12

Concrete Construction

12–1 CONSTRUCTION APPLICATIONS OF CONCRETE

Concrete, or more properly portland cement concrete, is one of the world's most versatile and widely used construction materials. Its use in the paving of highways and airfields is described in Chapter 8. Other construction applications, which range from its use in foundations for small structures, through structural components such as beams, columns, and wall panels, to massive concrete dams, are discussed in this chapter.

The production of concrete is described in Chapter 7. Because concrete has little strength in tension, virtually all concrete used for structural purposes contains reinforcing material embedded in the concrete to increase the concrete member's tensile strength. Such concrete is called *reinforced concrete.* While the steel reinforcing *(rebar)* described in Section 12–4 is most commonly used, metal and plastic fibers dispersed in the concrete mix are also available.

A typical distribution of concrete construction costs for a reinforced concrete building is shown in Figure 12–1. The objective of the construction manager should be to develop a construction plan which minimizes construction costs while meeting all safety and quality requirements. Major elements of a concrete construction cost analysis include:

Formwork costs including labor, equipment, and materials.

Cost of reinforcing steel and its placement.

Concrete materials, equipment, and labor for placing, curing, and finishing the concrete.

Since formwork cost may make up as much as 60% of total concrete construction cost, every effort must be made to reduce formwork cost using the methods suggested in Section 12–3.

Cast-in-Place Concrete

Concrete structural members have traditionally been built in-place by placing the plastic concrete into forms and allowing it to harden. The forms are removed after the concrete has developed sufficient strength to support its own weight and the weight of any construction loads. Typical shapes and types of concrete structural members are described in the following paragraphs. The construction and use of concrete forms are described in Section 12–3.

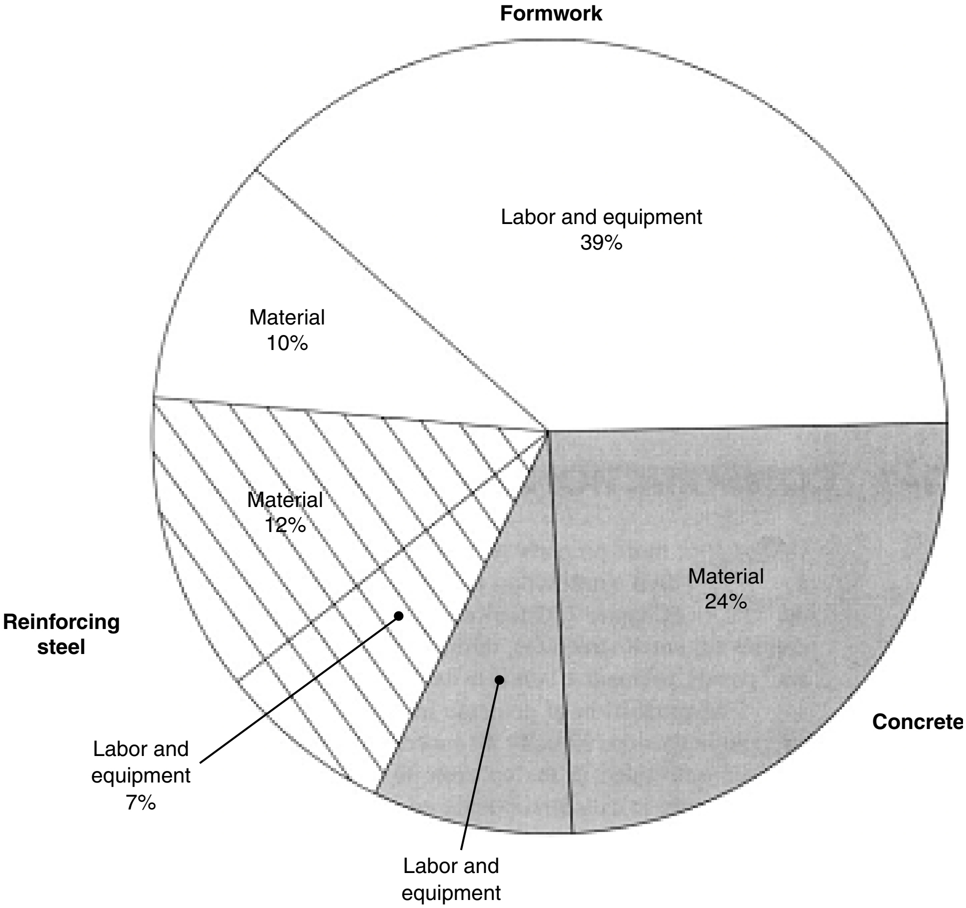


Figure 12–1 Typical distribution of concrete construction costs.

Walls and Wall Footings

Although almost any type of concrete wall may be cast in-place, this method of construction is now used primarily for foundation walls, retaining walls, tank walls, and walls for special-purpose structures such as nuclear reactor containment structures. High-rise concrete structures often use a concrete column and beam framework with curtain wall panels inserted between these members to form the exterior walls. Columns are normally of either circular or rectangular cross section. Some typical cast-in-place wall and column shapes are illustrated in Figure 12–2. In placing concrete into wall and column forms, care must be taken to avoid segregation of aggregate and paste that may result from excessive freefall distances. Another problem frequently encountered in wall construction is the formation of void spaces in the concrete under blockouts for windows, pipe chases, and so on. This can be prevented by using concrete with adequate workability accompanied by careful tamping or vibration of the concrete in these areas during placing.

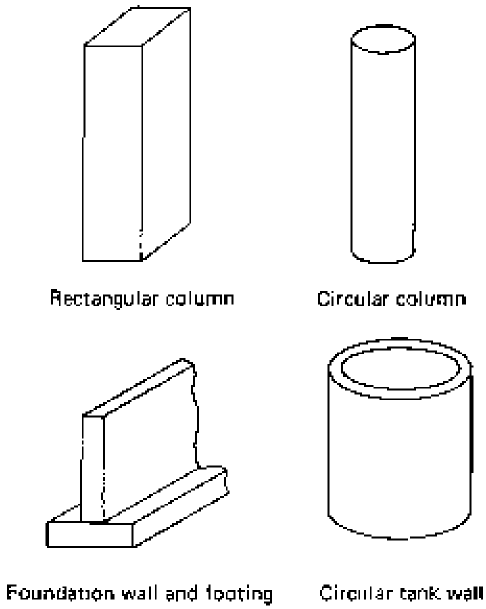


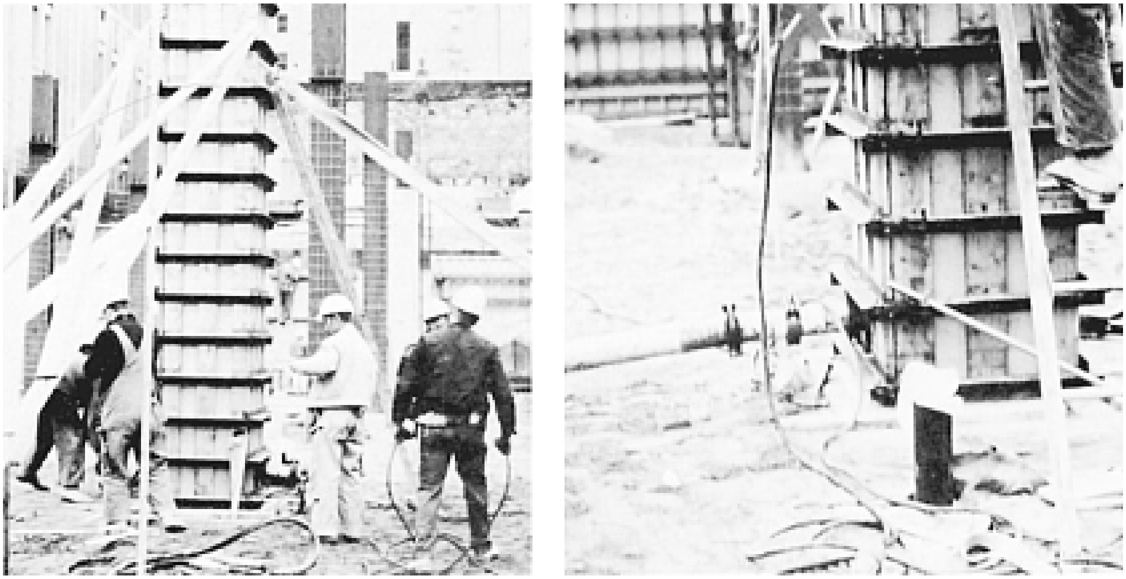
Figure 12–2 Typical cast-in-place column and wall shapes.

The relatively new technique of pumping concrete into vertical forms through the bottom of the form may also be used to eliminate the formation of voids in the concrete. Figure 12–3 shows a 2-ft (0.6-m)-square column form 18 ft (5.5 m) high being prepared for pumping. Notice the method of attachment of the pumping hose to the form shown in Figure 12–3b. When the form is filled to the required height, the gate on the form fixture is closed and the pumping hose is removed.

Floors and Roofs

There are a number of different types of structural systems used for concrete floors and roofs. Such systems may be classified as one-way or two-way slabs. When the floor slab is principally supported in one direction (i.e., at each end) this is referred to as a *one-way slab. Two-way slabs* provide support in two perpendicular directions. Flat slabs are supported directly by columns without edge support.

One-Way Slabs. Supporting beams, girders, and slabs may be cast at one time (monolithically), as illustrated in Figure 12–4a. However, columns are usually constructed prior to casting the girders, beams, and slabs to eliminate the effect of shrinkage of column concrete on the other members. This type of construction is referred to as *beam-and-slab* or as slab-beam-and-girder construction. Notice that the outside beam is referred to as a *spandrel beam.* When beams are replaced by more closely spaced joists, the type of construction illustrated in Figure 12–4b results. Joists may be either straight or tapered, as shown. The double joist in the illustration is used to carry the additional load imposed by the partition above it. Slabs may also be supported by nonintegral beams. Such supporting beams may



a. Preparation of form

b. Pumping hose in place on fixture at bottom of form

Figure 12–3 Pumping concrete into bottom of column form. (Courtesy of Gates & Sons, Inc.)

be made of precast or cast-in-place concrete, timber, steel, or other materials. This type of construction is referred to as *solid slab construction.*

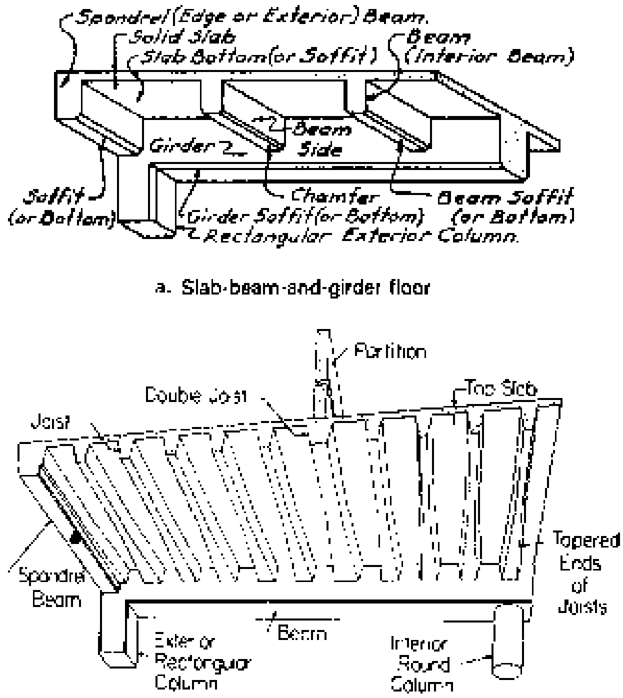
Two-Way Slabs. The principal type of two-way slab is the *waffle slab,* illustrated in Figure 12–5. Notice that this is basically a joist slab with joists running in two perpendicular directions.

Flat Slabs. Slabs may be supported directly by columns without the use of beams or joists. Such slabs are referred to as *flat slabs* or *flat plate slabs.* A flat plate slab is illustrated in Figure 12–6a. A flat slab is illustrated in Figure 12–6b. Note that the flat slab uses column capitals to distribute the column reaction over a larger area of slab, while the drop panels serve to strengthen the slab in this area of increased stress. Both of these measures reduce the danger of the column punching through the slab when the slab is loaded.

