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CHAPTER 11

Placing and Finishing Concrete

PREPARATION BEFORE PLACING

Preparation prior to placing concrete for pavements or slabs on grade includes compacting, trimming, and moistening the subgrade (Figs. 11-1, 11-2, and 11-3); erecting the forms; and setting the reinforcing steel and other embedded items securely in place. Moistening the subgrade is important, especially in hot, dry weather to keep the dry subgrade from drawing too much water from the concrete; it also increases the immediate air-moisture level thereby decreasing the amount of evaporation from the concrete surface. The strength or bearing capacity of the subgrade should be adequate to support anticipated structural loads.

In cold weather, concrete must not be placed on a frozen subgrade. Snow, ice, and other debris must be removed from within the forms before concrete is placed. Where concrete is to be deposited on rock or hardened concrete, all loose material must be removed, and cut faces should be nearly vertical or horizontal rather than sloping.

Recently placed concrete requiring an overlay is usually roughened shortly after hardening to produce a better

Fig. 11-1. A base course foundation for concrete pavement is shaped by an auto-trimmer to design grades, cross section and alignment by automatic sensors that follow string lines. (69935)

Fig. 11-2. Water trucks with spray-bars are used to moisten subgrades and base course layers to achieve adequate compaction and to reduce the amount of water drawn out of concrete as it's placed. (69931)

Fig. 11-3. (top) Adequate compaction of a base course foundation for concrete pavement can be achieved by using a vibratory roller. (bottom) Vibratory plate compactors are also used to prepare subgrades under slabs. (69934, 69930)

bond with the next placement. As long as no laitance (a weak layer of concrete), dirt, or loose particles are present, newly hardened concrete requires little preparation prior to placing freshly mixed concrete on it. When in service for a period of time, old hardened concrete usually requires mechanical cleaning and roughening prior to placement of new concrete. The subject of placing freshly mixed concrete on hardened concrete is discussed in more detail under the sections entitled "Placing on Hardened Concrete" and "Construction Joints."

Forms should be accurately set, clean, tight, adequately braced, and constructed of or lined with materials that will impart the desired off-the-form finish to the hardened concrete. Wood forms, unless oiled or otherwise treated with a form-release agent, should be moistened before placing concrete, otherwise they will absorb water from the concrete and swell. Forms should be made for removal with minimum damage to the concrete. With wood forms, use of too large or too many nails should be avoided to facilitate removal and reduce damage. For architectural concrete, the form-release agent should be a nonstaining material. See Hurd (1979) and ACI Committee 347 (1999) for more information on formwork.

Reinforcing steel should be clean and free of loose rust or mill scale when concrete is placed. Unlike subgrades, reinforcing steel can be colder than 0°C (32°F) with special considerations. See "Concreting Aboveground" in Chapter 14 for more details. Mortar splattered on reinforcing bars from previous placements need not be removed from steel and other embedded items if the next lift is to be completed within a few hours; loose, dried mortar, however, must be removed from items that will be encased by later lifts of concrete.

All equipment used to place concrete must be clean and in good working condition. Standby equipment should be available in the event of a breakdown.

Fig. 11-4. Wheelbarrows are used to place concrete in areas that are not easily accessed by other placement methods. (69929)

Fig. 11-5. The swing arm on a conveyor belt allows fresh concrete to be placed fairly evenly across a deck. (70002)

DEPOSITING THE CONCRETE

Concrete should be deposited continuously as near as possible to its final position without objectionable segregation (Figs. 11-4, 11-5, 11-6, 11-7, and 11-8). In slab construction, placing should be started along the perimeter at one end of the work with each batch discharged against previously placed concrete. The concrete should not be dumped in separate piles and then leveled and worked together; nor should the concrete be deposited in large piles and moved horizontally into final position. Such practices result in segregation because mortar tends to flow ahead of the coarser material.

In general, concrete should be placed in walls, thick slabs, or foundations in horizontal layers of uniform thickness; each layer should be thoroughly consolidated before the next is placed. The rate of placement should be rapid enough so that previously placed concrete has not yet set when the next layer of concrete is placed upon it. Timely placement and adequate consolidation will prevent flow lines, seams, and planes of weakness (cold joints) that result

Fig. 11-6. Dump trucks deposit concrete ahead of a slip-form paver that places the entire width of a street in one pass. Epoxy coated dowels on metal chairs are positioned at a joint and spiked down to the base course just ahead of the paver. (69936)

Fig. 11-7. Curb machines continuously extrude low-slump concrete into a shape that immediately stands without support of formwork. (69937)

Fig. 11-8. Concrete should be placed as near as possible to its final position. (70009)

from placing freshly mixed concrete on concrete past initial set. Layers should be about 150 to 500 mm (6 to 20 in.) thick for reinforced members and 380 to 500 mm (15 to 20 in.) thick for mass work; the thickness will depend on the width between forms and the amount of reinforcement.

To avoid segregation, concrete should not be moved horizontally over too long a distance as it is being placed in forms or slabs. In some work, such as placing concrete in sloping wingwalls or beneath window openings in walls, it is necessary to move the concrete horizontally within the forms, but this should be kept to a minimum.

Where standing water is present, concrete should be placed in a manner that displaces the water ahead of the concrete but does not allow water to be mixed in with the concrete; to do so will reduce the quality of the concrete. In all cases, water should be prevented from collecting at the ends, in corners, and along faces of forms. Care should be taken to avoid disturbing saturated subgrade soils so they maintain sufficient bearing capacity to support structural loads.

Chutes and dropchutes are used to move concrete to lower elevations without segregation and spattering of mortar on reinforcement and forms. Properly designed concrete has been allowed to drop by free fall into caissons. Results of a field test to determine if concrete could be dropped vertically 15 meters (50 ft) into a caisson without segregation proved that there was no significant difference in aggregate gradation between control samples as delivered and free-fall samples taken from the bottom of the caisson (Turner 1970). More recent field studies indicate that free fall of concrete from heights of up to 46 m (150 ft)—directly over reinforcing steel or at a high slump—does not result in segregation of the concrete ingredients nor reduce compressive strength (Suprenant 2001). However, if a baffle is not used to control the flow of concrete onto sloped surfaces at the end of an inclined chute, segregation can occur.

Concrete is sometimes placed through openings, called windows, in the sides of tall, narrow forms. When a chute discharges directly through the opening without controlling concrete flow at the end of the chute there is danger of segregation. A collecting hopper should be used outside the opening to permit the concrete to flow more smoothly through the opening; this will decrease the tendency to segregate.

When concrete is placed in tall forms at a fairly rapid rate, some bleed water may collect on the top surface, especially with non-air-entrained concrete. Bleeding can be reduced by placing more slowly and by using concrete of a stiffer consistency, particularly in the lower portion of the form. When practical, concrete should be placed to a level 300 mm to 400 mm (about a foot) below the top of tall forms and an hour or so allowed for the concrete to partially set. Placing should resume before the surface hardens to avoid formation of a cold joint. If practical to work around vertical reinforcing steel, it is good practice to overfill the form by 25 mm (an inch) or so and cut off the excess concrete after it has stiffened and bleeding has ceased.

In monolithic placement of deep beams, walls, or columns, to avoid cracks between structural elements, concrete placement should stop (usually about 1 hr) to allow settlement of the deep element before concreting is continued in any slabs, beams, or girders framing into them. The delay should be short enough to allow the next layer of concrete to knit with the previous layer by vibration, thus preventing cold joints and honeycombing (ACI Committee 304 2000). Haunches and column capitals are considered part of the floor or roof slab and should be placed integrally with them.

PLACING CONCRETE UNDERWATER

Concrete should be placed in the air rather than underwater whenever possible. When it must be placed underwater, the work should be done under experienced supervision. The basic principles for normal concrete work in the dry apply, with common sense, to underwater concreting. The following special points, however, should be observed:

The slump of the concrete should be specified at 150 to 230 mm (6 to 9 in.) and the mixture should have a maximum water-cementitious materials ratio of 0.45. Generally, the cementitious materials content will be 390 kg/m^3 (600 lb/yd^3) or more.

It is important that the concrete flow without segregation; therefore, the aim in proportioning should be to obtain a cohesive mixture with high workability. Antiwashout admixtures can be used to make concrete cohesive enough to be placed in limited depths of water, even without tremies. Using rounded aggregates, a higher percentage of fines, and entrained air should help to obtain the desired consistency.

The current in the water through which the concrete is deposited should not exceed 3 m (10 ft) per minute.

Methods for placing concrete underwater include the following: tremie, concrete pump, bottom-dump buckets, grouting preplaced aggregate, toggle bags, bagwork, and the diving bell.

A tremie is a smooth, straight pipe long enough to reach the lowest point to be concreted from a working platform above the water. The diameter of the tremie pipe should be at least 8 times the diameter of the maximum size of aggregate. A hopper to receive the concrete is attached to the top of the pipe. The lower end of the tremie should be kept buried in the fresh concrete to maintain a seal below the rising top surface and to force the concrete to flow in beneath it by pressure. Placing should be continuous with as little disturbance to the previously placed concrete as possible. The top surface should be kept as level as possible. See ACI Committee 304 (2000) for additional information.

Mobile concrete pumps with a variable radius boom makes easy work of placing concrete underwater. Because the flexible hose on a concrete pump is similar to a tremie, the same placement techniques apply.

With the grouting preplaced aggregate method, the forms are first filled with clean coarse aggregate, then the voids in the coarse aggregate are filled with a grout to produce concrete. Grouting preplaced aggregate has advantages when placing concrete in flowing water. Concrete can be placed more quickly and economically than by conventional placement methods. However, the method is very specialized and should only be performed by qualified experienced personnel.

Sand bags half full of plastic concrete can be used for small jobs, filling gaps, or temporary work. The tied end should face away from the outside.

SPECIAL PLACING TECHNIQUES

Concrete may be placed by methods other than the usual cast-in-place method. These methods, such as shotcreting, are described in Chapter 18. No matter what method is used, the basics of mixing, placing, consolidating, and curing apply to all portland cement concretes.

CONSOLIDATING CONCRETE

Consolidation is the process of compacting fresh concrete; to mold it within the forms and around embedded items and reinforcement; and to eliminate stone pockets, honeycomb, and entrapped air (Fig. 11-9). It should not remove significant amounts of intentionally entrained air in air-entrained concrete.

Consolidation is accomplished by hand or by mechanical methods. The method chosen depends on the consistency of the mixture and the placing conditions, such as complexity of the formwork and amount and spacing of reinforcement. Generally, mechanical methods using either internal or external vibration are the preferred methods of consolidation.

Workable, flowing mixtures can be consolidated by hand rodding, that is, thrusting a tamping rod or other suitable tool repeatedly into the concrete. The rod should be long enough to reach the bottom of the form or lift and thin enough to easily pass between the reinforcing steel and the forms. Low-slump concrete can be transformed into flowing concrete for easier consolidation through the use of superplasticizers without the addition of water to the concrete mixture.

Spading can be used to improve the appearance of formed surfaces. A flat, spadelike tool should be repeatedly inserted and withdrawn adjacent to the form. This forces the larger coarse aggregates away from the forms and assists entrapped air voids in their upward movement toward the top surface where they can escape. A mixture designed to be readily consolidated by hand methods should not be consolidated by mechanical methods; otherwise, the concrete is likely to segregate under intense mechanical action.

Fig. 11-9. Honeycomb and rock pockets are the results of inadequate consolidation. (50207)

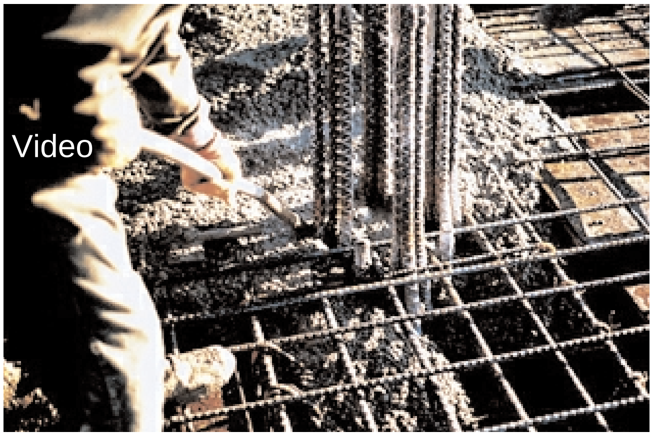


Fig. 11-10. Proper vibration makes possible the placement of stiff concrete mixtures, even in heavily-reinforced concrete members. (55806)

Fig. 11-11. Internal vibrators are commonly used to consolidate concrete in walls, columns, beams, and slabs. (69970)

Even in highly reinforced elements, proper mechanical consolidation makes possible the placement of stiff mixtures with the low water-cementitious materials ratios and high coarse-aggregate contents associated with high-quality concrete (Fig. 11-10). Among the mechanical methods are centrifugation, used to consolidate moderate-to-high-slump concrete in making pipes, poles, and piles; shock or drop tables, used to compact very stiff low-slump concrete in the manufacture of architectural precast units; and vibration—internal and external.

