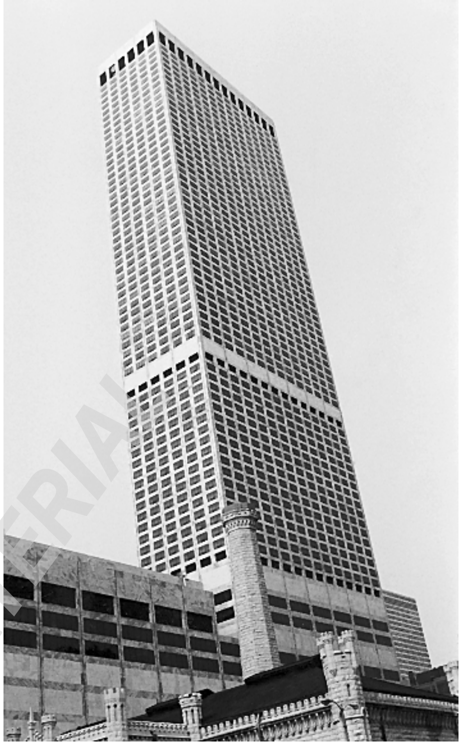
CHAPTER 1

INTRODUCTION



Water Tower Place, Chicago, 74 stories, tallest concrete building in the United States.

1.1 STRUCTURAL CONCRETE

The design of different structures is achieved by performing, in general, two main steps: (1) determining the different forces acting on the structure using proper methods of structural analysis, and (2) proportioning all structural members economically, considering the safety, stability, serviceability, and functionality of the structure. Structural concrete is one of the materials commonly used to design all types of buildings. Its two component materials, concrete and steel, work together to form structural members that can resist many types of loadings. The key to its performance lies in strengths that are complementary: Concrete resists compression and steel reinforcement resists tension forces.

The term *structural concrete* indicates all types of concrete used in structural applications. Structural concrete may be plain, reinforced, prestressed, or partially prestressed concrete; in addition, concrete is used in composite design. Composite design is used for any structural member, such as beams or columns, when the member contains a combination of concrete and steel shapes.

1.2 HISTORICAL BACKGROUND

The first modern record of concrete is as early as 1760, when John Smeaton used it in Britain in the first lock on the river Calder [1]. The walls of the lock were made of stones filled in with concrete. In 1796, J. Parker discovered Roman natural cement, and 15 years later Vicat burned a mixture of clay and lime to produce cement. In 1824, Joseph Aspdin manufactured portland cement in Wakefield, Britain. It was called portland cement because when it hardened, it resembled stone from the quarries of the Isle of Portland.

In France, François Marte Le Brun built a concrete house in 1832 in Moissac, in which he used concrete arches of 18-ft span. He used concrete to build a school in St. Aignan in 1834 and a church in Corbarièce in 1835. Joseph Louis Lambot [2] exhibited a small rowboat made of reinforced concrete at the Paris Exposition in 1854. In the same year, W. B. Wilkinson of England obtained a patent for a concrete floor reinforced by twisted cables. The Frenchman François Cignet obtained his first patent in 1855 for his system of iron bars, which were embedded in concrete floors and extended to the supports. One year later, he added nuts at the screw ends of the bars, and in 1869, he published a book describing the applications of reinforced concrete.

Joseph Monier, who obtained his patent in Paris on July 16, 1867, was given credit for the invention of reinforced concrete [3]. He made garden tubs and pots of concrete reinforced with iron mesh, which he exhibited in Paris in 1867. In 1873, he registered a patent to use reinforced concrete in tanks and bridges, and four years later, he registered another patent to use it in beams and columns [1].

In the United States, Thaddeus Hyatt conducted flexural tests on 50 beams that contained iron bars as tension reinforcement and published the results in 1877. He found that both concrete and steel can be assumed to behave in a homogeneous manner for all practical purposes. This assumption was important for the design of reinforced concrete members using elastic theory. He used prefabricated slabs in his experiments and considered prefabricated units to be best cast in T-sections and placed side by side to form a floor slab. Hyatt is generally credited with developing the principles upon which the analysis and design of reinforced concrete are now based.

A reinforced concrete house was built by W. E. Ward near Port Chester, New York, in 1875. It used reinforced concrete for walls, beams, slabs, and staircases. P. B. In 1877, Write described in the *American Architect and Building News* the applications of reinforced concrete in Ward's house as a new method in building construction.

