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 the 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. 1.1a). If the bending stress
is equal to or 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. 1.1b).

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 (see 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.

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 stress.
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 2009 edition of the IBC are covered in this book. 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 2008 edition of Building Code Requirements for Structural Concrete (ACI 318–08) and Commentary. ACI 318–08 is one of a number of codes and standards that is referenced by the IBC. These documents, which can be found in Chap. 35 of the 2009 IBC, are considered part of the requirements of the IBC to the prescribed extent of each reference (see Section 101.4 of the 2009 IBC). Amendments to ACI 318–08 are given in IBC Section 1908.

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 1.1 of that document). The term “structural concrete” refers to all plain and reinforced concrete members used for structural purposes. Section 1.1 also identifies the types of concrete members that are not addressed in the Code and includes general provisions for earthquake resistance.

Throughout this book, section numbers from the 2009 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.

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 comprehensive discussion on loads.

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 10 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 10 is applicable to the design of members in structures that are located in areas of low-to-moderate seismic risk. Seismic risk is related to seismic design category (SDC), which is defined in IBC 1613.5.6. In general, SDC is determined on the basis of the level of seismicity and soil type at the site and on the occupancy 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. 21 relate design and detailing requirements to the type of structural member and the SDC. The provisions of ACI Chaps. 1 through 19 and 22 are considered to be adequate for structures assigned to SDC A; no additional requirements need to be satisfied (also see IBC 1908.1.2). ACI Table R21.1.1 gives the sections of ACI Chap. 21 that need to be satisfied as a function of SDC.

Table 1.1 contains a summary of the reinforced concrete members addressed in Chaps. 6 through 10 of this book. Included in the table is the applicability of the information presented in these chapters related to SDC. For example, the design and detailing requirements presented in Chap. 6 are applicable to beams and one-way slabs in buildings assigned to SDC A.

The information presented in Chaps. 6 through 10 is not as limited as it first might appear. In fact, this information 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 the SDC is for the building. The same is true in regards to the design strength interaction diagram for a column as well as for other important items.

It is also important to point out that 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 21.2.2). This is usually satisfied in typical beams because these bars are needed over the full length to support the stirrups. In regards 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 21.3.3 need not be satisfied (ACI 21.2.3).

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Reinforced Concrete Member(s)</th>
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<td>10</td>
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<td>A, B, C</td>
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Table 1.1: Applicability of Design and Detailing Requirements in Chaps. 6 through 10
Methods to determine the SDC and comprehensive design and detailing procedures for reinforced concrete members in all SDCs can be found in Ref. 3.

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 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.

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. Because they are primarily subjected to the effects from bending (and the accompanying shear), members in one-way systems are commonly referred to as flexural members.

Members in a one-way system 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. 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.

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 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 flat, it is commonly used as the ceiling of the space below; this results in significant cost savings.

Similar to the flat plate system is the flat slab system (Fig. 1.8). Drop panels are provided around the columns to increase moment and shear capacity of the slab. They also help to decrease slab deflection. Column capitals or brackets are sometimes provided at the top of columns.

The two-way system depicted in Fig. 1.9 is referred to as a two-way joist system or a waffle slab system. This system consists of rows of concrete joists at right angles to each other, which are formed by standard metal domes. Solid concrete heads are provided at the columns for shear strength. Such systems provide a viable solution in cases where heavy loads need to be supported on long spans.

Design and detailing requirements for two-way systems are given in Chap. 7.

1.4.3 Columns
A column is a structural member in a building that supports axial loads from the roof and floor members and that transfers the loads to the foundation. Load transfer to columns was illustrated in the previous section for both one-way and two-way systems. Columns
are usually oriented vertically in a building, but any orientation can be provided if needed.

In addition to axial loads, columns may be subjected to bending moments caused by gravity loads or by lateral loads. In general, columns that are part of the structural system that resists lateral loads (i.e., the lateral-force-resisting system) are typically subjected to axial loads, bending moments, and shear forces due to gravity and lateral loads. As such, columns are also referred to as \textit{members subjected to combined axial load and bending}.