Vibration

Vibration, either internal or external, is the most widely used method for consolidating concrete. When concrete is vibrated, the internal friction between the aggregate particles is temporarily destroyed and the concrete behaves like a liquid; it settles in the forms under the action of gravity and the large entrapped air voids rise more easily to the surface. Internal friction is reestablished as soon as vibration stops.

Vibrators, whether internal or external, are usually characterized by their frequency of vibration, expressed as the number of vibrations per second (Hertz), or vibrations per minute (vpm); they are also designated by the amplitude of vibration, which is the deviation in millimeters (inches) from the point of rest. The frequency of vibration can be measured using a vibrating reed tachometer.

When vibration is used to consolidate concrete, a standby vibrator should be on hand at all times in the event of a mechanical breakdown.

Internal Vibration. Internal or immersion-type vibrators, often called spud or poker vibrators (Figs. 11-10 and 11-11), are commonly used to consolidate concrete in walls, columns, beams, and slabs. Flexible-shaft vibrators consist of a vibrating head connected to a driving motor by a flexible shaft. Inside the head, an unbalanced weight connected to the shaft rotates at high speed, causing the head to revolve in a circular orbit. The motor can be powered by electricity, gasoline, or air. The vibrating head is usually cylindrical with a diameter ranging from 20 to 180 mm (¾ to 7 in.). Some vibrators have an electric motor built right into the head, which is generally at least 50 mm (2 in.) in diameter. The dimensions of the vibrator head as well as its frequency and amplitude in conjunction with the workability of the mixture affect the performance of a vibrator.

Small-diameter vibrators have high frequencies ranging from 160 to 250 Hz (10,000 to 15,000 vpm) and low amplitudes ranging between 0.4 and 0.8 mm (0.016 and 0.03 in.). As the diameter of the head increases, the frequency decreases and the amplitude increases. The effective radius of action of a vibrator increases with increasing diameter. Vibrators with a diameter of 20 to 40 mm (¾ to 1½ in.) have a radius of action in freshly mixed concrete ranging between 75 and 150 mm (3 and 6 in.), whereas the radius of action for vibrators of 50- to 80-mm (2- to 3-in.) diameter ranges between 180 and 350 mm (7 and 14 in.). Table 11-1 shows the range of characteristics and applications for internal vibrators for various applications.

Proper use of internal vibrators is important for best results. Vibrators should not be used to move concrete horizontally since this causes segregation. Whenever possible, the vibrator should be lowered vertically into the concrete at regularly spaced intervals and allowed to descend by gravity. It should penetrate to the bottom of the layer being placed and at least 150 mm (6 in.) into any previously placed layer. The height of each layer or lift should be about the length of the vibrator head or generally a maximum of 500 mm (20 in.) in regular formwork.

In thin slabs, the vibrator should be inserted at an angle or horizontally in order to keep the vibrator head completely immersed. However, the vibrator should not be dragged around randomly in the slab. For slabs on grade, the vibrator should not make contact with the sub-

Table 11-1. Range of Characteristics, Performance, and Applications of Internal* Vibrators

Group	Diameter of head, mm (in.)	Recommended frequency, vibrations per minute**	Suggested values of: Eccentric moment, mm-kg in.-lb (10^{-3})	Suggested values of: Average amplitude, mm (in.)	Suggested values of: Centrifugal force, kg (lb)	Approximate values of: Radius of action,† mm (in.)	Approximate values of: Rate of concrete placement, m^3/h (yd^3/h)‡	Application
1	20-40 (¾-1½)	9000-15,000	3.5-12 (0.03-0.10)	0.4-0.8 (0.015-0.03)	45-180 (100-400)	80-150 (3-6)	0.8-4 (1-5)	Plastic and flowing concrete in very thin members and confined places. May be used to supplement larger vibrators, especially in prestressed work where cables and ducts cause congestion in forms. Also used for fabricating laboratory test specimens.
2	30-60 (1¼-2½)	8500-12,500	9-29 (0.08-0.25)	0.5-1.0 (0.02-0.04)	140-400 (300-900)	130-250 (5-10)	2.3-8 (3-10)	Plastic concrete in thin walls, columns, beams, precast piles, thin slabs, and along construction joints. May be used to supplement larger vibrators in confined areas.
3	50-90 (2-3½)	8000-12,000	23-81 (0.20-0.70)	0.6-1.3 (0.025-0.05)	320-900 (700-2000)	180-360 (7-14)	4.6-15 (6-20)	Stiff plastic concrete (less than 80-mm [3-in.] slump) in general construction such as walls, columns, beams, prestressed piles, and heavy slabs. Auxiliary vibration adjacent to forms of mass concrete and pavements. May be gang mounted to provide full-width internal vibration of pavement slabs.
4	80-150 (3-6)	7000-10,500	8-290 (0.70-2.5)	0.8-1.5 (0.03-0.06)	680-1800 (1500-4000)	300-510 (12-20)	11-31 (15-40)	Mass and structural concrete of 0 to 50-mm (2-in.) slump deposited in quantities up to 3 m^3 (4 yd^3) in relatively open forms of heavy construction (powerhouses, heavy bridge piers, and foundations). Also used for auxiliary vibration in dam construction near forms and around embedded items and reinforcing steel.
5	130-150 (5-6)	5500-8500	260-400 (2.25-3.50)	1.0-2.0 (0.04-0.08)	1100-2700 (2500-6000)	400-610 (16-24)	19-38 (25-50)	Mass concrete in gravity dams, large piers, massive walls, etc. Two or more vibrators will be required to operate simultaneously to mix and consolidate quantities of concrete of 3 m^3 (4 yd^3) or more deposited at one time into the form.

* Generally, extremely dry or very stiff concrete does not respond well to internal vibrators.
** While vibrator is operating in concrete.
† Distance over which concrete is fully consolidated.
‡ Assumes the insertion spacing is 1½ times the radius of action, and that vibrator operates two-thirds of time concrete is being placed. These ranges reflect not only the capability of the vibrator but also differences in workability of the mix, degree of deaeration desired, and other conditions experienced in construction.
Adapted from ACI 309.

grade. The distance between insertions should be about 1½ times the radius of action so that the area visibly affected by the vibrator overlaps the adjacent previously vibrated area by a few centimeters (inches).

The vibrator should be held stationary until adequate consolidation is attained and then slowly withdrawn. An insertion time of 5 to 15 seconds will usually provide adequate consolidation. The concrete should move to fill the hole left by the vibrator on withdrawal. If the hole does not refill, reinsertion of the vibrator at a nearby point should solve the problem.

Adequacy of internal vibration is judged by experience and by changes in the surface appearance of the concrete. Changes to watch for are the embedment of large aggregate particles,general batch leveling, the appearance of a thin film of mortar on the top surface, and the cessation of large bubbles of entrapped air escaping at the surface. Internal vibration may significantly affect the entrained-air-void system in concrete (Stark 1986, and Hover 2001). Detailed guidance for proper vibration should be followed (ACI Committee 309).

Allowing a vibrator to remain immersed in concrete after paste accumulates over the head is bad practice and can result in nonuniformity. The length of time that a vibrator should be left in the concrete will depend on the workability of the concrete, the power of the vibrator, and the nature of the section being consolidated.

In heavily-reinforced sections where an internal vibrator cannot be inserted, it is sometimes helpful to vibrate the reinforcing bars by attaching a form vibrator to their exposed portions. This practice eliminates air and water trapped under the reinforcing bars and increases bond between the bars and surrounding concrete; use this method only if the concrete is still workable under the action of vibration. Internal vibrators should not be attached to reinforcing bars for this purpose because the vibrators may be damaged.

Revibration of previously compacted concrete can be done to both fresh concrete as well as any underlying layer that has partially hardened. Revibration is used to improve bond between concrete and reinforcing steel, release water trapped under horizontal reinforcing bars, and remove additional entrapped air voids. In general, if concrete becomes workable under revibration, the practice is not harmful and may be beneficial.

External Vibration. External vibrators can be form vibrators, vibrating tables, or surface vibrators such as vibratory screeds, plate vibrators, vibratory roller screeds, or vibratory hand floats or trowels. Form vibrators, designed to be securely attached to the outside of the forms, are especially useful (1) for consolidating concrete in members that are very thin or congested with reinforcement, (2) to supplement internal vibration, and (3) for stiff mixes where internal vibrators cannot be used.

Attaching a form vibrator directly to the form generally is unsatisfactory. Rather, the vibrator should be attached to a steel plate that in turn is attached to steel I-beams or channels passing through the form stiffeners themselves in a continuous run. Loose attachments can result in significant vibration energy losses and inadequate consolidation.

Form vibrators can be either electrically or pneumatically operated. They should be spaced to distribute the intensity of vibration uniformly over the form; optimum spacing is best found by experimentation. Sometimes it may be necessary to operate some of the form vibrators at a different frequency for better results; therefore, it is recommended that form vibrators be equipped with controls to regulate their frequency and amplitude. Duration of external vibration is considerably longer than for internal vibration—generally between 1 and 2 minutes. A reed tachometer can not only determine frequency of vibration, but also give a rough estimate of amplitude of vibration by noting the oscillation of the reed at various points along the forms. This will assist in identifying dead spots or weak areas of vibration. A vibrograph could be used if more reliable measurements of frequency and amplitude are needed.

Form vibrators should not be applied within the top meter (yard) of vertical forms. Vibration of the top of the form, particularly if the form is thin or inadequately stiffened, causes an in-and-out movement that can create a gap between the concrete and the form. Internal vibrators are recommended for use in this area of vertical forms.

Vibrating tables are used in precasting plants. They should be equipped with controls so that the frequency and amplitude can be varied according to the size of the element to be cast and the consistency of the concrete. Stiffer mixtures generally require lower frequencies (below 6000 vpm) and higher amplitudes (over 0.13 mm [0.005 in.]) than more workable mixtures. Increasing the frequency and decreasing the amplitude as vibration progresses will improve consolidation.

Surface vibrators, such as vibratory screeds (Figs. 11-12, 11-13, and 11-14), are used to consolidate concrete in floors and other flatwork. Vibratory screeds give positive control of the strikeoff operation and save a great deal of labor. When using this equipment, concrete need not have slumps in excess of 75 mm (3 in.). For greater than 75 mm slumps, care should be taken because surface vibration of such concrete will result in an excessive accumulation of mortar and fine material on the surface; this may reduce wear resistance. For the same reason, surface vibrators

Fig. 11-12. Vibratory screeds such as this truss-type unit reduce the work of strikeoff while consolidating the concrete. (55801)

Fig. 11-13. Where floor tolerances are not critical, an experienced operator using this vibratory screed does not need screed poles supported by chairs to guide the screed. Instead, he visually matches elevations to forms or previous passes. The process is called wet screeding. (69938)

Fig. 11-14. A laser level stimulating the sensors on this screed guides the operator as he strikes off the concrete. Screed poles and chairs are not needed and fewer workers are required to place concrete. Laser screeds interfaced with total station surveying equipment can also strike off sloped concrete surfaces. (69939)

should not be operated after the concrete has been adequately consolidated.

Because surface vibration of concrete slabs is least effective along the edges, a spud or poker-type vibrator should be used along the edge forms immediately before the vibratory screed is applied.

Vibratory screeds are used for consolidating slabs up to 250 mm (10 in.) thick, provided such slabs are nonreinforced or only lightly reinforced (welded-wire fabric). Internal vibration or a combination of internal and surface vibration is recommended for reinforced slabs. More detailed information regarding internal and external vibration of concrete can be obtained from ACI Committee 309.

Consequences of Improper Vibration. Following are some of the worst defects caused by undervibration: (1) honeycomb; (2) excessive amount of entrapped air voids, often called bugholes; (3) sand streaks; (4) cold joints; (5) placement lines; and (6) subsidence cracking.

