Grades of Reinforcing Steel

Grades of Reinforcing Steel

Reinforcing bars may be rolled from billet steel, axle steel, or rail steel. Only occasionally, however, are they rolled from old train rails or locomotive axles. These latter steels have been cold-worked for many years and are not as ductile as the billet steels.

There are several types of reinforcing bars, designated by the ASTM, which are listed after this paragraph. These steels are available in different grades as **Grade 50, Grade 60**, and so on, where Grade 50 means the steel has a specified yield point of 50,000 psi, Grade 60 means 60,000 psi, and so on.

Grades of Reinforcing Steel

1. ASTM A615: Deformed and plain billet steel bars. These bars, which must be marked with the letter S (for type of steel), are the most widely used reinforcing bars in the United States. Bars are of four minimum yield strength levels: 40,000 psi (280 MPa); 60,000 psi (420 MPa); 75,000 psi (520 MPa); and 80,000 psi (550 MPa).

2. ASTM A706: Low-alloy deformed and plain bars. These bars, which must be marked with the letter W (for type of steel), are to be used where controlled tensile properties and/or specially controlled chemical composition is required for welding purposes. They are available in two grades: 60,000 psi (420 MPa) and 80,000 psi (550 MPa), designated as Grade 60 (420) and Grade 80 (550), respectively.

Grades of Reinforcing Steel

3. ASTM A996: Deformed rail steel or axle steel bars. They must be marked with the letter R (for type of steel).

4. When deformed bars are produced to meet both the A615 and A706 specifications, they must be marked with both the letters S and W.

Grades of Reinforcing Steel

Almost all reinforcing bars conform to the A615 specification. Bars conforming to the A706 specification are intended for certain uses when welding and/or bending are of particular importance. Bars conforming to this specification may not always be available from local suppliers.

There is only a small difference between the prices of reinforcing steel with yield strengths of 40 ksi and 60 ksi. As a result, the 60-ksi bars are the most commonly used in reinforced concrete design. When bars are made from steels with f_y of 60 ksi or more, the ACI (Section 3.5.3.2) states that the specified yield strength must be the stress corresponding to a strain of 0.35%.

Grades of Reinforcing Steel

For bars with *fy* less than 60 ksi, the yield strength shall be taken as the stress corresponding to a strain of 0.5%. The ACI (Section 9.4) has established an upper limit of 80 ksi on yield strengths permitted for design calculations for reinforced concrete. If the ACI were to permit the use of steels with yield strengths greater than 80 ksi, it would have to provide other design restrictions, since the yield strain of 80 ksi steel is almost equal to the ultimate concrete strain in compression. (This last sentence will make sense after the reader has studied Chapter 2.)

There has been gradually increasing demand through the years for Grade 75 and Grade 80 steel, particularly for use in high-rise buildings, where it is used in combination with high strength concretes. The results are smaller columns, more rentable floor space, and smaller foundations for the resulting lighter buildings.

Grades of Reinforcing Steel

Grade 75 and Grade 80 steel are appreciably higher in cost, and the #14 and #18 bars are often unavailable from stock and will probably have to be specially ordered from the steel mills. This means that there may have to be a special rolling to supply the steel. As a result, its use may not be economically justified unless at least 50 or 60 tons are ordered.

The modulus of elasticity for non-prestressed steels is considered to be equal to 29×10^6 psi. For prestressed steels, it varies somewhat from manufacturer to manufacturer, with a value of 27×10^6 psi being fairly common.

SI Bar Sizes and Material Strengths

TABLE 1.1 Reinforcement Bar Sizes and Areas

Standard Inch-Pound Bars			Soft Metric Bars		
Bar No.	Diameter (in.)	Area (in.^{2})	Bar No.	Diameter (mm)	Area (mm^2)
3	0.375	0.11	10	9.5	71
4	0.500	0.20	13	12.7	129
5	0.625	0.31	16	15.9	199
6	0.750	0.44	19	19.1	284
7	0.875	0.60	22	22.2	387
8	1.000	0.79	25	25.4	510
9	1.128	1.00	29	28.7	645
10	1.270	1.27	32	32.3	819
11	1.410	1.56	36	35.8	1006
14	1.693	2.25	43	43.0	1452
18	2.257	4.00	57	57.3	2581

Corrosive Environments

Corrosive Environments

When reinforced concrete is subjected to deicing salts, seawater, or spray from these substances, it is necessary to provide special corrosion protection for the reinforcing. The structures usually involved are bridge decks, parking garages, wastewater treatment plants, and various coastal structures. We must also consider structures subjected to occasional chemical spills that involve chlorides.

