



# STRUCTURAL STEEL DESIGN



## LRFD APPROACH

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## CHAPTER (1) : Introduction

**Structural steel:** is an alloy of iron and carbon .The adding of carbon to the iron , some toughness is obtain ,this is steel .Structural steel is specified using the American Society for Testing and Materials (ASTM) designation .

### Some Common Steel Structure



**Building**



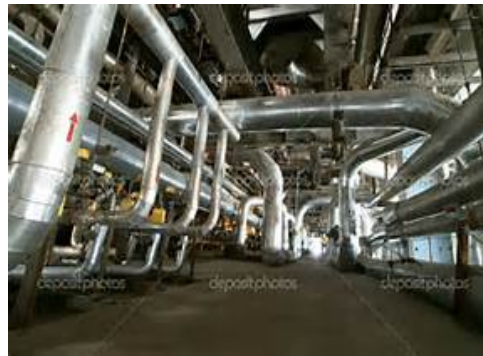
**Bridges**



**Towers**



**Tanks**



**Pipelines**



**Ships**

### Advantages of Structural Steel

1. High strength of steel per unit weight .
2. Uniformity : the properties of steel do not change with time .
3. Elasticity : it follows Hook s' law up to fairly high strength .
4. Permanence : steel frames that are properly maintained will last indefinitely .



5. Ductility : extensive deformation without failure under high tensile stresses .
6. Toughness : they have both strength and ductility .

### **Disadvantages of Structural Steel**

1. Corrosion : when freely exposed to air & water .
2. Fireproofing costs :
3. Susceptibility to buckling .
4. Fatigue : strength may be reduced with time if it is subject to large number of stress (tensile strength) .
5. Brittle fracture : when steel lose its ductility brittle fracture may occur

### **Types of steel**

1. **Carbon steels** : High strength low –alloy steel and yield strength of 36 ksi .The carbon steel are A36 , A53 , A500 (grade 36 ) ,as shown in Table (1-1).
2. **High-strength low-alloy steel** :have a distinct yield point range from 50 to 70 ksi .The types shown in Table (1-1) and are A913 , A992 ,A572 , (grade 50) .
3. **Corrosion – Resistant , High- Strength ,Low Alloy**: The yield strength ranging from 50 ksi .The types shown in Table (1-1) are A242 and A588.



**Table 1-1** Structural steel material properties

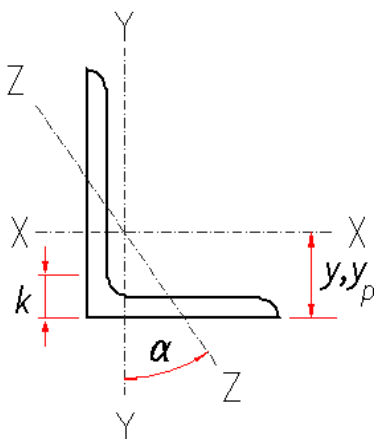
Steel Type	ASTM Designation or Grade of Structural Steel	$F_y$ (ksi)	$F_u$ (ksi)
Carbon Steel	A36	36	58-80
	A53 Grade B	35	60
	A500 Grade B	42 or 46	58
	A500 Grade C	46 or 50	62
High-Strength, Low-Alloy	A913	50-70	60-90
	A992	50-65	65
	A572 Grade 50	50	65
Corrosion-Resistant, High-Strength, Low-Alloy	A242	50	70
	A588	50	70

## Steel Sections

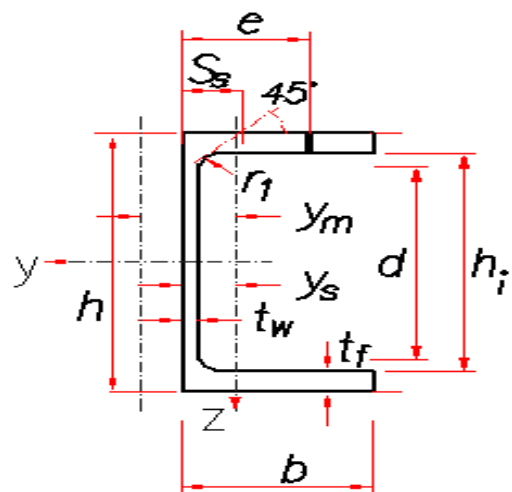
The first structural shapes made in the US were angle iron rolled in **1819** .

