17

Joints in Concrete Construction

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17.1 Introduction

Restrained volumetric changes result in strains and ensuing stresses that lead to cracking. For a concrete system to be viable long term, it is essential to reduce the magnitude and extent of cracking by imposing artificial crack locations through the use of joints that relieve the stress levels and sometimes reduce them to a negligible magnitude. In essence, such joints can be viewed as artificial cracks. This chapter utilizes American Concrete Institute (ACI) committee reports and standards on this subject as a background, particularly ACI 224.3R, *Joints in Concrete Construction* (ACI Committee 224, 1995), and ACI 350, *Environmental Engineering Concrete Structures* (ACI Committee 350, 2006). Informational discussions on this subject are also utilized from the references provided at the end of the chapter.

It is important to note that the type of joint utilized depends on the function it must serve. As a general classification, the following are the types of joints commonly used today:

- *Construction joints*
- *Contraction joints* (secondary movement joints)
- *Expansion joints* (principal movement joints; sometimes referred to as *isolation joints*)

Drying shrinkage, carbonation, irreversible creep, fluctuating ambient temperature changes, and externally imposed loads are all factors that induce tensile stress conditions exceeding the modulus of rupture

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of concrete, resulting in cracking. An example of the magnitude of strains developed by direct elastic strains from external loads and the resulting volumetric changes for a normal concrete specimen subjected to 900-psi (6.2-MPa) compression is presented below (Nawy, 2008):

Immediate elastic strain: $\varepsilon_e = 250 \times 10^{-6}$ in./in.

Shrinkage strain after one year: $\varepsilon_{sh} = 500 \times 10^{-6}$ in./in.

Creep strain after one year: $\varepsilon_{cr} = 750 \times 10^{-6}$ in./in.

Total strain: $\varepsilon_T = 1500 \times 10^{-6}$ in./in.

If the element is 12 ft (3.65 m) long, the resulting dimensional change is 1500×10^{-6} (12 × 12) = 0.22 in. A rise in temperature of 65°F results in an additional change of 65(5.5×10^{-6} in./in.)(12 × 12) = 0.05 in. to give a total dimensional change of 0.22 + 0.05 = 0.27 in. If the element is restrained as part of a monolithic concrete structure, as is usually the case, this element will be subjected to a significant tensile force that will cause extensive cracking or even failure. Some of these cracks can be prevented from opening by providing continuous horizontal and vertical reinforcement in the structure that would resist the tensile forces in the orthogonal directions.

Cracking resulting from these unavoidable strain gradients has always been a significant factor that the designer must consider in any structural design; hence, the use of joints is inevitable. It would be rare to find a structural system of reasonable size that is constructed without the use of construction joints, contraction (control) joints, expansion (isolation) joints, and shrinkage strips—separately or in combination (Fintel, 1974). If, apart from construction joints, other types of joints are to serve as stress relievers, it can be assumed that if enough reinforcement is provided in the direction of the induced forces to prevent the cracks from opening, then no joint would be needed; however, it would be economically prohibitive to do so as the volume of reinforcement required to perform this task would be significant.

Because the induced forces are highly indeterminate, engineering judgment has to be exercised in interpreting the imprecise guidelines in codes and the literature which often render conflicting solutions. This chapter attempts to synthesize in a compact manner the generally accepted industry approaches for the design of joints in concrete.

17.2 Construction Joints

For many structures, construction joints are required to accommodate the construction sequence for placement of concrete. The amount of concrete that can practically be placed in any operation is a function of the batching and mixing capacity and the time available for placing the concrete in the particular segment that is placed. The construction joint is the separating plane between the old (parent) concrete and the new concrete batch. As a result, the spacing of the construction joints must not interfere with flexural and shear continuity through the interface between the parent concrete and the concrete that is placed thereafter. To achieve this continuity, the hardened concrete must be clean and free of laitance if even a few hours elapse between successive placements. The ACI 318 Building Code stipulates that existing concrete should be moistened thoroughly before placement of the fresh concrete so the parent and the new concrete can achieve full monolithic behavior (ACI Committee 224, 1995; ACI Committee 318, 2008). Because the spacing of the construction joints is determined by the volume of the batch, it is often advisable in large area walls to have the construction joint coincide with the contraction (movement) joint. A spacing of 20 to 30 ft (6.1 to 9.1 m) for contraction joints in reinforced concrete continuous walls is often chosen. It is thus logical to use the contraction joint as a construction joint, with a spacing of 20 to 30 ft, depending on the number of openings in the wall. Figure 17.1 shows two types of construction joints: a butt joint in structural slabs and a tongue-and-groove joint with the option of a water stop for use in a liquid-retaining structure.