E. L. Ransome, head of the Concrete Steel Company in San Francisco, used reinforced concrete in 1879 and deformed bars for the first time in 1884. During 1889–1891, he built the two-story Leland Stanford Museum in San Francisco using reinforced concrete. He also built a reinforced concrete bridge in San Francisco. In 1900, after Ransome introduced the reinforced concrete skeleton, the thick wall system started to disappear in construction. He registered the skeleton type of structure in 1902, using spiral reinforcement in the columns as was suggested by Armand Considére of France. A. N. Talbot, of the University of Illinois, and F. E. Turneaure and M. O. Withney, of the University of Wisconsin, conducted extensive tests on concrete to determine its behavior, compressive strength, and modulus of elasticity.

In Germany, G. A. Wayass bought the French Monier patent in 1879 and published his book on Monier methods of construction in 1887. Rudolph Schuster bought the patent rights in Austria, and the name of Monier spread throughout Europe, which is the main reason for crediting Monier as the inventor of reinforced concrete.

In 1900, the Ministry of Public Works in France called for a committee headed by Armand Considére, chief engineer of roads and bridges, to establish specifications for reinforced concrete, which were published in 1906.

Reinforced concrete was further refined by introducing some precompression in the tension zone to decrease the excessive cracks. This refinement was the preliminary introduction of partial and full prestressing. In 1928, Eugene Freyssinet established the practical technique of using prestressed concrete [4].

The Barwick House, a three-story concrete building built in 1905, Montreal, Canada.

From 1915 to 1935, research was conducted on axially loaded columns and creep effects on concrete; in 1940, eccentrically loaded columns were investigated. Ultimate-strength design started to receive special attention, in addition to diagonal tension and prestressed concrete. The American Concrete Institute Code (ACI Code) specified the use of ultimate-strength design in 1963 and included this method in all later codes. Building codes and specifications for the design of reinforced concrete structures are established in most countries, and research continues on developing new applications and more economical designs.

1.3 ADVANTAGES AND DISADVANTAGES OF REINFORCED CONCRETE

Reinforced concrete, as a structural material, is widely used in many types of structures. It is competitive with steel if economically designed and executed.

The advantages of reinforced concrete can be summarized as follows:

1. It has a relatively high compressive strength.
2. It has better resistance to fire than steel.
3. It has a long service life with low maintenance cost.
4. In some types of structures, such as dams, piers, and footings, it is the most economical structural material.
5. It can be cast to take the shape required, making it widely used in precast structural components. It yields rigid members with minimum apparent deflection.

The disadvantages of reinforced concrete can be summarized as follows:

1. It has a low tensile strength of about one-tenth of its compressive strength.
2. It needs mixing, casting, and curing, all of which affect the final strength of concrete.
3. The cost of the forms used to cast concrete is relatively high. The cost of form material and artisanry may equal the cost of concrete placed in the forms.
4. It has a low compressive strength as compared to steel (the ratio is about 1:10, depending on materials), which leads to large sections in columns of multistory buildings.
5. Cracks develop in concrete due to shrinkage and the application of live loads.

1.4 CODES OF PRACTICE

The design engineer is usually guided by specifications called the codes of practice. Engineering specifications are set up by various organizations to represent the minimum requirements necessary for the safety of the public, although they are not necessarily for the purpose of restricting engineers.

Most codes specify design loads, allowable stresses, material quality, construction types, and other requirements for building construction. The most significant code for structural concrete design in the United States is the Building Code Requirements for Structural Concrete, ACI 318, or the ACI Code. Most of the design examples of this book are based on this code. Other codes of practice and material specifications in the United States include the International Code, the Uniform Building Code, Standard Building Code, National Building Code, Basic Building Code, South Florida Building Code, American Association of State Highway and Transportation Officials (AASHTO) specifications, and specifications issued by the American Society for Testing and Materials (ASTM), American Railway Engineering Association (AREA), and Bureau of Reclamation, Department of the Interior.

Different codes other than those of the United States include the British Standard (BS) Code of Practice for Reinforced Concrete, CP 110 and BS 8110; the National Building Code of Canada; the German Code of Practice for Reinforced Concrete, DIN 1045; Specifications for Steel Reinforcement (U.S.S.R.); and Technical Specifications for the Theory and Design of Reinforced Concrete Structures, CC-BA (France), and the CEB Code (Comitè European Du Beton).