Precast Concrete

Precast concrete is concrete that has been cast into the desired shape prior to placement in a structure. There are a number of advantages obtained by removing the concrete forming, placing, finishing, and curing operations from the construction environment. Precasting operations usually take place in a central plant where industrial production techniques may be used. Since standard shapes are commonly used, the repetitive use of formwork permits

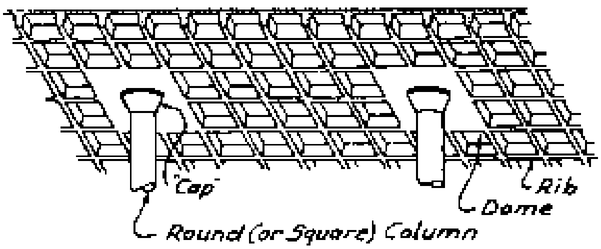
Figure 12–4 Floor slab construction. (Courtesy of Concrete Reinforcing Steel Institute)



a. Slab-beam-and-girder floor

b. Concrete joist floor

Figure 12–5 Waffle slab. (Courtesy of Concrete Reinforcing Steel Institute)



forms to be of high quality at a low cost per unit. These forms and plant finishing procedures provide better surface quality than is usually obtained in the field. Because of controlled environment and procedures, concrete quality control is also usually superior to that of cast-in-place concrete. Forming procedures used make it relatively simple to incorporate prestressing in structural members. Many of the common members described next are prestressed. Upon arrival at the job site, precast structural members may be erected much more rapidly than conventional cast-in-place components.

There are a number of standard shapes commonly used for precast concrete structural members. Figure 12–7 illustrates some common beam and girder sections. The inverted tee shape is normally used with a cast-in-place concrete slab which forms the upper flange of the section.

Figure 12–6 Flat slab and flat plate slab. (Courtesy of Concrete Reinforcing Steel Institute)

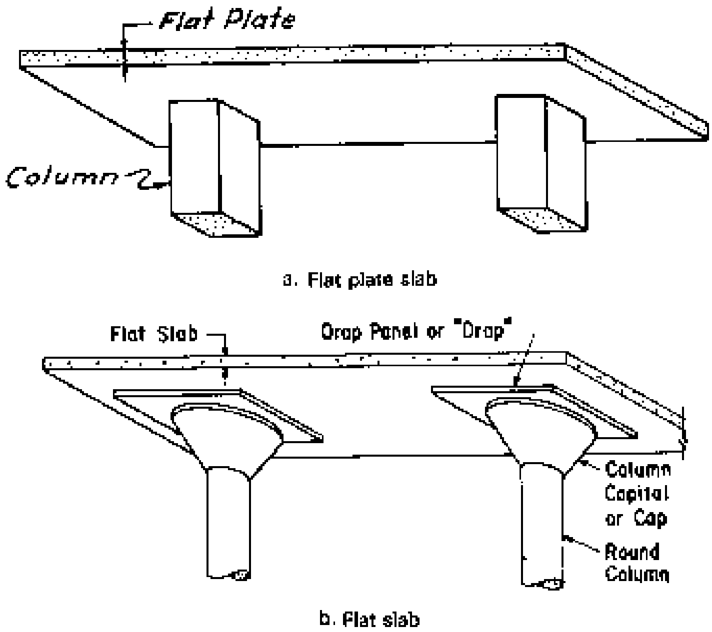
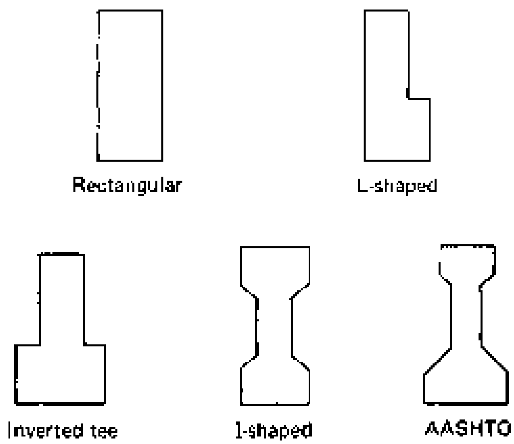


Figure 12–7 Precast beam and girder shapes.



Precast concrete joists and purlins (roof supports spanning between trusses or arches) are most often of the I- or T-section shape. Sizes commonly available provide depths of 8 to 12 in. (20 to 30 cm) and lengths of 10 to 20 ft (3 to 6 m). Precast roof and floor panels (often integral slabs and beams) include flat, hollow-core, tee, double-tee, and channel slabs. These shapes are illustrated in Figure 12–8. Concrete planks are commonly available in thicknesses of 1 to 4 in. (2.5 to 10.1 cm), widths of 15 to 32 in. (38 to 81 cm), and lengths of 4 to 10 ft (1.2 to 3 m). Hollow-core planks range from 4 to 12 in. (10 to 30 cm) in thickness, are usually 4 or 8 ft (1.2 or 2.4 m) wide, and range from 15 to 50 ft (4.6 to 15.3 m) in

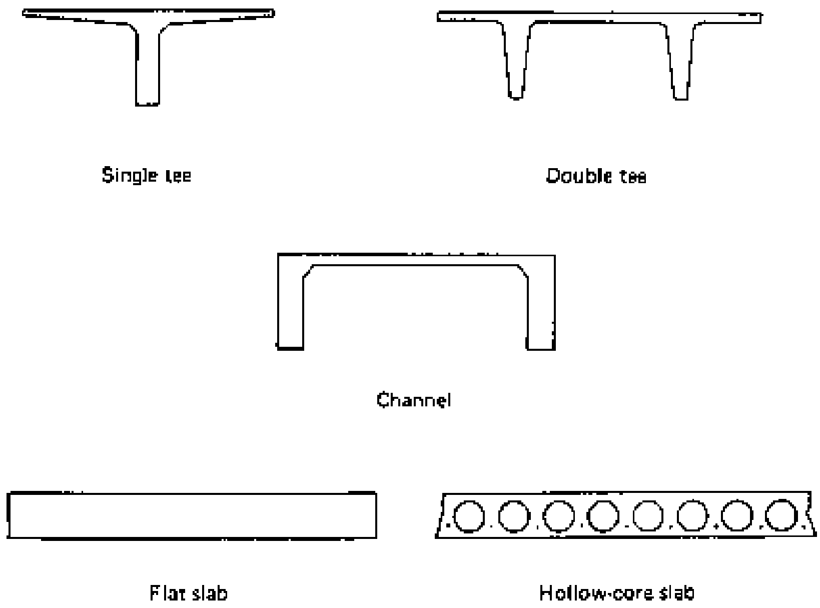


Figure 12–8 Precast slab shapes.

length. Channel slabs range from 2 to 5 ft (0.6 to 1.5 m) wide and from 15 to 50 ft (4.6 to 15.3 m) in length. Tee and double-tee slabs are available in widths of 4 to 12 ft (1.2 to 3.7 m) and spans of 12 ft (3.7 m) up to 100 ft (30.5 m).

Wall panels may also be precast, hauled to the site, and erected. However, the major use of precast wall panels (excluding tilt-up construction) is for curtain-wall construction, in which the panels fit between the structural framework to form exterior walls. In this type of construction, the walls serve to provide a weatherproof enclosure and transmit any wind loads to the frame. The building frame actually supports all loads.

Tilt-up construction is a special form of precast wall construction in which wall panels are cast horizontally at the job site and then erected. The wall panels are usually cast on the previously placed building floor slab using only edge forms to provide the panel shape. The floor slab thus serves as the bottom form for the panel. Panels may also be cast one on top of another where slab space is limited. A bond-breaker compound is applied to the slab to prevent the tilt-up panel from sticking to the slab. Figure 12–9 illustrates the major steps in a tilt-up construction project.

Some suggestions for obtaining the best results with tilt-up construction procedures include:

Do

- Pour a high-quality slab.
- Keep all plumbing and electrical conduits at least 1 in. under floor surface.
- Vibrate the slab thoroughly.

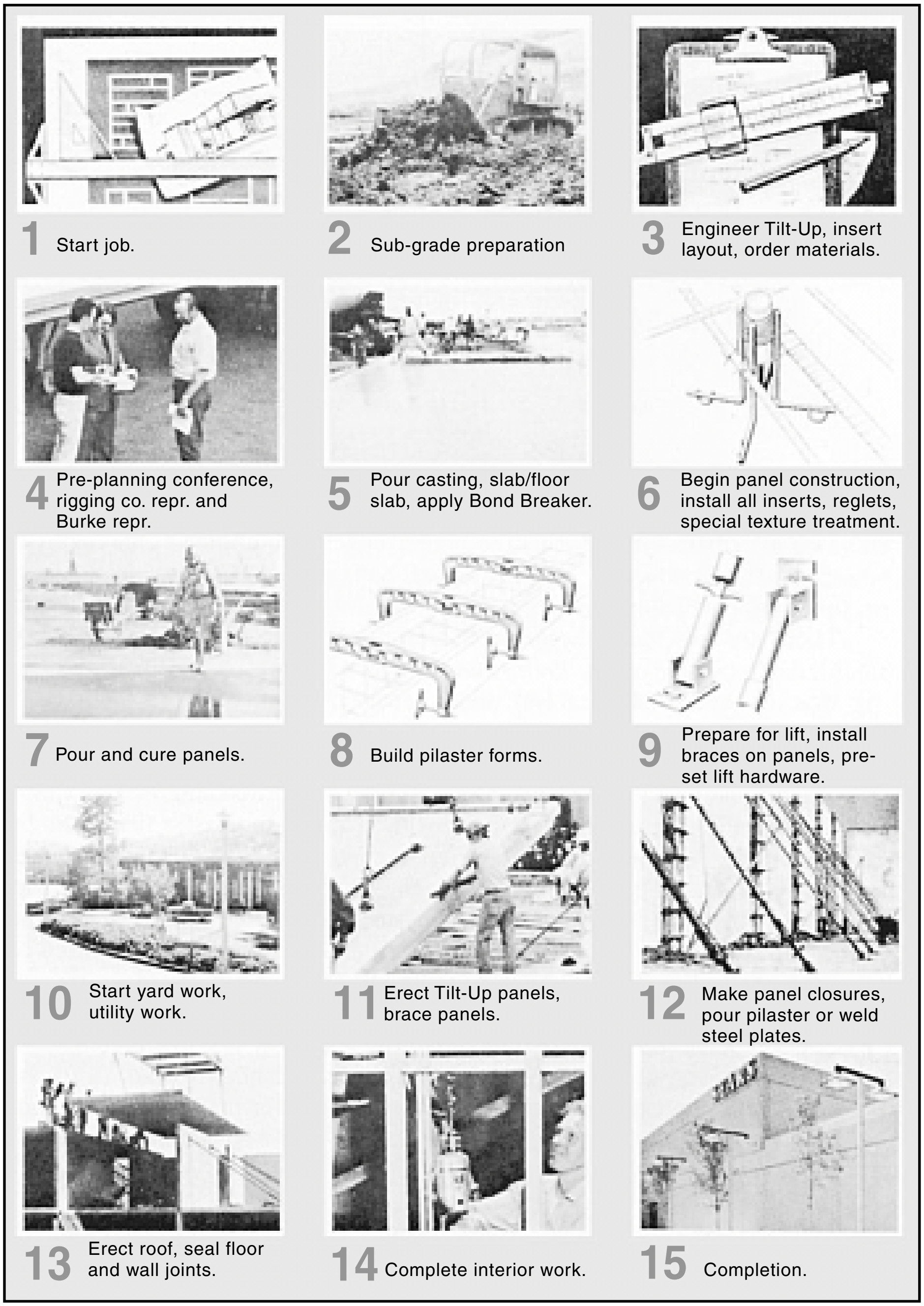


Figure 12–9 Steps in tilt-up construction. (Courtesy of The Burke Company)

- Let cranes operate on the floor slab.
- Pour wall panels with their exterior face down.
- Use load-spreading frames when lifting panels that have been weakened by windows and other cutouts.

Don't

- Erect steel framework before raising wall panels.
- Fail to cure floor slab properly.
- Move crane farther than necessary when raising wall panels.
- Lay wall panels down after lifting.