There are two types of steel shape available :

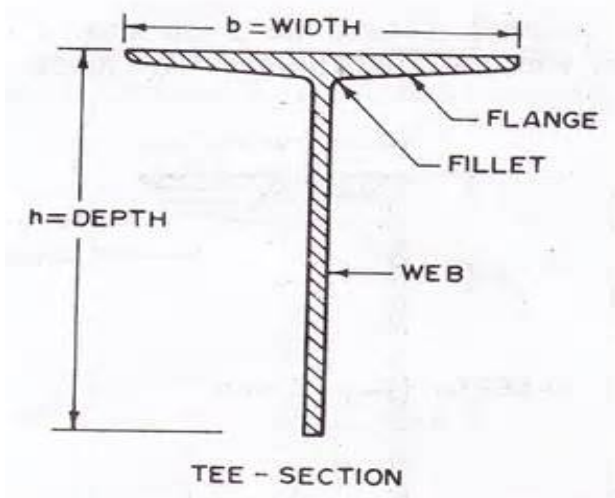
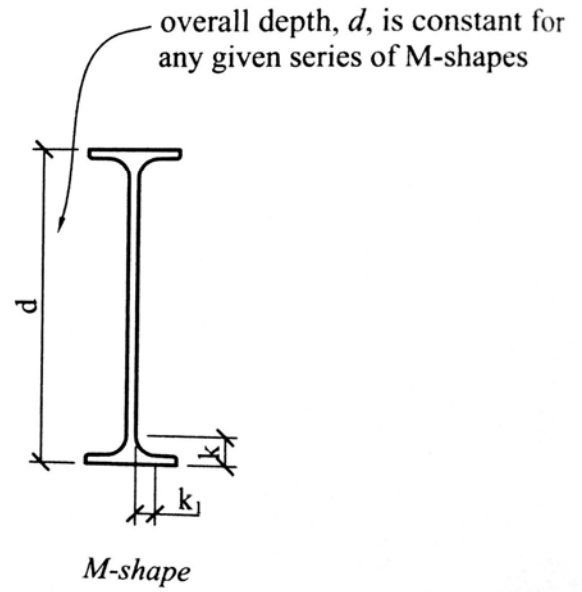
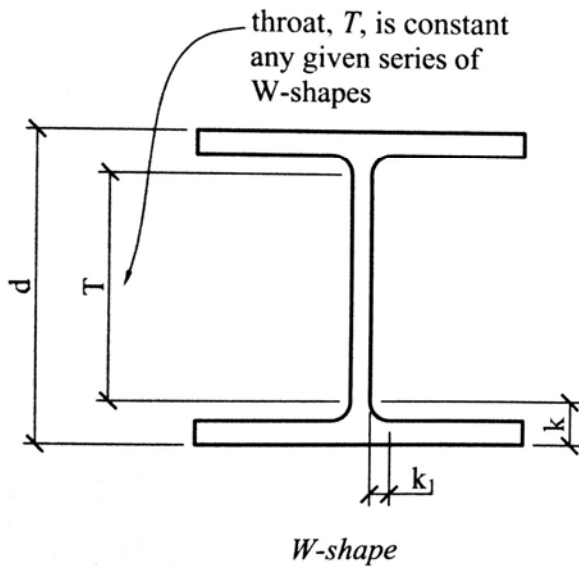
1. **Rolled steel shapes** : The dimensions and properties obtained from part 1 of the AISC .