Design and detailing requirements for columns are given in Chap. 8.

1.4.4 Walls

In general terms, a \textit{wall} is a member, usually vertical, that is used to enclose or separate spaces in a building or structure. Walls are usually categorized as non–load-bearing and load-bearing: A non–load-bearing wall supports primarily its own weight, whereas a load-bearing wall supports loads from the floor and roof systems. Like columns, load-bearing walls are typically designed for the effects due to axial loads and bending moments, and are referred to as \textit{members subjected to combined axial load and bending}.

Illustrated in Fig. 1.10 are walls that are provided around elevator and stair openings in the core of a building. In addition to supporting tributary gravity loads, they are used alone or in combination with moment frames to resist the effects from wind and earthquakes. Such walls are commonly referred to as \textit{shear walls}.

\textit{Basement walls} or \textit{foundation walls} resist the effects from gravity loads plus lateral earth pressure that acts perpendicular to the plane of the wall. Illustrated in Fig. 1.11 is a reinforced concrete foundation wall that resists the axial loads from a reinforced concrete wall and lateral soil pressure.

Design and detailing requirements for walls are given in Chap. 9.

1.4.5 Foundations

Foundation systems transfer the loads from the structure above to the soil or rock below the building. There are primarily two types of foundation systems: shallow foundations and deep foundations.

\textit{Footings} and \textit{mats} are two common types of shallow foundations. A spread footing spreads the load from the superstructure above to the soil so that the stress in the soil...
is less than its allowable bearing capacity. Illustrated in Fig. 1.3 is an isolated spread footing that is supporting a column in a one-way system. A mat foundation is a large concrete slab that supports some or all of the columns and walls in a building. Shown in Fig. 1.10 is a mat foundation beneath the core walls. The loads from the supported members are transferred to the soil, and the mat is designed so that the maximum soil pressure does not exceed the allowable bearing capacity of the soil.

Piles and drilled piers are deep foundations that are frequently used to support columns and walls in building structures. Both types of foundation members extend below the strata of poor soil to a level where the soil is adequate to support the loads from the structure above.

Design and detailing requirements for both shallow and deep foundations are given in Chap. 10.

### 1.5 Drawings and Specifications

#### 1.5.1 Overview

The design and construction of a reinforced concrete building requires input from a variety of design professionals. Structural engineers are responsible for producing structural
drawings and specifications that are used to eventually build the structure. Drawings and specifications, as well as other documents, are referred to as construction documents or contract documents.

Once the construction documents have been reviewed and approved by the local building authority, a number of important processes are set in motion. One of the first things to move forward is the production of the reinforcing steel placing drawings by the reinforcing steel supplier. As the name suggests, these drawings are used in the actual construction of the structure.

Additional information on construction and placing drawings, as well as other pertinent information, is covered in the following sections.

1.5.2 Construction Documents

The following definition of construction documents is given in IBC 202:

Written, graphic, and pictorial documents prepared or assembled for describing the design, location, and physical characteristics of the elements of a project necessary for obtaining a building permit.

Construction documents consist of calculations, drawings, specifications, and any other data that are needed to indicate compliance with the governing building code. IBC 107 describes the information that must be included in the construction documents, who must prepare them (the registered design professional), and procedures that are used by the building official for approving them.

IBC 1603 and ACI 1.2 contain minimum requirements for construction documents. The following design loads and information must be included in the construction documents (see IBC 1603):

- Floor live load
- Roof live load
- Roof snow load
- Wind design data
- Earthquake design data
- Geotechnical information
- Flood design data
- Special loads

These items are typically listed on the General Notes sheet of the structural drawings. Chapter 3 of this book provides a summary of loads that are typically required in the design of building structures.

For reinforced concrete structures, the following information must also be provided in the construction documents (see ACI 1.2.1):

- Specified compressive strength of all concrete mixtures utilized in the structure at the ages or stages of construction for which each part of the structure is designed.
• Specified strength or grade of all reinforcement utilized in the structure.
• Size and location of all structural members, reinforcement, and anchors.
• Provisions for dimensional changes resulting from creep, shrinkage, and temperature.
• Anchorage length of reinforcement and location and length of lap splices.
• Type and location of mechanical and welded splices of reinforcement.

