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Structural-steel Design

Introduction to LRFD Designs
ASD

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Dead Load

Table 17-12
Densities of Common Materials

Substance	Density, lb/ft^3	Substance	Density, lb/ft^3
ASHLAR, MASONRY		River mud	90.0
Granite, syenite, gneiss	143–187	Soil	70.0
Limestone, marble	143–174	Stone riprap	65.0
Sandstone, bluestone	131–150		
		MINERALS	
MORTAR RUBBLE MASONRY		Asbestos	131–174
Granite, syenite, gneiss	137–174	Barytes	280
Limestone, marble	137–162	Basalt	168–199
Sandstone, bluestone	125–137	Bauxite	159
		Borax	106–112
DRY RUBBLE MASONRY		Chalk	112–162
Granite, syenite, gneiss	118–143	Clay, marl	112–162
Limestone, marble	118–131	Dolomite	181
Sandstone, bluestone	112–118	Feldspar, orthoclase	156–162
		Gneiss, serpentine	150–168
BRICK MASONRY		Granite, syenite	156–193
Pressed brick	137–143	Greenstone, trap	174–199
Common brick	112–125	Gypsum, alabaster	143–174
Soft brick	93.5–106	Hornblende	187
		Limestone, marble	156–174
CONCRETE MASONRY		Magnesite	187
Cement, stone, sand	137–150	Phosphate rock, apatite	199
Cement, slag, etc.	118–143	Porphyry	162–181
Cement, cinder, etc.	93.5–106	Pumice, natural	23.1–56.1

Table 17-13
Weights of Building Materials

Material	Weight, lb/ft^2	Material	Weight, lb/ft^2
CEILINGS		**PARTITIONS**	
Channel suspended system	1	Wood studs, 2 × 4	
Lathing and plastering	See Partitions	12-16 in. o. c.	2
Acoustical fiber tile	1	Steel studs	
		12-16 in. o. c.	1
FLOORS		Drywall, 1/2 in.	2
Steel deck	See Manufacturer	Drywall, 5/8 in.	2 1/2
Concrete-reinforced, 1 in.		Plaster, 1 in.	
Stone	12 1/2	Cement	10
Structural lightweight	9 1/2	Gypsum	5
Concrete-plain, 1 in.		Lathing	
Stone	12	Metal	1/2
Structural lightweight	9	Gypsum board, 1/2 in.	2
Nonstructural lightweight	3 to 9		
Finishes		**WALLS**	
Terrazzo, 1 in.	13	Brick	
Ceramic or quarry tile, 3/4 in.	10	4 in.	40
Linoleum, 1/4 in.	1	8 in.	80

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Live Loads for ASCE 07 - 2016

Table 4.3-1 Minimum Uniformly Distributed Live Loads, L_o, and Minimum Concentrated Live Loads

Occupancy or Use	Uniform, L_o psf (kN/m²)	Live Load Reduction Permitted? (Sec. No.)	Multiple-Story Live Load Reduction Permitted? (Sec. No.)	Concentrated lb (kN)	Also See Section
Apartments (See Residential)					
Access floor systems					
Office use	50 (2.40)	Yes (4.7.2)	Yes (4.7.2)	2,000 (8.90)	
Computer use	100 (4.79)	Yes (4.7.2)	Yes (4.7.2)	2,000 (8.90)	
Armories and drill rooms	150 (7.18)	No (4.7.5)	No (4.7.5)		
Assembly areas					
Fixed seats (fastened to floors)	60 (2.87)	No (4.7.5)	No (4.7.5)		
Lobbies	100 (4.79)	No (4.7.5)	No (4.7.5)		
Movable seats	100 (4.79)	No (4.7.5)	No (4.7.5)		
Platforms (assembly)	100 (4.79)	No (4.7.5)	No (4.7.5)		
Stage floors	150 (7.18)	No (4.7.5)	No (4.7.5)		
Reviewing stands, grandstands, and bleachers	100 (4.79)	No (4.7.5)	No (4.7.5)		4.14
Stadiums and arenas with fixed seats (fastened to the floor)	60 (2.87)	No (4.7.5)	No (4.7.5)		4.14
Other assembly areas	100 (4.79)	No (4.7.5)	No (4.7.5)		
Balconies and decks	1.5 times the live load for the area served. Not required to exceed 100 psf (4.79 kN/m²)	Yes (4.7.2)	Yes (4.7.2)		
Catwalks for maintenance access	40 (1.92)	Yes (4.7.2)	Yes (4.7.2)	300 (1.33)	
Corridors					
First floor	100 (4.79)	Yes (4.7.2)	Yes (4.7.2)		
Other floors	Same as occupancy served except as indicated				