Prestressed Concrete

Prestressed concrete is concrete to which an initial compression load has been applied. Since concrete is quite strong in compression but weak in tension, prestressing serves to increase the load that a beam or other flexural member can carry before allowable tensile stresses are reached. Figure 12–10 illustrates the stress pattern across a beam section resulting from external loads and prestressing. The use of prestressing in a concrete structural member permits a smaller, lighter member to be used in supporting a given load. Prestressing also reduces the amount of deflection in a beam. Since the member is always kept under compression, any cracking that does occur will remain closed up and not be apparent. These advantages of prestressing are offset somewhat by the higher material, equipment, and labor cost involved in the production of prestressed components. Nevertheless, the use of prestressing, particularly in precast structural members, has become widespread.

There are two methods for producing prestress in concrete members: pretensioning and posttensioning. *Pretensioning* places the prestressing material (reinforcing steel or prestressing cables) under tension in the concrete form before the member is poured. After

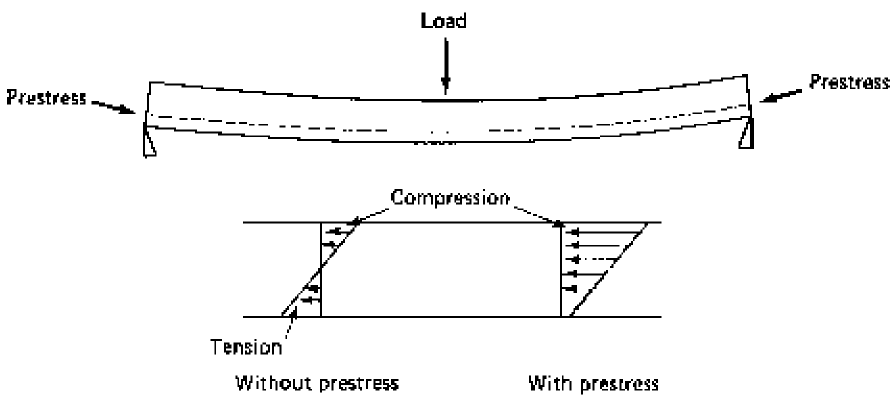


Figure 12–10 Stresses in a prestressed simple beam.

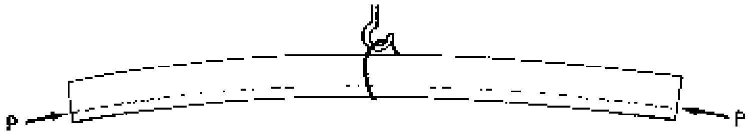


Figure 12–11 Lifting prestressed beam at the center.

the concrete has hardened, the external tensioning devices are removed. Bonding between the concrete and the prestressing steel holds the prestressing in place and places the concrete under compression. *Posttensioning* places the prestressing steel (usually placed inside a metal or plastic tube cast into the member) under tension after the concrete member has been erected. The prestressing is then tensioned by jacks placed at each end of the member. After the prestressing load has been applied, the prestressing steel is anchored to the concrete member by mechanical devices at each end or by filling the prestressing tubes with a cementing agent. After the steel has been anchored to the member, jacks are removed and the prestressing steel is cut off flush with the ends of the member.

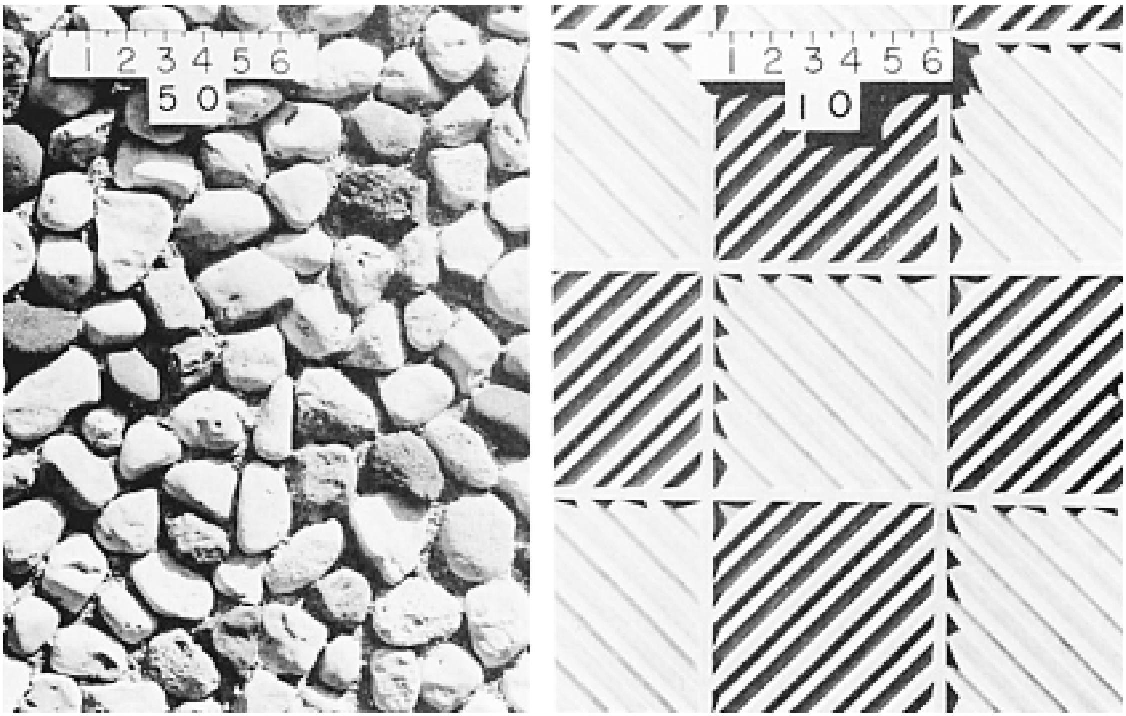
Caution must be observed in handling and transporting pretensioned prestressed members, particularly if they are asymmetrically stressed. In the beam of Figure 12–11, the prestressing has been placed off center in the lower portion of the beam. This placement better offsets the tension that would normally occur in the lower chord when the beam is loaded. If this beam were to be lifted at the top center, it would tend to bend as shown, resulting in tension along the top chord. The presence of the off-center compression load provided by the prestressing would serve to increase the tension in the top chord and may cause failure of the member prior to erection. Hence this type of beam should not be raised using a center lift. It should be lifted by the ends or by using multiple lift points along the beam.

Architectural Concrete

The architectural use of concrete to provide appearance effects has greatly increased in recent years. Architectural effects are achieved by the shape, size, texture, and color used. An example of the use of shape and texture in a wall treatment is given in Figure 12–12. Here precast panels made from a mix of white quartz aggregate and white cement were applied to the exterior of the building frame to achieve the desired color and three-dimensional surface. The availability of plastic forms and form liners has made it possible to impart special shapes to concrete at a relatively low cost.

Some of the major methods used for obtaining architectural concrete effects include exposed aggregate surfaces (Figure 12–13a), special surface designs and textures achieved by the use of form liners (Figure 12–13b), and mechanically produced surfaces (Figure 12–14). Exposed aggregate surfaces are produced by removing the cement paste from the exterior surface, exposing the underlying aggregate. A method frequently used is to coat the interior surface of the form with a retarder. After the concrete has cured enough to permit the removal of the forms, the cement paste near the surface (whose curing has been retarded) is removed by brushing and washing or by sandblasting. In the case of horizontal surfaces, a retarder may be applied to the surface after final troweling. Surface textures and designs such as those

Figure 12–12 Application of architectural concrete. (Courtesy of Portland Cement Association)



a. Exposed aggregate

b. Pattern produced by a form liner

Figure 12–13 Architectural concrete surfaces. (Courtesy of Portland Cement Association)

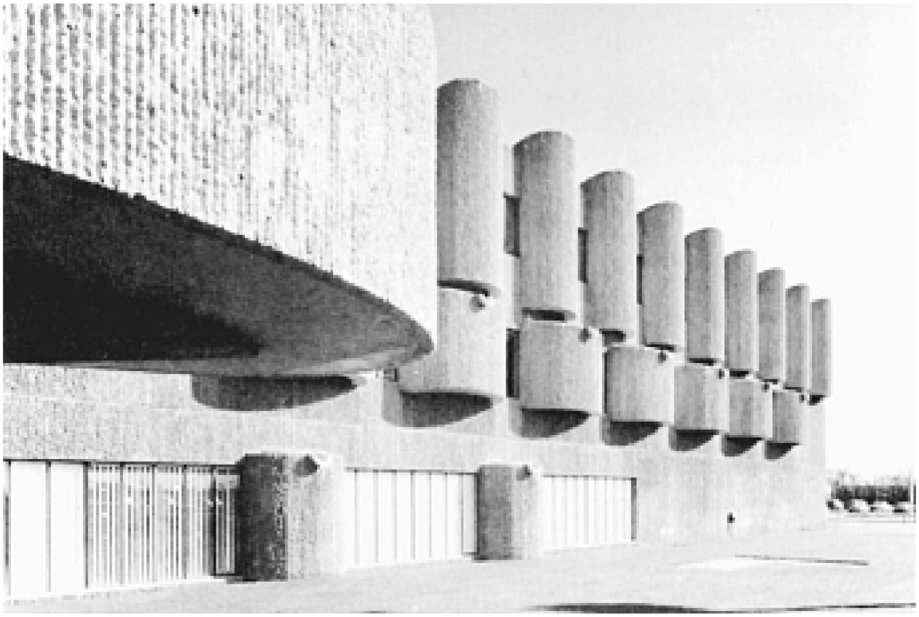


Figure 12–14 Mechanically produced concrete surface texture. (Courtesy of Portland Cement Association)

illustrated in Figure 12–13b may be achieved by using form liners of plastic, rubber, or wood. Sandblasting or mechanical hammering may also be used to produce special surface effects. To achieve the surface texture of the building shown in Figure 12–14, a form liner was used to produce triangular surface ridges, which were then chipped with a hammer.

12–2 CONCRETE CONSTRUCTION PRACTICES

Concrete construction involves concrete batching, mixing, transporting, placing, consolidating, finishing, and curing. The production and transportation of concrete are described in Section 7–2. In this section, we will discuss the equipment and methods involved in placing, consolidating, finishing, and curing concrete used for structural purposes. Special considerations for pouring concrete during extremely hot or cold weather are also described. The use of concrete in paving is described in Chapter 8.

Transporting and Handling

A number of different items of equipment are available for moving concrete from the mixer to its final position. Equipment commonly used includes wheelbarrows, buggies, chutes, conveyors, pumps, buckets, and trucks. Regardless of the equipment used, care must be taken

Figure 12–15 Concrete pump and truck mixer. (Courtesy of Morgen Manufacturing Co.)

to avoid segregation when handling plastic concrete. The height of free fall should be limited to about 5 ft (1.5 m) unless downpipes or ladders are used to prevent segregation. Downpipes having a length of at least 2 ft (0.6 m) should be used at the end of concrete conveyors.

Wheelbarrows have a very limited capacity (about 1½ cu ft or 0.04 m^3) but are often used for transporting and placing small amounts of concrete. Push buggies that carry 6 to 11 cu ft (0.17 to 0.31 m^3) and powered buggies carrying up to ½ cu yd (0.38 m^3) are often employed on building construction projects. However, these items of equipment are gradually being replaced by concrete pumps capable of moving concrete from a truck directly into final position up to heights of 500 ft (152 m) or more. Truck-mounted concrete pumps equipped with placement booms such as that shown in Figure 12–15 are widely used in building construction.

Concrete conveyors are available to move concrete either horizontally or vertically. Chutes are widely used for moving concrete from the mixer to haul units and for placing concrete into forms. Truck mixers are equipped with integral retracting chutes that may be used for discharging concrete directly into forms within the radius of the chute. When chuting concrete, the slope of the chute must be high enough to keep the chute clean but not high enough to produce segregation of the concrete. Concrete buckets attached to cranes are capable of lifting concrete to the top of highrise buildings and of moving concrete over a wide area. Concrete buckets are equipped with a bottom gate and a release mechanism for unloading concrete at the desired location. The unloading mechanism may be powered or may be operated manually. The use of remotely controlled power-operated bucket gates reduces the safety hazard involved in placing concrete above ground level.

