50) + 0.8(-65) = 268\text{ k}$

Load Factors

■ Example 2 (cont'd)

4. $U = 1.2D + 1.6W + 0.5L + 0.5(L_r \text{ or } S \text{ or } R)$
   a. $U = 1.2(455) + 1.6(80) + 0.5(250) + 0.5(50) = 518\text{ k}$
   b. $U = 1.2(455) + 1.6(-65) + 0.5(250) + 0.5(50) = 286\text{ k}$
5. $U = 1.2D + 1.0E + 0.5L + 0.2S$
   a. $U = 1.2(200) + 1.0(60) + 0.5(250) + 0.2(0) = 425\text{ k}$
   b. $U = 1.2(200) + 1.0(-70) + 0.5(250) + 0.2(0) = 295\text{ k}$
6. $U = 0.9D + 1.6W + 1.6H$
   a. $U = 0.9(200) + 1.6(80) + 1.6(0) = 308\text{ k}$
   b. $U = 0.9(200) + 1.6(-65) + 1.6(0) = 76\text{ k}$
7. $U = 0.9D + 1.0E + 1.6H$
   a. $U = 0.9(200) + 1.0(60) + 1.6(0) = 240\text{ k}$
   b. $U = 0.9(200) + 1.0(-70) + 1.6(0) = 110\text{ k}$

Strength (or Resistance) Factors

- Strength factors are usually reduction factors that applied to the strength (stress, force, moment) of the member to account for the uncertainties in material strengths, dimensions, and workmanship.
- With a resistance factor, the designer attempts to account for imperfection in analysis theory, variation in material properties, and imperfect dimensions.

Strength (or Resistance) Factors

- This can be accomplished by multiplying the theoretical ultimate strength (also called nominal strength) of each member by a capacity reduction factor ϕ, which generally less than one.
- These values are 0.85 for columns, 0.75 or 0.90 for tension members, 0.90 for bending or shear in beams, and so on.
- Typical reduction factors are provided in Table 1 (Table 2.2, Text).

Strength (or Resistance) Factors

Table 1. Typical Resistance (Strength) Factors

Type of Loading	ϕ
Bearing on the projected areas of pins, web yielding under concentrated loads, slip-resistant bolt shear values	1.00
Beams on bending and shear, fillet welds with stress parallel to weld axis, groove welds base metal	0.90
Columns, web crippling, edge distance, and bearing capacity at holes	0.85
Shear on effective area of full-penetration groove welds, tension normal to the effective area of partial-penetration groove welds.	0.80
Bolts in tension, plug, or slot welds, fracture in the net section of tension members	0.75
Bearing on bolts (other than A307)	0.65
Bearing on concrete foundations	0.60

Reliability and the LRFD Specification

- Reliability
  - The reliability of an engineering system can be defined as the system's ability to fulfill its design functions for a specified period of time.
  - In the context of this course, it refers to the estimated percentage of times that the strength of a member will equal or exceed the maximum loading applied to that member during its estimated life (say 25 years).

Reliability and the LRFD Specification

- Reliability
  - Motivation
    - Assume that a designer states that his or her designs are 99.6 percent reliable (this is usually the case obtained with most LRFD design).
    - If we consider the designs of 1000 structures, this does not mean that 4 of the 1000 structures will fall flat on the ground, but rather it means that those structures at some time will be loaded into the plastic range and perhaps the strain hardening range. So excessive deformation and slight damage might occur, but a complete failure.

Reliability and the LRFD Specification

- LRFD Specification
  - In the previous example, it would be desirable to have 100%-reliability.
  - However, this is an impossible goal statistically. There will always be a chance of failure (unreliability), say 2 or 3 %.
  - The goal of the LRFD Specification was to keep this to very small and consistent percentage.

Reliability and the LRFD Specification

- LRFD Specification
  - To do this, the resistance or strength R of each member of steel structure as well as the maximum loading Q, expected during the life of the structure, are computed.
  - A structure then is s said to be safe if

$$R \geq Q \qquad (1)$$

Reliability and the LRFD Specification

- LRFD Specification
  - General Form

$$\phi R_n \geq \sum_{i=1}^{m} \gamma_i L_{ni} \qquad (2)$$

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

Reliability and the LRFD Specification

- 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.