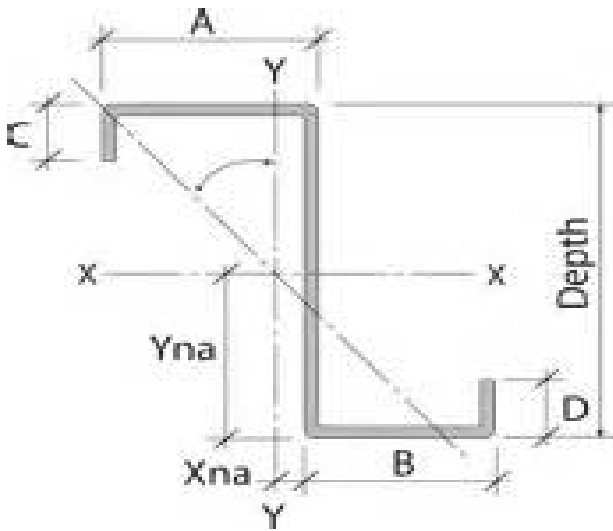
**Angle Section**



**Channel Section**



**Rectingular Hollow- Section**



**Z- Section**

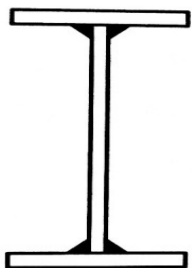


**Circular Hollow- Section**

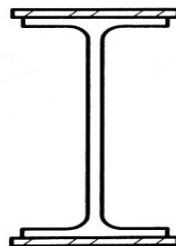
2. **Built-up shapes** :The shapes could be made from plate stock .Examples plate girders and box girders .

### Built-up Sections

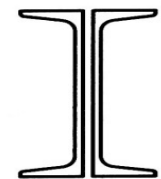
Built-up sections include welded plate girders and plates welded to the top or bottom flanges of W-sections. Plate girders are used to support heavy loads where the listed



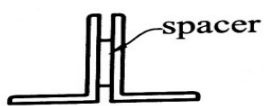
*a. plate girder*



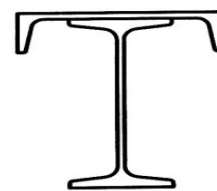
*b. reinforced W-section*



*c. (2)-C12 × 25*



*d. (2)-L6 × 4 × 3/8*



*e. S12 × 31.8 with C10 × 15.3 cap channel*



1. A  $W27 \times 114$  is a W section approximately 27 in deep, weighing 114 lb/ft.
2. An  $S12 \times 35$  is an S section 12 in deep, weighing 35 lb/ft.
3. An  $HP12 \times 74$  is a bearing pile section approximately 12 in deep, weighing 74 lb/ft. Bearing piles are made with the regular W rolls, but with thicker webs to provide better resistance to the impact of pile driving. The width and depth of these sections are approximately equal, and the flanges and webs have equal or almost equal thickness.
4. An  $M8 \times 6.5$  is a miscellaneous section 8 in deep, weighing 6.5 lb/ft. It is one of a group of doubly symmetrical H-shaped members that cannot by dimensions be classified as a W, S, or HP section, as the slope of their inner flanges is other than  $16 \frac{2}{3}$  percent.
5. A  $C10 \times 30$  is a channel 10 in deep, weighing 30 lb/ft.
6. An  $MC18 \times 58$  is a miscellaneous channel 18 in deep, weighing 58 lb/ft, which cannot be classified as a C shape because of its dimensions.
7. An  $HSS14 \times 10 \times 5/8$  is a rectangular hollow structural section 14 in deep, 10 in wide, with a  $5/8$ -in wall thickness. It weighs 93.10 lb/ft. Square and round HSS sections are also available.
8. An  $L6 \times 6 \times 1/2$  is an equal leg angle, each leg being 6 in long and  $1/2$  in thick.
9. A  $WT18 \times 151$  is a tee obtained by splitting a  $W36 \times 302$ . This type of section is known as a structural tee.
10. Rectangular steel sections are classified as wide *plates* or narrow *bars*.

