

CHAPTER 1

Introduction

1.1 Reinforced Concrete

1.1.1 Definition of Reinforced Concrete

Reinforced concrete is concrete in which reinforcing bars or other types of reinforcement have been integrated to improve one or more properties of the concrete. For many years, it has been utilized as an economical construction material in one form or another in buildings, bridges, and many other types of structures throughout the world. A large part of its worldwide appeal is that the basic constituent materials—cement, sand, aggregate, water, and reinforcing bars—are widely available and that it is possible to construct a structure using local sources of labor and materials.

In addition to being readily obtainable, reinforced concrete has been universally accepted because it can be molded essentially into any shape or form, is inherently rigid, and is inherently fire-resistant. With proper protection of the reinforcement, a reinforced concrete structure can be very durable and can have a long life even under harsh climatic or environmental conditions. Reinforced concrete structures have also demonstrated that they can provide a safe haven from the potentially devastating effects of earthquakes, hurricanes, floods, and tornadoes.

Based on these and other advantages, it is evident that reinforced concrete can provide viable and cost-effective solutions in a variety of applications. This book focuses on the design of reinforced concrete members in building structures.

1.1.2 Mechanics of Reinforced Concrete

Concrete is a brittle, composite material that is strong in compression and weak in tension. Cracking occurs when the concrete tensile stress in a member reaches the tensile strength due to externally applied loads, temperature changes, or shrinkage. Concrete members that do not have any type of reinforcement in them will typically fail very suddenly once the first tension cracks form because there is nothing to prevent the cracks from propagating completely through the member.

Consider the simply-supported, unreinforced concrete beam shown in Fig. 1.1 that is subjected to a concentrated load P at midspan. From strength of materials, the maximum tensile bending stress occurs at the bottom fibers of the beam section at midspan and the maximum compressive bending stress occurs at the top fibers. Because concrete is stronger in compression than in tension, the beam will be able to support the concentrated load and its own weight as long as the maximum bending stress is less than the tensile strength of the concrete in bending (Fig. 1.1*a*). If the bending stress is equal to or

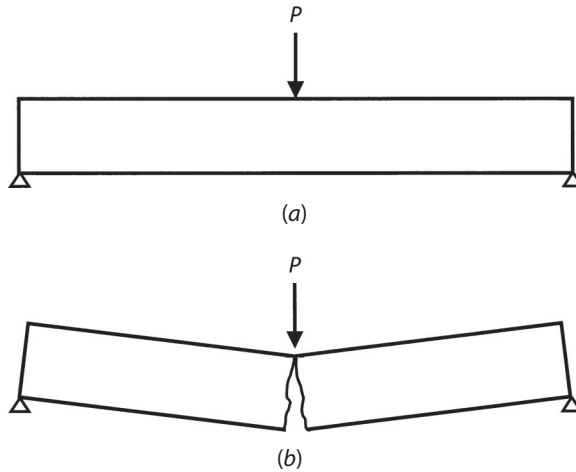


FIGURE 1.1 Response of a simply-supported, unreinforced concrete beam due to external loading. (a) Bending stress less than the tensile strength of the concrete in bending. (b) Bending stress greater than the tensile strength of the concrete in bending.

greater than the tensile strength, a crack will form immediately at the bottom fiber of the beam and it will propagate instantaneously to the top fiber, splitting the beam in two (Fig. 1.1*b*).

A different sequence of events would take place if reinforcing bars were present near the bottom of the simply-supported beam. Like in the case of an unreinforced concrete beam, a crack will form at the bottom fiber of the reinforced concrete beam at midspan when the bending stress is equal to or greater than the tensile strength of the concrete in bending. However, in contrast to the unreinforced beam, crack propagation will be arrested by the presence of the reinforcement, which has a much greater tensile strength than that of the concrete.

If the magnitude of the concentrated load increases, the crack at midspan will propagate upward in a stable manner and additional cracks will form at other locations along the span where the bending stress exceeds the tensile strength of the concrete (Fig. 1.2). Assuming that the beam has sufficient shear strength, this process continues until the concrete crushes in compression or until the reinforcement fails in tension. It is shown in subsequent chapters of this book that it is desirable to have the reinforcement fail in tension before the concrete fails in compression.