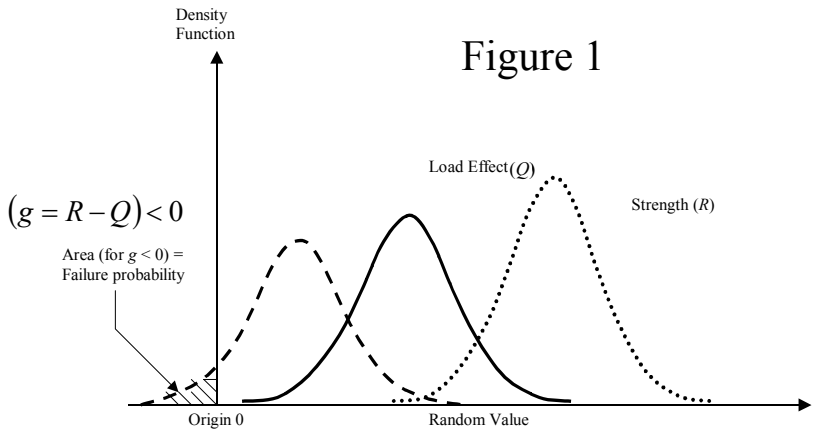
Reliability and the LRFD Specification

- LRFD Specification
  - The actual values of R and Q are random variables and it is therefore impossible to say with 100% certainty that R is always equal or greater than Q for a particular structure.
  - No matter how carefully a structure is designed, there will be always some chance that Q exceeds R as shown in Figure 1.

Reliability and the LRFD Specification

- LRFD Specification

Figure 1



Reliability and the LRFD Specification

- LRFD Specification
  - Reliability Index β
    - A measure of reliability can be defined by introducing a parameter β, called the reliability index.

      β can be computed using structural reliability theory and knowledge of the first and second moment statistical characteristics (i.e., mean and *COV*) for both the strength and load variables.

Reliability and the LRFD Specification

- LRFD Specification
  - Reliability Index β (cont'd)
    - For two variables and linear performance function, the reliability index b can be defined as the shortest distance from the origin to the failure line as shown in Fig. 2. Mathematically, it can be expressed as

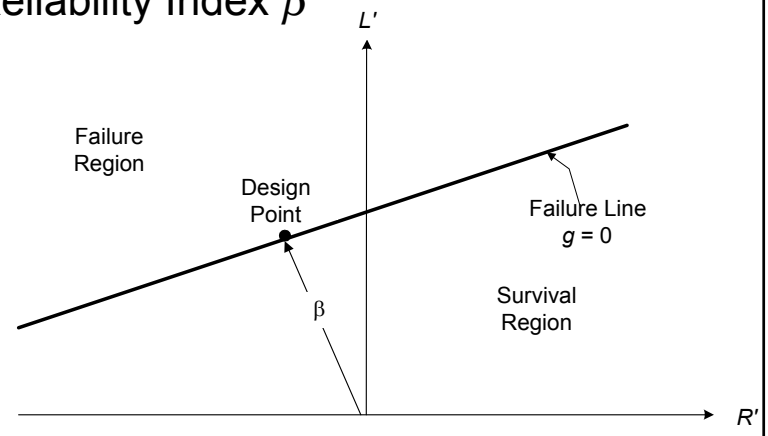
$$\beta = \frac{\mu_R - \mu_Q}{\sqrt{\sigma_R^2 - \sigma_Q^2}} \qquad (2)$$

μ = mean value of strength or load variable
σ = standard deviation of strength or load variable

Reliability and the LRFD Specification

Figure 2

- Reliability Index β



The reliability index β is the shortest distance from the origin to the failure surface.

Reliability and the LRFD Specification

- LRFD Specification
  - Reliability Index β (cont'd)
    - The important relationship between the reliability index β and the probability of failure P_f is given by

$$P_f = 1 - \Phi(\beta) \qquad (3)$$

where $\Phi(.)$ = cumulative probability distribution function of the standard normal distribution.