Honeycomb results when the spaces between coarse aggregate particles do not become filled with mortar. Faulty equipment, improper placement procedures, a concrete mix containing too much coarse aggregate, or congested reinforcement can cause honeycomb.

Excessive entrapped air voids are similar to, but not as severe as honeycomb. Vibratory equipment and operating procedures are the primary causes of excessive entrapped air voids, but the other causes of honeycomb apply too.

Sand streaks results when heavy bleeding washes mortar out from along the form. A wet, harsh mixture that lacks workability because of an insufficient amount of mortar or fine aggregate may cause sand streaking. Segregation from striking reinforcing steel without adequate vibration may also contribute to streaking.

Cold joints are a discontinuity resulting from a delay in placement that allowed one layer to harden before the adjacent concrete was placed. The discontinuity can reduce the structural integrity of a concrete member if the successive lifts did not properly bond together. The concrete can be kept alive by revibrating it every 15 minutes or less depending on job conditions. However, once the time of initial setting approaches, vibration should be discontinued and the surface should be suitably prepared for the additional concrete.

Placement lines or "pour" lines are dark lines between adjacent placements of concrete batches. They may occur if, while vibrating the overlying layer, the vibrator did not penetrate the underlying layer enough to knit the layers together.

Subsidence cracking may occur at or near the initial setting time as concrete settles over reinforcing steel in relatively deep elements that have not been adequately vibrated. Revibration at the latest time that the vibrator will sink into the concrete under its own weight may eliminate these cracks.

Defects from overvibration include: (1) segregation as vibration and gravity causes heavier aggregates to settle while lighter aggregates rise; (2) sand streaks; (3) loss of entrained air in air-entrained concrete; (4) excessive form deflections or form damage; and (5) form failure caused by excessive pressure from vibrating the same location too long and/or placing concrete more quickly than the designed rate of pour.

Undervibration is more often a problem than overvibration.

CONCRETE SLABS

Concrete slabs can be finished in many ways, depending on the intended service use. Various colors and textures, such as exposed-aggregate or a pattern-stamped surface, may be called for. Some surfaces may require only strikeoff and screeding to proper contour and elevation, while for other surfaces a broomed, floated, or troweled finish may be specified. Details are given in ACI Committee 302, Kosmatka (1991), Panarese (1995), PCA (1980a), and Farny (2001).

The mixing, transporting, and handling of concrete for slabs should be carefully coordinated with the finishing operations. Concrete should not be placed on the subgrade or into forms more rapidly than it can be spread, struck off, consolidated, and bullfloated or darbied. In fact, concrete should not be spread over too large an area before strikeoff, nor should a large area be struck off and bleed water allowed to accumulate before bullfloating or darbying.

Finishing crews should be large enough to correctly place, finish, and cure concrete slabs with due regard for the effects of concrete temperature and atmospheric conditions on the setting time of the concrete and the size of the placement to be completed.

Subgrade Preparation

Cracks, slab settlement, and structural failure can often be traced to an inadequately prepared and poorly compacted subgrade. The subgrade on which a slab on ground is to be placed should be well drained, of uniform bearing capacity, level or properly sloped, and free of sod, organic matter, and frost. The three major causes of nonuniform support are: (1) the presence of soft unstable saturated soils or hard rocky soils, (2) backfilling without adequate compaction, and (3) expansive soils. Uniform support cannot be achieved by merely dumping granular material on a soft area. To prevent bridging and settlement cracking, soft or saturated soil areas and hard spots (rocks) should be dug out and filled with soil similar to the surrounding subgrade or if a similar soil is not available, with granular material such as sand, gravel, or crushed stone. All fill materials must be compacted to provide the same uniform support as the rest of the subgrade. Proof rolling the subgrade using a fully-loaded dump truck or similar heavy equipment is commonly used to identify areas of unstable soils that need additional attention.

During subgrade preparation, it should be remembered that undisturbed soil is generally superior to compacted material for supporting concrete slabs. Expansive, compressible, and potentially troublesome soils should be evaluated by a geotechnical engineer; a special slab design may be required.

The subgrade should be moistened with water in advance of placing concrete, but should not contain puddles or wet, soft, muddy spots when the concrete is placed.

Subbase

A satisfactory slab on ground can be built without a subbase. However, a subbase is frequently placed on the subgrade as a leveling course to equalize minor surface irregularities, enhance uniformity of support, bring the site to the desired grade, and serve as a capillary break between the slab and the subgrade.

Where a subbase is used, the contractor should place and compact to near maximum density a 100-mm (4-in.) thick layer of granular material such as sand, gravel, crushed stone, or slag. If a thicker subbase is needed for achieving the desired grade, the material should be compacted in thin layers about 100 mm (4 in.) deep unless tests determine compaction of thicker a lift is possible (Fig. 11-15). Subgrades and subbases can be compacted with small plate vibrators, vibratory rollers, or hand tampers. Unless the subbase is well compacted, it is better not to use a subbase; simply leave the subgrade uncovered and undisturbed.

Fig. 11-15. Nuclear gauges containing radioactive sources used to measure soil density and moisture can determine if a subbase has been adequately compacted. (69932)

Vapor Retarders and Moisture-Problem Prevention

Many of the moisture problems associated with enclosed slabs on ground (floors) can be minimized or eliminated by (1) sloping the landscape away from buildings, (2) using a 100-mm (4-in.) thick granular subbase to form a capillary break between the soil and the slab, (3) providing drainage for the granular subbase to prevent water from collecting under the slab, (4) installing foundation drain tile, and (5) installing a vapor retarder, often polyethylene sheeting.

For years vapor retarders have been mistakenly called vapor barriers. A vapor retarder slows the movement of water vapor by use of a 0.15 to 0.25 mm (6 to 10 mil) polyethylene film that is overlapped approximately 150 mm (6 in.) at the edges. A vapor retarder does not stop 100% of vapor migration; a vapor barrier does. Vapor barriers are thick, rugged multiple-ply-reinforced membranes that are sealed at the edges. Vapor retarders are discussed in this text because they are more commonly used; but many of the following principles apply to vapor barriers as well.

A vapor retarder should be placed under all concrete floors on ground that are likely to receive an impermeable floor covering such as sheet vinyl tile or be used for any purpose where the passage of water vapor through the floor might damage moisture-sensitive equipment or materials in contact with the floor. However, a few project sites with deep groundwater tables and sandy soils containing very low silt or clay contents may not require the use of a vapor retarder under concrete slabs.

Vapor retarders placed directly under concrete slabs may increase the time delay before final finishing due to longer bleeding times, particularly in cold weather. To minimize this effect, a minimum 75-mm (3-in.) thick layer of approved granular, self-draining compactible subbase material should be placed over the vapor barrier (or insulation if present) (ACI Committee 302). Some contractors find only 75 mm of granular sand over polyethylene sheeting to be slippery, somewhat dangerous, and difficult to keep in place while concreting. A 150 to 200 mm (6 to 8 in.)-thick subbase will alleviate this problem. The subbase over a vapor retarder must be kept from getting saturated by rain or construction activities to prevent excessive vapor migration after the concrete slab is placed.

If concrete is placed directly on a vapor retarder, the water-cementitious materials ratio should be kept low (0.45 or less) because excess mix water can only escape to the surface as bleed water. Because of a longer bleeding period, settlement cracking over reinforcement and shrinkage cracking is more likely. For more information see ACI (2001) and ACI Committee 302.

Good quality, well-consolidated concrete at least 100-mm (4-in.) thick is practically impermeable to the passage of liquid water unless the water is under considerable pressure; however, such concrete—even concrete several times as thick—is not impermeable to the passage of water vapor.

Water vapor that passes through a concrete slab evaporates at the surface if it is not sealed. Floor coverings such as linoleum, vinyl tile, carpeting, wood, and synthetic surfacing effectively seal the moisture within the slab; eventually this moisture may deteriorate latex adhesives causing the floor covering to loosen, buckle, or blister.

To prevent problems with floor covering materials caused by moisture within the concrete, the following steps should be taken: (1) use a low water-cement ratio concrete, (2) moist-cure the slab for 7 days, (3) allow the slab a 2-or-more-month drying period (Hedenblad 1997 and 1998), and (4) test the slab moisture condition before installing the floor covering.

In one commonly used test (ASTM F 1869), the moisture vapor emission rate from a concrete slab is determined by taping a domed plastic vapor barrier with a desiccant under it to the floor. After about 72 hours the desiccant is weighed and the moisture vapor emission rate is calculated. The slab is considered dry enough for placing a flooring material if the moisture vapor emission rate is below either 1.4 or 2.3 $kg/m^2/1000\ m^2$ (3 or 5 $lbs/ft^2/1000\ ft^2$) depending on the type of floor covering to be installed. Flooring-material manufacturers often have their own recommended test and specified moisture limits for installing their product. For more information and additional tests for water vapor transmission, see "Moisture Testing" in Chapter 16, Kosmatka (1985), and PCA (2000).

Insulation is sometimes installed over the vapor barrier to assist in keeping the temperature of a concrete floor above the dew point; this helps prevent moisture in the air from condensing on the slab surface. This practice also creates a warm floor for thermal comfort. Codes and specifications often require insulation at the perimeter of a floor slab. Placing insulation under the entire slab on ground for energy conservation alone usually cannot be justified economically. For more details, see PCA (1985).

Forms

Edge forms and intermediate screeds should be set accurately and firmly to the specified elevation and contour for the finished surface. Slab edge forms are usually metal or wood braced firmly with wood or steel stakes to keep them in horizontal and vertical alignment. The forms should be straight and free from warping and have sufficient strength to resist concrete pressure without bulging. They should also be strong enough to support any mechanical placing and finishing equipment used.

Rain Protection

Prior to commencing placing of concrete, the owner and contractor should be aware of procedures to be followed in the event of rain during the placing operation. Protective coverings such as polyethylene sheets or tarpaulins should be available and onsite at all times. When rain occurs, all batching and placing operations should stop and the fresh concrete should be covered to the extent that the rain does not indent the surface of the concrete or wash away the cement paste. When rain ceases, the covering should be removed and remedial measures taken such as surface retexturing or reworking in-place plastic concrete, before concrete placing resumes.

Placing and Spreading

Placement should start at the far point of a slab and proceed toward the concrete supply source. The concrete, which should be placed as close as possible to its final position, should slightly overfill the forms and be roughly leveled with square ended shovels or concrete rakes. Large voids trapped in the concrete during placing should be removed by consolidation.

Screeding (Strikeoff)

Screeding or strikeoff is the process of cutting off excess concrete to bring the top surface of a slab to proper grade. The template used in the manual method is called a straightedge, although the lower edge may be straight or slightly curved, depending on the surface specified. It should be moved across the concrete with a sawing motion while advancing forward a short distance with each movement. There should be a surplus (surcharge) of concrete against the front face of the straightedge to fill in low areas as the straightedge passes over the slab. A 150-mm (6-in.) slab needs a surcharge of about 25 mm (1 in.). Straightedges are sometimes equipped with vibrators that consolidate the concrete and assist in reducing the strikeoff work. This combination of straightedge and vibrator is called a vibratory screed (Fig. 11-12). Vibratory screeds are discussed earlier in this chapter under "Consolidating Concrete." Screeding, consolidation, and bullfloating must be completed before excess bleed water collects on the surface.

Bullfloating or Darbying

To eliminate high and low spots and to embed large aggregate particles, a bullfloat or darby (Fig. 11-16 top) should be used immediately after strikeoff. The long-handle bullfloat (Fig. 11-16 bottom) is used on areas too large to reach with a short-handle darby. Highway straightedges are often used to obtain very flat surfaces (Fig. 11-17). For non-air-entrained concrete, these tools can be made of wood; for air-entrained concrete they should be of aluminum or magnesium alloy.

Fig. 11-16. (top) Darbying brings the surface to the specified level and is done in tight places where a bullfloat cannot reach. (bottom) Bullfloating must be completed before any bleed water accumulates on the surface. (70010, 69940, 70011)

Fig. 11-17. Highway straightedges are used on highway pavement and floor construction where very flat surfaces are desired. (69941)

Bullfloating or darbying must be completed before bleed water accumulates on the surface. Care must be taken not to overwork the concrete as this could result in a less durable surface.