1.5 DESIGN PHILOSOPHY AND CONCEPTS

The design of a structure may be regarded as the process of selecting the proper materials and proportioning the different elements of the structure according to state-of-the-art engineering science and technology. In order to fulfill its purpose, the structure must meet the conditions of safety, serviceability, economy, and functionality. This can be achieved using design approach-based strain limits in concrete and steel reinforcement.

The unified design method (UDM) is based on the strength of structural members assuming a failure condition, whether due to the crushing of the concrete or to the yield of the reinforcing steel bars. Although there is some additional strength in the bars after yielding (due to strain hardening), this additional strength is not considered in the analysis of reinforced concrete members. In this approach, the actual loads, or working loads, are multiplied by load factors to obtain the factored design loads. The load factors represent a high percentage of the factor for safety required in the design. Details of this method are presented in Chapters 3, 4, and 11. The

ACI Code emphasizes this method of design, and its provisions are presented in the body of the Code. The reason for introducing this approach by the ACI Code relates to the fact that different design methods were developed for reinforced and prestressed concrete beams and columns. Also, design procedures for prestressed concrete were different from reinforced concrete. The purpose of the Code approach is to simplify and unify the design requirements for reinforced and prestressed flexural members and compression members.

A second approach for the design of reinforced and prestressed concrete flexural and compression members is called the strength design method, or the alternative provisions (ADM), as introduced in the ACI Code, Appendix B. When this method is used in the design, the designer must adhere to all sections of Appendixes B and C and substitute accordingly for the corresponding sections of the Code. Reinforcement limits, strength reduction factors, load factors, and moment redistribution are affected. The provisions of this method satisfy the Code and are equally acceptable.

A third approach for the design of concrete members is called the strut and tie method (STM). The provisions of this method are introduced in the ACI Code, Appendix A. It applies effectively in regions of discontinuity such as support and load applications on beams. Consequently, the structural element is divided into segments and then analyzed using the truss analogy approach, where the concrete resists compression forces as a strut, while the steel reinforcement resists tensile forces as a tie.

A basic method that is not commonly used is called the working stress design or the elastic design method. The design concept is based on the elastic theory assuming a straight line stress distribution along the depth of the concrete section under service loads. The members are proportioned on the basis of certain allowable stresses in concrete and steel. The allowable stresses are fractions of the crushing strength of concrete and yield strength of steel. This method has been deleted from the ACI Code. The application of this approach is still used in the design of prestressed concrete members under service load conditions, as shown in Chapter 19.

Limit state design is a further step in the strength design method. It indicates the state of the member in which it ceases to meet the service requirements such as losing its ability to withstand external loads, or suffering excessive deformation, cracking, or local damage. According to the limit state design, reinforced concrete members have to be analyzed with regard to three limiting states:

1. Load carrying capacity (safety, stability, and durability)
2. Deformation (deflections, vibrations, and impact)
3. The formation of cracks.

The aim of this analysis is to ensure that no limiting state will appear in the structural member during its service life.

1.6 UNITS OF MEASUREMENT

Two units of measurement are commonly used in the design of structural concrete. The first is the U.S. customary system (lying mostly in its human scale and its ingenious use of simple numerical proportions), and the second is the SI (Le Système International d'Unités), or metric, system.

The metric system is planned to be in universal use within the coming few years. The United States is committed to change to SI units. Great Britain, Canada, Australia, and other countries have been using SI units for several years.

The base units in the SI system are the units of length, mass, and time, which are the meter (m), the kilogram (kg), and the second (s), respectively. The unit of force, a derived unit called the newton (N), is defined as the force that gives the acceleration of 1 meter per second per second ($1\,\text{m/s}^2$) to a mass of 1 kg, or $1\,\text{N} = 1\,\text{kg} \times \text{m/s}^2$.

The weight of a body, W, which is equal to the mass, m, multiplied by the local gravitational acceleration, g ($9.81\,\text{m/s}^2$), is expressed in newtons (N). The weight of a body of 1 kg mass is $W = mg = 1\,\text{kg} \times 9.81\,\text{m/s}^2 = 9.81\,\text{N}$.