Reliability and the LRFD Specification

Target Reliability Indices or Levels (AISC)

Structural Type	Target Reliability Level (β_0)
Metal structures for buildings (dead, live, and snow loads)	3
Metal structures for buildings (dead, live, and wind loads)	2.5
Metal structures for buildings (dead, live, and snow, and earthquake loads)	1.75
Metal connections for buildings (dead, live, and snow loads)	4 to 4.5
Reinforced concrete for buildings (dead, live, and snow loads)	
ductile failure	3
brittle failure	3.5

Advantages of LRFD

- 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
  - Easier and consistent for code calibration.

Computer Example

- The computer program INSTEP32 design software can be used to perform the necessary calculations for load combinations provided by Eqs. 1 through 7.
- This program can also assist you in solving many of the problems presented in the textbook.

Computer Example

- Installation of INSTEP32
  1. Insert the CD-ROM in your computer.
  2. In Windows Explorer, open the INSTEP32 directory on the CD-ROM.
  3. Double-click on Setup.
  4. The Setup program will guide you through the installation process.

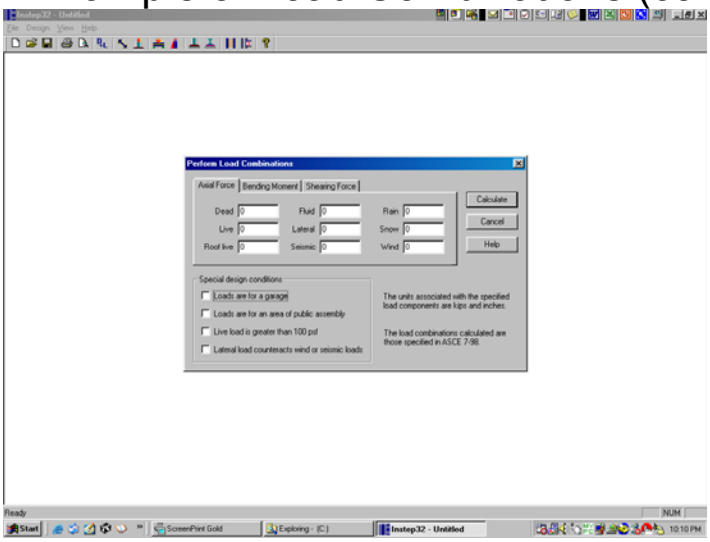
  INSTEP32 can be started by clicking the INSTEP32 icon on the Start Menu on the desktop.

Computer Example

- Example 3: Load Combinations
  - To perform the calculations for load combinations, start INSTEP32 and then select Design– Load Combinations from the menu bar.
  - After you have done this, that data entry dialogue shown in the following slides will appear.

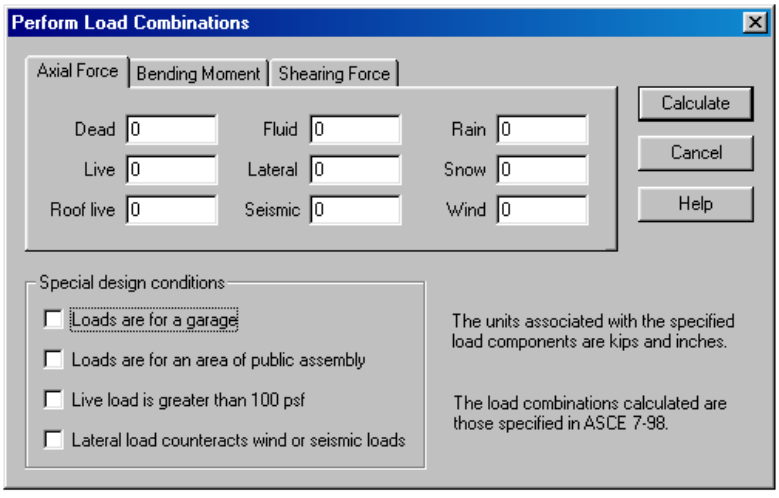
Computer Example

- Example 3: Load Combinations (cont'd)