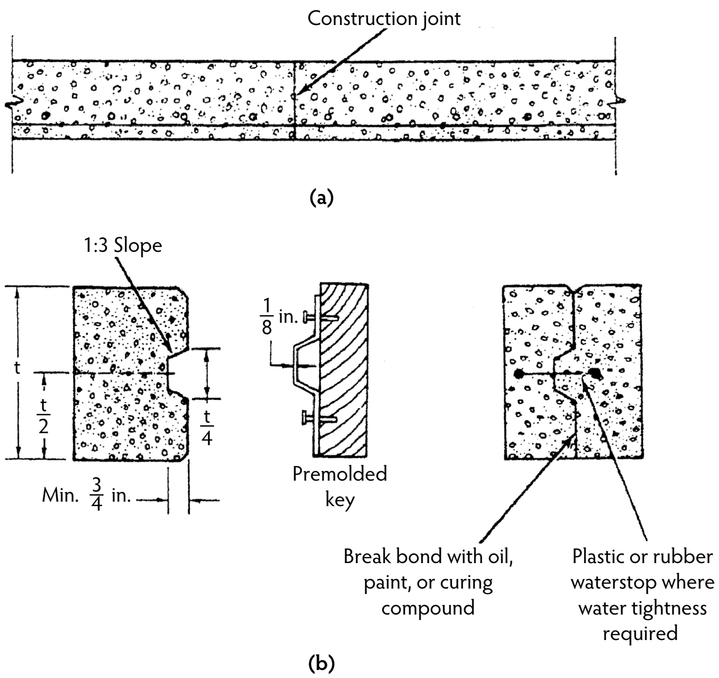

FIGURE 17.1 Typical construction joint assembly: (a) butt joint, (b) tongue-and-groove joint.

17.3 Contraction Joints

Tensile stresses result from drying shrinkage and ambient temperature drops in restrained concrete elements that are prevented from contracting. These tensile stresses resulting from the incipient volumetric change can be reduced to tolerable levels through the use of contraction joints, sometimes referred to as *control joints*. Typically, four methods are commonly used to create contraction joints in concrete surfaces: forming, tooling, sawing, and placement of joint formers (ACI Committee 224, 1995). To form a plane of weakness at the designed spacing, the joints are imposed during concrete placement by tacking rubber, plastic, wooden, or metal strips or caps to the inner faces of the forms to create notches, such as those shown in Figure 17.2.

17.3.1 Formed Contraction Joints

Joint formers can be used to create contraction joints as well as expansion (isolation) joints. Expansion joints usually have removable caps over the expansion joint material. After the concrete hardens, the cap is removed and the void space is caulked and sealed. Joint formers can be either rigid or flexible. Contraction joints are not meant to be isolation joints but are merely made by forming a weakened plane in the concrete with a rigid plastic strip. These strips are essentially T-shaped elements that are inserted to a proper depth into the freshly placed concrete, usually with a bar cutter. The cap must be pulled out prior to bullfloating or troweling the concrete surface. When such joints are formed at construction joint locations in concrete slabs and walls, they serve both as construction and contraction control joints. Tongue-and-groove joints can be made with preformed metal or plastic strips or built to job requirements. The strips have to be securely fastened so they cannot be dislodged during the process of concrete placement and consolidation. Prefabricated circular forms can be used as column isolation joints; these one-piece elements are left in place.