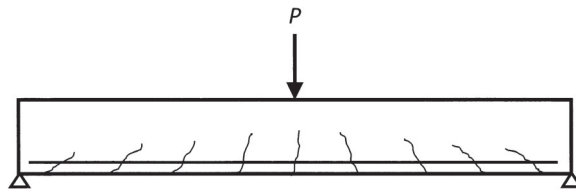


FIGURE 1.2 Response of a simply-supported, reinforced concrete beam due to external loading.

What is important to remember from this discussion is that reinforcement, which has a tensile strength much greater than that of concrete, is used to counteract tensile stresses in a reinforced concrete member, and that the reinforcement becomes effective in resisting tension only after cracking occurs. One of the major tasks in designing reinforced concrete members is to determine the required amount and location of reinforcement.

The focus of this book is on the design of reinforced concrete members in building structures where the primary reinforcement is steel reinforcing bars or steel wire reinforcement that is not prestressed. Such reinforcement is commonly referred to as *mild reinforcement* or *nonprestressed reinforcement*; a *nonprestressed concrete member* is a reinforced concrete member that contains this type of reinforcement. A discussion on the material properties of concrete and reinforcing steel is given in Chap. 2.

1.2 Building Codes and Standards

In the United States and throughout the world, the design and construction of building structures is regulated by building codes. The main purpose of a building code is to protect public health, safety, and welfare. Building code provisions are founded on principles that do not unnecessarily increase construction costs; do not restrict the use of new materials, products, or methods of construction; and do not give preferential treatment to particular types or classes of materials, products, or methods of construction.

Many cities, counties, and states in the United States and some international jurisdictions have adopted the *International Building Code*[®] (IBC[®]) for the design and construction of building structures. The provisions of the 2015 edition of the IBC are covered in this book.¹ Chapter 16 of the IBC prescribes minimum nominal loads that must be used in the design of any structure. Chapter 3 contains a summary of these loads as they pertain to the design of reinforced concrete buildings.

Section 1901.2 of the IBC requires that structural concrete be designed and constructed in accordance with the provisions of Chap. 19 of the IBC and the 2014 edition of *Building Code Requirements for Structural Concrete (ACI 318–14) and Commentary*.² ACI 318–14 is one of a number of codes and standards that are referenced by the IBC. These documents, which can be found in Chap. 35 of the 2015 IBC, are considered part of the requirements of the IBC to the prescribed extent of each reference (see Section 101.4 of the 2015 IBC). Modifications to ACI 318–14 are given in IBC Section 1905.

Even though it is an American Concrete Institute (ACI) standard, ACI 318 is commonly referred to as the “ACI Code” or the “Code.” The ACI Code provides minimum requirements for the design and construction of structural concrete members (see Section 1.2.5 of that document). The term “structural concrete” refers to all plain and reinforced concrete members used for structural purposes. Section 1.4 identifies the types of concrete members that are not addressed in the Code.

Throughout this book, section numbers from the 2015 IBC are referenced as illustrated by the following: Section 1901.2 is denoted as IBC 1901.2. Similarly, Section 10.2 of the ACI Code is referenced as ACI 10.2 and Section R10.2 of the Commentary is referenced as ACI R10.2. This book contains information, data, and equations from the Code in both inch-pound and SI units. SI equivalents immediately follow the inch-pound items.

It is important to acquire the building code of the local jurisdiction at the onset of any project. Local building authorities may have amended the IBC or other adopted

codes, and it is the responsibility of the registered design professional to be aware of such amendments before designing the building.

1.3 Strength and Serviceability

Design philosophies related to reinforced concrete members have changed over the years. Until the early 1960s, the primary design method for reinforced concrete was *working stress design*. In this method, members are proportioned so that the maximum elastic stresses due to service loads are less than or equal to allowable stresses prescribed in the Code.

The *strength design method* was included for the first time in the 1956 edition of the Code, and it became the preferred design method in the 1971 Code. The strength design method requires that both strength and serviceability requirements be satisfied in the design of any reinforced concrete member. In general, reinforced concrete members are proportioned to resist factored load effects and to satisfy requirements for deflection and cracking.