Computer Example

- Example 3: Load Combinations



Computer Example

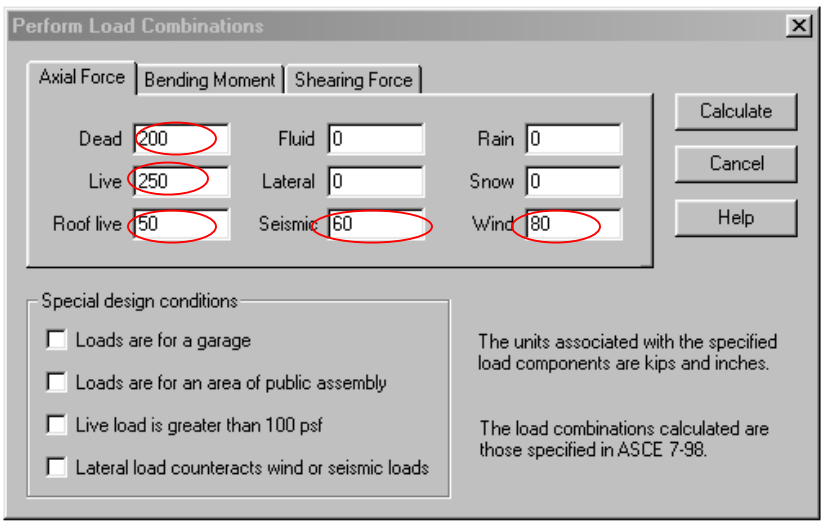
- Example 3: Load Combinations

  Using the computer program INSTEP32, compute the governing factored loads for each of the following: D = 200 k, L_r = 50 k, L = 250 k, W = 80 k, and E = 60 k.

The input and output of the program is shown in the next slides. Therefore, the critical factored load for design is 665 k.

Computer Example

- Example 3: Load Combinations



Computer Example

■ Example 3: Load Combinations (cont'd)

Instep32--Structural Steel Design with AISC LRFD Procedures
Clemson University Department of Civil Engineering

Client:	Designed by:
Project:	Checked by:
Topic:	Date:

Computed LRFD Load Combinations (ASCE 7-98)

Specified Load Components

	Axial	Bending	Shear
Dead Load D	200.000000	0.000000	0.000000
Live Load L	250.000000	0.000000	0.000000
Roof Live Load L	50.000000	0.000000	0.000000
Fluid Load F	0.000000	0.000000	0.000000
Lateral Load H	0.000000	0.000000	0.000000
Earthquake Load E	60.000000	0.000000	0.000000
Rain Load R	0.000000	0.000000	0.000000
Snow Load S	0.000000	0.000000	0.000000
Wind Load W	80.000000	0.000000	0.000000

Computer Example

■ Example 3: Load Combinations (cont'd)

Calculated Combined Loading Using ASCE 7-98

Group 1 Load Combination	Axial	Bending	Shear
1.4(D+F)	280.000000	0.000000	0.000000
Group 2 Load Combinations	**Axial**	**Bending**	**Shear**
1.2(D+F) + 1.6(L+H) + 0.5Lr	665.000000	0.000000	0.000000
1.2(D+F) + 1.6(L+H) + 0.5S	640.000000	0.000000	0.000000
1.2(D+F) + 1.6(L+H) + 0.5R	640.000000	0.000000	0.000000
Group 3 Load Combinations	**Axial**	**Bending**	**Shear**
1.2D + 1.6Lr + 0.5L	445.000000	0.000000	0.000000
1.2D + 1.6S + 0.5L	365.000000	0.000000	0.000000
1.2D + 1.6R + 0.5L	365.000000	0.000000	0.000000
1.2D + 1.6Lr + 0.8W	384.000000	0.000000	0.000000
1.2D + 1.6S + 0.8W	304.000000	0.000000	0.000000
1.2D + 1.6R + 0.8W	304.000000	0.000000	0.000000

Critical Factored load

Computer Example

- Example 3: Load Combinations (cont'd)

Group 4 Load Combinations	Axial	Bending	Shear
1.2D + 1.6W + 0.5L + 0.5Lr	518.000000	0.000000	0.000000
1.2D + 1.6W + 0.5L + 0.5S	493.000000	0.000000	0.000000
1.2D + 1.6W + 0.5L + 0.5R	493.000000	0.000000	0.000000

Group 5 Load Combination	Axial	Bending	Shear
1.2D + 1.0E + 0.5L + 0.2S	425.000000	0.000000	0.000000

Group 6 Load Combination	Axial	Bending	Shear
0.9D + 1.6W + 1.6H	308.000000	0.000000	0.000000

Group 7 Load Combination	Axial	Bending	Shear
0.9D + 1.0E + 1.6H	240.000000	0.000000	0.000000