Although truck mixers are most often employed for hauling plastic concrete to the job site, dump trucks equipped with special concrete bodies are also available for hauling concrete. The bodies of such trucks are designed to reduce segregation during hauling and provide easy cleaning and dumping. When using nonagitator trucks for hauling concrete, specifications may limit the truck speed and maximum haul distance that may be used. Temperature, road condition, truck body type, and mix design are the major factors that influence the maximum safe hauling distance. Railway cars designed for hauling concrete are also available but are not widely used.

Placing and Consolidating

The movement of plastic concrete into its final position (usually within forms) is called *placing.* Before placing concrete, the underlying surface and the interior of all concrete forms must be properly prepared. Concrete forms must be clean and tight and their interior surfaces coated with form oil or a parting agent to allow removal of the form from the hardened concrete without damaging the surface of the concrete.

When concrete is poured directly onto a subgrade, the subgrade should be moistened or sealed by a moisture barrier to prevent the subgrade from absorbing water from the plastic concrete. When placing fresh concrete on top of hardened concrete, the surface of the hardened concrete should be roughened to provide an adequate bond between the two concrete layers. To improve bonding between the layers, the surface of the hardened concrete should also be coated with grout or a layer of mortar before the fresh concrete is placed. Concrete is usually placed in layers 6 to 24 in. (15 to 61 cm) thick except when pumping into the bottom of forms. When placing concrete in layers, care must be taken to ensure that the lower layer does not take its initial set before the next layer is poured.

As explained in Chapter 7, the strength, watertightness, durability, and wear resistance of concrete are largely determined by the water/cement ratio of the concrete mix. Therefore, do not allow construction crews or transit mix operators to add additional water to the mix for the purpose of increasing the workability of the plastic concrete. If a more workable mix is needed, the mix design should be modified accordingly. The addition of one of the workability agents described in Chapter 7 should provide plastic concrete with acceptable workability.

Concrete may also be pneumatically placed by spraying it onto a surface. Concrete placed by this process is designated *shotcrete* by the American Concrete Institute but is also called *pneumatically applied concrete, gunned concrete,* or *gunite.* Since a relatively dry mix is used, shotcrete may be applied to overhead and vertical surfaces. As a result, shotcrete is often used for constructing tanks, swimming pools, and tunnel liners, as well as for repairing damaged concrete structures.

Concrete may be placed underwater by the use of a tremie or by pumping. A *tremie* (see Figure 10–21) is nothing more than a vertical tube with a gate at the bottom and a hopper on top. In operation the tremie tube must be long enough to permit the concrete hopper to remain above water when the lower end of the tremie is placed at the desired location. With the gate closed, the tremie is filled with concrete and lowered into position. The gate is then opened, allowing concrete to flow into place. The pressure of the plastic concrete inside the tremie prevents water from flowing into the tremie. The tremie is raised as concrete is poured, but care must be taken to keep the bottom end of the tremie immersed in the plastic concrete.

Consolidation is the process of removing air voids in concrete as it is placed. Concrete vibrators are normally used for consolidating concrete, but hand rodding or spading may be employed. Immersion-type electric, pneumatic, or hydraulic concrete vibrators are widely used. However, form vibrators or vibrators attached to the outside of the concrete forms are sometimes employed. Vibrators should not be used to move concrete horizontally, as this practice may produce segregation of the concrete mix. Vibrators should be inserted into the concrete vertically and allowed to penetrate several inches into the previously placed layer of concrete. The vibrator should be withdrawn and moved to another location when cement paste becomes visible at the top of the vibrator.

Finishing and Curing

Finishing is the process of bringing the surface of concrete to its final position and imparting the desired surface texture. Finishing operations include screeding, floating, troweling, and brooming. *Screeding* is the process of striking off the concrete in order to bring the concrete surface to the required grade. When the concrete has hardened sufficiently so that a worker's foot makes only a small impression in the surface, the concrete is floated with a wood or metal float. *Floating* smooths and compacts the surface while embedding aggregate particles. *Troweling* with a steel trowel follows floating when a smooth dense surface is desired. A three-unit riding-type power trowel is shown in Figure 12–16. Finally, the concrete may be *broomed* by drawing a stiff broom across the surface. This technique is used when a textured skid-resistant surface is desired.

The completion of cement hydration requires that adequate moisture and favorable temperatures be maintained after concrete is placed. The process of providing the required water and maintaining a favorable temperature for a period of time after placing concrete is referred to as *curing.* Methods for maintaining proper concrete temperatures in hot-weather and cold-weather concreting are described in this chapter. Methods used to retain adequate curing moisture include covering the concrete surface with wet straw or burlap, ponding water on the surface, covering the surface with paper or plastic sheets, and applying curing compounds. The use of sprayed-on curing compounds applied immediately after finishing has become widespread in recent years.

Vacuum dewatering may be employed to reduce the amount of free water present in plastic concrete after the concrete has been placed and screeded. The dewatering process involves placing a mat having a porous lower surface on top of the concrete and applying a vacuum to the mat. Vacuum within the mat causes excess water from the mix to flow into the mat and eventually to the vacuum source. Removal of excess water results in a lower water/cement ratio and a denser mix. Floating and troweling then follow as usual. In concept, vacuum dewatering permits placing concrete with a high water content (for good workability) while obtaining the strength and durability of concrete with a low water/cement ratio. Other advantages claimed for concrete placed by this method include high early strength, increased ultimate strength and wear resistance, reduced

FIGURE 12–16 Ride-on power trowel. (Courtesy of Wacker Corporation)

shrinkage, reduced permeability, and increased resistance to freeze/thaw damage. While the vacuum dewatering process was invented and patented in the United States in 1935, it has not been widely used in this country. Recent improvements in the equipment used for the process have led to increased use of the process in both Europe and the United States.

When constructing large slabs and decks, concrete may be placed by chutes, buckets, or side discharge conveyors. Mechanical finishing may be supplied by roller finishers, oscillating strike-off finishers, large power floats, or other types of finishers. Figure 12–17 shows a large slab being poured directly from a truck mixer and finished by a roller finisher.

Hot-Weather Concreting

The rate of hardening of concrete is greatly accelerated when concrete temperature is appreciably higher than the optimum temperature of 50 to 60° F (10 to 15.5° C). Ninety degrees Fahrenheit (32° C) is considered a reasonable upper limit for concreting operations. In addition to reducing setting time, higher temperatures reduce the amount of slump for a given mix. If additional water is added to obtain the desired slump, additional cement must also be added or the water-cement ratio will be increased with corresponding strength reduction. High temperatures, especially when accompanied by winds and low humidity, greatly increase the shrinkage of concrete and often lead to surface cracking of the concrete. Several steps may be taken to reduce the effect of high temperatures on concreting

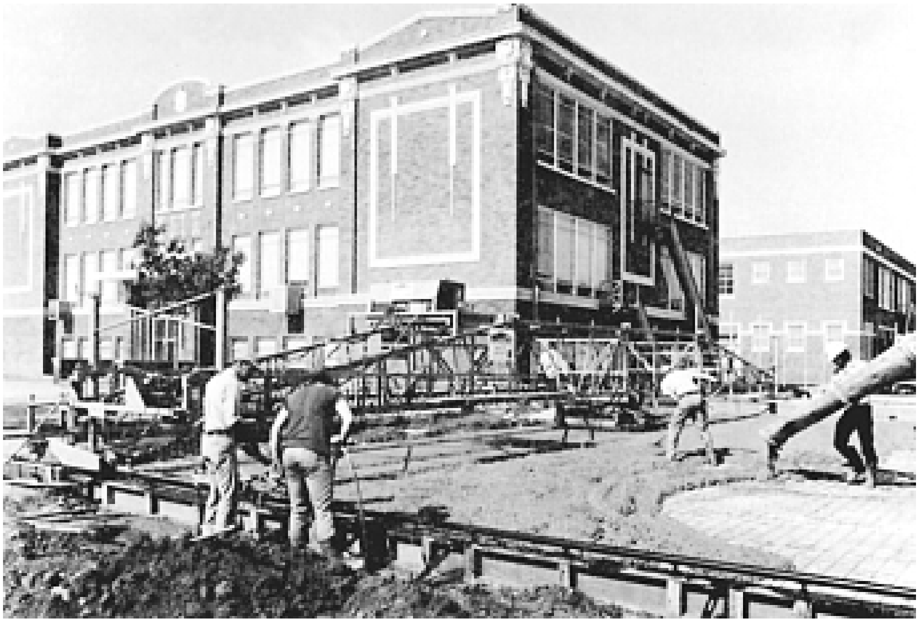


Figure 12–17 Roller finisher being used on large slab pour. (Courtesy of Terex Roadbuilding)

operation. The temperature of the plastic concrete may be lowered by cooling the mixing water and/or aggregates before mixing. Heat gain during hydration may be reduced by using Type IV (low-heat) cement or by adding a retarder. Air-entraining agents, water-reducing agents, or workability agents may be used to increase the workability of the mix without changing water/cement ratios. It is also advisable to reduce the maximum time before discharge of ready-mixed concrete from the normal 1½ to 1 h or less. The use of shades or covers will be helpful in controlling the temperature of concrete after placement. Moist curing should start immediately after finishing and continue for at least 24 h.

Cold-Weather Concreting

The problems of cold-weather concreting are essentially opposite to those of hot-weather concreting. Concrete should not be placed on a frozen surface and must not be allowed to freeze during the first 24 h after placing to avoid permanent damage and loss of strength. Concrete forms and reinforcing steel should be free of frost, ice, and snow and at a temperature above freezing. Specifications often require that, when air temperature is 40˚/F (5˚ C) or less, concrete be placed at a minimum temperature of 50˚ F (10˚ C) and that this temperature be maintained for at least 3 d after placing. However, the American Concrete Institute (ACI) recommends that a temperature of 70˚ F (21˚ C) be maintained for 3 d or 50˚ F (10˚ C) be maintained for 5 d after pouring to ensure that the concrete will attain its design strength. Type III (high early strength) cement or an accelerator may be used to reduce concrete setting time during low temperatures. The air content of the concrete mix should be checked to ensure that the air content does not exceed mix design specifications. Mix water and/or aggregates may be heated prior to mixing to raise the temperature of the plastic concrete. However, cement should not be allowed to contact hot water. Therefore, the aggregate should be mixed with the heated water prior to adding cement to the mix. The use of unvented heaters inside an enclosure during the first 36 h after placing may cause the concrete surface to dust after hardening. To avoid this problem, any fuel-burning heaters used during this period must be properly vented. When heat is used for curing, the concrete must be allowed to cool gradually at the end of the heating period or cracking may result.

12–3 CONCRETE FORMWORK

General Requirements for Formwork

The principal requirements for concrete formwork are that it be safe, produce the desired shape and surface texture, and be economical. Procedures for designing formwork that will be safe under the loads imposed by plastic concrete, workers and other live loads, and external forces (such as wind loads) are explained in Chapter 13. Construction procedures relating to formwork safety are discussed later in this section. Requirements for the shape (including deflection limitations) and surface texture of the finished concrete are normally contained in the construction plans and specifications. Since the cost of concrete formwork often exceeds the cost of the concrete itself, the necessity for economy in formwork is readily apparent.

Typical Formwork

A typical *wall form* with its components is illustrated in Figure 12–18. Sheathing may be either plywood or lumber. Double wales are often used as illustrated so that form ties may be inserted between the two wales. With a single wale it would be necessary to drill the wales for tie insertion. While the pressure of the plastic concrete is resisted by form ties, bracing must be used to prevent form movement and to provide support against wind loads or other lateral loads. Typical form ties are illustrated in Figure 12–19. Form ties may incorporate a spreader device to maintain proper spacing between form walls until the concrete is placed. Otherwise, a removable spreader bar must be used for this purpose. Ties are of two principal types, continuous single-member and internally disconnecting. *Continuous single-member ties* may be pulled out after the concrete has hardened or they may be broken off at a weakened point just below the surface after the forms are removed. Common types of *internally disconnecting ties* include the coil tie and stud rod (or she-bolt) tie. With internally disconnecting ties, the ends are unscrewed to permit form removal with the internal section left embedded in the concrete. The holes remaining in the concrete surface after the ends of the ties are removed are later plugged or grouted.