The preceeding operations should level, shape, and smooth the surface and work up a slight amount of cement paste. Although sometimes no further finishing is required, on most slabs bullfloating or darbying is followed by one or more of the following finishing operations: edging, jointing, floating, troweling, and brooming. A slight hardening of the concrete is necessary before the start of any of these finishing operations. When the bleed-water sheen has evaporated and the concrete will sustain foot pressure with only about 6-mm (¼-in.) indentation, the surface is ready for continued finishing operations (Fig. 11-18).

Fig. 11-18. Power floating using walk-behind and ride-on equipment. Footprints indicate proper timing. When the bleedwater sheen has evaporated and the concrete will sustain foot pressure with only slight indentation, the surface is ready for floating and final finishing operations. (69942)

Video

Warning: *One of the principal causes of surface defects in concrete slabs is finishing while bleed water is on the surface. If bleed water is worked into the surface, the water-cement ratio is significantly increased which reduces strength, entrained-air content, and watertightness of the surface. Any finishing operation performed on the surface of a concrete slab while bleed water is present can cause crazing, dusting, or scaling* (PCA 2001). Floating and troweling the concrete (discussed later) before the bleeding process is completed may also trap bleed water under the finished surface producing a weakened zone or void under the finished surface; this occasionally results in delaminations. The use of low-slump concrete with an adequate cement content and properly graded fine aggregate will minimize bleeding and help ensure maintenance-free slabs. For exterior slabs, air entrainment also reduces bleeding. ACI Committee 302 and Farny (2001) present the placing and finishing techniques in more detail and PCA (2001) discusses defects.

Edging and Jointing

Edging is required along all edge forms and isolation and construction joints in floors and outdoor slabs such as walks, drives, and patios. Edging densifies and compacts concrete next to the form where floating and troweling are less effective, making it more durable and less vulnerable to scaling, chipping, and popouts.

In the edging operation, the concrete should be cut away from the forms to a depth of 25 mm (1 in.) using a pointed mason trowel or a margin trowel. Then an edger should be held almost flat on the surface and run with the front of the tool slightly raised to prevent the edger from leaving too deep an impression. Edging may be required after each subsequent finishing operation for interior slabs.

Proper jointing practices can eliminate unsightly random cracks. Contraction joints, also called control joints, are made with a hand groover or by inserting strips of plastic, wood, metal, or preformed joint material into the unhardened concrete. When hand methods are used to form control joints in exterior concrete slabs, mark the forms to accurately locate the joints. Prior to bullfloating, the edge of a thin strip of wood or metal may be used to knock down the coarse aggregate where the joint will be hand tooled. The slab should then be jointed immediately after bullfloating or in conjunction with the edging operation. Control joints also can be made in hardened concrete by sawing. Jointing is discussed further under the heading "Making Joints in Floors and Walls" later in this chapter.

Floating

After the concrete has been hand-edged and hand-jointed, it should be floated with a hand float or with a finishing machine using float blades (Fig. 11-18).

The purpose of floating is threefold: (1) to embed aggregate particles just beneath the surface; (2) to remove slight imperfections, humps, and voids; and (3) to compact the mortar at the surface in preparation for additional finishing operations. The concrete should not be overworked as this may bring an excess of water and fine material to the surface and result in subsequent surface defects.

Hand floats usually are made of fiberglass, magnesium, or wood. The metal float reduces the amount of work required because drag is reduced as the float slides more readily over the concrete surface. A magnesium float is essential for hand-floating air-entrained concrete because a wood float tends to stick to and tear the concrete surface. The light metal float also forms a smoother surface than the wood float.

The hand float should be held flat on the concrete surface and moved with a slight sawing motion in a sweeping arc to fill in holes, cut off lumps, and smooth ridges. When finishing large slabs, power floats can be used to reduce finishing time.

Floating produces a relatively even (but not smooth) texture that has good slip resistance and is often used as a final finish, especially for exterior slabs. Where a float finish is the desired final finish, it may be necessary to float the surface a second time after it has hardened a little more.

Marks left by hand edgers and groovers are normally removed during floating unless the marks are desired for decorative purposes; in such cases the edger and groover should be used again after final floating.

Troweling

Where a smooth, hard, dense surface is desired, floating should be followed by steel troweling (Fig. 11-19). Troweling should not be done on a surface that has not been floated; troweling after only bullfloating or darbying is not an adequate finishing procedure.

It is customary when hand-finishing large slabs to float and immediately trowel an area before moving the

Fig. 11-19. Hand floating (right hand) the surface with a hand float held flat on the concrete surface and moved in a sweeping arc with a slight sawing motion. Troweling (left hand) with blade tilted is performed before moving the kneeboards. (69933)

kneeboards. These operations should be delayed until the concrete has hardened sufficiently so that water and fine material are not brought to the surface. Too long a delay, of course, will result in a surface that is too hard to float and trowel. The tendency, however, is to float and trowel the surface too soon. Premature floating and troweling can cause scaling, crazing, or dusting and a surface with reduced wear resistance.

Spreading dry cement on a wet surface to take up excess water is a bad practice and can cause crazing. Such wet spots should be avoided, if possible, by adjustments in aggregate gradation, mix proportions, and consistency. When wet spots do occur, finishing operations should be delayed until the water either evaporates or is removed with a rubber floor squeegee or by dragging a soft rubber garden hose. If a squeegee or hose is used, care must be taken so that excess cement paste is not removed with the water.

The first troweling may produce the desired surface free of defects. However, surface smoothness, density, and wear resistance can all be improved by additional trowelings. There should be a lapse of time between successive trowelings to permit the concrete to become harder. As the surface stiffens, each successive troweling should be made with smaller trowels, using progressively more tilt and pressure on the trowel blade. The final pass should make a ringing sound as the trowel moves over the hardening surface.

A power trowel is similar to a power float, except that the machine is fitted with smaller, individual steel trowel blades that are adjustable for tilt and pressure on the concrete surface. When the first troweling is done by machine, at least one additional troweling by hand should be done to remove small irregularities. If necessary, tooled edges and joints should be rerun after troweling to maintain uniformity and true lines.

Exterior concrete should not be troweled for several reasons: (1) because it can lead to a loss of entrained air caused by overworking the surface, and (2) troweled surfaces can be slippery when wet. Floating and brooming should be sufficient for outdoor concrete.

Brooming

Brooming should be performed before the concrete has thoroughly hardened, but it should be sufficiently hard to retain the scoring impression to produce a slip-resistant surface (Fig. 11-20). Rough scoring can be achieved with a rake, a steel-wire broom, or a stiff, coarse, fiber broom; such coarse-textured brooming usually follows floating. If a finer texture is desired, the concrete should be floated to a smooth surface and then brushed with a soft-bristled broom. Interior concrete could also be troweled before brooming. Best results are obtained with brooms that are specially made for texturing concrete. Slabs are usually broomed transversely to the main direction of traffic.

Highway pavements are textured by "tining" the surface with stiff wires; this improves traction and reduces hydroplaning (Fig. 11-21).

Fig. 11-20. Brooming provides a slip-resistant surface mainly used on exterior concrete. (69943)

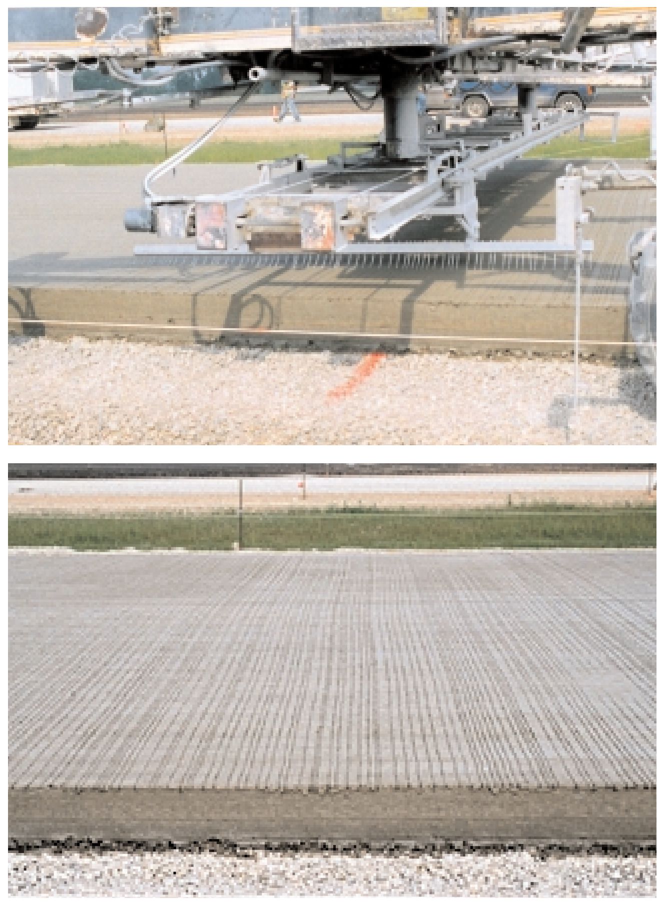


Fig. 11-21. (top) This machine is tining the surface of fresh concrete. (bottom) Tining of pavements improves tire traction and reduces hydroplaning. (69944, 69945)

Curing and Protection

All newly placed and finished concrete slabs should be cured and protected from drying, from extreme changes in temperature, and from damage by subsequent construction and traffic.

Curing should begin immediately after finishing (Fig. 11-22). Curing is needed to ensure continued hydration of the cement, strength gain of the concrete, and a minimum of early drying shrinkage.

Special precautions are necessary when concrete work continues during periods of adverse weather. In cold weather, arrangements should be made in advance for heating, covering, insulating, or enclosing the concrete. Hot-weather work may require special precautions against rapid evaporation and drying and high temperatures.

Fig. 11-22. An excellent method of wet curing is to completely cover the surface with wet burlap and keep it continuously wet during the curing period. (69946)

PLACING ON HARDENED CONCRETE

Bonded Construction Joints in Structural Concrete

A bonded construction joint is needed between two structural concrete placements. When freshly mixed concrete is placed in contact with existing hardened concrete, a high-quality bond and watertight joint are required. Poorly bonded construction joints are usually the result of (1) lack of bond between old and new concrete, or (2) a weak porous layer in the hardened concrete at the joint. The quality of a bonded joint therefore depends on the quality of the hardened concrete and preparation of its surface.

In columns and walls, the concrete near the top surface of a lift is often of inferior quality to the concrete below. This may be due to poor consolidation or use of badly proportioned or high-slump mixtures that cause excessive laitance, bleeding, and segregation. Even in well-proportioned and carefully consolidated mixtures, some aggregate particle settlement and water gain (bleeding) at the top surface is unavoidable; this is particularly true with high rates of placement. Also, the encasing formwork prevents the escape of moisture from the fresh concrete. While formwork provides adequate curing as long as it remains in place, the top surface where there is no encasing formwork may dry out too rapidly; this may result in a weak porous layer unless protection and curing are provided.

Preparing Hardened Concrete

When freshly mixed concrete is placed on recently hardened concrete, certain precautions must be taken to secure a well-bonded, watertight joint. The hardened concrete must be clean, sound, and reasonably rough with some coarse aggregate particles exposed. Any laitance, soft mortar, dirt, wood chips, form oil, or other foreign materials must be removed since they could interfere with proper bonding of the subsequent placement.

The surface of old concrete upon which fresh concrete is to be placed must be thoroughly roughened and cleaned of all dust, surface films, deposits, loose particles, grease, oil, and other foreign material. In most cases it will be necessary to remove the entire surface down to sound concrete. Roughening and cleaning with lightweight chipping hammers, waterblasting, scarifiers, sandblasting (Fig. 11-23), shotblasting and hydrojetting are some of the satisfactory methods for exposing sound concrete. Care must be taken to avoid contamination of the clean surface before a bonding grout and overlay concrete are placed.