Should the reinforcement be insufficiently protected, it will corrode; as it corrodes, the resulting oxides occupy a volume far greater than that of the original metal. The results are large outward pressures that can lead to severe cracking and spalling of the concrete. This reduces the concrete protection, or *cover*, for the steel, and corrosion accelerates. Also, the *bond*, or sticking of the concrete to the steel, is reduced. The result of all of these factors is a decided reduction in the life of the structure.

Corrosive Environments

Section 7.7.6 of the code requires that for corrosive environments, more concrete cover must be provided for the reinforcing; it also requires that special concrete proportions or mixes be used.

The lives of such structures can be greatly increased if *epoxy-coated reinforcing* bars are used. Such bars need to be handled very carefully so as not to break off any of the coating. Furthermore, they do not bond as well to the concrete, and their embedment lengths will have to be increased somewhat for that reason, as you will learn in Chapter 7. A new type of bar coating, a dual coating of a zinc alloy and an epoxy coating, was introduced in the 2011 ACI 318 Code. Use of stainless steel reinforcing, as described in Section 1.14, can also significantly increase the service life of structures exposed to corrosive environments.

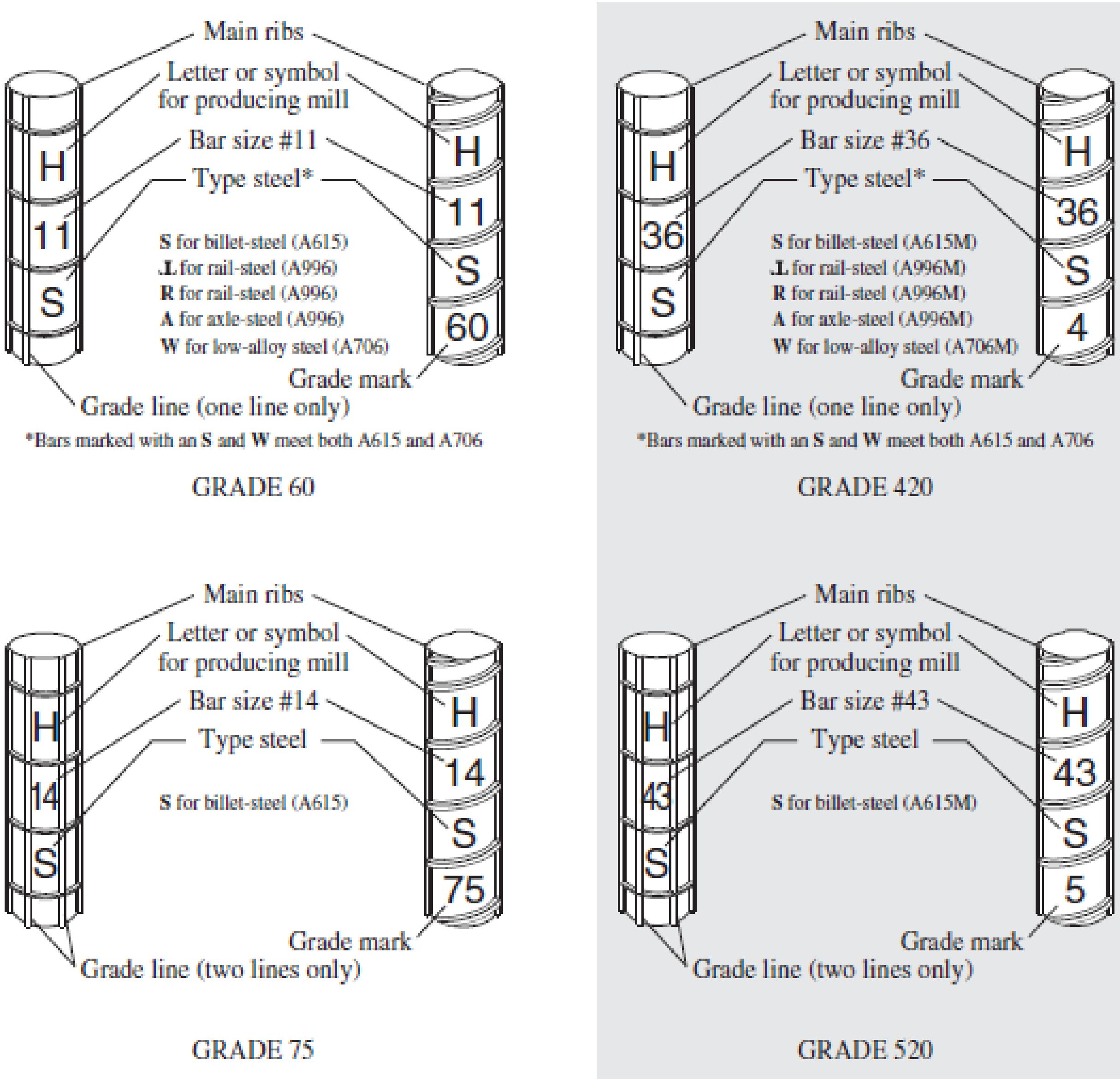
Identifying Marks on Reinforcing Bars

Identifying Marks on Reinforcing Bars