**Table 1-2** Structural steel shapes and corresponding ASTM designation

Structural Steel Shapes	ASTM Designation	Min $F_y$ (ksi)	Min $F_u$ (ksi)
W-shape	A913**	50-70	60-90
	A992*	50-65	65
M- and S-shapes	A36	36	58-80
Channels (C- and MC-shapes)	A36*	36	58-80
	A572 Grade 50	50	65
Angles and plates	A36	36	58-80
Steel Pipe	A53 Grade B	35	60
Round HSS	A500 Grade B*	42	58
	A500 Grade C	46	62
Square and Rectangular HSS	A500 Grade B*	46	58
	A500 Grade C	50	62

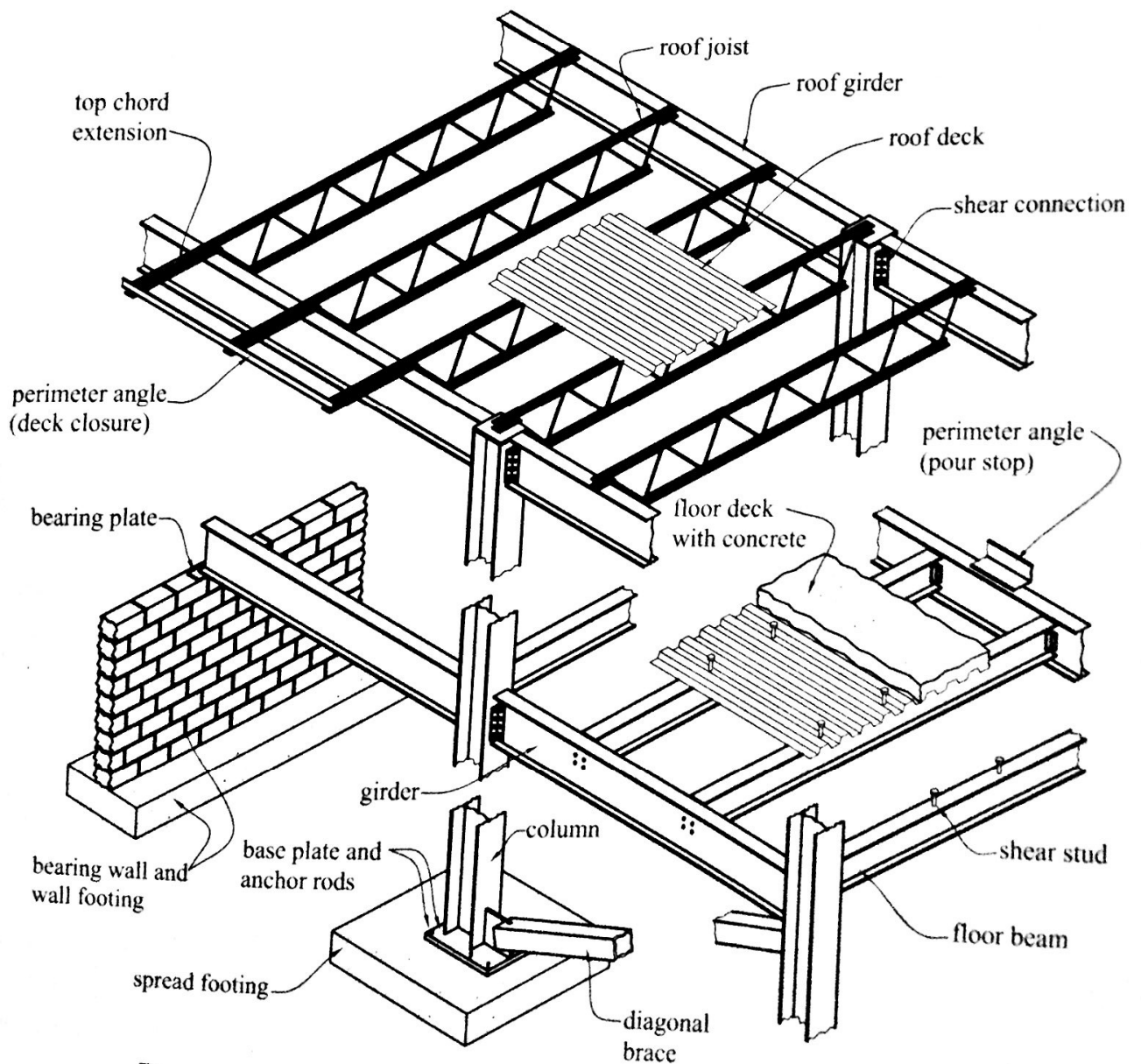
\* Preferred material specification for the different shapes.