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Load and Resistance Factor Design (LRFD)

The load combinations appropriate for LRFD are given in the applicable building code or, in its absence, ASCE/SEI 7 Section 2.3. For LRFD, the available strength is referred to as the design strength. All of the LRFD provisions are structured so that the design strength must equal or exceed the required strength. This is presented in AISC *Specification* Section B3.1 as

$$R_u \le \phi R_n \qquad (2\text{-}1)$$

In this equation, R_u is the required strength determined by analysis for the LRFD load combinations, R_n is the nominal strength determined according to the AISC *Specification* provisions, and ϕ is the resistance factor given by the AISC *Specification* for a particular limit state. Throughout this Manual, tabulated values of ϕR_n, the design strength, are given for LRFD. These values are tabulated as blue numbers in columns with the heading LRFD.

LOADS

Structural loads are classified as follows.

Dead load (D)—The weight of the structure and all other permanently installed features in the building, including built-in partitions.

Live load (L)—The gravity load due to the intended usage and occupancy; includes the weight of people, furniture, and movable equipment and partitions. In LRFD, the notation L refers to floor live loads and L_r, to roof live loads.

Rain load (R)—Load due to the initial rainwater or ice, excluding the contribution of ponding.

Snow load (S).

Wind load (W).

Earthquake load (E).

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Enviromental Loads Mccormac

2.5 Environmental Loads

Environmental loads are caused by the environment in which a particular structure is located. For buildings, environmental loads are caused by rain, snow, wind, temperature change, and earthquakes. Strictly speaking, environmental loads are live loads, but they are the result of the environment in which the structure is located. Even though they do vary with time, they are not all- caused by gravity or operating conditions, as is typical with other live loads. A few comments are presented in the paragraphs that follow concerning the different types of environmental loads:

1. Snow. In the colder states, snow loads are often quite important. One inch of snow is equivalent to a load of approximately 0.5 psf (pounds per square foot), but it may be higher at lower elevations where snow is denser. For roof designs, snow loads varying from 10 to 40 psf are commonly used, the magnitude depending primarily on the slope of the roof and, to a lesser degree, on the character of the roof surface. The larger values are used for flat roofs, the smaller ones for sloped roofs. Snow tends to slide off sloped roofs, particularly those with metal or slate surfaces. A load of approximately 10 psf might be used for 45° slopes and a 40-psf load for flat roofs. Studies of snowfall records in areas with severe winters may indicate the occurrence of snow loads much greater than 40 psf, with values as high as 200 psf in some western states.

2. Rain. Though snow loads are a more severe problem than rain loads for the usual roof, the situation may be reversed for flat roofs, particularly those in warmer climates. If water on a flat roof accumulates faster than it runs off, the result is called *ponding*, because the increased load causes the roof to deflect into a dish shape that can hold more water, which causes greater deflections, and so on. This process continues until an equilibrium is reached or until collapse occurs. Ponding is a serious matter, as illustrated by the large number of flat-roof failures that occur during rainstorms every year in the United States. It has been claimed that almost 50 percent of the lawsuits faced by building designers are concerned with roofing systems.[3] Ponding is one of the most common subjects of such litigation.

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3. Wind loads. A survey of engineering literature for the past 150 years reveals many references to structural failures caused by wind. Perhaps the most infamous of these have been bridge failures, such as those of the Tay Bridge in Scotland in 1879 (which caused the deaths of 75 persons) and the Tacoma Narrows Bridge in Tacoma, Washington, in 1940. But there have also been some disastrous building failures due to wind during the same period, such as that of the Union Carbide Building in Toronto in 1958. It is important to realize that a large percentage of building failures due to wind have occurred during the erection of the building.[4]

[4] "Wind Forces on Structures, Task Committee on Wind Forces. Committee on Loads and Stresses, Structural Division, ASCE, Final Report," *Transactions ASCE* 126, Part II (1961): 1124–1125.

4. Earthquake loads. Many areas of the world fall in "earthquake territory," and in those areas it is necessary to consider seismic forces in design for all types of structures. Through the centuries, there have been catastrophic failures of buildings, bridges, and other structures during earthquakes. It has been estimated that as many as 50,000 people lost their lives in the 1988 earthquake in Armenia.[7] The 1989 Loma Prieta and 1994 Northridge earthquakes in California caused many billions of dollars of property damage, as well as considerable loss of life.

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2.6 Load and Resistance Factor Design (LRFD) and Allowable Strength Design (ASD)

The AISC Specification provides two acceptable methods for designing structural steel members and their connections. These are Load and Resistance Factor Design (LRFD) and Allowable Strength Design (ASD). As we will learn in this textbook, both procedures are based on limit states design principles, which provide the boundaries of structural usefulness.