Multiples and submultiples of the base SI units can be expressed through the use of prefixes. The prefixes most frequently used in structural calculations are the kilo (k), mega (M), milli (m), and micro (μ). For example,

$$1\text{ km} = 1000\text{ m} \quad 1\text{ mm} = 0.001\text{ m} \quad 1\,\mu\text{m} = 10^{-6}\text{ m}$$

$$1\text{ kN} = 1000\text{ N} \quad 1\text{ Mg} = 1000\text{ kg} = 10^{6}\text{ g}$$

1.7 LOADS

Structural members must be designed to support specific loads.

Loads are those forces for which a given structure should be proportioned. In general, loads may be classified as dead or live.

Dead loads include the weight of the structure (its self-weight) and any permanent material placed on the structure, such as tiles, roofing materials, and walls. Dead loads can be determined with a high degree of accuracy from the dimensions of the elements and the unit weight of materials.

Live loads are all other loads that are not dead loads. They may be steady or unsteady or movable or moving; they may be applied slowly, suddenly, vertically, or laterally, and their magnitudes may fluctuate with time. In general, live loads include the following:

- Occupancy loads caused by the weight of the people, furniture, and goods
- Forces resulting from wind action and temperature changes
- The weight of snow if accumulation is probable
- The pressure of liquids or earth on retaining structures
- The weight of traffic on a bridge
- Dynamic forces resulting from moving loads (impact), earthquakes, or blast loading

The ACI Code does not specify loads on structures; however, occupancy loads on different types of buildings are prescribed by the American National Standards Institute (ANSI) [5]. Some typical values are shown in Table 1.1. Table 1.2 on page 7 shows weights and specific gravity of various materials.

AASHTO and AREA specifications prescribe vehicle loadings on highway and railway bridges, respectively. These loads are given in Refs. 6 and 7.

Snow loads on structures may vary between 10 and $40\,\text{lb/ft}^2$ (0.5 and $2\,\text{kN/m}^2$), depending on the local climate.

Wind loads may vary between 15 and $30\,\text{lb/ft}^2$, depending on the velocity of wind. The wind pressure of a structure, F, can be estimated from the following equation:

$$F = 0.00256 C_s V^2 \tag{1.1}$$

where

V = velocity of air (mi/h)
C_s = shape factor of the structure
F = the dynamic wind pressure (lb/ft^2)

Table 1.1 Typical Uniformly Distributed Design Loads

		Design Live Load	
Occupancy	**Contents**	**lb/ft^2**	**kN/m^2**
Assembly hall	Fixed seats	60	2.9
	Movable seats	100	4.8
Hospital	Operating rooms	60	2.9
	Private rooms	40	1.9
Hotel	Guest rooms	40	1.9
	Public rooms	100	4.8
	Balconies	100	4.8
Housing	Private houses and apartments	40	1.9
	Public rooms	100	4.8
Institution	Classrooms	40	1.9
	Corridors	100	4.8
Library	Reading rooms	60	2.9
	Stack rooms	150	7.2
Office building	Offices	50	2.4
	Lobbies	100	4.8
Stairs (or balconies)		100	4.8
Storage warehouses	Light	100	4.8
	Heavy	250	12.0
Yards and terraces		100	4.8

Table 1.2 Density and Specific Gravity of Various Materials

	Density		
Material	**lb/ft^3**	**kg/m^3**	**Specific Gravity**
Building materials			
Bricks	120	1,924	1.8–2.0
Cement, portland, loose	90	1,443	—
Cement, portland, set	183	2,933	2.7–3.2
Earth, dry, packed	95	1,523	—
Sand or gravel, dry, packed	100–120	1,600–1,924	—
Sand or gravel, wet	118–120	1,892–1,924	—
Liquids			
Oils	58	930	0.9–0.94
Water (at 4 °C)	62.4	1,000	1.0
Ice	56	898	0.88–0.92
Metals and minerals			
Aluminum	165	2,645	2.55–2.75
Copper	556	8,913	9.0
Iron	450	7,214	7.2
Lead	710	11,380	11.38
Steel, rolled	490	7,855	7.85
Limestone or marble	165	2,645	2.5–2.8
Sandstone	147	2,356	2.2–2.5
Shale or slate	175	2,805	2.7–2.9
Normal-weight concrete			
Plain	145	2,324	2.2–2.4
Reinforced or prestressed	150	2,405	2.3–2.5

As an example, for a wind of 100 mi/h with $C_s = 1$, the wind pressure is equal to 25.6 lb/ft^2. It is sometimes necessary to consider the effect of gusts in computing the wind pressure by multiplying the wind velocity in Eq. 1.1 by a gust factor, which generally varies between 1.1 and 1.3.