It is essential for people in the shop and the field to be able to identify at a glance the sizes and grades of reinforcing bars. If they are not able to do this, smaller and lower-grade bars other than those intended by the designer may be used. To prevent such mistakes, deformed bars have rolled-in identification markings on their surfaces. These markings are described in the following list and are illustrated in Figure 1.4.

1. The producing company is identified with a letter.
2. The bar size number (3 to 18) is given next.
3. Another letter is shown to identify the type of steel (S for billet, R in addition to a rail sign for rail steel, A for axle, and W for low alloy).

Identifying Marks on Reinforcing Bars



Courtesy of Concrete Reinforcing Steel Institute.

Identifying Marks on Reinforcing Bars

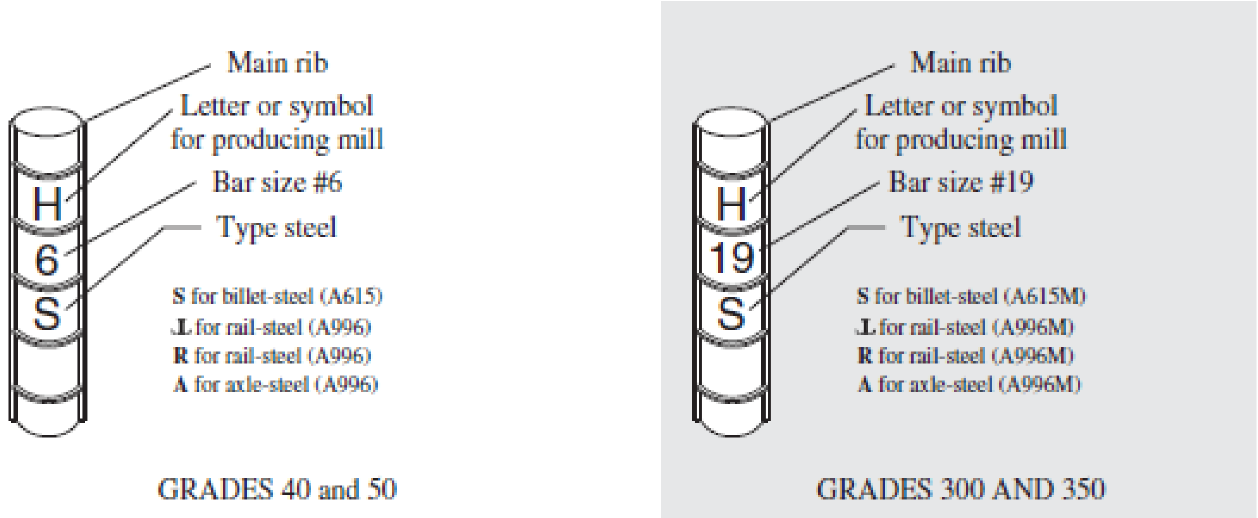


FIGURE 1.4 Identification marks for ASTM standard bars.

4. Finally, the grade of the bars is shown either with numbers or with continuous lines. **A Grade 60 bar has either the number 60 on it or a continuous longitudinal line in addition to its main ribs.** A Grade 75 bar will have the number 75 on it or two continuous lines in addition to the main ribs.

Introduction to Loads

Introduction to Loads

Perhaps the most important and most difficult task faced by the structural designer is the accurate estimation of the loads that may be applied to a structure during its life. No loads that may reasonably be expected to occur may be overlooked. After loads are estimated, the next problem is to decide the worst possible combinations of these loads that might occur at one time. For instance, would a highway bridge completely covered with ice and snow be simultaneously subjected to fast-moving lines of heavily loaded trailer trucks in every lane and to a 90-mile lateral wind, or is some lesser combination of these loads more reasonable?