Structural drawings must show the size, section, and relative locations of all of structural members in a building. The following items are usually included in a typical set of drawings:

• Foundation plans
• Framing plans for all levels at and above ground
• Schedules for the structural members, including foundations, beams, slabs, columns, and walls
• Sections and details

It is important that the structural and architectural drawings be coordinated on a regular basis.

The size of the structural members can be given directly on the plans, or the members can be identified by marks on the plan with the sizes given in applicable schedules (the latter is typically done for beams, columns, walls, and foundations). The same is done for the size, spacing, and length of reinforcing bars. Either method of identification (or both) can be utilized in a project.

Typical details are provided for various types of members utilized in the structure. These details, along with sections cut at various locations in the structure, help in illustrating specific information about the structure.

Specifications are documents that supplement the structural drawings and provide additional information on materials, methods of construction, and quality assurance. Specifications for structural concrete are given in ACI 301. This specification may be referenced or incorporated in its entirety in the construction documents of any reinforced concrete building project together with additional requirements for the specific project. Included in ACI 301 is information on the following:

• Formwork and formwork accessories
• Reinforcement and reinforcement supports
• Concrete mixtures
• Handling, placing, and constructing
• Architectural concrete
• Lightweight concrete
• Mass concrete
• Prestressed concrete
• Shrinkage-compensating concrete
Mandatory and optional requirements checklists are also provided in ACI 301. Although these checklists do not form a part of ACI 301, they assist in selecting and specifying project requirements in the project specifications. The mandatory requirements checklist includes requirements pertaining to specific qualities, procedures, materials, and performance criteria that are not specifically defined in ACI 301. The optional requirements checklist contains a list of actions that are required or available when the specifications are being developed.

A number of master specifications are available that can be utilized in a reinforced concrete building project. One such specification is MasterSpec.5 Section 033000 of that specification contains comprehensive specifications for cast-in-place concrete. Master specifications can be modified by deleting and inserting text to meet the specific requirements of a project.

1.5.3 Placing Drawings
Once the construction documents have been approved by the local building authority, the documents are used by the reinforcing steel detailer in the preparation of placing drawings and bar lists. Placing drawings are used by the ironworkers at the job site to place (or, install) the reinforcing steel in the formwork. Bar lists are used by the reinforcing steel fabricator to fabricate the reinforcing bars.

When preparing the placing drawings for a specific project, the detailer uses the structural drawings and the specifications to determine the quantity, lengths, bend types, and positioning of the reinforcing bars in all of the members in the structure. The registered design professional reviews and approves the placing drawings once they are complete. Additional information on placing drawings and many other important aspects related to reinforcing steel can be found in Ref. 6.

1.6 Construction of Reinforced Concrete Buildings

1.6.1 Overview
Although each reinforced concrete building is unique, the following sequence of events occurs in the construction of any cast-in-place concrete building with mild reinforcement:

1. Erect formwork
2. Place reinforcement
3. Place concrete
4. Strip forms and provide reshores

This cycle is repeated for each floor of the building. Numerous activities occur within each segment of construction.

It is safe to state that no structure can be built that is perfectly level, plumb, straight, and true. This does not imply that contractors are doing their jobs improperly; rather, it is simply a reality that must be accepted because of the inherent nature of construction.

Fortunately, constructing a “perfect” structure is not necessary. However, some requirements must be established so that the actual structure performs as originally
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Construction tolerances provide permissible variations in dimensions and locations of the members in a structure. Tolerances are essentially limits within which the work is to be performed. ACI 117 contains comprehensive specifications for tolerances in reinforced concrete construction and materials. This document can be referenced or used in its entirety in the project specifications.

Details of the construction process are covered in the following sections. Included is information that can be incorporated in the preliminary design stages to help in achieving an economical structure.