Partially set or recently hardened concrete may only require stiff-wire brushing. In some types of construction

Fig. 11-23. Sandblasting can clean any size or shape surface – horizontal, vertical or overhead. Consult local environmental regulations regarding sandblasting. (55805)

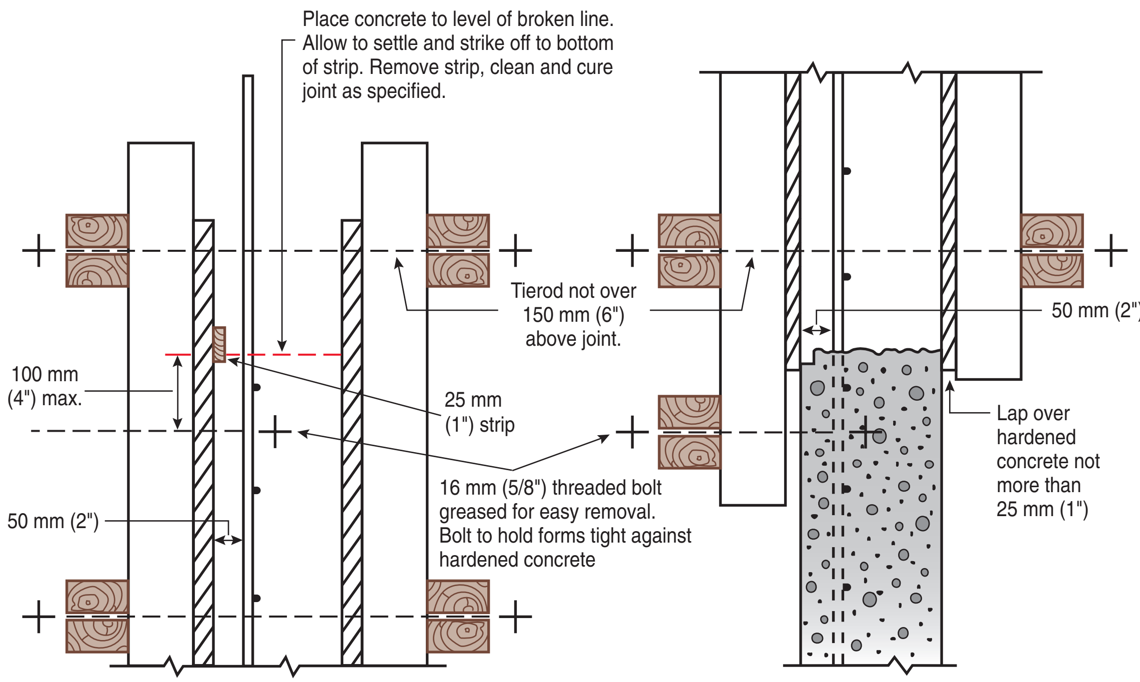


Fig. 11-24. A straight, horizontal construction joint can be built using this detail.

such as dams, the surface of each concrete lift is cut with a high-velocity air-water jet to expose clean, sound concrete just before final set. This is usually done 4 to 12 hours after placing. The surface must then be protected and continuously cured until concreting is resumed for the next lift.

For two-course floors, the top surface of the base slab can be roughened just before it sets with a steel or stiff fiber broom. The surface should be level, heavily scored, and free of laitance; then it should be protected until it is thoroughly cleaned just before the grout coat and topping mix are placed. When placing a bonded topping on a floor slab, the base slab should be cleaned of all laitance, dust, debris, grease or other foreign substances by using one of the following methods:

a. Wet- or dry-grit sandblasting
b. High-pressure water blasting
c. Mechanical removal by scabblers, or grinding wheels
d. Power brooming and vacuuming

Hardened concrete may be left dry or be moistened before new concrete is placed on it; however, the surface should not be wet or have any free-standing water. Laboratory studies indicate a slightly better bond is obtained on a dry surface than on a damp surface; however, the increased moisture level in the hardened concrete and in the environment around the concrete reduces water loss from the concrete mixture. This can be very beneficial, especially on hot, dry days.

For making a horizontal construction joint in reinforced concrete wall construction, good results have been obtained by constructing the forms to the level of the joint, overfilling the forms a few centimeters (inches), and then removing the excess concrete just before hardening occurs; the top surface then can be manually roughened with stiff brushes. The procedure is illustrated in Fig. 11-24.

In the case of vertical construction joints cast against a bulkhead, the concrete surface generally is too smooth to permit proper bonding. So, particular care should be given to removal of the smooth surface finish before reerecting the forms for placing freshly mixed concrete against the joint. Stiff-wire brushing may be sufficient if the concrete is less than three days old; otherwise, bushhammering or sandblasting may be needed, followed by washing with clean water to remove all dust and loose particles.

Bonding New to Previously Hardened Concrete

Care must be used when making horizontal construction joints in wall sections where freshly-mixed concrete is to be placed on hardened concrete. A good bond can be obtained by placing a rich concrete (higher cement and sand content than normal) in the bottom 150 mm (6 in.) of the new lift and thoroughly vibrating the joint interface. Alternatively, a cement-sand grout can be scrubbed into a clean surface immediately ahead of concreting.

A topping concrete mix for slabs can be bonded to the previously prepared base slab by one of the following procedures:

1. **Portland cement-sand grouting:** A 1 to 1 cement-sand grout having a water-cement ratio of not greater than 0.45, mixed to a creamlike consistency, is scrubbed into the prepared dry or damp (no free water) base slab surface.

2. **Latex.** A latex-bonding agent is added to the cement-sand grout and is spread in accordance with the latex manufacturer's direction.
3. **Epoxy.** An approved epoxy-bonding agent placed on the base concrete, prepared in accordance with the epoxy manufacturer's direction.

The bonding procedure should produce tensile bond strength with the base concrete in excess of 1.0 MPa (150 psi).

Grout is placed just a short distance ahead of the overlay or top-course concrete (Fig. 11-25). This method may also be applicable to horizontal joints in walls. The grout should not be allowed to dry out prior to the overlay placement; otherwise, the dry grout may act as a poor surface for bonding. The surface of the base slab should have been prepared by one of the methods discussed previously. Overlays are discussed further under "Patching, Cleaning, and Finishing" later in this chapter.

Fig. 11-25. Application of a bonding grout just ahead of the overlay concrete. The grout must not dry out before the concrete is placed. (51995)

Video

MAKING JOINTS IN FLOORS AND WALLS

The following three types of joints are common in concrete construction: isolation joints, contraction joints, and construction joints.

Isolation Joints

Isolation joints (Fig. 11-26) permit both horizontal and vertical differential movements at adjoining parts of a structure. They are used, for example, around the perimeter of a floor on ground, around columns, and around machine foundations to separate the slab from the more rigid parts of the structure.

Isolation-joint material (often called expansion-joint material) can be as thin as 6 mm (¼ in.) or less, but 13-mm

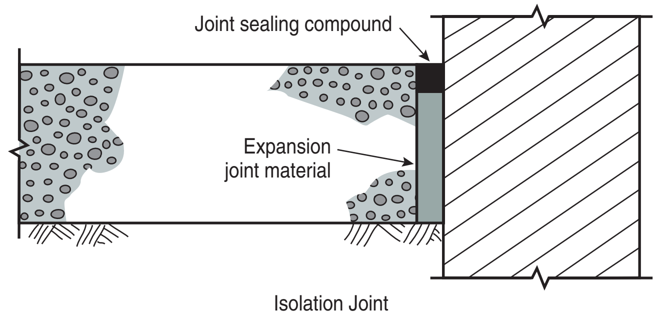


Fig. 11-26. Isolation joints permit horizontal and vertical movements between abutting faces of a slab and fixed parts of a structure.

(½-in.) material is commonly used. Care should be taken to ensure that all the edges for the full depth of the slab are isolated from adjoining construction; otherwise cracking can occur.

Columns on separate footings are isolated from the floor slab either with a circular or square-shaped isolation joint. The square shape should be rotated to align its corners with control and construction joints.

Contraction Joints

Contraction joints (Fig. 11-27) provide for movement in the plane of a slab or wall and induce controlled cracking caused by drying and thermal shrinkage at preselected locations. Contraction joints (also sometimes called con-

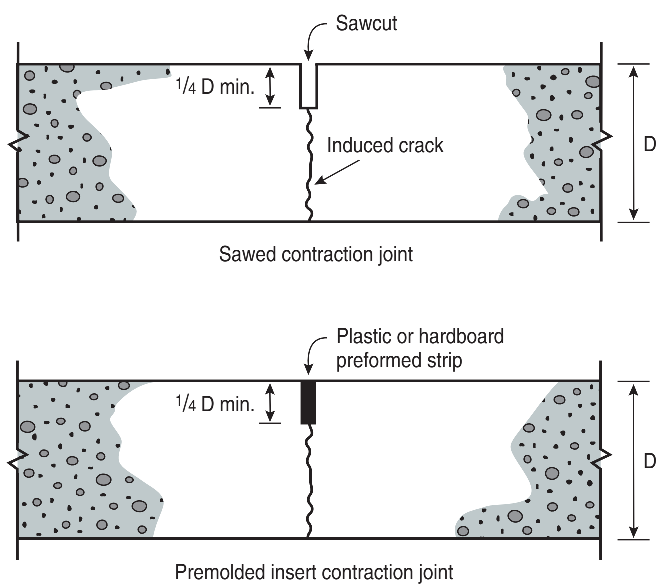


Fig. 11-27. Contraction joints provide for horizontal movement in the plane of a slab or wall and induce controlled cracking caused by drying and thermal shrinkage.

trol joints) should be constructed to permit transfer of loads perpendicular to the plane of a slab or wall. If no contraction joints are used, or if they are too widely spaced in slabs on ground or in lightly reinforced walls, random cracks may occur; cracks are most likely when drying and thermal shrinkage produce tensile stresses in excess of the concrete's tensile strength.

Contraction joints in slabs on ground can be made in several ways. One of the most common methods is to saw a continuous straight slot in the top of the slab (Fig. 11-28). This creates a plane of weakness in which a crack will form. Vertical loads are transmitted across a contraction joint by aggregate interlock between the opposite faces of the crack providing the crack is not too wide and the spacing between joints is not too great. Crack widths at saw-cut contraction joints that exceed 0.9 mm (0.035 in.) do not reliably transfer loads. The effectiveness of load transfer by aggregate interlock depends on more than crack width. Other factors include: slab thickness, subgrade support, load magnitude, repetitions of load, and aggregate angularity. Steel dowels (Figs. 11-6 and 11-29b) may be used to increase load transfer at contraction joints when heavy wheel loads are anticipated. Sizes and spacing of dowels, which are placed at the center of the slab depth, are shown in Farny (2001). See ACI Committee 302 and PCA (1982) for further discussions on doweled joints.

Sawing must be coordinated with the setting time of the concrete. It should be started as soon as the concrete has hardened sufficiently to prevent aggregates from being dislodged by the saw (usually within 4 to 12 hours after the concrete hardens); sawing should be completed before drying shrinkage stresses become large enough to produce cracking. The timing depends on factors such as mix proportions, ambient conditions, and type and hardness of aggregates. New dry-cut sawing techniques allow saw cutting to take place shortly after final finishing is completed. Generally, the slab should be cut before the concrete cools, when the concrete sets enough to prevent raveling or tearing while saw cutting, and before drying-shrinkage cracks start to develop.

Fig. 11-28. Sawing a continuous cut in the top of a slab is one of the most economical methods for making a contraction joint. (69947)

Contraction joints also can be formed in the fresh concrete with hand groovers or by placing strips of wood, metal, or preformed joint material at the joint locations. The top of the strips should be flush with the concrete surface. Contraction joints, whether sawed, grooved, or preformed, should extend into the slab to a depth of at least *one-fourth* the slab thickness or a minimum of 25 mm (1 in.) deep. It is recommended that the joint depth not exceed one-third the slab thickness if load transfer from aggregate interlock is important.

Contraction joints in walls are also planes of weakness that permit differential movements in the plane of the wall. The thickness of the wall at a contraction joint should be reduced by 25%, preferably 30%. Under the guidance of the design engineer, in lightly reinforced walls, half of the horizontal steel rebars should be cut at the joint. Care must be taken to cut alternate bars precisely at the joint. At the corners of openings in walls where contraction joints are located, extra diagonal or vertical and horizontal reinforcement should be provided to control cracking. Contraction joints in walls should be spaced not more than about 6 meters (20 ft) apart. In addition, contraction joints should be placed where abrupt changes in wall thickness or height occur, and near corners—if possible, within 3 to 4 meters (10 to 15 ft). Depending on the structure, these joints may need to be caulked to prevent the passage of water through the wall. Instead of caulking, a waterstop (or both) can be used to prevent water from leaking through the crack that occurs in the joint.