An in-depth discussion on the fundamental requirements of strength and serviceability is given in Chap. 4. Presented are the basic concepts of required strength (including load combinations) and design strength (including strength reduction factors).

Chapter 5 contains the general principles of the strength design method. This method is based on the fundamental conditions of static equilibrium and compatibility of strains. The information presented in this chapter forms the basis for the design of reinforced concrete sections subjected to flexure, axial load, or a combination of both.

1.4 Reinforced Concrete Members in Building Structures

1.4.1 Overview

Structural members in any structure must be designed to safely and economically support the weight of the structure and to resist all of the loads superimposed on the structure. In ordinary buildings, superimposed loads typically consist of live loads due to the inhabitants, dead loads due to items permanently attached to the building, and lateral loads due to wind or earthquakes. Some types of buildings must also be designed for extraordinary loads such as explosions or vehicular impact. Chapter 3 provides a discussion on loads commonly encountered in building structures.

A typical reinforced concrete building is made up of a variety of different reinforced concrete members. The members work together to support the applicable loads, which are transferred through load paths in the structure to the foundation members. The loads are ultimately supported by the soil or rock adjoining the foundations.

Unlike other typical types of construction commonly used in building structures, such as structural steel and timber, reinforced concrete construction possesses inherent continuity. Cast-in-place reinforced concrete structures are essentially monolithic with reinforcement that extends into adjoining members. As such, reinforced concrete members are analyzed as continuous members in a statically indeterminate structure where bending moments, shear forces, and axial forces are transferred through the joints. Understanding the behavior and response of a reinforced concrete structure is imperative in the proper analysis, design, and detailing of the members in the structure.

Chapters 6 through 11 of this book contain the design and detailing requirements for typical reinforced concrete members found in building structures. A summary of the different member types that are addressed in these chapters is given in the following sections.

It is important to note that the information presented in Chaps. 6 through 11 is applicable to the design of members in structures that are located in areas of low, moderate, and high seismic risk. Seismic risk is related to seismic design category (SDC), which is defined in IBC 1613.3.5. In general, SDC is determined on the basis of the level of seismicity and soil type at the site and on the risk category of the building. Buildings assigned to SDC A and B are located in areas of low seismic risk, whereas buildings assigned to SDC C are located in areas of moderate seismic risk. SDC D, E, and F are assigned to buildings located in areas of high seismic risk.

The provisions in ACI Chap. 18, which are applicable to structures assigned to SDC B through F, relate design and detailing requirements to the type of structural member and the SDC. The provisions of ACI Chaps. 1 through 17 and 19 through 26 must be satisfied for all members, and are considered to be adequate for structures assigned to SDC A. ACI Table R18.2 gives the sections of ACI Chap. 18 that need to be satisfied as a function of SDC.

It is important to point out that the information presented in Chaps. 6 through 11 forms the basis of design regardless of SDC. For example, the determination of the nominal moment strength of a beam is required in the design of that member no matter what SDC has been assigned to the building. The same is true in regard to the design strength interaction diagram for a column as well as for other important items.

Satisfying the requirements for SDC B is readily achievable for beams and columns without any special design or detailing. In particular, beams in structures assigned to SDC B must have at least two bars that are continuous at both the top and bottom of the section that must be developed at the face of the supports (ACI 18.3.2). This is usually satisfied in typical beams because these bars are needed over the full length to support the stirrups. In regard to columns, column dimensions in typical buildings are such that the clear height of the column is greater than five times the cross-sectional dimension of the column in the direction of analysis; thus, in many cases, the special shear requirements of ACI 18.3.3 need not be satisfied.

Methods to determine the SDC can be found in Chap. 11 and comprehensive design and detailing procedures for reinforced concrete members in all SDCs can be found in Chaps. 6 through 11.

1.4.2 Floor and Roof Systems

Overview

Reinforced concrete structural systems can be formed into virtually any geometry to meet any requirement. Regardless of the geometry, standardized floor and roof systems are available that provide cost-effective solutions in typical situations. The most common types are classified as one-way systems and two-way systems. Examined later are the structural members that make up these types of systems.