The shape factor, C_s, varies with the horizontal angle of incidence of the wind. On vertical surfaces of rectangular buildings, C_s may vary between 1.2 and 1.3. Detailed information on wind loads can be found in Ref. 5.

1.8 SAFETY PROVISIONS

Structural members must always be proportioned to resist loads greater than the service or actual load in order to provide proper safety against failure. In the strength design method, the member is designed to resist factored loads, which are obtained by multiplying the service loads by load factors. Different factors are used for different loadings. Because dead loads can be estimated quite accurately, their load factors are smaller than those of live loads, which have a high degree of uncertainty. Several load combinations must be considered in the design to compute the maximum and minimum design forces. Reduction factors are used for some combinations of loads to reflect the low probability of their simultaneous occurrences. The ACI Code presents specific values of load factors to be used in the design of concrete structures (see Chapter 3, Section 3.5).

In addition to load factors, the ACI Code specifies another factor to allow an additional reserve in the capacity of the structural member. The nominal strength is generally calculated using accepted analytical procedure based on statistics and equilibrium; however, in order to account for the degree of accuracy within which the nominal strength can be calculated, and for adverse variations in materials and dimensions, a strength reduction factor, ϕ, should be used in the strength design method. Values of the strength reduction factors are given in Chapter 3, Section 3.6.

To summarize the above discussion, the ACI Code has separated the safety provision into an overload or load factor and to an undercapacity (or strength reduction) factor, ϕ. A safe design is achieved when the structure's strength, obtained by multiplying the nominal strength by the reduction factor, ϕ, exceeds or equals the strength needed to withstand the factored loadings (service loads times their load factors). For example,

$$M_u \leq \phi M_n \quad \text{and} \quad V_u \leq \phi V_n \tag{1.2}$$

where

M_u and V_u = external factored moment and shear forces

M_n and V_n = nominal flexural strength and shear strength of the member, respectively

Given a load factor of 1.2 for dead load and a load factor of 1.6 for live load, the overall safety factor for a structure loaded by a dead load, D, and a live load, L, is

$$\text{Factor of safety} = \frac{1.2D + 1.6L}{D + L}\left(\frac{1}{\phi}\right) = \frac{1.2 + 1.6(L/D)}{1 + (L/D)}\left(\frac{1}{\phi}\right) \tag{1.3}$$

The factor of safety for the various values of ϕ and L/D ratios is shown below.

ϕ	**0.9**				**0.8**				**0.7**			
L/D	0	1	2	3	0	1	2	3	0	1	2	3
Factor of Safety	1.33	1.56	1.63	1.67	1.50	1.74	1.83	1.88	1.71	2.00	2.10	2.15

For members subjected to flexure (beams), with tension-controlled sections, $\phi = 0.9$, and the factor of safety ranges between 1.33 for $L/D = 0$ and 1.67 for $L/D = 3$. These values are less than those specified by the ACI Code 318–99 of 1.56 for $L/D = 0$ and 1.81 for $L/D = 3.0$ based on load factors of 1.4 for the dead load and 1.7 for the live load. This reduction ranges between 17 and 8% respectively.

For members subjected to axial forces (spiral columns), $\phi = 0.7$, and the factor of safety ranges between 1.71 for $L/D = 0$ and 2.15 for $L/D = 3$. The increase in the factor of safety in columns reflects the greater overall safety requirements of these critical building elements.

A general format of Eq. 1.2 may be written as follows [8]:

$$\phi R \geq \upsilon_0 \Sigma(\upsilon_i Q_i) \tag{1.4}$$

where

R_n = nominal strength of the structural number
ϕ = undercapacity factor (<1.0)
ΣQ_i = sum of load effects
υ_i = overload factor
υ_0 = analysis factor (>1.0)

The subscript i indicates the load type, such as dead load, live load, and wind load. The analysis factor, υ_0, is greater than 1.0 and is introduced to account for uncertainties in structural analysis. The overload factor, υ_i, is introduced to account for several factors such as an increase in live load due to a change in the use of the structure and variations in erection procedures. The design concept is referred to as load and resistance factor design (LRFD) [8,9].