1.6.2 Formwork Installation

Overview

According to ACI 347, formwork is the total system of support for freshly placed concrete, including the mold or sheathing that contacts the concrete and all supporting members, hardware, and necessary bracing. In essence, formwork is a temporary structure whose main purpose is to support and contain fresh concrete until it can support itself. Concrete buildings require formwork for vertical members (columns and walls) and horizontal members (slabs, beams, and joists). In addition to the weight of fresh concrete, formwork must be designed to support construction loads (workers, material, and equipment) and to resist the effects from wind.

The cost of formwork usually accounts for approximately 50% to 60% of the total cost of the concrete frame. Thus, selecting the proper forming system is crucial to the success of any project. Specifying standard form sizes, repeating the size and shape of concrete members wherever possible, and striving for simple formwork are mandatory in achieving a cost-effective structure.

The type of formwork system to be used is dictated primarily by the structural system that will be utilized in the building. Formwork materials are shipped to the job site and erected. The process of erecting the formwork includes the following:

1. Lifting, positioning, and assembling the various formwork elements.
2. Installing shoring to support the formwork, the weight of the fresh concrete, and the construction loads.

To help ensure that the concrete does not bond to the forms, a form release agent or coating may be applied to the inside of the formwork at this stage. The coating also helps prevent wood formwork from absorbing water from the concrete mixture.

The following is a typical construction sequence in a conventional cast-in-place concrete building:

1. Build formwork for vertical elements
2. Place reinforcement for vertical elements
3. Place concrete for vertical elements
4. Strip formwork for vertical elements
5. Build formwork for horizontal elements
6. Place reinforcement for horizontal elements
7. Place concrete for horizontal elements
The forms for the horizontal elements are stripped after a sufficient amount of time, and the process is repeated in multistory construction. Several levels of reshores are typically required below the newly constructed level to support the weight of the fresh concrete and the construction loads.

Brief descriptions of various types of vertical and horizontal forming systems that are commonly used in reinforced concrete building construction follow. Additional information on these and other types of forming systems can be found in Ref. 9.

**Vertical Forming Systems**

As noted earlier, the construction of vertical members in the structure (columns and walls) precedes the construction of horizontal members. The following systems are commonly used to form vertical members in a concrete building:

1. Conventional column/wall system
2. Ganged system
3. Jump forms
4. Slipforms
5. Self-raising forms

Slipform and self-raising formwork are classified as crane-independent systems where formwork panels are moved vertically by mainly proprietary mechanisms. Here, we describe the first three systems.

**Conventional Column/Wall System**  
A conventional column forming system consists of plywood sheathing that is nailed together and stiffened by vertical studs. The sides of the forms are held together by clamps that help prevent buckling of the sheathing due to the horizontal pressure imposed by the fresh concrete. Prior to construction of the formwork, a template is made on the floor slab or foundation to accurately locate the position of the column. Round columns are typically formed by steel forms.

In a conventional wall forming system, studs and wales support plywood sheathing that form the wall. Tie rods resist the pressure exerted by the fresh concrete and help maintain the specified thickness of the wall. Wood spreaders can also be used to maintain wall thickness.

**Ganged Systems**  
Ganged systems are large wall form units that consist of aluminum or plywood panels joined together and braced by aluminum or steel frames. Once the system has been assembled on the ground, it is raised into place by a crane. Ganged formwork produces smoother concrete walls that have fewer joints than those constructed with conventional systems.

**Jump Forms**  
Jump forms consist of an upper-framed panel form that is used to form the concrete in a wall member and a supporting structure that is attached to the completed wall below, which carries the entire assembly. Once the concrete in the upper-framed panel form gains sufficient strength, the jump forms are lifted to the next level and the process is repeated.
Horizontal Framing Systems

Wood System  A conventional wood system consists of lumber and/or plywood and is used to form slabs, beams, and foundations. Wood shoring is typically set on wood mudsills. The pieces of this system are made and erected on site.

Metal System  A conventional metal system consists of aluminum joists and stringers that support plywood sheathing. Aluminum or steel scaffolding is commonly used for shoring. Similar to the wood system, this system is also built on site.