Column forms are similar to wall forms except that studs and wales are replaced by column clamps or yokes that resist the internal concrete pressure. A typical column form is shown

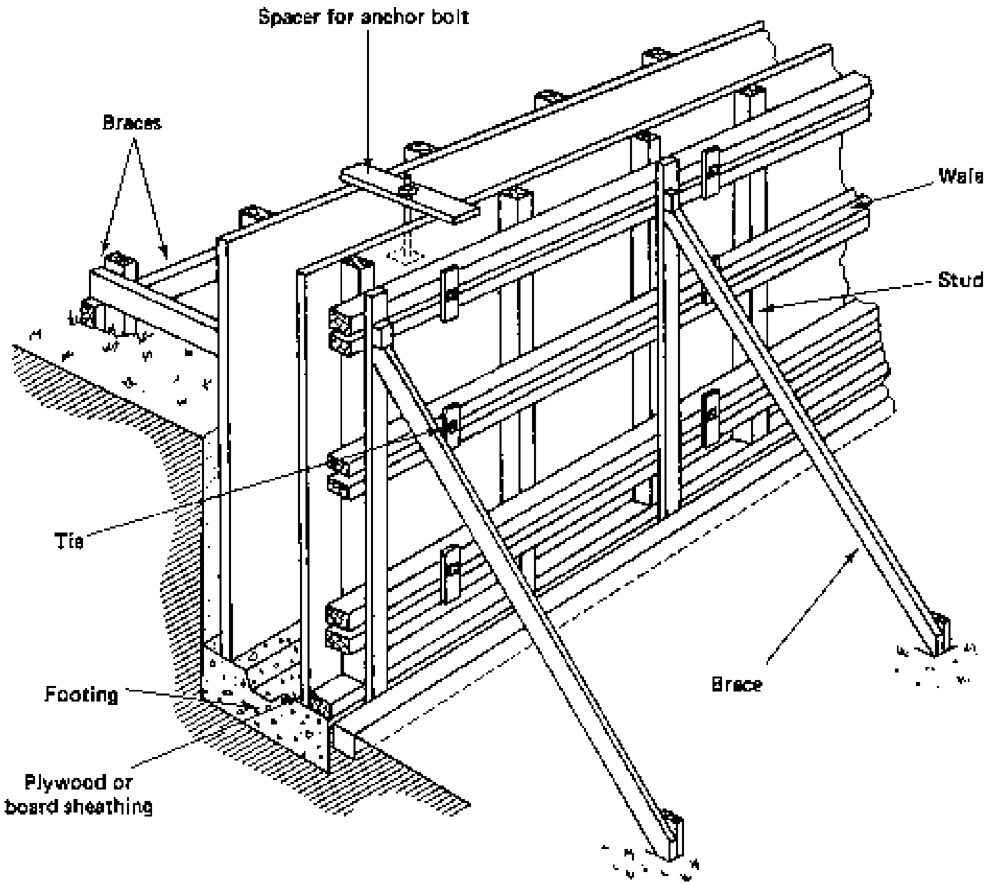
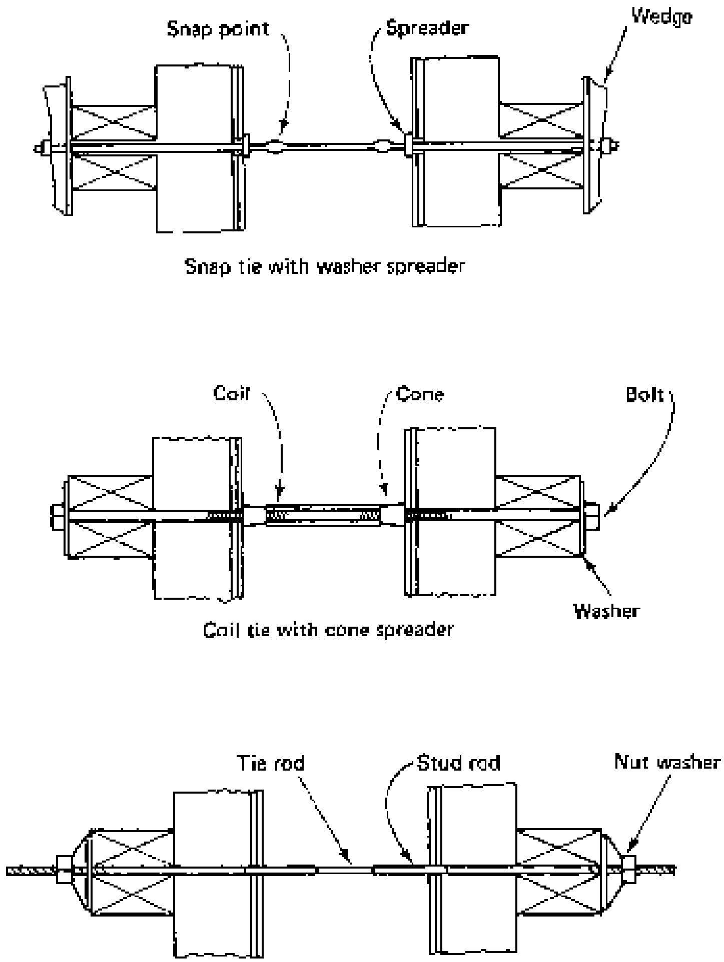


Figure 12–18 Typical wall form.

in Figure 12–20. Yokes may be fabricated of wood, wood and bolts (as shown), or of metal. Commercial column clamps (usually of metal) are available in a wide range of sizes (Figure 12–3). Round columns are formed with ready-made fiber tubes or steel reinforced fiberglass forms. Openings or "windows" may be provided at several elevations in high, narrow forms to facilitate placement of concrete. Special fittings may also be inserted near the bottom of vertical forms to permit pumping concrete into the form from the bottom.

Figure 12–21 illustrates a typical elevated floor or desk slab form with its components identified. Forming for a slab with an integral beam is illustrated in Figure 12–22. Forming for the one-way and two-way slabs described in Section 12–1 is usually accomplished using commercial pan forms. Figure 12–23 illustrates the use of long pans for a one-way joist slab. Figure 12–24 shows a waffle slab formed with dome pans. Such pan forms may be made of metal or plastic. Wooden stairway forms suitable for constructing stairways up to 3 ft wide are illustrated in Figure 12–25.

Figure 12–19 Typical form ties.



Minimizing Cost of Formwork

Since formwork may account for 40 to 60% of the cost of concrete construction, it is essential that the formwork plan be carefully developed and thoroughly evaluated. A cost comparison should be made of all feasible forming systems and methods of operation. Such an analysis must include the cost of equipment and labor required to install reinforcing steel and to place and finish the concrete, as well as the cost of formwork, its erection, and removal. The formwork plan that provides the required safety and construction quality at the minimum overall cost should be selected for implementation.

In general, lower formwork cost will result from repetitive use of forms. Multiple-use forms may be either standard commercial types or custom-made by the contractor. Contractor-fabricated forms should be constructed using assembly-line techniques

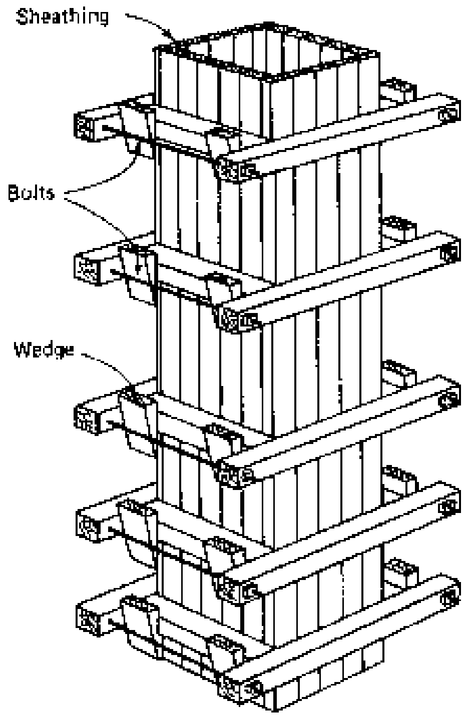


Figure 12–20 Typical column form. (U.S. Department of the Army)

whenever possible. *Flying forms,* large sections of formwork moved by crane from one position to another, are often economical in repetitive types of concrete construction. Where appropriate, the use of slip forms and the tilt-up construction techniques described earlier can greatly reduce forming costs. A flying form is pictured in Figure 12–26.

Construction Practices

Forms must be constructed with tight joints to prevent the loss of cement paste, which may result in honeycombing. Before concrete is placed, forms must be aligned both horizontally and vertically and braced to remain in alignment. Form alignment should be continuously monitored during concrete placement, and adjustments made if necessary. When a vertical form is wider at the bottom than at the top, an uplift force will be created as the form is filled. Such forms must be anchored against uplift. Inspect the interior of all forms and remove any debris before placing concrete. Use drop chutes or rubber elephant trunks to avoid segregation of aggregate and paste when placing concrete into high vertical forms. Free-fall distance should be limited to 5 ft or less. When vibrating concrete in vertical forms, allow the vibrator head to penetrate through the freshly placed concrete about 1 in. (2.5 cm) [but not more than 8 in. (20 cm)] into the previously placed layer of concrete. It is possible to bulge or rupture any wall or column form by inserting a large vibrator deep into previously placed, partially set concrete. However, revibration of previously compacted

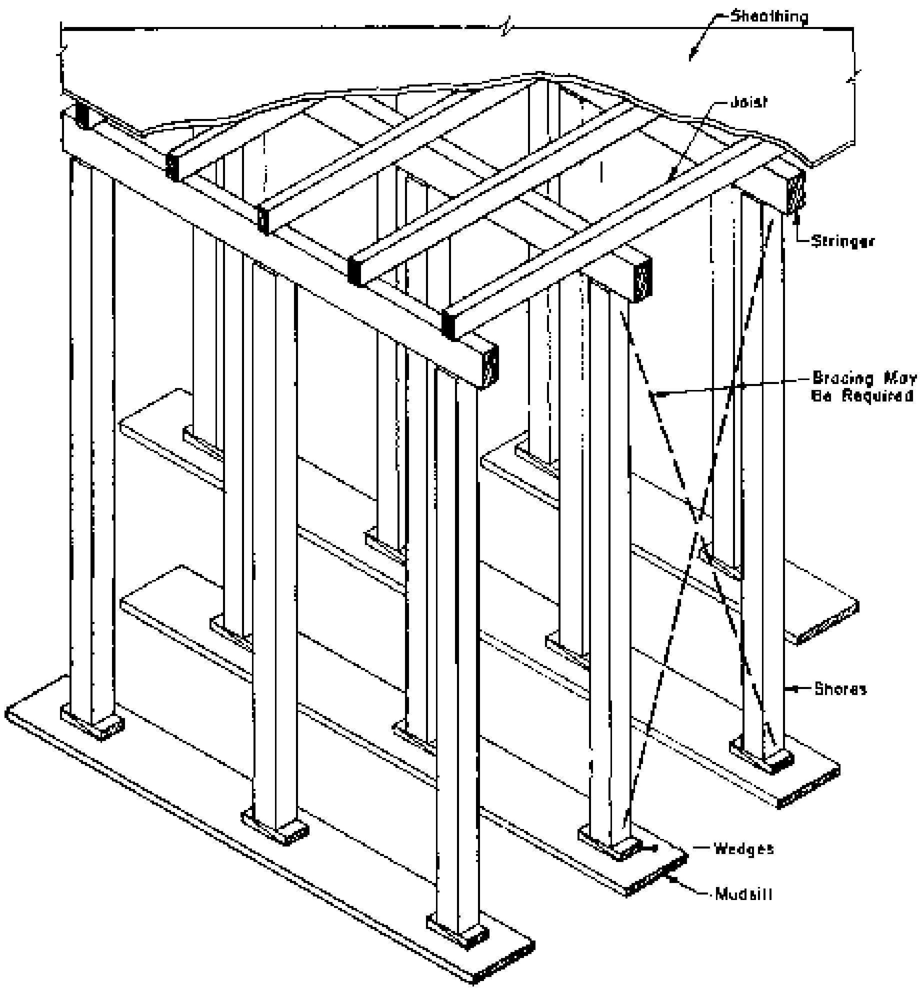


Figure 12–21 Form for elevated slab. (Courtesy of American Concrete Institute)

concrete is not harmful to the concrete as long as it becomes plastic when vibrated. When pumping forms from the bottom, it is important to fill the forms rapidly so that the concrete does not start to set up before filling is completed. If the pump rate is so low that setting begins, excessive pressure will be produced inside the form, resulting in bulging or rupturing of the form.