1.9 STRUCTURAL CONCRETE ELEMENTS

Structural concrete can be used for almost all buildings, whether single story or multistory. The concrete building may contain some or all of the following main structural elements, which are explained in detail in other chapters of the book:

- *Slabs* are horizontal plate elements in building floors and roofs. They may carry gravity loads as well as lateral loads. The depth of the slab is usually very small relative to its length or width (Chapters 9 and 17).
- *Beams* are long, horizontal or inclined members with limited width and depth. Their main function is to support loads from slabs (Chapters 3 and 4).
- *Columns* are critical members that support loads from beams or slabs. They may be subjected to axial loads or axial loads and moments (Chapters 10 and 11).
- *Frames* are structural members that consist of a combination of beams and columns or slabs, beams, and columns. They may be statically determinate or statically indeterminate frames (Chapter 16).
- *Footings* are pads or strips that support columns and spread their loads directly to the soil (Chapter 13).
- *Walls* are vertical plate elements resisting gravity as well as lateral loads as in the case of basement walls (Chapter 14).

1.10 STRUCTURAL CONCRETE DESIGN

The first step in the design of a building is the general planning carried out by the architect to determine the layout of each floor of the building to meet the owner's requirements. Once the architectural plans are approved, the structural engineer then determines the most adequate structural system to ensure the safety and stability of the building. Different structural options must be considered to determine the most economical solution based on the materials available and the soil condition. This result is normally achieved by

1. Idealizing the building into a structural model of load-bearing frames and elements
2. Estimating the different types of loads acting on the building
3. Performing the structural analysis using computer or manual calculations to determine the maximum moments, shear, torsional forces, axial loads, and other forces
4. Proportioning the different structural elements and calculating the reinforcement needed
5. Producing structural drawings and specifications with enough details to enable the contractor to construct the building properly

1.11 ACCURACY OF CALCULATIONS

In the design of concrete structures, exact calculations to determine the size of the concrete elements are not needed. Calculators and computers can give an answer to many figures after the decimal point. For a practical size of a beam, slab, or column, each dimension should be approximated to the nearest 1 or $\frac{1}{2}$ inch. Moreover, the steel bars available in the market are limited to specific diameters and areas, as shown in Table A.12 (Appendix A). The designer should choose a group of bars from the table with an area equal to or greater than the area obtained from calculations. Also, the design equations in this book based on the ACI Code are approximate. Therefore, for a practical and economical design, it is adequate to use four figures (or the full number with no fractions if it is greater than four figures) for the calculation of forces, stresses, moments, or dimensions such as length or width of section. For strains, use five or six figures because strains are very small quantities measured in a millionth of an inch (for example, a strain of 0.000358 in./in.). Stresses are obtained by multiplying the strains by the modulus of elasticity of the material, which has a high magnitude (for example, 29,000,000 lb/in.^{2}) for steel. Any figures less than five or six figures in strains will produce quite a change in stresses.

Examples

For forces, use 28.45 K, 2845 lb, 567.8 K (four figures).
For force/length, use 2.451 K/ft or 2451 lb/ft.
For length or width, use 14.63 in., 1.219 ft (or 1.22 ft).
For areas, use 7.537 in.^{2}, and for volumes, use 48.72 in.^{3}.
For strains, use 0.002078.

1.12 CONCRETE HIGH-RISE BUILDINGS

High-rise buildings are becoming the dominant feature of many U.S. cities; a great number of these buildings are designed and constructed in structural concrete.

Although at the beginning of the century the properties of concrete and joint behavior of steel and concrete were not fully understood, a 16-story building, the Ingalls Building, was constructed in Cincinnati in 1902 with a total height of 210 ft (64 m). In 1922, the Medical Arts Building, with a height of 230 ft (70 m), was constructed in Dallas, Texas. The design of concrete buildings was based on elastic theory concepts and a high factor of safety, resulting in large concrete sections in beams and columns. After extensive research, high-strength concrete and high-strength steel were allowed in the design of reinforced concrete members. Consequently, small concrete sections as well as savings in materials were achieved, and new concepts of structural design were possible.

To visualize how high concrete buildings can be built, some structural concrete skyscrapers are listed in Table 1.3. The CN Tower is the world's tallest free-standing concrete structure.