\*\* A913 is a low-alloy, high-strength steel.



## 1.8 BASIC STRUCTURAL STEEL ELEMENTS

The basic structural steel elements and members that are used to resist gravity loads in steel-framed buildings as shown in Figures 1-13 and 1-14 will now be discussed.



**Figure 1-13** Typical steel building — basic structural elements (3-D).



## **Design Methods and Load Combinations**

### **DESIGN BASIS**

The AISC (American Institute of Steel Construction) Specification and Part 2 of the AISC *Manual* describe the basis of design, for LRFD ((Load and Resistance Factor Design) .

### **DESIGN BASIS**

Designs shall be made according to the provisions for Load and Resistance Factor Design (**LRFD**) not to the provisions for (**ASD**) (Allowable Strength Design) .

### **Design for Strength Using Load and Resistance Factor Design (LRFD)**

Design according to the provisions for *Load and Resistance Factor Design* (LRFD) satisfies the requirements of this Specification . All provisions of this Specification, except for those in Section B3.4, shall apply :

$$R_u \leq \phi R_n$$

Where :

$R_u$  = Required strength (LRFD)

$R_n$  = Nominal strength,

$\phi$  = Resistance factor,

$\phi R_n$  = Design strength

**Table 2-1** Resistance factors

<b>Limit State</b>	<b>Resistance Factor (<math>\phi</math>)</b>
Shear	1.0 or 0.9
Flexure	0.90
Compression	0.90
Tension (yielding)	0.90
Tension (rupture)	0.75



## Load combinations

The building code recognize that all structural loads do not occur at the same time and their maximum values may not happen at the same time .The load combinations or critical combination of loads to be used for design are prescribed in ASCE 7 load standard .The basic load combinations for LRFD are :

1.  $1.4 (D + F)$
2.  $1.2 (D + F + T) + 1.6 (L + H) + 0.5 (L_r \text{ or } S \text{ or } R)$
3.  $1.2 D + 1.6 (L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.8 W)$
4.  $1.2 D + 1.6 W + L + 0.5 (L_r \text{ or } S \text{ or } R)$
5.  $1.2 D + 1.0 E + L + 0.25$
6.  $0.9 D + (1.6 W + 1.6 H)$  (D always opposes W and H)
7.  $0.9 D + (1.0 E + 1.6 H)$  (D always opposes E and H)

Where :

- D = Dead load
- F = Fluid loads
- T = Self –straining force (temperature)
- L = Floor live load
- H = Lateral soil pressure ,hydrostatic pressures
- $L_r$  = Roof live load
- S = Snow load
- R = Rain load
- W = Wind load
- E = Load effect due to horizontal and vertical earthquake



## Load Combinations, Factored Loads, and Load Effects

Determine the ultimate or factored load for a roof beam subjected to the following service loads:

$$\begin{aligned} \text{Dead load} &= 35 \text{ psf} \\ \text{Snow load} &= 25 \text{ psf} \\ \text{Wind load} &= 15 \text{ psf upwards} \\ &10 \text{ psf downwards} \end{aligned}$$

### SOLUTION

$$\begin{aligned} D &= 35 \text{ psf} \\ S &= 25 \text{ psf} \\ W &= -15 \text{ psf or } 10 \text{ psf} \end{aligned}$$