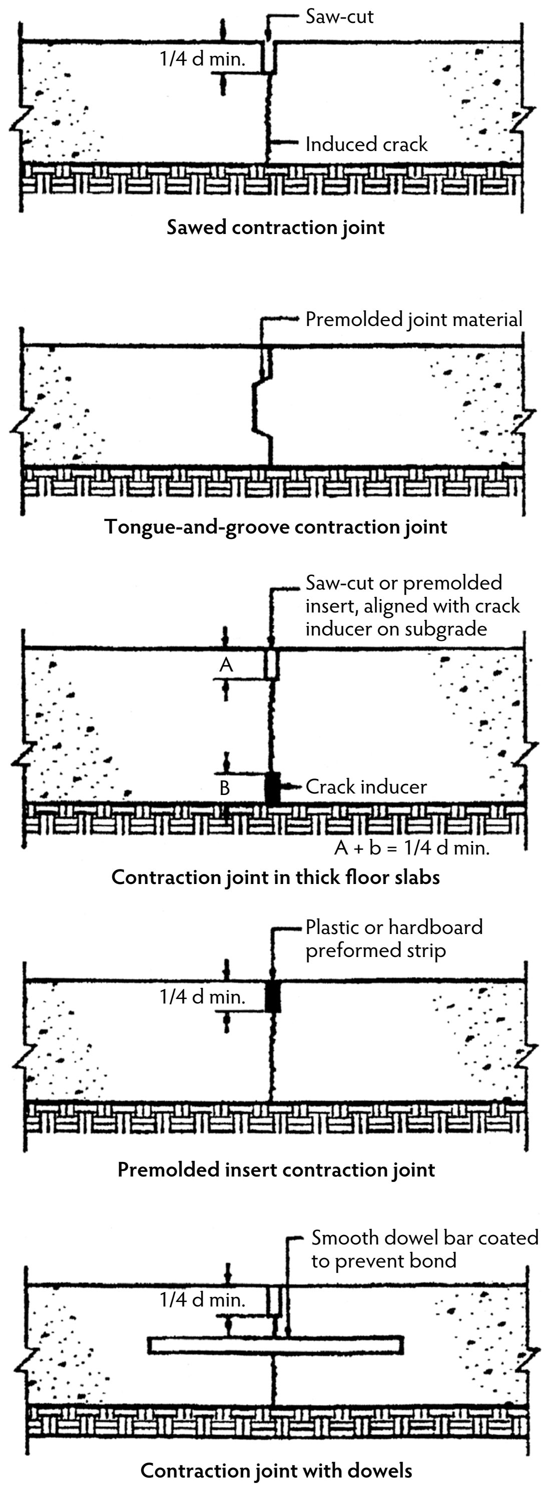

FIGURE 17.2 Contraction joint types. (From ACI Committee 224, *Joints in Concrete Construction*, ACI 224.3R-95, American Concrete Institute, Farmington Hills, MI, 1995, pp. 1–44; ACI Committee 302, *Guide for Concrete Floor and Slab Construction*, ACI 302.1R-89, American Concrete Institute, Farmington Hills, MI, 1989.)

TABLE 17.1 Contraction Joint Spacings

Author	Spacing
Merrill (1943)	20 ft (6 m) for walls with frequent openings 25 ft (7.5 m) for solid walls
Fintel (1974)	15–20 ft (4.5–6 m) for walls and slabs on grade; recommends joint placement at abrupt changes in plan and at changes in building height to account for potential stress concentrations
Wood (1981)	20–30 ft (6 to 9 m) for walls
PCA (1982)	20–25 ft (6 to 7.5 m) for walls depending on number of openings
ACI 302.1R (1989)	15–20 ft (4.5–6 m) recommended until 302.1R-89, then changed to 24 to 36 times slab thickness
ACI 350R (1983)	30 ft (9 m) in sanitary structures
ACI 350 (2006)	Joint spacing varies with amount and grade of shrinkage and temperature reinforcement
ACI 224R (1992)	One to three times the height of the wall in solid walls

Source: Data from ACI Committee 224, *Joints in Concrete Construction*, ACI 224.3R-95, American Concrete Institute, Farmington Hills, MI, 1995, pp. 1–44.

17.3.2 Tooled Joints

These contraction joints are tooled into the concrete surface during the finishing operations. A groove is formed to cause a weakened plane, which controls the location of the developing crack. Grooving tools with blades 1-1/2 to 2 in. (40 to 50 mm) in depth are used. The groove should be at least the thickness of the concrete. Cracks may develop within such a groove, although they also can occur at adjacent locations. At a tooled contraction joint, reinforcement in the concrete element should be reduced to *at least* 50% of the designed steel reinforcement or discontinued altogether (ACI Committee 350, 2006). As the distance between tooled joints increases, the volume of steel reinforcement not crossing the joint should be increased to control the tensile stresses that are developed. Often, tooled joints are of insufficient depth to function properly.

17.3.3 Sawed Joints

Sawed joints can reduce the intensity of labor required during the finishing process, but the necessary work and power equipment has to be available within a short period of time after the concrete hardens—namely, as soon as practicable The most favorable time is when the generated heat of hydration renders the concrete temperature at its peak, but the concrete has to be hardened enough that the surface is not damaged during the cutting operation. As with tooled joints, saw-cut grooves should be made at least 1/4 the depth of the member. Various types of sawing equipment and techniques are available, including diamond-studded blades and abrasive blades. If abrasive blades are used, it is important to set a limit on the magnitude of wear that is acceptable for blade replacement. A drawback to the use of sawed joints is the large equipment clearance required; for example, it is difficult to place the saw at a slab edge where it abuts a wall. Based on industry experience a contraction joint spacing not to exceed 25 ft (7.5 m) is advisable; however, guidelines on joint spacing are diverse and conflicting. Table 17.1 summarizes various recommendations for contraction joint spacing. The focus should be on what spacing will result in an as narrow and aesthetically acceptable crack width and appearance as possible.