The spacing of contraction joints in floors on ground depends on (1) slab thickness, (2) shrinkage potential of the concrete, (3) subgrade friction, (4) environment, and (5) the absence or presence of steel reinforcement. Unless reliable data indicate that more widely spaced joints are feasible, the suggested intervals given in Table 11-2 should be used for well-proportioned concrete with aggregates having normal shrinkage characteristics. Joint spacing should be decreased for concrete suspected of having high shrinkage characteristics. The panels created by contraction joints should be approximately square. Panels with excessive length-to-width ratio (more than 1½ to 1) are likely to crack at an intermediate location. In joint layout design it is also important to remember that contraction (control) joints should only terminate at a free edge or at an isolation joint. Contraction joints should never terminate at another contraction joint as cracking will be induced from the end of the terminated joint into the adjacent panel. This is sometimes referred to as sympathetic cracking. Refer to Fig. 11-31, which illustrates one possible joint layout solution to eliminate the potential for induced sympathetic cracking.

Table 11-2 (Metric). Spacing of Contraction Joints in Meters*

Slab thickness, mm	Maximum-size aggregate less than 19 mm	Maximum-size aggregate 19 mm and larger
100	2.4	3.0
125	3.0	3.75
150	3.75	4.5
175	4.25	5.25**
200	5.0**	6.0**
225	5.5**	6.75**
250	6.0**	7.5**

* Spacings are appropriate for slumps between 100 mm and 150 mm. If concrete cools at an early age, shorter spacings may be needed to control random cracking. (A temperature difference of only 6°C may be critical.) For slumps less than 100 mm, joint spacing can be increased by 20%.

** When spacings exceed 4.5 m, load transfer by aggregate interlock decreases markedly.

Table 11-2 (Inch-Pound Units). Spacing of Contraction Joints in Feet*

Slab thickness, in.	Maximum-size aggregate less than ¾ in.	Maximum-size aggregate ¾ in. and larger
4	8	10
5	10	13
6	12	15
7	14	18**
8	16**	20**
9	18**	23**
10	20**	25**

* Spacings are appropriate for slumps between 4 in. and 6 in. If concrete cools at an early age, shorter spacings may be needed to control random cracking. (A temperature difference of only 10°F may be critical.) For slumps less than 4 in., joint spacing can be increased by 20%.

** When spacings exceed 15 ft, load transfer by aggregate interlock decreases markedly.

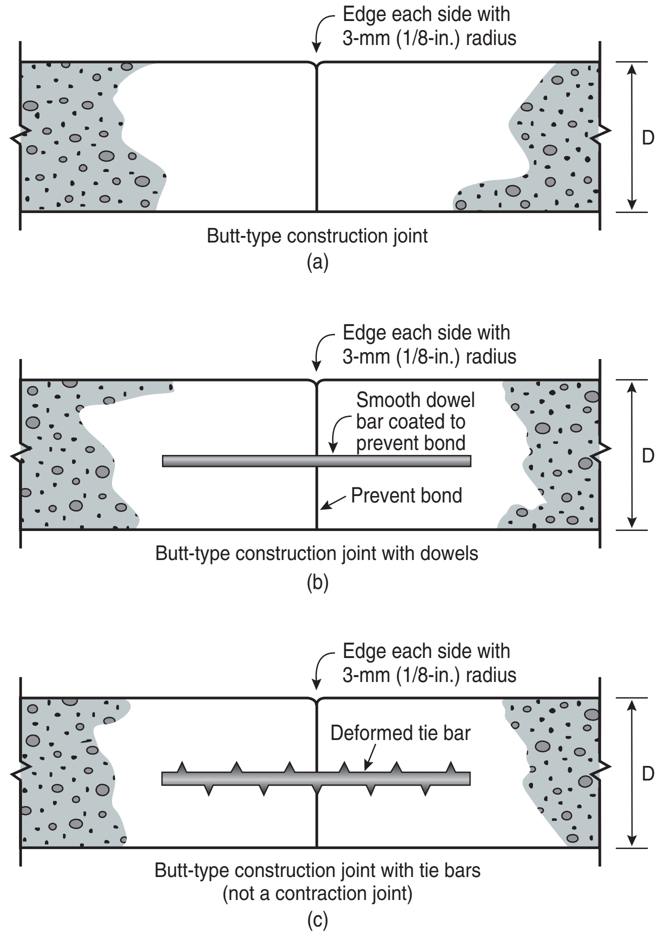


Fig. 11-29. Construction joints are stopping places in the process of construction. Construction-joint types (a) and (b) are also used as contraction joints.

Construction Joints

Construction joints (Fig. 11-29) are stopping places in the process of construction. A true construction joint should bond new concrete to existing concrete and permit no movement. Deformed tiebars are often used in construction joints to restrict movement. Because extra care is needed to make a true construction joint, they are usually designed and built to function as contraction or isolation joints. For example, in a floor on ground the construction joints align with columns and function as contraction joints and therefore are purposely made unbonded. The structural designer of suspended slabs should decide the location of construction joints. Oils, form-release agents, and paints are used as debonding materials. In thick, heavily-loaded floors, unbonded doweled construction joints are commonly used. For thin slabs, the flat-faced butt-type joint will suffice.

On most structures it is desirable to have wall joints that will not detract from appearance. When properly made, wall joints can become inconspicuous or hidden by rustication strips. They thus can become an architectural as well as a functional feature of the structure. However, if rustication strips are used in structures that may be exposed to deicing salts, such as bridge columns and abutments, care should be taken to ensure that the reinforcing steel has the required depth of concrete cover to prevent corrosion.

Horizontal joints in walls should be made straight, exactly horizontal, and should be placed at suitable locations. A straight horizontal construction joint can be made by nailing a 25 mm (1 in.) wood strip to the inside face of the form near the top (see Fig. 11-24). Concrete should then be placed to a level slightly above the bottom of the strip. After the concrete has settled and before it becomes too hard, any laitance that has formed on the top surface should be removed. The strip can then be removed and any irregularities in the joint leveled off. The forms are removed and then reerected above the construction joint for the next lift of concrete. To prevent concrete leakage from staining the wall below, gaskets should be used where forms contact previously placed hardened concrete.

A variation of this procedure makes use of a rustication strip instead of the 25 mm (1 in.) wood strip to form a groove in the concrete for architectural effect (Fig. 11-30). Rustication strips can be V-shaped, rectangular, or slightly beveled. If V-shaped, the joint should be made at the point of the V. If rectangular or beveled, the joint should be made at the top edge of the inner face of the strip.

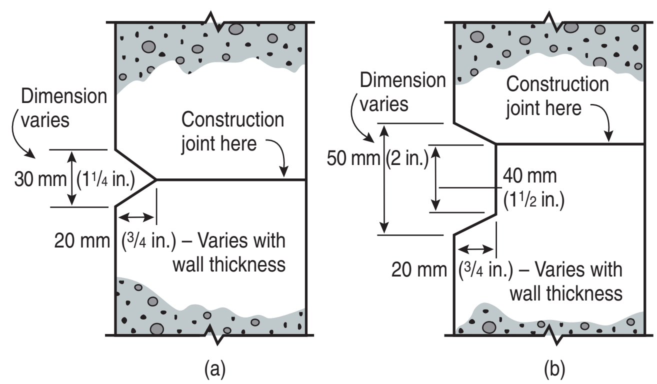


Fig. 11-30. Horizontal construction joints in walls with V-shaped (a) and beveled (b) rustication strips.

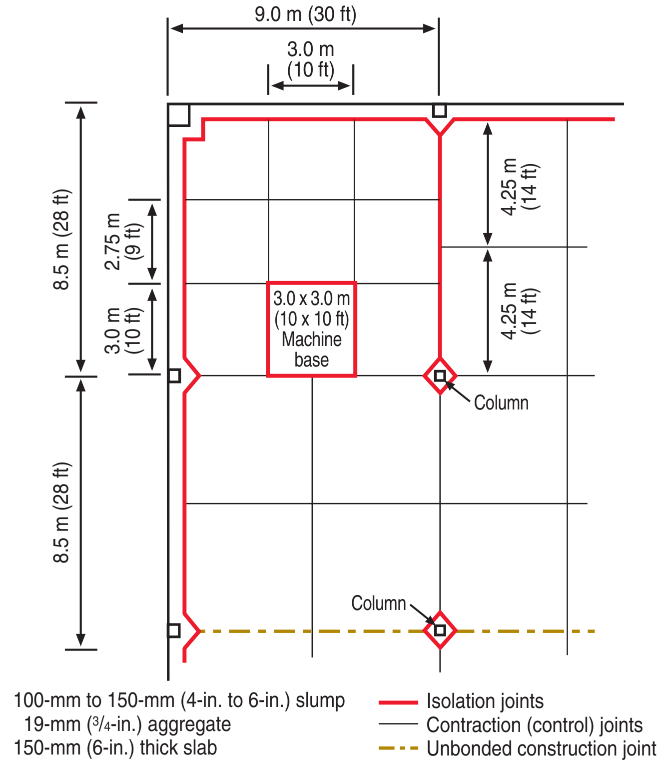


Fig. 11-31. Typical joint layout for a 150-mm (6-in.) thick concrete floor on ground.

JOINT LAYOUT FOR FLOORS

A typical joint layout for all three joint types—isolation, contraction, and construction—is illustrated in Fig. 11-31. Isolation joints are provided around the perimeter of the floor where it abuts the walls and around all fixed elements that may restrain movement of the slab. This includes columns and machinery bases that penetrate the floor slab. With the slab isolated from other building elements, the remaining task is to locate and correctly space contraction joints to eliminate random cracking. Construction joint locations are coordinated with the floor contractor to accommodate work schedules and crew size. Unbonded construction joints should coincide with the contraction joint pattern and act as contraction joints. Construction joints should be planned to provide long-strips for each placement rather than a checker-board pattern. Contraction joints are then placed to divide the long-strips into relatively square panels, with panel length not exceeding 1.5 times the width. Contraction joints should stop at free edges or isolation joints. For more information on joints, see ACI Committee 302 (1996), PCA (1982), and Farny (2001). For joints in walls, see PCA (1982), PCA (1982a), PCA (1984), PCA (1984a), and PCA (1984b).

FILLING FLOOR JOINTS

There are three options for treating joints: they can be filled, sealed, or left open. The movement at contraction joints in a floor is generally very small. For some industrial and commercial uses, these joints can be left unfilled or unsealed. Where there are wet conditions, hygienic and dust-control requirements, or considerable traffic by small, hard-wheel vehicles, joint filling is necessary.

The difference between a filler and a sealer is the hardness of the material; fillers are more rigid than sealers and provide support to joint edges. In many places where traffic loading is light, a resilient material such as a polyurethane elastomeric sealant is satisfactory. However, heavy-traffic areas require support for joint edges to prevent spalling at saw-cuts; in such cases a good quality, semi-rigid epoxy or polyurea filler with a Shore Hardness of A-80 or D-50 (ASTM D 2240) should be used. The material should be installed full depth in the saw cut, without a backer rod, and flush with the floor surface.

Isolation joints are intended to accommodate movement; thus a flexible, elastomeric sealant should be used to keep foreign materials out of the joint.

UNJOINTED FLOORS

An unjointed floor, or one with a limited number of joints, can be constructed when joints are unacceptable. Three unjointed floor methods are suggested:

1. A prestressed floor can be built through the use of post-tensioning. With this method, steel strands in ducts are tensioned after the concrete hardens to produce compressive stress in the concrete. This compressive stress will counteract the development of tensile stresses in the concrete and provide a crack-free floor. Large areas, 1000 m^2 (10,000 ft^2) and more, can be constructed in this manner without intermediate joints.
2. Large areas—a single day of slab placement, usually 800 to 1000 m^2 (8000 to 10,000 ft^2)—can be cast without contraction joints when the amount of distributed steel in the floor is about one-half of one percent of the cross-sectional area of the slab. Special effort should be made to reduce subgrade friction in floors without contraction joints. Farny (2001) discusses use of distributed steel in floors.
3. Concrete made with expansive cement can be used to offset the amount of drying shrinkage to be anticipated after curing. Contraction joints are not needed when construction joints are used at intervals of 10 to 35 meters (40 to 120 ft). Large areas, up to 2000 m^2 (20,000 ft^2), have been cast in this manner without joints. Steel reinforcement is needed in order to produce compressive stresses during and after the expansion period—this is a form of prestressing.

REMOVING FORMS

It is advantageous to leave forms in place as long as possible to continue the curing period. However, there are times when it is necessary to remove forms as soon as possible. For example, where a rubbed finish is specified, forms must be removed early to permit the first rubbing before the concrete becomes too hard. Furthermore, it is often necessary to remove forms quickly to permit their immediate reuse.