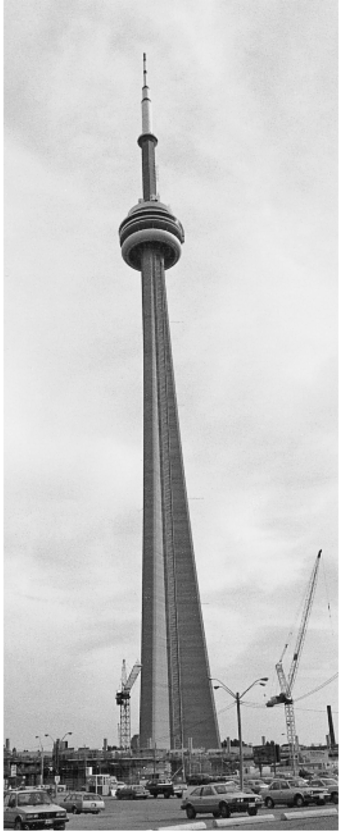
The reader should realize that most concrete buildings are relatively low and range from one to five stories. Skyscrapers and high-rise buildings constitute less than 10% of all concrete buildings.

Photos of some different concrete buildings and structures are shown.

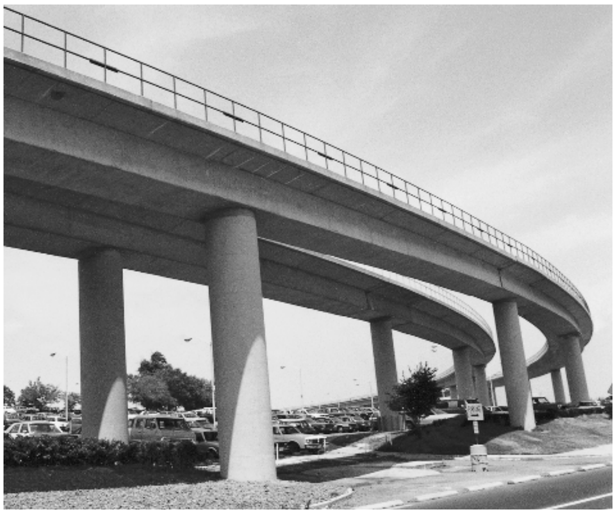
Renaissance Center, Detroit, Michigan.

Marina City Towers, Chicago, Illinois.

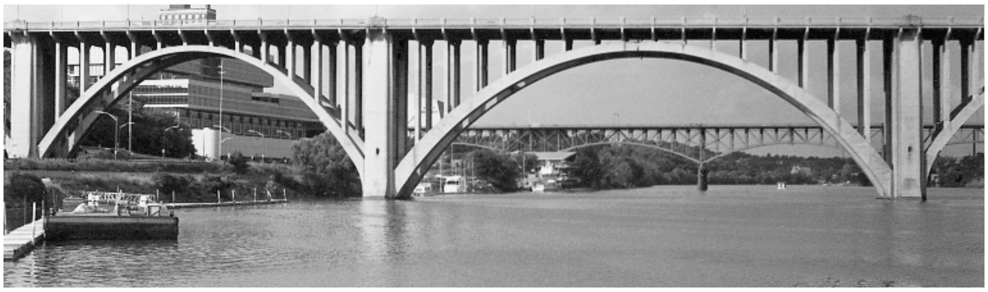
City Center, Minneapolis, Minnesota.



CN Tower, Toronto, Canada (height 1465 ft, or 447 m).



Concrete bridge for the city transit system, Washington, DC.



Concrete bridge, Knoxville, Tennessee.

Reinforced concrete grain silo using the slip form system, Brookings, South Dakota.

Table 1.3 Examples of Reinforced Concrete Skyscrapers

Year	Structure	Location	Stories	Height, ft (m)
1965	Lake Point Tower	Chicago	70	645 (197)
1969	One Shell Plaza	Houston	52	714 (218)
1975	Peachtree Center Plaza Hotel	Atlanta	71	723 (220)
1976	Water Tower Place	Chicago	74	859 (262)
1976	CN Tower	Toronto	—	1465 (447)
1977	Renaissance Center Westin Hotel	Detroit	73	740 (226)
1983	City Center	Minneapolis	40	528 (158)

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