17.3.4 Contraction Joint Effectiveness

The effectiveness of a contraction joint is governed by whether any reinforcement passes through it. ACI 318 and ACI 350 consider a contraction joint to be fully effective when no reinforcing bars traverse the joint. For a partially effective contraction joint, a maximum 50% of the design reinforcement is allowed. Any reinforcement exceeding this limit would render the joint useless in controlling the volumetric change cracking in the structural system. It is therefore essential to provide a complete break in the reinforcement

TABLE 17.2 Expansion Joint Spacings

Author	Spacings
Lewerenz (1907)	75 ft (23 m) for walls
Hunter (1953)	80 ft (25 m) for walls and insulated roofs
	30–40 ft (9–12 m) for uninsulated walls
Billig (1960)	100 ft (30 m) maximum building length without joints; recommends joint placement at abrupt changes in plan and at changes in building heights to account for potential stress concentrations
Wood (1981)	100–120 ft (30–35 m) for walls
Indian Standards Institution (1964)	148 ft (45 m) maximum building length between joints
PCA (1982)	200 ft (60 m) maximum building length without expansion joint
Kaminetsky (2001)	100 ft (30 m) maximum in environmental structures (see also Table 17.5)

Source: Data from ACI Committee 224, *Joints in Concrete Construction*, ACI 224.3R-95, American Concrete Institute, Farmington Hills, MI, 1995, pp. 1–44.

at the joint. It is recommended that bars should be stopped at 1-1/2 to 2 in. (3-1/2 to 5 cm) away from the joint at both sides of the joint line. A bond breaker should be placed between successive placements at contraction and construction joints, similar to expansion joints, and should pass through the entire structure in one plane. If the joints are not aligned, movement at a joint could induce cracking in an unjoined portion of the structure until the crack intercepts another joint (ACI Committee 224, 1995).

17.4 Expansion Joints

17.4.1 Structural Response

Expansion joints are effective isolation joints that divide a structure, including its foundation, into separate isolated units. This becomes necessary in large structural systems where continuity restraint induces significant stresses and large forces due to temperature changes, including ambient temperature variations, during a 24-hour period. The resulting cracking becomes considerably magnified at the lower segment of a wall if it is highly restrained by monolithic attachment to the stiff foundation slab, particularly in liquid-retaining structures. Such structures usually have high walls and stiff thick foundation slabs and cannot tolerate seepage caused by wide cracks that can be avoided. Expansion joints serve to isolate segments that are affected by large dimensional changes due to expansion, contraction, and differential settlement and also prevent cracking when walls change in direction. As an example, the contraction or elongation of a 190-ft (58-m) long wall in an environmental structure subjected to an ambient temperature change of 60°F (34°C) using a concrete coefficient of expansion of 5.5×10^{-6}/°F (9.9×10^{-6}/°C) would undergo a dimensional change equal to $5.5 \times 10^{-6} \times 60(190 \times 12) = 0.75$ in. (19 mm). Because the wall is monolithically cast with the stiff foundation slab, the lower wall segment will develop severe vertical cracking, as the upper segments are less restrained and can move relatively more freely. To avoid such long-term failure, expansion joints are vital. The joint width should be sufficient to prevent portions of the structure on either side of the joint from coming in contact.

17.4.2 Expansion Joint Width

The width of expansion joints can vary between 1 and 6 inches (25 and 150 mm), with 2 in. (50 mm) being typical. Such joints also serve an additional function as construction joints. As discussed in the case of contraction joints, no definitive standards are available that address the necessary spacing of expansion joints. A rule-of-thumb approach and good engineering judgment should be relied upon when specifying joint widths. Table 17.2 provides general guidelines for recommended spacings in various systems under different conditions.

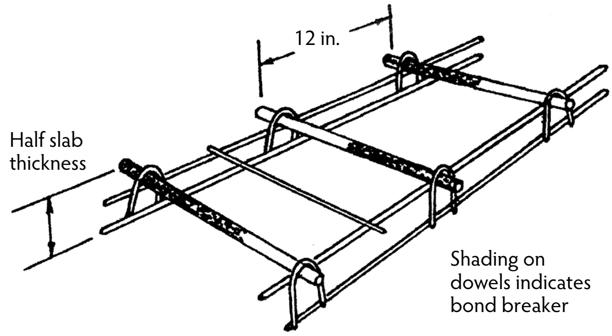

FIGURE 17.3 Example of a dowel bar assembly. (From ACI Committee 224, *Joints in Concrete Construction*, ACI 224.3R-95, American Concrete Institute, Farmington Hills, MI, 1995, pp. 1–44.)