It is common for one type of floor or roof system to be specified on one entire level of a building; this is primarily done for cost savings. However, there may be cases that warrant a change in framing system. The feasibility of using more than one type of floor or roof system at any given level needs to be investigated carefully.

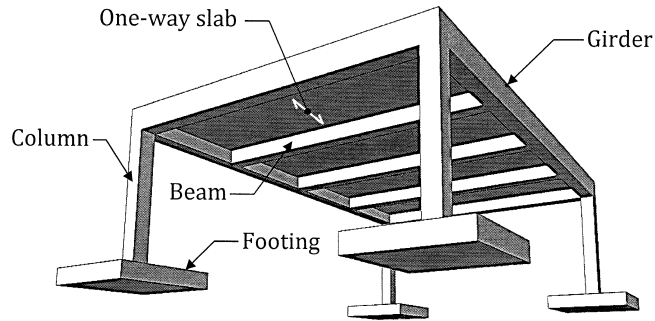


FIGURE 1.3 One-way slab system.

One-Way Systems

A one-way reinforced concrete floor or roof system consists of members that have the main flexural reinforcement running in one direction. In other words, reactions from supported loads are transferred primarily in one direction. Members in one-way systems are commonly beams and one-way slabs.

Beams and one-way slabs are usually horizontal but can be provided at a slope if needed. Sloped members are commonly used at the roof level to accommodate drainage requirements.

Illustrated in Fig. 1.3 is a *one-way slab system*. The load that is supported by the slabs is transferred to the beams that span perpendicular to the slabs. The beams, in turn, transfer the loads to the girders, and the girders transfer the loads to the columns (Note: a girder is a beam that usually supports one or more beams framing into it from one side or from two sides). Individual spread footings may carry the column loads to the soil below. It is evident that load transfer between the members of this system occurs in one direction.

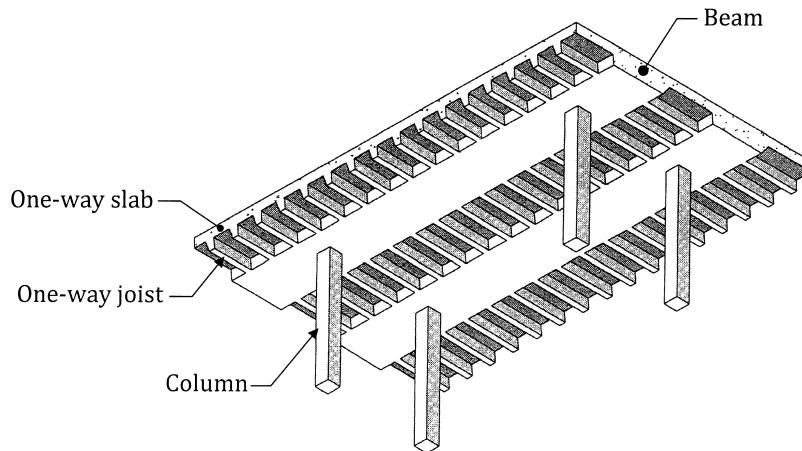


FIGURE 1.4 Standard one-way joist system.

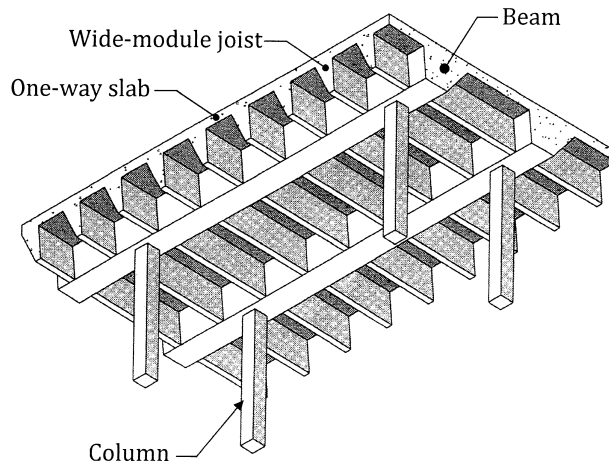


FIGURE 1.5 Wide-module joist system.