In any case, shoring should not be removed until the concrete is strong enough to satisfactorily carry the stresses from both the dead load of the structure and any imposed construction loads. The concrete should be hard enough so that the surfaces will not be injured in any way when reasonable care is used in removing forms. In general, for concrete temperatures above 10°C (50°F), the side forms of reasonably thick, supported sections can be removed 24 hours after concreting. Beam and floor slab forms and supports (shoring) may be removed between 3 and 21 days, depending on the size of the member and the strength gain of the concrete. For most conditions, it is better to rely on the strength of the concrete as determined by in situ or field-cured specimen testing rather than arbitrarily selecting an age at which forms may be removed. Advice on reshoring is provided by ACI Committee 347.

For form removal, the designer should specify the minimum strength requirements for various members. The age-strength relationship should be determined from representative samples of concrete used in the structure and field-cured under job conditions. It should be remembered, however, that strengths are affected by the materials used, temperature, and other conditions. The time required for form removal, therefore, will vary from job to job.

A pinch bar or other metal tool should not be placed against the concrete to wedge forms loose. If it is necessary to wedge between the concrete and the form, only wooden wedges should be used. Stripping should be started some distance away from and move toward a projection. This relieves pressure against projecting corners and reduces the chance of edges breaking off.

Recessed forms require special attention. Wooden wedges should be gradually driven behind the form and the form should be tapped lightly to break it away from the concrete. Forms should not be pulled off rapidly after wedging has been started at one end; this is almost certain to break the edges of the concrete.

PATCHING, CLEANING, AND FINISHING

After forms are removed, all bulges, fins, and small projections can be removed by chipping or tooling. Undesired bolts, nails, ties, or other embedded metal can be removed or cut back to a depth of 13 mm (½ in.) from the concrete surface. When required, the surface can be rubbed or ground to provide a uniform appearance. Any cavities such as tierod holes should be filled unless they are intended for decorative purposes. Honeycombed areas must be repaired and stains removed to present a concrete surface that is uniform in color. All of these operations can be minimized by exercising care in constructing the formwork and placing the concrete. In general, repairs are easier to make and more successful if they are made as soon as practical, preferably as soon as the forms are removed. However, the procedures discussed below apply to both new and old hardened concrete.

Holes, Defects, and Overlays

Patches usually appear darker than the surrounding concrete; therefore, some white cement should be used in mortar or concrete for patching where appearance is important. Samples should be applied and cured in an inconspicuous location, perhaps a basement wall, several days in advance of patching operations to determine the most suitable proportions of white and gray cements. Steel troweling should be avoided since this darkens the patch.

Bolt holes, tierod holes, and other cavities that are small in area but relatively deep should be filled with a dry-pack mortar. The mortar should be mixed as stiff as is practical: use 1 part cement, 2½ parts sand passing a 1.25 mm (No. 16) sieve, and just enough water to form a ball when the mortar is squeezed gently in the hand. The cavity should be clean with no oil or loose material and kept damp with water for several hours. A neat-cement paste should be scrubbed onto the void surfaces, but not allowed to dry before the mortar is placed. The mortar should be tamped into place in layers about 13 mm (½ in.) thick. Vigorous tamping and adequate curing will ensure good bond and minimum shrinkage of the patch.

Concrete used to fill large patches and thin-bonded overlays should have a low water-cement ratio, often with a cement content equal to or greater than the concrete to be repaired. Cement contents range from 360 to 500 kg per cubic meter (600 to 850 lb per cubic yard) and the water-cement ratio is usually 0.45 or less. The aggregate size should be no more than ⅓ the patch or overlay thickness. A 9.5-mm (⅜-in.) nominal maximum size coarse aggregate is commonly used. The sand proportion can be higher than usual, often equal to the amount of coarse aggregate, depending on the desired properties and application.

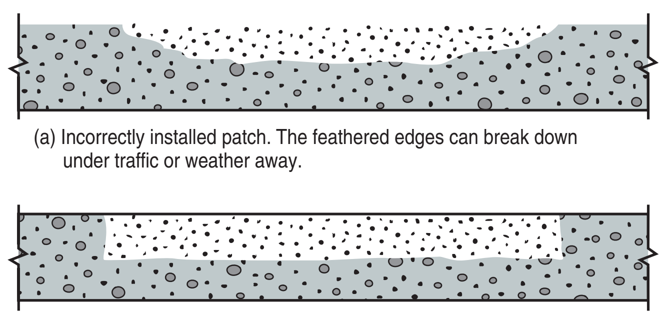
Before the patching concrete is applied, the surrounding concrete should be clean and sound (Fig. 11-32). Abrasive methods of cleaning (sandblasting, hydrojetting, waterblasting, scarification, or shotblasting) are usually required. For overlays, a cement-sand grout, a cement-sand-latex grout, or an epoxy bonding agent should be applied to the prepared surface with a brush or broom (see the earlier section "Bonding New to Previously Hardened Concrete"). Typical grout mix proportions are 1 part cement and 1 part fine sand and latex or epoxy admixtures. The grout should be applied immediately before the new concrete is placed. The grout should not be allowed to dry before the freshly mixed concrete is placed; otherwise bond may be impaired. The concrete may be dry or damp when the grout is applied *but not wet* with free-standing water. The minimum thickness for most patches and overlays is 20 mm (¾ in.). Some structures, like bridge decks, should have a minimum repair thickness of 40 mm (1½ in.). A superplasticizer is one of many admixtures often added to overlay or repair concrete to reduce the water-cement ratio and to improve workability and ease of consolidation (Kosmatka 1985a).

Honeycombed and other defective concrete should be cut out to expose sound material. If defective concrete is left adjacent to a patch, moisture may get into the voids; in time, weathering action will cause the patch to spall. The edges of the defective area should be cut or chipped straight and at right angles to the surface, or slightly undercut to provide a key at the edge of the patch. No featheredges should be permitted (Fig. 11-33). Based on the size of the patch, either a mortar or a concrete patching mixture should be used.

Shallow patches can be filled with a dry-pack mortar as described earlier. This should be placed in layers not more than 13 mm (½ in.) thick, with each layer given a scratch finish to improve bond with the subsequent layer. The final layer can be finished to match the surrounding concrete by floating, rubbing, or tooling, or on formed surfaces by pressing a section of form material against the patch while still plastic.

Deep patches can be filled with concrete held in place by forms. Such patches should be reinforced and doweled to the hardened concrete (*Concrete Manual* 1981). Large,

Fig. 11-32. Concrete prepared for patch installation. (69972)



(a) Incorrectly installed patch. The feathered edges can break down under traffic or weather away.

(b) Correctly installed patch. The chipped area should be at least 20 mm (3/4 in.) deep with the edges at right angles or undercut to the surface.

Fig. 11-33. Patch installation.

Fig. 11-34. Good curing is essential to successful patching. This patch is covered with polyethylene sheeting plus rigid insulation to retain moisture and heat for rapid hydration and strength gain. (40434)

shallow vertical or overhead repairs may best be accomplished by shotcreting. Several proprietary low-shrinkage cementitious repair products are also available.

Curing Patches

Following patching, good curing is essential (Fig. 11-34). Curing should be started immediately to avoid early drying. Wet burlap, wet sand, plastic sheets, curing paper, tarpaulins, or a combination of these can be used. In locations where it is difficult to hold these materials in place, an application of two coats of membrane-curing compound is often the most convenient method.

Cleaning Concrete Surfaces

Concrete surfaces are not always uniform in color when forms are removed; they may have a somewhat blotchy appearance and there may be a slight film of form-release agent in certain areas. There may be mortar stains from leaky forms or there may be rust stains. Flatwork can also become discolored during construction. Where appearance is important, all surfaces should be cleaned after construction has progressed to the stage where there will be no discoloration from subsequent construction activities.

There are three techniques for cleaning concrete surfaces: water, chemical, and mechanical (abrasion). Water dissolves dirt and rinses it from the surface. Chemical cleaners, usually mixed with water, react with dirt to separate it from the surface, and then the dirt and chemicals are rinsed off with clean water. Mechanical methods—sandblasting is most common—remove dirt by abrasion.

Before selecting a cleaning method, it should be tested on an inconspicuous area to be certain it will be helpful and not harmful. If possible, identify the characteristics of the discoloration because some treatments are more effective than others in removing certain materials.

Water cleaning methods include low-pressure washes, moderate-to-high-pressure waterblasting, and steam. Low-pressure washing is the simplest, requiring only that water run gently down the concrete surface for a day or two. The softened dirt then is flushed off with a slightly higher pressure rinse. Stubborn areas can be scrubbed with a nonmetallic-bristle brush and rinsed again. High-pressure waterblasting is used effectively by experienced operators. Steam cleaning must be performed by skilled operators using special equipment. Water methods are the least harmful to concrete, but they are not without potential problems. Serious damage may occur if the concrete surface is subjected to freezing temperatures while it is still wet; and water can bring soluble salts to the surface, forming a chalky, white deposit called efflorescence.

Chemical cleaning is usually done with water-based mixtures formulated for specific materials such as brick, stone, and concrete. An organic compound called a surfactant (surface-active agent), which acts as a detergent to wet the surface more readily, is included in most chemical cleaners. A small amount of acid or alkali is included to separate the dirt from the surface. For example, hydrochloric (muriatic) acid is commonly used to clean masonry walls and remove efflorescence. There can be problems related to the use of chemical cleaners. Their acid or alkaline properties can lead to reaction between cleaner and concrete as well as mortar, painted surfaces, glass, metals, and other building materials. Since chemical cleaners are used in the form of water-diluted solutions, they too can liberate soluble salts from within the concrete to form efflorescence. Some chemicals can also expose the aggregate in concrete. Chemicals commonly used to clean concrete surfaces and remove discoloration include weak solutions (1% to 10% concentration) of hydrochloric, acetic, or phosphoric acid. Diammonium citrate (20% to 30% water solution) is especially useful in removing discoloration stains and efflorescence on formed and flatwork surfaces. Chemical cleaners should be used by skilled operators taking suitable safety precautions. See Greening (1966) and PCA (1988) for more information.

Mechanical cleaning includes sandblasting, shotblasting, scarification, power chipping, and grinding. These methods wear the dirt off the surface rather than separate it from the surface. They, in fact, wear away both the dirt and some of the concrete surface; it is inevitable that there will be some loss of decorative detail, increased surface roughness, and rounding of sharp corners. Abrasive methods may also reveal defects (voids) hidden just beneath the formed surface.

Chemical and mechanical cleaning can each have an abrading effect on the concrete surface that may change the appearance of a surface compared to that of an adjacent uncleaned surface.

Finishing Formed Surfaces

Many off-the-form concrete surfaces require little or no additional treatment when they are carefully constructed with the proper forming materials. These surfaces are divided into two general classes: smooth and textured or patterned. Smooth surfaces are produced with plastic-coated forms, steel forms, fiberglass-reinforced plastic forms, formica forms, or tempered-hardboard forms. Textured or patterned surfaces are achieved with form liners, rough-sawn lumber, special grades and textures of plywood, or by fracturing the projections of a striated surface.

Rough-form finishes require patching of all tieholes and defects, unless tieholes are left open for architectural effect. Otherwise, these surfaces need no further work since texture and finish are imparted by the forms.

For a ***smooth off-the-form finish***, it is important to arrange the smooth-facing forming material and tierods in a symmetrical pattern. Studs and wales that are capable of preventing excessive deflections must support smooth-finish forms that are somewhat lightweight.

A ***smooth, rubbed finish*** is produced on a newly hardened concrete surface no later than the day following form removal. The forms are removed and necessary patching completed as soon as possible. The surface is then wetted and rubbed with a carborundum brick or other abrasive until a satisfactory uniform color and texture are produced.

A ***sand-floated finish*** can also be produced on newly hardened concrete surfaces. No later than 5 to 6 hours following form removal, the surface should be thoroughly wetted and rubbed with a wood float in a circular motion, working fine sand into the surface until the resulting finish is even and uniform in texture and color.

A ***grout cleandown (sack-rubbed finish)*** can be used to impart a uniform color and appearance to a smooth surface. After defects have been repaired, the surface should be saturated thoroughly with water and kept wet at least one hour before finishing operations begin. Next a grout of 1 part cement, 1½ to 2 parts of fine sand passing a 600 μm (No. 30) sieve, and sufficient water for a thick, creamy consistency should be prepared. It should be preshrunk by mixing at least one hour before use and then remixed without the addition of water and applied uniformly by brush, plasterer's trowel, or rubber float to completely fill all air bubbles and holes.