The values for service loads not given above are assumed to be zero; therefore,

$$\begin{aligned} \text{Floor live load, } L &= 0 \\ \text{Rain live load, } R &= 0 \\ \text{Seismic load, } E &= 0 \\ \text{Roof live load, } L_r &= 0 \end{aligned}$$

Using the LRFD load combinations, and noting that only downward-acting loads should be substituted in load combinations 1 through 5, and upward wind or seismic loads in load combinations 6 and 7, the controlling factored load is calculated as follows:

1.  $w_u = 1.4D = 1.4(35) = 49 \text{ psf}$
2.  $w_u = 1.2D + 1.6L + 0.5S$   
 $= 1.2(35) + 1.6(0) + 0.5(25) = 55 \text{ psf}$
- 3a.  $w_u = 1.2D + 1.6S + 0.8W$   
 $= 1.2(35) + 1.6(25) + 0.8(10) = \mathbf{90 \text{ psf (governs)}}$
- 3b.  $w_u = 1.2D + 1.6S + 0.5L$   
 $= 1.2(35) + 1.6(25) + 0.5(0) = 82 \text{ psf}$
4.  $w_u = 1.2D + 1.6W + L + 0.5S$   
 $= 1.2(35) + 1.6(10) + (0) + 0.5(25) = 71 \text{ psf}$
5.  $w_u = 1.2D + 1.0E + 0.5L + 0.2S$   
 $= 1.2(35) + 1.0(0) + 0.5(0) + 0.2(25) = 47 \text{ psf}$
6.  $w_u = 0.9D + 1.6W$  ( $D$  must always oppose  $W$  in load combination 6)  
 $= 0.9(35) + 1.6(-15)$  (upward wind load is taken as negative)  
 $= 7.5 \text{ psf}$



$$\begin{aligned} 7. \quad w_u &= 0.9D + 1.0E \quad (D \text{ must always oppose } E \text{ in load combination 7}) \\ &= 0.9(35) + 1.0(0) \\ &= 31.5 \text{ psf} \end{aligned}$$

In this example, load combinations 6 and 7 resulted in net positive (or downward) load. However, load combinations 6 and 7 may sometimes result in net negative (or upward) factored loads that would also have to be considered in the design of the structural member.

- For strength calculations, the controlling factored load is  $w_u = 90 \text{ psf}$ .

If controlling service loads are required, these would be calculated using ASD load combinations 8 through 15.

## EXAMPLE 2-4

### Load Combinations, Factored Loads, and Load Effects

- Determine the factored axial load or the required axial strength for a column in an office building with the given service loads below.
- Calculate the required *nominal* axial compression strength of the column.

Given service axial loads on the column:

$$\begin{aligned} P_D &= 75 \text{ kips (dead load)} \\ P_L &= 150 \text{ kips (floor live load)} \\ P_S &= 50 \text{ kips (snow load)} \\ P_W &= \pm 100 \text{ kips (wind load)} \\ P_E &= \pm 50 \text{ kips (seismic load)} \end{aligned}$$

### SOLUTION

- Note that downward loads take on positive values, while upward loads take on negative values. The factored loads are calculated as

- $P_u = 1.4 P_D = 1.4 (75 \text{ kips}) = 105 \text{ kips}$
- $P_u = 1.2 P_D + 1.6 P_L + 0.5 P_S$   
 $= 1.2 (75) + 1.6 (150) + 0.5 (50) = 355 \text{ kips (governs)}$
- $P_u = 1.2 P_D + 1.6 P_S + 0.5 P_L$   
 $= 1.2 (75) + 1.6 (50) + 0.5 (150) = 245 \text{ kips}$
- $P_u = 1.2 P_D + 1.6 P_S + 0.8 P_W$   
 $= 1.2 (75) + 1.6 (50) + 0.8 (100) = 240 \text{ kips}$
- $P_u = 1.2 P_D + 1.6 P_W + 0.5 P_L + 0.5 P_S$   
 $= 1.2 (75) + 1.6 (100) + 0.5 (150) + 0.5 (50) = 350 \text{ kips}$