Concrete forms are removed after the concrete has developed the required strength. When removing (or *stripping*) concrete forms, care must be taken to minimize damage to the surface of the concrete during the removal process.

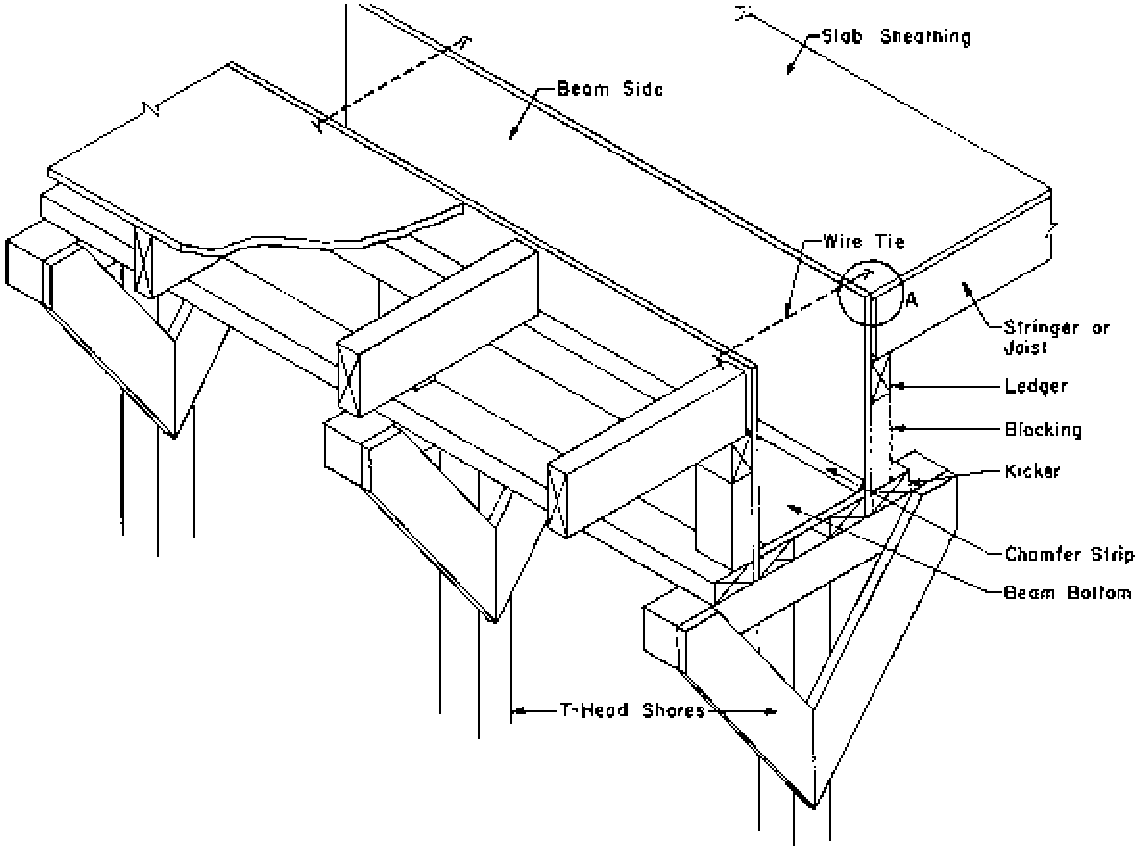


Figure 12–22 Beam and slab form. (Courtesy of American Concrete Institute)

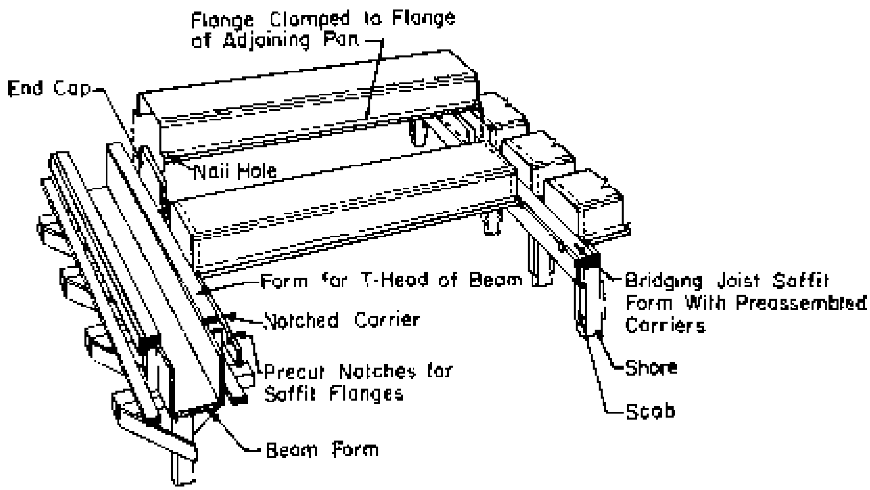
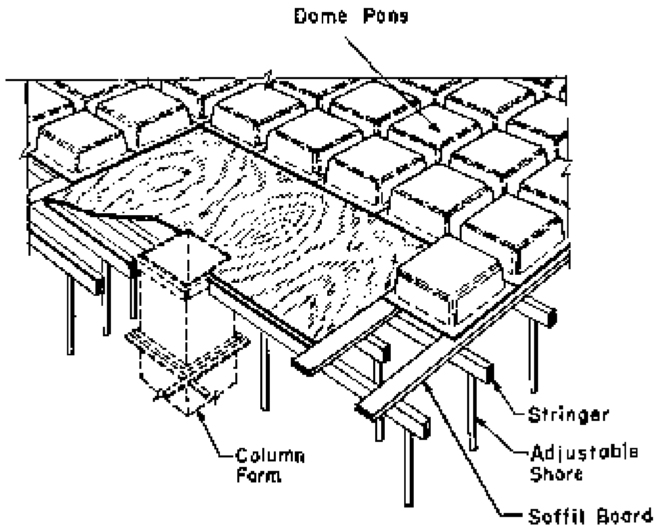


Figure 12–23 One-way slab form. (Courtesy of American Concrete Institute)

Figure 12–24 Two-way slab form. (Courtesy of American Concrete Institute)



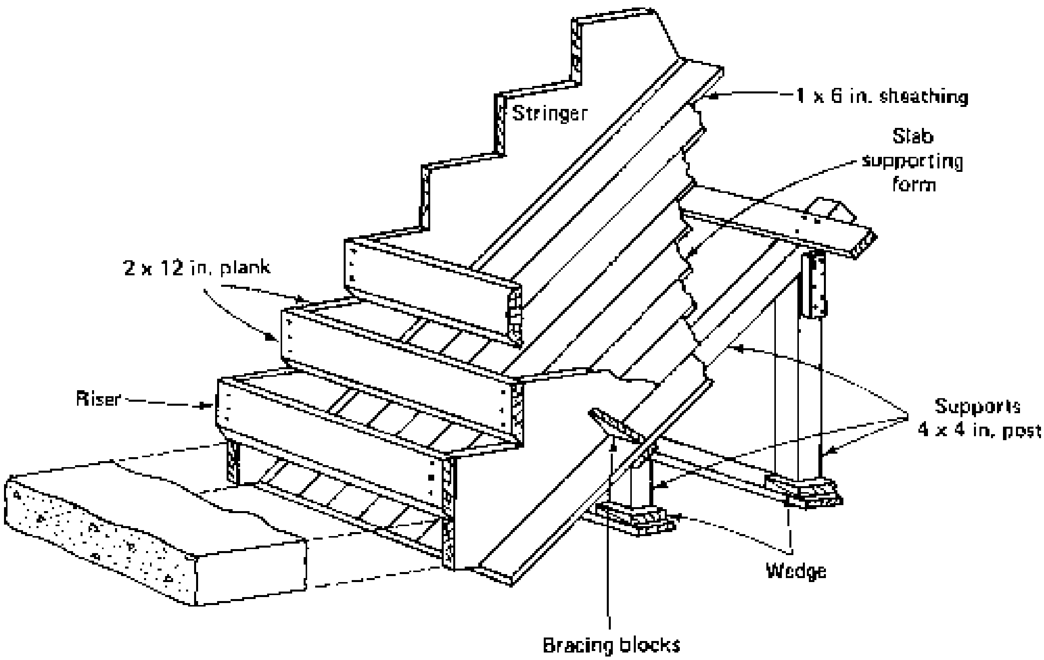


Figure 12–25 Wood form for stairway. (U.S. Department of the Army)

Figure 12–26 Repositioning flying form. (Courtesy of CMI Terex Corporation)

Expansion and Control Joints

Expansion and control joints are used to permit differential movement of wall sections, columns, and slabs caused by concrete shrinkage, temperature and moisture changes, and foundation settlement. Interior columns should be isolated from floor slabs by either providing a blockout in the floor slab around the column before placing the slab or forming a pinwheel isolation joint at the column. To construct a pinwheel isolation joint, contraction or construction joints are placed around the column at 90° angles to each other in line with the column sides. In either method, the column is wrapped with a preformed joint filler before placing concrete around the column. (See also the discussion of expansion and control joints of Section 14–1.)

Formwork Safety

The frequency and serious consequences of formwork failure require that special attention be paid to this aspect of construction safety. The requirements for safe formwork design are explained in Chapter 13. The following are some safety precautions that should be observed in constructing formwork.

1. Provide adequate foundations for all formwork. Place mudsills under all shoring that rests on the ground. Typical mudsills are illustrated in Figure 12–27. Check surrounding excavations to ensure that formwork does not fail due to embankment failure.
2. Provide adequate bracing of forms, being particularly careful of shores and other vertical supports. Ensure that all connections are properly secured, especially nailed

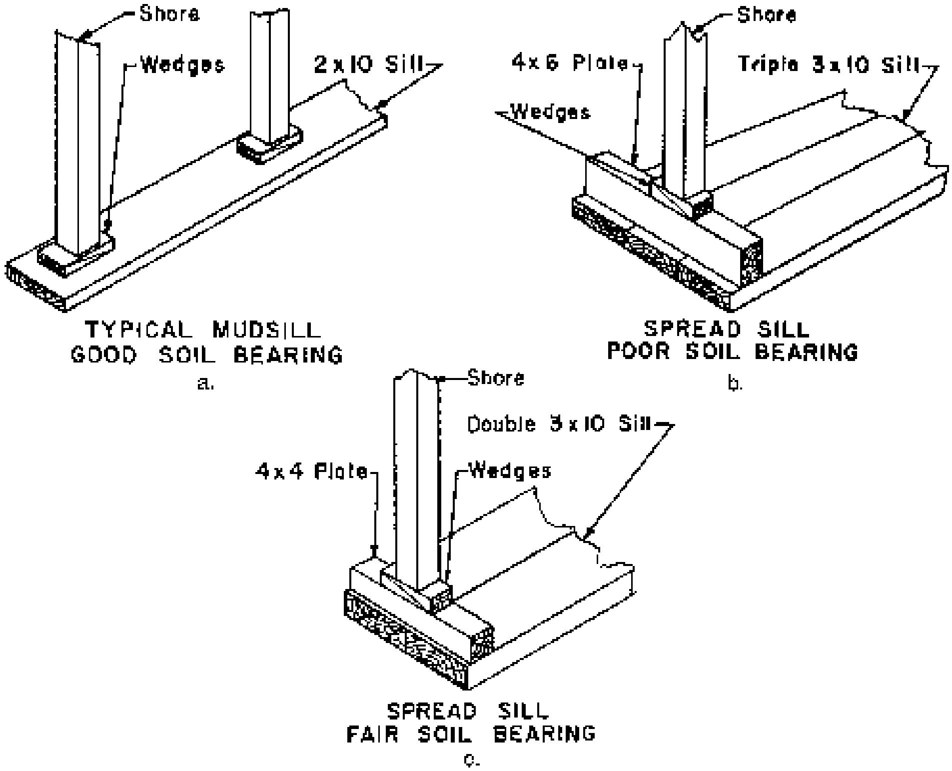


Figure 12–27 Mudsills. (Courtesy of American Concrete Institute)

connections. Vibration from power buggies or concrete vibrators may cause connections to loosen or supports to move.