The surface should be vigorously floated with a wood, sponge rubber, or cork float immediately after applying the grout to fill any small air holes (bugholes) that are left; any remaining excess grout should be scraped off with a sponge-rubber float. If the float pulls grout from the holes, a sawing motion of the tool should correct the difficulty; any grout remaining on the surface should be allowed to stand undisturbed until it loses some of its plasticity but not its damp appearance. Then the surface should be rubbed with clean, dry burlap to remove all excess grout. All air holes should remain filled, but no visible film of grout should remain after the rubbing. Any section being cleaned with grout must be completed in one day, since grout remaining on the surface overnight is difficult to remove.

If possible, work should be done in the shade and preferably during cool, damp weather. During hot or dry weather, the concrete can be kept moist with a fine fog spray.

The completed surface should be moist-cured by keeping the area wet for 36 hours following the clean down. When completely dry, the surface should have a uniform color and texture.

SPECIAL SURFACE FINISHES

Patterns and Textures

A variety of patterns and textures can be used to produce decorative finishes. Patterns can be formed with divider strips or by scoring or stamping the surface just before the concrete hardens. Textures can be produced with little effort and expense with floats, trowels, and brooms; more elaborate textures can be achieved with special techniques (Fig. 11-35). See Kosmatka (1991).

Exposed-Aggregate Concrete

An exposed-aggregate finish provides a rugged, attractive surface in a wide range of textures and colors. Select aggregates are carefully chosen to avoid deleterious substances; they are usually of uniform size such as 9.5 to 12.5 mm (⅜ to ½ in.) or larger. They should be washed thoroughly before use to assure satisfactory bond. Flat or elongated aggregate particles should not be used since they are easily dislodged when the aggregate is exposed. Caution should be exercised when using crushed stone; it not only has a greater tendency to stack during the seeding operation (requiring more labor), but it also may be undesirable in some applications (pool decks, for example).

The aggregate should be evenly distributed or seeded in one layer onto the concrete surface immediately after the slab has been bullfloated or darbied. The particles must be completely embedded in the concrete. This can be done by lightly tapping with a wooden hand float, a darby, or the broad side of a piece of lumber; then, when the concrete can support a finisher on kneeboards, the surface should be hand-floated with a magnesium float or darby until the mortar completely surrounds and slightly covers all the aggregate particles.

Methods of exposing the aggregate usually include washing and brushing, using retarders, and scrubbing. When the concrete has hardened sufficiently, simultaneously brushing and flushing with water should expose the aggregate. In washing and brushing, the surface layer of mortar should be carefully washed away with a light spray of water and brushed until the desired exposure is achieved.

Fig. 11-35. Patterned, textured, and colored concretes are very attractive. (59031, 53598, 59003, 47835, 44898)

Since timing is important, test panels should be made to determine the correct time for exposing the aggregate without dislodging the particles. On large jobs, a water-insoluble retarder can be sprayed or brushed on the surface immediately after floating, but on small jobs this may not be necessary. When the concrete becomes too hard to produce the required finish with normal washing and brushing, a dilute hydrochloric acid can be used. Surface preparation should be minimized and applicable local environmental laws should be followed.

Two other methods for obtaining an exposed aggregate surface are: (1) the monolithic technique where a select aggregate, usually gap-graded, is mixed throughout the batch of concrete, and (2) the topping technique in which the select exposed-aggregate is mixed into a topping that is placed over a base slab of conventional concrete.

The aggregate in exposed-aggregate concrete can also be exposed by methods other than those already discussed. The following techniques expose the aggregate after the concrete has hardened to a compressive strength of around 28 MPa (4000 psi):

Abrasive blasting is best applied to a gap-graded aggregate concrete. The nozzle should be held perpendicular to the surface and the concrete removed to a maximum depth of about one-third the diameter of the coarse aggregate.

Waterblasting can also be used to texture the surface of hardened concrete, especially where local ordinances prohibit the use of sandblasting for environmental reasons. High-pressure water jets are used on surfaces that have or have not been treated with retarders.

In tooling or bushhammering, a layer of hardened concrete is removed and the aggregate is fractured at the surface. The surfaces attained can vary from a light scaling to a deep, bold texture obtained by jackhammering with a single-pointed chisel. Combs and multiple points can be used to produce finishes similar to some finishes used on cut stone.

Grinding and polishing will produce an exposed-aggregate concrete such as terrazzo, which is primarily used indoors. This technique is done in several successive steps using either a stone grinder or diamond-disk grinder. Each successive step uses finer grit than the preceding one. A polishing compound and buffer can then be used for a honed finish.

Regardless of the method employed, it is wise for the contractor to make a preconstruction mock-up (field sample) for each finish to determine the timing and steps involved; in addition, the mock-up is used to obtain aesthetic approval from the architect and owner. For more information see Kosmatka (1991), PCA (1972), and PCA (1995).

Colored Finishes

Colored concrete finishes for decorative effects in both interior and exterior applications can be achieved by four different methods: (1) the one-course or integral method, (2) the two-course method, (3) the dry-shake method, and (4) stains and paints (discussed below).

Color pigments added to the concrete in the mixer to produce a uniform color is the basis for the one-course method. Both natural and synthetic pigments are satisfactory if they are: (1) insoluble in water, (2) free from soluble salts and acids, (3) fast to sunlight, (4) fast to alkali and weak acids, (5) limited to small amounts of calcium sulphate, and (6) ground fine enough so that 90% passes a 45 micron screen. Use only the minimum amount necessary to produce the desired color and not more than 10% by weight of the cement.

In the two-course method, a base slab is placed and left with a rough texture to bond better to a colored topping layer. As soon as the base slab can support a cement mason's weight, the topping course can be placed. If the base slab has hardened, prepare a bonding grout for the base slab prior to placing the topping mix. The topping mix is normally 13 mm (½ in.) to 25 mm (1 in.) thick, with a ratio of cement to sand of 1:3 or 1:4. The mix is floated and troweled in the prescribed manner. The two-course method is more commonly used because it is more economical than the one-course method.

In the dry-shake method, a prepackaged dry-color material is cast onto the surface of a concrete slab. The dry-shake material is applied after the concrete has been screeded and darbied or bullfloated, excess moisture has evaporated from the surface, and preliminary floating has been done. Two-thirds of the dry material is shaken evenly by hand over the surface and thoroughly floated into the surface in a manner that evenly distributes the material. Immediately, the rest of the material is cast onto the surface and floated as before. The surface can then be troweled at the same time as a typical slab. For exterior surfaces that will be exposed to freezing and thawing, little or no troweling followed by brooming with a soft bristle concrete broom is usually sufficient.

Stains, Paints, and Clear Coatings

Many types of stains, paints and clear coatings can be applied to concrete surfaces. Among the principal paints used are portland cement base, latex-modified portland cement, and latex (acrylic and polyvinyl acetate) paints (PCA 1992). However, stains and paints are used only when it is necessary to color existing concrete. It is difficult to obtain a uniform color with dyes or stains; therefore, the manufacturer's directions should be closely followed.

Portland cement based paints can be used on either interior or exterior exposures. The surface of the concrete should be damp at the time of application and each coat should be dampened as soon as possible without disturbing the paint. Damp curing of conventional portland cement paint is essential. On open-textured surfaces, such as concrete masonry, the paint should be applied with stiff-bristle brushes (scrub brushes). Paint should be worked well into the surface. For concrete with a smooth or sandy finish, whitewash or Dutch-type calcimine brushes are best.

The latex materials used in latex-modified portland cement paints retard evaporation, thereby retaining the necessary water for hydration of the portland cement. When using latex-modified paints, moist curing is not required.

Most latex paints are resistant to alkali and can be applied to new concrete after 10 days of good drying weather. The preferred method of application is by long-fiber, tapered nylon brushes 100 to 150 mm (4 to 6 in.) wide; however, roller or spray methods can also be used. The paints may be applied to damp, but not wet surfaces. If the surface is moderately porous, or if extremely dry conditions prevail, prewetting the surface is advisable.

Clear coatings are frequently used on concrete surfaces to (1) prevent soiling or discoloration of the concrete by air pollution, (2) to facilitate cleaning the surface if it does become dirty, (3) to brighten the color of the aggregates, and (4) to render the surface water-repellent and thus prevent color change due to rain and water absorption. The better coatings often consist of methyl methacrylate forms of acrylic resin, as indicated by a laboratory evaluation of commercial clear coatings (Litvin 1968). The methyl methacrylate coatings should have a higher viscosity and solids content when used on smooth concrete, since the original appearance of smooth concrete is more difficult to maintain than the original appearance of exposed-aggregate concrete.

Other materials, such as silane and siloxane penetrating sealers, are commonly used as water repellents for many exterior concrete applications.

PRECAUTIONS

Protect Your Head and Eyes. Construction equipment and tools represent constant potential hazards to busy construction personnel. That's why hard hats are required on construction projects. It is therefore recommended that some sort of head protection, such as a hard hat or safety hat, be worn when working any construction job, large or small.

Proper eye protection is essential when working with cement or concrete. Eyes are particularly vulnerable to blowing dust, splattering concrete, and other foreign objects. On some jobs it may be advisable to wear full-cover goggles or safety glasses with side shields. Actions that cause dust to become airborne should be avoided. Local or general ventilation can control exposures below applicable exposure limits; respirators may be used in poorly ventilated areas, where exposure limits are exceeded, or when dust causes discomfort or irritation.

Protect Your Back. All materials used to make concrete—portland cement, sand, coarse aggregate, and water—can be quite heavy, even in small quantities. When lifting heavy materials, the back should be straight, legs bent, and the weight between the legs as close to the body as possible. Mechanical equipment should be used to place concrete as close as possible to its final position. After the concrete is deposited in the desired area by chute, pump, or wheelbarrow, it should be pushed—not lifted—into final position with a shovel; a short-handled, square-end shovel is an effective tool for spreading concrete, but special concrete rakes or come-alongs also can be used. Excessive horizontal movement of the concrete should be avoided; it not only requires extra effort, but may also lead to segregation of the concrete ingredients.

Protect Your Skin. When working with fresh concrete, care should be taken to avoid skin irritation or chemical burns (see warning statement in the box). Prolonged contact between fresh concrete and skin surfaces, eyes, and clothing may result in burns that are quite severe, including third-degree burns. Eyes and skin that come in contact with fresh concrete should be flushed thoroughly with clean water. If irritation persists, consult a physician. For deep burns or large affected skin areas, seek medical attention immediately.

The A-B-Cs of fresh concrete's effect on skin are:

Abrasive Sand contained in fresh concrete is abrasive to bare skin.

Basic & Caustic Portland cement is alkaline in nature, so wet concrete and other cement mixtures are strongly basic (pH of 12 to 13). Strong bases—like strong acids—are harmful, or caustic to skin.

Drying Portland cement is hygroscopic—it absorbs water. In fact, portland cement needs water to harden. It will draw water away from any material it contacts—including skin.

Clothing worn as protection from fresh concrete should not be allowed to become saturated with moisture from fresh concrete because saturated clothing can transmit alkaline or hygroscopic effects to the skin. Clothing that becomes saturated from contact with fresh concrete should be rinsed out promptly with clear water to prevent continued contact with skin surfaces. Waterproof gloves, a long-sleeved shirt, and long pants should be worn. If you must stand in fresh concrete while it is being placed, screeded, or floated, wear rubber boots high enough to prevent concrete from getting into them (PCA 1998).

WARNING: Contact with wet (unhardened) concrete, mortar, cement, or cement mixtures can cause SKIN IRRITATION, SEVERE CHEMICAL BURNS (THIRD-DEGREE), or SERIOUS EYE DAMAGE. Frequent exposure may be associated with irritant and/or allergic contact dermatitis. Wear waterproof gloves, a long-sleeved shirt, full-length trousers, and proper eye protection when working with these materials. If you have to stand in wet concrete, use waterproof boots that are high enough to keep concrete from flowing into them. Wash wet concrete, mortar, cement, or cement mixtures from your skin immediately. Flush eyes with clean water immediately after contact. Indirect contact through clothing can be as serious as direct contact, so promptly rinse out wet concrete, mortar, cement, or cement mixtures from clothing. Seek immediate medical attention if you have persistent or severe discomfort.

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