Main flexural reinforcement for the one-way slabs is placed in the direction parallel to load transfer, which is the short direction. Similarly, the main flexural reinforcement for the beams and girders is placed parallel to the length of these members. Concrete for the slabs, beams, and girders is cast at the same time after the forms have been set and the reinforcement has been placed in the formwork. This concrete is also integrated with columns. In addition, reinforcing bars are extended into adjoining members. Like all cast-in-place systems, this clearly illustrates the monolithic nature of reinforced concrete structural members.

A *standard one-way joist system* is depicted in Fig. 1.4. The one-way slab transfers the load to the joists, which transfer the loads to the column-line beams (or, girders). This system utilizes standard forms where the clear spacing between the ribs is 30 in or less. Because of its relatively heavy weight and associated costs, this system is not used as often as it was in the past.

Similar to the standard one-way joist system is the *wide-module joist system* shown in Fig. 1.5. The clear spacing of the ribs is typically 53 or 66 in, which, according to the Code, technically makes these members beams instead of joists. Load transfer follows the same path as that of the standard joist system.

Reinforced concrete stairs are needed as a means of egress in buildings regardless of the number of elevators that are provided. Many different types of stairs are available, and the type of stair utilized generally depends on architectural requirements. Stair systems are typically designed as one-way systems.

Design and detailing requirements for one-way systems (one-way slabs and beams) are given in Chap. 6.

Two-Way Systems

As the name suggests, two-way floor and roof systems transfer the supported loads in two directions. Flexural reinforcement must be provided in both directions.

A *two-way beam-supported slab system* is illustrated in Fig. 1.6. The slab transfers the load in two orthogonal directions to the column-line beams, which, in turn, transfer the

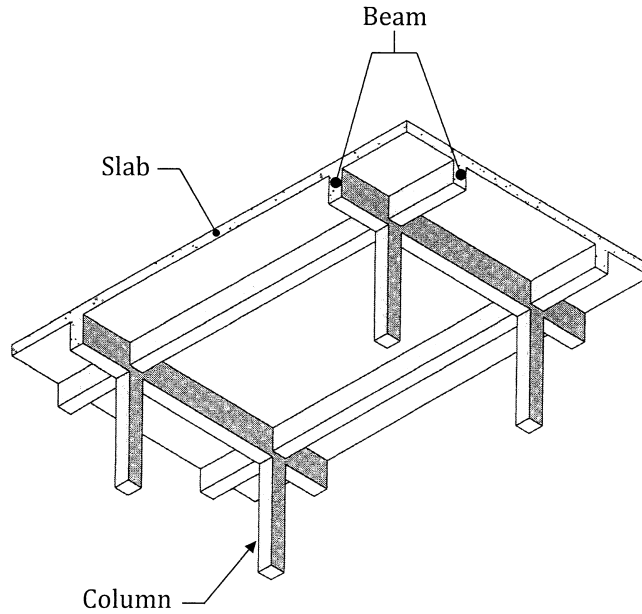


FIGURE 1.6 Two-way beam-supported slab system.

loads to the columns. Like a standard one-way joist system, this system is not utilized as often as it once was because of cost.

A *flat plate system* is shown in Fig. 1.7. This popular system, which is frequently used in residential buildings, consists of a slab supported by columns. The formwork that is required is the simplest of all floor and roof systems. Because the underside of the slab is

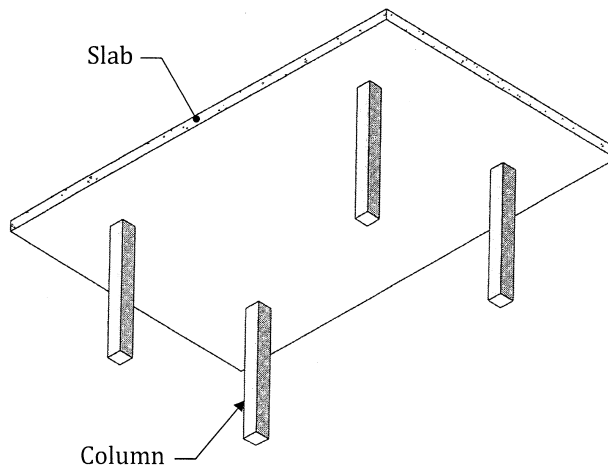


FIGURE 1.7 Flat plate system.