The term limit state is used to describe a condition at which a structure or part of a structure ceases to perform its intended function. There are two categories of limit states: strength and serviceability.

Strength limit states define load-carrying capacity, including excessive yielding, fracture, buckling, fatigue, and gross rigid body motion. Serviceability limit states define performance, including deflection, cracking, slipping, vibration, and deterioration. All limit states must be prevented

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2.3 LOAD COMBINATIONS FOR STRENGTH DESIGN

2.3.1 Basic Combinations. Structures, components, and foundations shall be designed so that their design strength equals or exceeds the effects of the factored loads in the following combinations. Effects of one or more loads not acting shall be considered. Seismic load effects shall be combined loads in accordance with Section 2.3.6. Wind and seismic loads need not be considered to act simultaneously. Refer to Sections 1.4, 2.3.6, 12.4, and 12.14.3 for the specific definition of the earthquake load effect E. Each relevant strength limit state shall be investigated.

1. $1.4D$
2. $1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$
3. $1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.5W)$
4. $1.2D + 1.0W + L + 0.5(L_r \text{ or } S \text{ or } R)$
5. $0.9D + 1.0W$

L_r = roof L.L
S : Snow
R = Rain

Case (1) only DL
Gravity (2) D + L + Environment Loads
(3) Heavy roof Load

Nomenclature

D	dead loads	kips or kips/ft
E	earthquake load	kips or kips/ft
H	load due to lateral pressure	kips/ft^2
L	live loads due to occupancy	kips or kips/ft
L_r	roof live load	kips or kips/ft
Q	load effect produced by service load	kips
R	load due to rainwater or ice	kips or kips/ft
R_n	nominal strength	–
S	snow load	kips or kips/ft
U	required strength to resist factored loads	–
W	wind load	kips or kips/ft

Symbols

γ	load factor	–
ϕ	resistance factor	–
Ω	safety factor	–

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Note that *D*, *L*, *W*, *S*, etc. are loads in a general sense, which includes bending moment, shear, axial force, and torsional moment. Sometimes these internal forces are called *load effects*. Thus, the symbol *D* means dead load, dead load moment, dead load shear, dead load axial force, etc. An explanation of the statistics relating to snow and wind load factors is given by Ravindra, Cornell, and Galambos [1.32]. The factors for earthquake *E* are reduced from 1.5 in the 1986 LRFD Specification to 1.0 in the 1993 Specification. This

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Resistance Factors ϕ :

$$\phi = \begin{cases} 0.90 & \textit{Tension members (yielding state)} \\ 0.75 & \textit{Tension members (fracture state)} \\ 0.85 & \textit{Compression members} \\ 0.90 & \textit{Beams (flexure and shear)} \\ 0.75 & \textit{Fasteners} \end{cases}$$

⇒ 0.90

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Allowable Strength Design (ASD)

Allowable strength design is similar to what is known as allowable stress design in that they are both carried out at the same load level. Thus, the same load combinations are used. The difference is that for strength design, the primary provisions are given in terms of forces or moments rather than stresses. In every situation, these strength provisions can be transformed into stress provisions by factoring out the appropriate section property. In many cases, the provisions are already given directly in terms of stress.

The load combinations appropriate for ASD are given by the applicable building code or, in its absence, ASCE/SEI 7 Section 2.4. For ASD, the available strength is referred to as the allowable strength. All of the ASD provisions are structured so that the allowable strength must equal or exceed the required strength. This is presented in AISC *Specification* Section B3.2 as

$$R_a \leq \frac{R_n}{\Omega} \tag{2-2}$$

In this equation, R_a is the required strength determined by analysis for the ASD load combinations, R_n is the nominal strength determined according to the AISC *Specification* provisions, and Ω is the safety factor given by the *Specification* for a particular limit state. Throughout this Manual, tabulated values of R_n/Ω, the allowable strength, are given for ASD. These values are tabulated as black numbers on a green background in columns with the heading ASD.

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combined with other loads in accordance with Section 2.4.5. Wind and seismic loads need not be considered to act simultaneously. Refer to Sections 1.4, 2.4.5, 12.4, and 12.14.3 for the specific definition of the earthquake load effect E.

Increases in allowable stress shall not be used with the loads or load combinations given in this standard unless it can be demonstrated that such an increase is justified by structural behavior caused by rate or duration of load.