Introduction to Loads

The next few sections of this chapter provide a brief introduction to the types of loads with which the structural designer must be familiar. The purpose of these sections is not to discuss loads in great detail but rather to give the reader a feel for the subject. As will be seen, **loads are classed as being dead, live, or environmental.**

Dead Loads

Dead Loads

Dead loads are loads of constant magnitude that remain in one position. They include the weight of the structure under consideration as well as any fixtures that are permanently attached to it. For a reinforced concrete building, some dead loads are the frames, walls, floors, ceilings, stairways, roofs, and plumbing.

To design a structure, it is necessary for the weights or dead loads of the various parts to be estimated for use in the analysis. The exact sizes and weights of the parts are not known until the structural analysis is made and the members of the structure are selected. The weights, as determined from the actual design, must be compared with the estimated weights. If large discrepancies are present, it will be necessary to repeat the analysis and design using better estimated weights.

Dead Loads

Reasonable estimates of structure weights may be obtained by referring to similar structures or to various formulas and tables available in most civil engineering handbooks. An experienced designer can estimate very closely the weights of most structures and will spend little time repeating designs because of poor estimates.

The approximate weights of some common materials used for floors, walls, roofs, and the like are given in Table 1.2.

TABLE 1.2 Weights of Some Common Building Materials

Reinforced concrete (12 in.)	150 psf	2×12 @ 16-in. double wood floor	7 psf
Acoustical ceiling tile	1 psf	Linoleum or asphalt tile	1 psf
Suspended ceiling	2 psf	Hardwood flooring ($\frac{7}{8}$ in.)	4 psf
Plaster on concrete	5 psf	1-in. cement on stone-concrete fill	32 psf
Asphalt shingles	2 psf	Movable steel partitions	4 psf
3-ply ready roofing	1 psf	Wood studs with $\frac{1}{2}$-in. gypsum	8 psf
Mechanical duct allowance	4 psf	Clay brick wythes (4 in.)	39 psf

Live Loads

Live Loads

Live loads are loads that can change in magnitude and position. They include occupancy loads, warehouse materials, construction loads, overhead service cranes, equipment operating loads, and many others. In general, they are induced by gravity.

Some typical floor live loads that act on building structures are presented in Table 1.3. These loads, which are taken from Table 4-1 in ASCE 7-10, act downward and are distributed uniformly over an entire floor. By contrast, roof live loads are 20 psf (pounds per square feet) maximum distributed uniformly over the entire roof.

Among the many other types of live loads are:

Traffic loads for bridges—Bridges are subjected to series of concentrated loads of varying magnitude caused by groups of truck or train wheels.

Live Loads

Impact loads—Impact loads are caused by the vibration of moving or movable loads. It is obvious that a crate dropped on the floor of a warehouse or a truck bouncing on uneven pavement of a bridge causes greater forces than would occur if the loads were applied gently and gradually. Impact loads are equal to the difference between the magnitude of the loads actually caused and the magnitude of the loads had they been dead loads.

Longitudinal loads—Longitudinal loads also need 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. It is not difficult to imagine the tremendous longitudinal force developed when the driver of a 40-ton trailer truck traveling at 60 mph suddenly has to apply the

Live Loads

brakes while crossing a highway bridge. There are other longitudinal load situations, such as ships running into docks and the movement of traveling cranes that are supported by building frames.

Miscellaneous loads*—**Among the other types of live loads with which the structural designer will have to contend are ***soil pressures (such as the exertion of lateral earth pressures on walls or upward pressures on foundations), ***hydrostatic pressures*** (such as water pressure on dams, inertia forces of large bodies of water during earthquakes, and uplift pressures on tanks and basement structures), ***blast loads*** (caused by explosions, sonic booms, and military weapons), and ***centrifugal forces*** (such as those caused on curved bridges by trucks and trains or similar effects on roller coasters).