Joist-Slab and Dome Forming System  One-way and two-way joist systems are formed by pan forms and dome forms, respectively. These forms come in standard sizes and are made of steel and fiberglass. The forms are nailed to plywood sheathing and are supported by wood or metal shoring.

Flying Form System  A flying form system is a crane-set system that is constructed and assembled as one unit and moved from floor to floor. Flying forms typically consist of sheathing panels that are supported on aluminum joists. These elements, in turn, are supported by steel or aluminum trusses, which have telescoping legs that are used as shoring.

As the name implies, the formwork assembly is flown to the next level by a crane once the concrete on that level has cured and attained sufficient strength.

1.6.3 Reinforcement Installation

Once the formwork has been erected, the required reinforcement is installed in the columns and walls using the placing drawings. For columns, the reinforcement consists of longitudinal bars and transverse reinforcement in the form of either ties or spirals. One or two layers of vertical and horizontal reinforcing bars are provided in walls; in some cases, horizontal ties are required as well. In general, reinforcement is tied together with metal wires into what are commonly referred to as reinforcement cages.

The reinforcement in all of the beams, slabs, and other horizontal structural members is placed and supported in the formwork according to the placing drawings. Inserts for mechanical and electrical equipment and openings for ducts and conduits are some of the typical elements that must be positioned at their proper locations in the formwork as well. Beams require longitudinal and transverse reinforcement, whereas slabs typically require only longitudinal reinforcement at the top and bottom of the section in one or two directions.

Additional information on reinforcement, including recommended practices for placing reinforcing bars, can be found in Ref. 6.

1.6.4 Concrete Placement

Concrete is deposited into the forms after the reinforcement and other construction items, such as ducts and conduits, have been installed at the proper locations. Prior to placement, the concrete is mixed and transported to the job site. Depending on a number of factors, on-site ready-mix plants are sometimes used.

Belt conveyors, buckets and cranes, chutes, drop chutes, and pumping are the most popular methods of transporting concrete to the point where it is needed in the structure. Project size and site constraints are just two of the many factors that dictate which method is the most effective in a particular project.
Once placed, the concrete is consolidated by hand or mechanical vibrators to ensure that the fresh concrete is properly compacted within the forms and around the reinforcement and other embedded items. Proper consolidation also helps in eliminating honeycombs and entrapped air in the mix.

Finishing the exposed concrete surfaces occurs shortly after consolidation. Many attributes can be achieved at this stage, including desired appearance, texture, or wearing qualities.

It is very important to ensure that all newly placed and finished concrete be cured and protected from rapid drying, extreme changes in temperature, and damage from future construction activities. Curing should begin as soon as possible after finishing so that hydration of the cement and strength gain of the concrete continues. Columns and walls are usually cured after the forms are stripped, whereas slabs and beams are cured before and after their formwork is stripped.

Comprehensive information on batching, mixing, transporting, and handling concrete can be found in Ref. 10.

### 1.6.5 Formwork Removal

Formwork is typically removed (stripped) after the concrete has gained sufficient strength to carry its own weight plus any construction loads. Generally, the formwork is not stripped before the concrete has reached at least 70% of its design compressive strength. Various admixtures are available to accelerate strength development of concrete at an early age so that forms can be stripped sooner (see Chap. 2).

Temporary vertical support is required for the stripped concrete members that have not yet acquired their design strength. Reshores and backshores are two types of shoring that is provided beneath horizontal concrete members after the forms and original shoring has been removed.

- Reshores are spaced relatively far apart; this allows the horizontal members to deflect, permitting the forms and original shores to be removed from a large area. Reduced stripping costs are usually realized when using reshores.
- Backshores are spaced closer than reshores. The horizontal members are not allowed to deflect, resulting in a small area over which the forms and original shoring can be removed. This permits stripping to occur sooner than if reshores were used.

Reshores and backshores are removed after the structural members have acquired sufficient strength to support all of the required loads. More information on shoring and reshoring of concrete buildings can be found in Ref. 11.

### References


7. American Concrete Institute (ACI), Committee 117. 2006. Specifications for Tolerances for Concrete Construction and Materials and Commentary, ACI 117–06. ACI, Farmington Hills, MI.