(continued)



$$\begin{aligned} 5. \quad P_u &= 1.2 P_D + 1.0 P_E + 0.5 P_L + 0.2 P_S \\ &= 1.2 (75) + 1.0 (50) + 0.5 (150) + 0.2 (50) = 225 \text{ kips} \end{aligned}$$

Note that  $P_D$  must always oppose  $P_W$  and  $P_E$  in load combinations 6 and 7:

$$\begin{aligned} 6. \quad P_u &= 0.9 P_D + 1.6 P_W \\ &= 0.9 (75) + 1.6 (-100) = -92.5 \text{ kips (governs)} \end{aligned}$$

$$\begin{aligned} 7. \quad P_u &= 0.9 P_D + 1.0 P_E \\ &= 0.9 (75) + 1.0 (-50) = 17.5 \text{ kips} \end{aligned}$$

- The factored axial *compression* load on the column is 355 kips.
- The factored axial *tension* force on the column is 92.5 kips.

The column, base plate, anchor bolts, and foundation will need to be designed for both the downward factored load of 355 kips and the factored net uplift, or tension, load of 92.5 kips.

- b. Nominal axial compression strength of the column;  $P_n = P_u/\phi = 355/0.90 = 394$  kips.

### Load Combinations—Factored Loads and Load Effects

Repeat Example 2-4 assuming that the structure is to be used as a parking garage.

#### SOLUTION

- a. For parking garages or areas used for public assembly or areas with a floor live load,  $L$ , greater than 100 psf, the multiplier of the floor live load in load combinations 3, 4, and 5 is 1.0. The factored loads are calculated as follows:

$$1. \quad P_u = 1.4 P_D = 1.4 (75) = 105 \text{ kips}$$

$$\begin{aligned} 2. \quad P_u &= 1.2 P_D + 1.6 P_L + 0.5 P_S \\ &= 1.2 (75) + 1.6 (150) + 0.5 (50) = 355 \text{ kips} \end{aligned}$$

$$\begin{aligned} 3a. \quad P_u &= 1.2 P_D + 1.6 P_S + 1.0 P_L \\ &= 1.2 (75) + 1.6 (50) + 1.0 (150) = 320 \text{ kips} \end{aligned}$$

$$\begin{aligned} 3b. \quad P_u &= 1.2 P_D + 1.6 P_S + 0.8 P_W \\ &= 1.2 (75) + 1.6 (50) + 0.8 (100) = 250 \text{ kips} \end{aligned}$$

$$\begin{aligned} 4. \quad P_u &= 1.2 P_D + 1.6 P_W + 1.0 P_L + 0.5 P_S \\ &= 1.2 (75) + 1.6 (100) + 1.0 (150) + 0.5 (50) = 425 \text{ kips (governs)} \end{aligned}$$



$$\begin{aligned} 5. \quad P_u &= 1.2 P_D + 1.0 P_E + 1.0 P_L + 0.2 P_S \\ &= 1.2 (75) + 1.0 (50) + 1.0 (150) + 0.2 (50) = 300 \text{ kips} \end{aligned}$$

Note that  $P_D$  must always oppose  $P_W$  and  $P_E$  in load combinations 6 and 7:

$$\begin{aligned} 6. \quad P_u &= 0.9 P_D + 1.6 P_W \\ &= 0.9 (75) + 1.6 (-100) = -92.5 \text{ kips (governs)} \end{aligned}$$

$$\begin{aligned} 7. \quad P_u &= 0.9 P_D + 1.0 P_E \\ &= 0.9 (75) + 1.0 (-50) = 17.5 \text{ kips} \end{aligned}$$

- The factored axial *compression* load on the column is 425 kips.
- The factored axial *tension* force on the column is 92.5 kips.

The column, base plate, anchor bolts, and foundation will need to be designed for both the downward factored load of 425 kips and the factored net uplift, or tension, load of 92.5 kips.

- b. Nominal axial compression strength of the column,  $P_n = P_u/\phi = 425/0.90 = 473$  kips.