3. Control the rate and location of concrete placement so that design loads are not exceeded.
4. Ensure that forms and supports are not removed before the concrete has developed the required strength. The process of placing temporary shores under slabs or structural members after forms have been stripped is called *reshoring*. Reshoring is a critical operation that must be carried out exactly as specified by the designer. Only a limited area should be stripped and reshored at one time. No construction loads should be allowed on the partially hardened concrete while reshoring is under way. Adequate bracing must be provided for reshoring.
5. When placing prefabricated form sections in windy weather, care must be taken to avoid injury caused by swinging of the form caused by wind forces.
6. Protruding nails are a major source of injury on concrete construction sites. As forms are stripped, form lumber must be promptly removed to a safe location and nails pulled.

12–4 REINFORCING STEEL

Concrete Reinforcing Steel

Concrete reinforcing steel is available as standard reinforcing bars, spirals (for column reinforcing), and welded wire fabric (WWF).

Reinforcing Bars

Reinforcing bars are usually deformed; that is, they are manufactured with ridges that provide an interlocking bond with the surrounding concrete. Deformed bars are available in the 11 American Society for Testing and Materials (ASTM) standard sizes listed in Table 12–1. Note that the size number of the bar indicates the approximate diameter of the bar in eighths of an inch (millimeters for metric sizes).

Two marking systems are used to identify ASTM standard reinforcing bars, the continuous line system and the number system. The systems are illustrated in Figure 12–28. The grade of reinforcing steel corresponds to its rated yield point in thousands of pounds per square inch.

Welded Wire Fabric

Welded wire fabric, commonly used for slab reinforcement, is available with smooth wire or deformed wire. Fabric is made from bright wire unless galvanized wire is specified.

Welded wire fabric is identified by the letters WWF followed by the spacing of longitudinal wires [in. (mm)], the spacing of transverse wires [in. (mm)], the size of longitudinal wires [sq in. 100 (mm^2)], and the size of transverse wires [sq in. $\times$ 100 (mm^2)]. Metric sizes are identified by the letter M preceding the wire sizes. Standard wire sizes are given in Table 12–2. Deformed wire is indicated by the letter D preceding the wire size. For example, “WWF 6 $\times$ 6–4.0 $\times$ 4.0 [152 $\times$ 152 MW 25.8 $\times$ MW 25.8]” denotes a square wire

Table 12–1 ASTM standard reinforcing bar sizes

Size Number	Metric Size Number	Weight lb/ft	Weight kg/m	Diameter in.	Diameter mm	Section Area sq in.	Section Area mm^2
3	10	0.376	0.560	0.375	9.52	0.11	71
4	13	0.668	0.994	0.500	12.70	0.20	129
5	16	1.043	1.552	0.625	15.88	0.31	200
6	19	1.502	2.235	0.750	19.05	0.44	284
7	22	2.044	3.042	0.875	22.22	0.60	387
8	25	2.670	3.973	1.000	25.40	0.79	510
9	29	3.400	5.059	1.128	28.65	1.00	645
10	32	4.303	6.403	1.270	32.26	1.27	819
11	36	5.313	7.906	1.410	35.81	1.56	1006
14	43	7.650	11.384	1.693	43.00	2.25	1452
18	57	13.600	20.238	2.257	57.33	4.00	2581

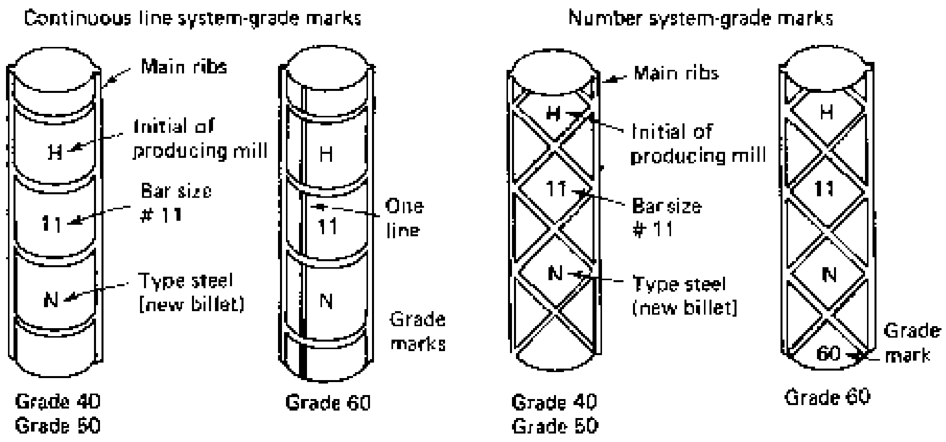


Figure 12–28 Reinforcing bar identification marks. (Courtesy of Concrete Reinforcing Steel Institute)

pattern with both transverse and longitudinal wires spaced 6 in. (152 mm) on center. Both wires are size W4 [0.04-sq in. (25.8-mm^2) section area]. Requirements for welded wire fabric are given in ASTM A185 and A497.

Spirals

Spirals are available in three standard rod sizes: ⅜ in. (0.95 cm), ½ in.(1.27 cm), and ⅝ in. (1.59 cm) in diameter. Standard spiral diameters (outside to outside) range from 12 in. (30 cm) to 33 in. (84 cm). Pitch (distance between centers of adjacent spirals) ranges from 1¾ in. (4.4 cm) to 3¼ in. (8.3 cm) by ¼-in. (0.64-cm) increments. Steel grades available include grades 40, 60, and 70.

Placement of Reinforcing

Since concrete is weak in resistance to tensile forces, reinforcing steel is used primarily to resist tension and thus prevent cracking or failure of the concrete member under tension. Tension may be induced by shrinkage of concrete as it hardens and by temperature changes as well as by bending and shear forces. Typical placement of reinforcing steel in concrete structural members is illustrated in Figure 12–29.

To provide protection of reinforcing steel against corrosion and fire, a minimum cover of concrete must be furnished. Building codes usually specify minimum cover requirements. The American Concrete Institute (ACI) recommends the following minimum cover when not otherwise specified:

- Slabs, joists, and walls not exposed to weather or ground: ¾ in. (1.9 cm).
- Beams, girders, and columns not exposed to weather or ground: 1½ in. (3.8 cm).
- Concrete placed in forms but exposed to weather or ground: 1½ in. (3.8 cm) for No. 5 bars or smaller; 2 in. (5.1 cm) for bars larger than No. 5.

Table 12–2 Steel wire data for welded wire fabric

Wire Size Number		Diameter		Area		Weight	
Smooth	*Deformed*	*in.*	*mm*	*sq in.*	*mm²*	*lb/ft*	*kg/m*
W31	D31	0.628	16.0	0.31	200	1.054	1.568
W28	D28	0.597	15.2	0.28	181	0.952	1.417
W26	D26	0.575	14.6	0.26	168	0.934	1.390
W24	D24	0.553	14.1	0.24	155	0.816	1.214
W22	D22	0.529	13.4	0.22	142	0.748	1.113
W20	D20	0.505	12.8	0.20	129	0.680	1.012
W18	D18	0.479	12.2	0.18	116	0.612	0.911
W16	D16	0.451	11.5	0.16	103	0.544	0.810
W14	D14	0.422	10.7	0.14	90	0.476	0.708
W12	D12	0.391	9.9	0.12	77	0.408	0.607
W11	D11	0.374	9.5	0.11	71	0.374	0.557
W10	D10	0.357	9.1	0.10	65	0.340	0.506
W9.5		0.348	8.8	0.095	61	0.323	0.481
W9	D9	0.338	8.6	0.09	58	0.306	0.455
W8.5		0.329	8.4	0.085	55	0.289	0.430
W8	D8	0.319	8.1	0.08	52	0.272	0.405
W7.5		0.309	7.8	0.075	48	0.255	0.379
W7	D7	0.299	7.6	0.07	45	0.238	0.354
W6.5		0.288	7.3	0.065	42	0.221	0.329
W6	D6	0.276	7.0	0.06	39	0.204	0.304
W5.5		0.265	6.7	0.055	35	0.187	0.278
W5	D5	0.252	6.4	0.05	32	0.170	0.253
W4.5		0.239	6.1	0.045	29	0.153	0.228
W4	D4	0.226	5.7	0.04	26	0.136	0.202
W3.5		0.211	5.4	0.035	23	0.119	0.177
W2.9		0.192	4.9	0.029	19	0.099	0.147
W2.5		0.178	4.5	0.025	16	0.085	0.126
W2		0.160	4.1	0.02	13	0.068	0.101
W1.4		0.134	3.4	0.014	9	0.048	0.071

- Concrete placed without forms directly on the ground: 3 in. (7.6 cm).
- At least one bar diameter of cover should be used in any case.

Reinforcing steel must be placed within the tolerances specified by the designer. General placement tolerances suggested by the Concrete Reinforcing Steel Institute (CRSI) include:

- Spacing of outside top, bottom, and side bars in beams, joists, and slabs: ±¼ in. (0.64 cm).
- Lengthwise position of bar ends:
  Sheared bars ±2 in. (5.1 cm).
  Bars with hooked ends ±½ in. (1.3 cm).

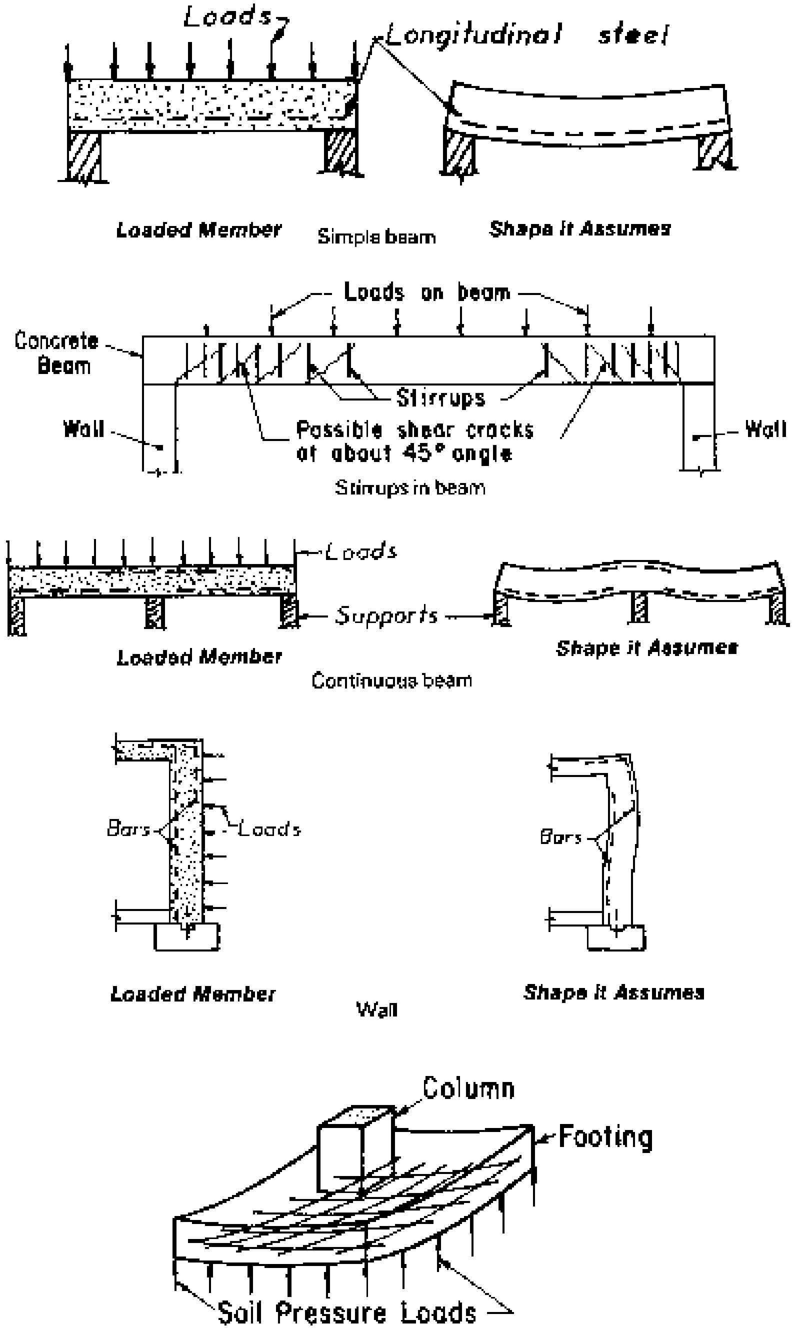
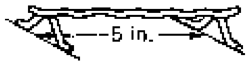
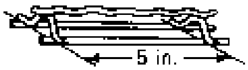
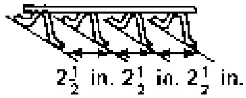
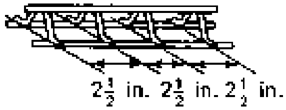
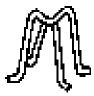
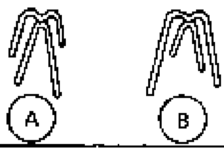
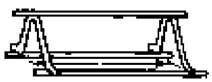
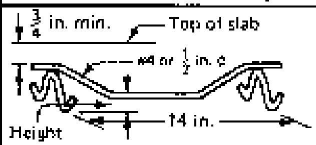