Live Loads

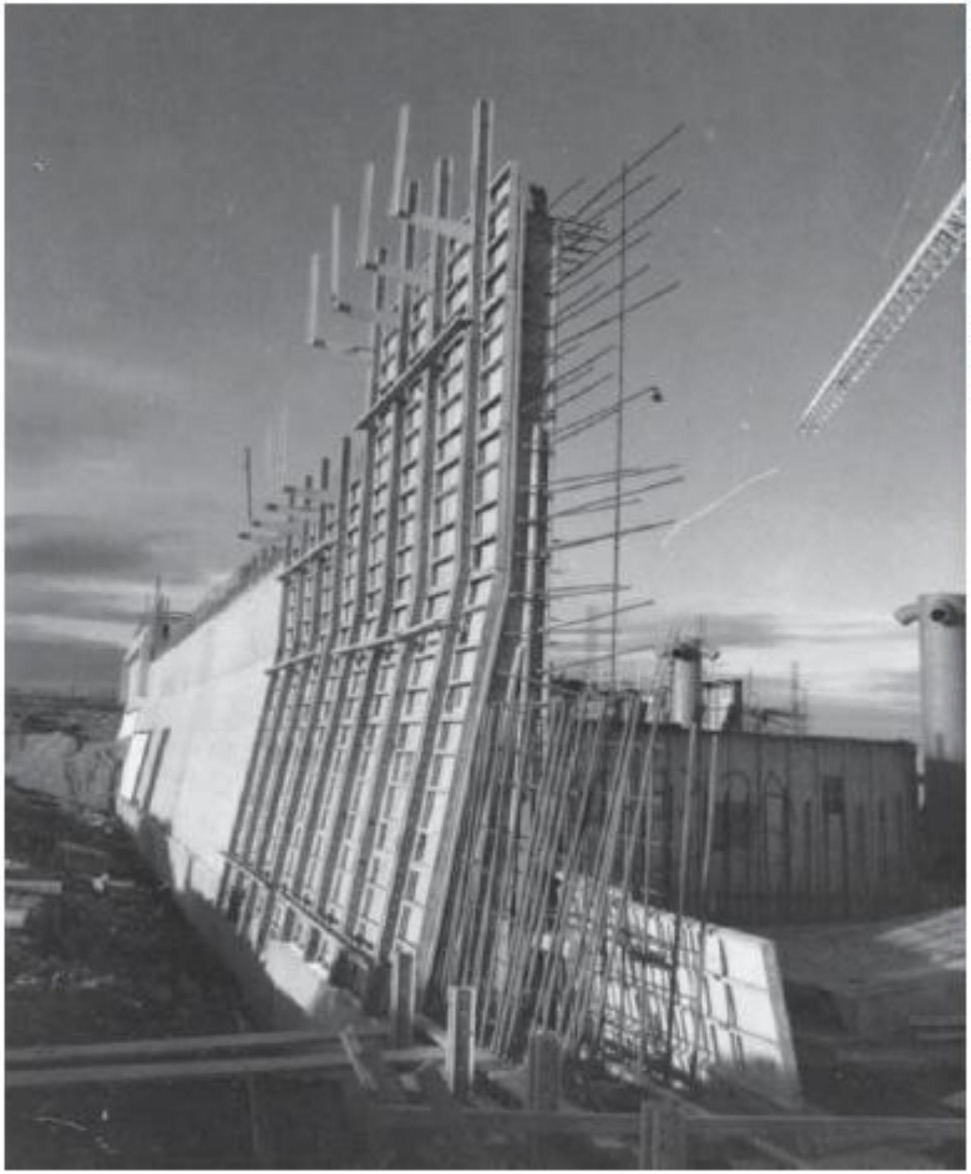
TABLE 1.3 Some Typical Uniformly Distributed Live Loads

Lobbies of assembly areas	100 psf	Classrooms in schools	40 psf
Dance hall and ballrooms	100 psf	Upper-floor corridors in schools	80 psf
Library reading rooms	60 psf	Stairs and exitways	100 psf
Library stack rooms	150 psf	Heavy storage warehouse	250 psf
Light manufacturing	125 psf	Retail stores—first floor	100 psf
Offices in office buildings	50 psf	Retail stores—upper floors	75 psf
Residential dwelling areas	40 psf	Walkways and elevated platforms	60 psf

psf = pounds per square foot

Live load reductions are permitted, according to Section 4.8 of ASCE 7, because is it unlikely that the entire structure will be subjected to its full design live load over its entire floor area all at one time. This reduction can significantly reduce the total design live load on a structure, resulting in much lower column loads at lower floors and footing loads.

Live Loads


Courtesy of The Burke Company.

Sewage treatment plant, Redwood City, California.