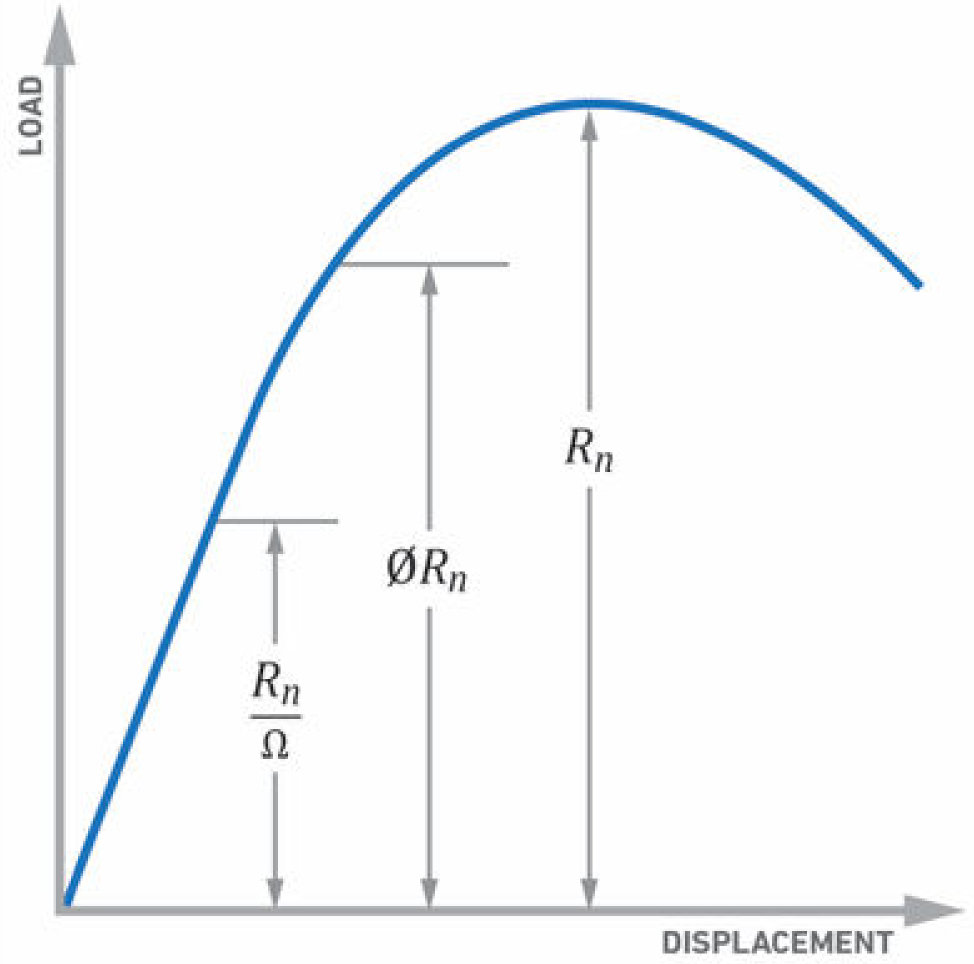
1. D
2. $D + L$
3. $D + (L_r \text{ or } S \text{ or } R)$
4. $D + 0.75L + 0.75(L_r \text{ or } S \text{ or } R)$
5. $D + (0.6W)$
6. $D + 0.75L + 0.75(0.6W) + 0.75(L_r \text{ or } S \text{ or } R)$
7. $0.6D + 0.6W$

Nomenclature

D	dead loads	kips or kips/ft
E	earthquake load	kips or kips/ft
H	load due to lateral pressure	kips/ft^2
L	live loads due to occupancy	kips or kips/ft
L_r	roof live load	kips or kips/ft
Q	load effect produced by service load	kips
R	load due to rainwater or ice	kips or kips/ft
R_n	nominal strength	–
S	snow load	kips or kips/ft
U	required strength to resist factored loads	–
W	wind load	kips or kips/ft

Symbols

γ	load factor	–
ϕ	resistance factor	–
Ω	safety factor	–



ASD Allowable Strength

The allowable strength of a member consists of the nominal strength of the member, R_n, divided by the appropriate safety factor, Ω. The safety factor is defined in AISC 360 as

$\Omega_b = 1.67$ [for flexure]

$\Omega_v = 1.5$ [for shear in webs of rolled I-shaped members]

$\Omega_v = 1.67$ [for shear in all other conditions]

$\Omega_c = 1.67$ [for compression]

$\Omega_t = 1.67$ [for tensile yielding]

$\Omega_t = 2.00$ [for tensile fracture]

$\Omega = 2.00$ [for shear rupture of bolts]

$\frac{1.5}{\phi} = \Omega$

L.L = 3DL

$\frac{1.5}{0.90} = 1.67$ bending

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