Figure 12–29 Placement of reinforcing steel. (Courtesy of Concrete Reinforcing Steel Institute)

Symbol	Bar support illustration	Type of support	Standard sizes
SB		Slab bolster	$\frac{3}{4}$, 1, $1\frac{1}{2}$, and 2 in. heights in 5 ft and 10 ft lengths
SBU*		Slab bolster upper	Same as SB
BB		Beam bolster	1, $1\frac{1}{2}$, 2; over 2 in. to 5 in. height in increments of $\frac{1}{4}$ in. in lengths of 5 ft
BBU*		Beam bolster upper	Same as BB
BC		Individual bar chair	$\frac{3}{4}$, 1, $1\frac{1}{2}$, and $1\frac{3}{4}$ in. heights
JC		Joist chair	4, 5, and 6 in. widths and $\frac{3}{4}$, 1, and $1\frac{1}{2}$ in. heights
HC		Individual high chair	2 to 15 in. heights in increments of $\frac{1}{4}$ in.
HCM*		High chair for metal deck	2 to 15 in. heights in increments of $\frac{1}{4}$ in.
CHC		Continuous high chair	Same as HC in 5 foot and 10 foot lengths
CHCU*		Continuous high chair upper	Same as CHC
CHCM*		Continuous high chair for metal deck	Up to 5 in. heights in increments of $\frac{1}{4}$ in.
JCU**		Joist chair upper	14 in. Span. Heights −1 in. through +$3\frac{1}{2}$ in. vary in $\frac{1}{4}$ in. increments

* Available in Class A only, except on special order.
** Available in Class A only, with upturned or end bearing legs.

Figure 12–30 Wire bar supports. (Courtesy of Concrete Reinforcing Steel Institute)

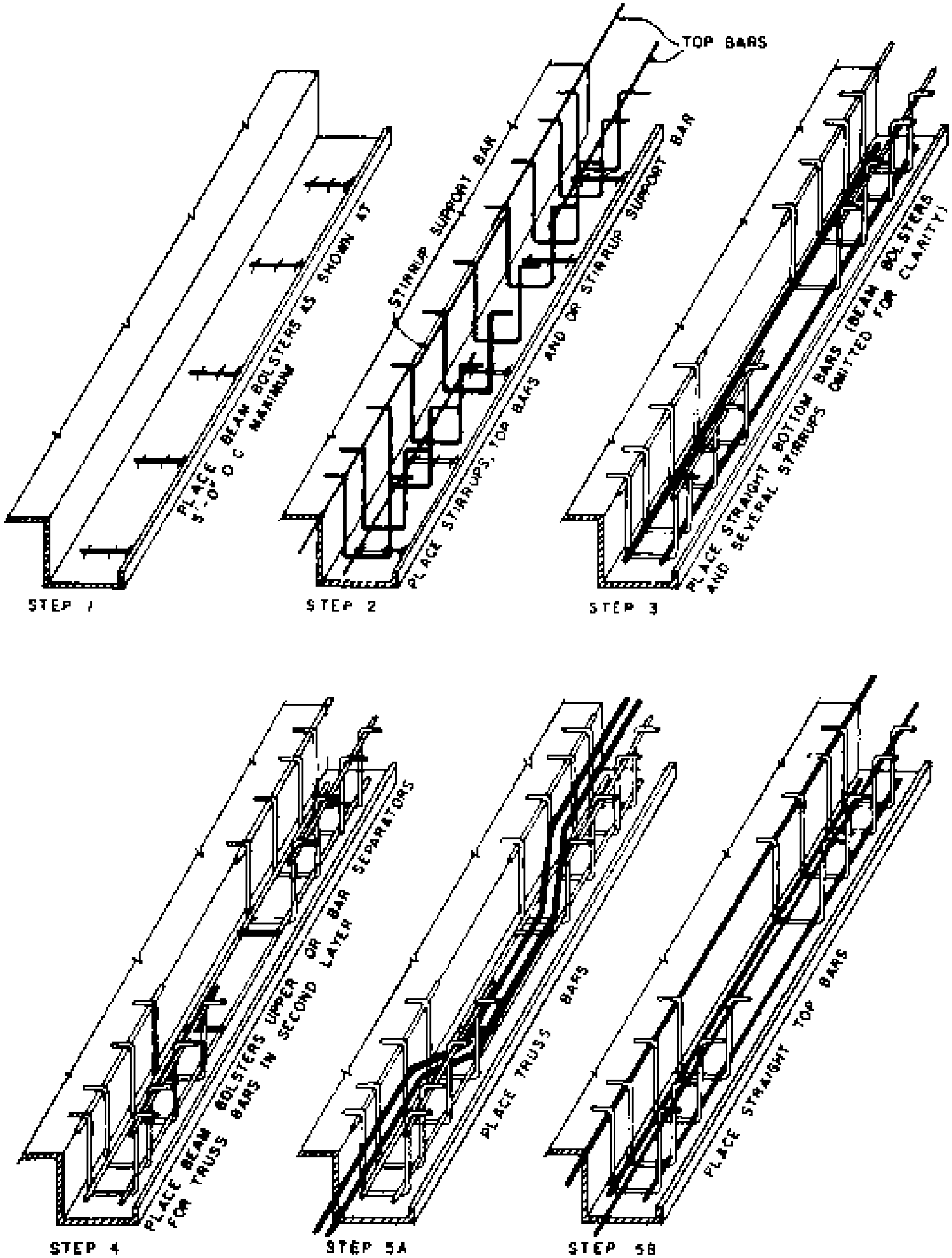


Figure 12–31 Placing reinforcing steel in a beam. (Courtesy of Concrete Reinforcing Steel Institute)

- Horizontal spacing of bars in slabs and walls: ±1 in. (2.5 cm).
- Stirrup spacing (distance between adjacent stirrups): ±1 in. (2.5 cm).

The minimum clear distance between parallel bars in columns should be the greater of 1½ bar diameters, 1½ in. (3.8 cm), or 1½ times the maximum aggregate size. For other than columns, the minimum clear distance between parallel bars should be the greater of one bar diameter, 1 in. (2.5 cm) or 1⅓ times the maximum aggregate size. Bars are maintained in their specified position by tying to adjacent bars or by the use of bar supports. Standard types and sizes of wire bar supports are illustrated in Figure 12–30. Figure 12–31 illustrates the CRSI-suggested sequence for placing reinforcing steel in a deep, heavily reinforced concrete beam when a preassembled reinforcing cage cannot be used.

12–5 QUALITY CONTROL

Common Deficiencies in Concrete Construction

Adequate quality control must be exercised over concrete operations if concrete of the required strength, durability, and appearance is to be obtained. Quality control measures specifically applicable to formwork are described in Section 12–3. Deficiencies in concrete construction practice may usually be traced to inadequate supervision of construction operations. A review by the U.S. Army Corps of Engineers has produced the following list of repetitive deficiencies observed in concrete construction.

Structural Concrete

1. Unstable form bracing and poor form alignment evidenced by form bulging, spreading, or inaccurately aligned members.
2. Poor alignment of reinforcing steel and exceeding prescribed tolerances.
3. Obvious cold joints in walls.
4. Excessively honeycombed wall areas.
5. Belated form tie removal, form stripping, and patching.
6. Inadequate compaction (mechanical vibration, rodding, or spading).

Concrete Slabs on Grade

1. Poor compaction of subgrade evidenced by slab settlement.
2. Saturation and damage to subgrade caused by water standing around foundation walls and/or inadequate storm drainage.
3. Uneven floor slab finishes.
4. Inadequate curing of floor slabs.

Inspection and Testing

The inspection and testing associated with concrete quality control may be grouped into five phases. These include mix design; concrete materials quality; batching, mixing, and transporting concrete; concrete placing, vibrating, finishing, and curing; and testing of fresh and hardened concrete at the job site. Mix design includes the quantity of each component in the mix, the type and gradation of aggregates, the type of cement, and so on. Aggregate testing includes tests for organic impurities and excessive fines, gradation, resistance to abrasion, and aggregate moisture. Control of concrete production includes accuracy of batching and the mixing procedures used. With modern concrete production equipment, the producer's quality control procedures and certification that specifications have been met may be all that is required in the way of production quality control. Transporting, placing, finishing, and curing procedures should be checked for compliance with specifications and with the general principles explained earlier.

Testing of concrete delivered to the job site involves testing of plastic concrete and performing strength tests on hardened concrete. The principal tests performed on plastic concrete include the slump test and tests for air and cement content. The temperature of plastic concrete should be checked for hot- or cold-weather concreting. The strength of hardened concrete is determined by compression tests on cylinder samples, by tensile splitting tests, or by flexure tests. Such tests are usually made after 7 and 28 d of curing. Standard cylinders used for compression tests are 6 in. (15.2 cm) in diameter by 12 in. (30.5 cm) high. Beam samples for flexure tests are usually 6 in. (15.2 cm) square by 20 in. (50.8 cm) long. A procedure for evaluating compression tests results, which is recommended by the American Concrete Institute, is contained in ACI 214.

Recent developments in concrete testing technology have greatly reduced the time required to obtain results from on-site testing of plastic concrete. For example, a nuclear water/cement gauge is now available which measures the cement content, water content, and water/cement ratio of plastic concrete within 15 min. When the relationship between the water/cement ratio and 28-d compressive strength of a concrete has been previously established, the ultimate compressive strength of a concrete being placed can be quickly predicted using the on-site reading from the nuclear water/cement gauge.

PROBLEMS

1. A steel reinforcing bar contains the markings "B 8 N 60." What are the size and strength of the bar?
2. What are the principal requirements that concrete formwork must satisfy?
3. What tests may be performed on plastic concrete delivered to the job site to ensure that it meets specification requirements? How might a rapid strength test be performed on plastic concrete?
4. What component usually accounts for the largest portion of concrete construction cost for a reinforced concrete building?

5. Briefly discuss the advantages and disadvantages of precast, prestressed concrete compared to cast-in-place concrete.
6. When placing parallel No. 8 (metric No. 25) reinforcing bars in a column form, what minimum clear distance between bars should be obtained if the maximum concrete aggregate size is 2 in. (51 mm)?
7. Why should interior columns be isolated from floor slabs? How is this usually accomplished?
8. What purpose do "wales" serve in a concrete wall form?
9. Give at least three precautions that should be observed in placing and consolidating concrete in vertical forms.
10. Develop a computer program to determine the minimum concrete cover over reinforcing bars, the minimum clear distance between parallel reinforcing bars, and the placement tolerances for a specified reinforced concrete design.

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