Environmental Loads

Environmental Loads

Environmental loads are loads caused by the environment in which the structure is located. **For buildings, they are caused by rain, snow, wind, temperature change, and earthquake.** Strictly speaking, these are also live loads, but they are the result of the environment in which the structure is located. Although they do vary with time, they are not all caused by gravity or operating conditions, as is typical with other live loads. In the next few paragraphs, a few comments are made about the various kinds of environmental loads.

1. ***Snow and ice.*** In the colder states, snow and ice loads are often quite important. One inch of snow is equivalent to approximately 0.5 psf, but it may be higher at lower elevations where snow is denser. For roof designs, snow loads of from 10 psf to 40 psf are

Environmental Loads

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 might be used for flat roofs.

Snow is a variable load, which may cover an entire roof or only part of it. Snow may slide off one roof and onto a lower one.

Environmental Loads

2. ***Rain.*** Although 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 equilibrium is reached or until collapse occurs.

Environmental Loads

3. ***Wind.*** 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 (Tacoma, Washington)** in 1940. There have also been some disastrous building failures from 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 from wind have occurred during the buildings' erection.

Environmental Loads

The magnitude and duration of wind loads vary with geographical locations, the heights of structures above ground, the types of terrain around the structures, the proximity of other buildings, the location with in the structure, and the character of the wind itself.

Environmental Loads

The basic form of the equation presented in the specification is

$$p = qCG$$

In this equation, *p* is the estimated wind load (in psf) acting on the structure. This wind load will vary with height above the ground and with the location on the structure. The quantity, *q*, is the reference velocity pressure. It varies with height and with exposure to the wind. The aerodynamic shape factor, *C*, is dependent upon the shape and orientation of the building with respect to the direction from which the wind is blowing. Lastly, the gust response factor, *G*, is dependent upon the nature of the wind and the location of the building. Other considerations in determining design wind pressure include importance factor and surface roughness.

Environmental Loads

4. *Seismic loads.* Many areas of the world are 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. 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. The 2008 earthquake in Sichuan Province, China, caused 69,000 fatalities and another 18,000 missing.

Environmental Loads

Recent earthquakes have clearly shown that the average building or bridge that has not been designed for earthquake forces can be destroyed by an earthquake that is not particularly severe. Most structures can be economically designed and constructed to withstand the forces caused during most earthquakes. The cost of providing seismic resistance to existing structures (called *retrofitting*), however, can be extremely high.

Some engineers seem to think that the seismic loads to be used in design are merely percentage increases of the wind loads. This assumption is incorrect, however, as seismic loads are different in their action and are not proportional to the exposed area of the building but rather are proportional to the distribution of the mass of the building above the particular level being considered.

Environmental Loads

Another factor to be considered in seismic design is the soil condition. Almost all of the structural damage and loss of life in the Loma Prieta earthquake occurred in areas that have soft clay soils. Apparently these soils amplified the motions of the underlying rock. It is well to understand that earthquakes load structures in an indirect fashion. The ground is displaced, and because the structures are connected to the ground, they are also displaced and vibrated. As a result, various deformations and stresses are caused throughout the structures.

From the preceding information, you can understand that no external forces are applied aboveground by earthquakes to structures.

Selection of Design Loads

Selection of Design Loads

To assist the designer in estimating the magnitudes of live loads with which he or she should proportion structures, various records have been assembled through the years in the form of building codes and specifications. These publications provide conservative estimates of live load magnitudes for various situations. One of the most widely used design-load specifications for buildings is that published by the American Society of Civil Engineers (ASCE).

The designer is usually fairly well controlled in the design of live loads by the building code requirements in his or her particular area. Unfortunately, the values given in these various codes vary from city to city, and the designer must be sure to meet the requirements of a particular locality. In the absence of a governing code, the ASCE Code is an excellent one to follow.

Selection of Design Loads

Courtesy of EFCO Corp.

Croke Park Stadium, Dublin, Ireland.

Selection of Design Loads

Some other commonly used specifications are:

1. For railroad bridges, American Railway Engineering Association (AREA).
2. For highway bridges, American Association of State Highway and Transportation Officials (AASHTO).
3. For buildings, the International Building Code (IBC).

These specifications will on many occasions clearly prescribe the loads for which structures are to be designed. Despite the availability of this information, the designer’s ingenuity and knowledge of the situation are often needed to predict what loads a particular structure will have to support in years to come. Over the past several decades, insufficient estimates of future traffic loads by bridge designers have resulted in a great number of replacements with wider and stronger structures.