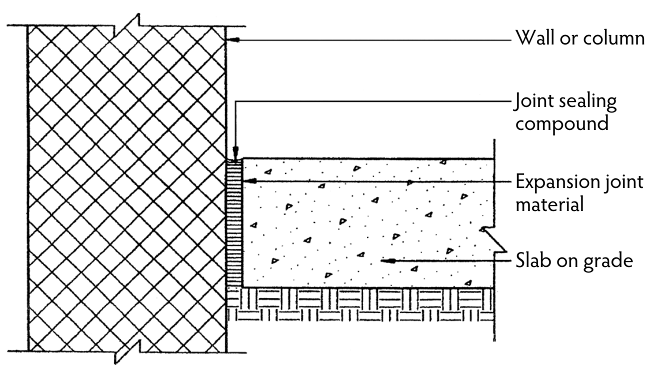

FIGURE 17.4 Isolation joint between a supported floor and a wall. (From ACI Committee 224, *Joints in Concrete Construction*, ACI 224.3R-95, American Concrete Institute, Farmington Hills, MI, 1995, pp. 1–44; PCA, *Building Movements and Joints*, Portland Cement Association, Skokie, IL, 1982.)

17.4.3 Expansion Joint Details

It is important to stress that the joint should extend through the entire height of the structure and through its foundation slab. Column footings should preferably not be placed at a joint. As in the case of construction joints, no reinforcement bars should pass through the joint but should terminate 2 in. (50 mm) from both faces of the joint. Dowels with breakers can be used to maintain plane (Fintel, 1974). The expansion joint can be covered, filled with a mastic filler, or left open. In the case of liquid-retaining structures, appropriate water stops have to be well designed, detailed, and properly installed to ensure complete liquid-tightness throughout the life of the structure. The water stops should also be suitable for minor foundation adjustments. Figure 17.3 shows a dowel assembly for an expansion joint, and Figure 17.4 illustrates an isolation joint between a supported slab and a wall.

17.4.4 Expansion Joints in Environmental Concrete Structures and Minimum Reinforcement Requirements

17.4.4.1 Expansion Joint Spacing

As previously discussed, expansion joints are isolation joints that divide a long structure into two segments joined by a resilient water stop and sealants. The water stop is designed to allow for anticipated movements in the structure. ACI 350R (ACI Committee 350, 2006) stipulates that "in general, expansion joint spacing preferably should not be greater than 120 ft (36 m)"; however, engineering practice over the decades and effluent leakage failures have revealed that this spacing limit is too excessive. A modification of the ACI

TABLE 17.3 Recommended Joint Width and Spacing

Temperature Range	Spacing Between Expansion Joints 12 m (40 ft) cm (in.)	18 m (60 ft) cm (in.)	24 m (80 ft) cm (in.)	30 m (100 ft) cm (in.)
Underground, 4.44°C (40°F)	1.27 (1/2)	1.50 (3/4)	2.22 (7/8)	2.54 (1)
Partly protected, above ground, 26.7°C (80°F)	1.90 (3/4)	2.22 (7/8)	2.54 (1)	—[a]
Unprotected, exposed roof slabs, 48.9°C (120°F)	2.22 (7/8)	2.54 (1)	—[a]	—[a]

[a] Not recommended

Source: Kaminetsky, D., in *ICJCRR: Repair and Rehabilitation: A Compilation from The Indian Concrete Journal*, Research & Consultancy Directorate, Thane, India, 2001.

350 standard given in Table 17.3 recommends joint spacings and widths, with a maximum spacing of 100 ft (30 m); otherwise, wide liquid-leaking cracks could develop that would render the structure ineffective for retaining treated effluent. Even so, current engineering practice, given the reinforcement percentage values set in ACI 350, often specifies an expansion joint spacing not to exceed 80 ft (24 m). It should be emphasized that the actual width of the joint should be at least *twice* the expected movement.

17.4.4.2 Reinforcement

Prevention of liquid leakage is a major factor to be considered when designing liquid-retaining structures such as water tanks and towers, water-treatment facilities, aeration tanks, and biofors, among others. Such structures are designed for both strength and long-term serviceability. Service stress levels in the concrete and the steel reinforcement are kept low—for example, 20,000 psi (138 MPa) in the reinforcement. The volumetric change reinforcement percentage to be used in such structures has to be higher than in non-liquid-retaining structures. The shrinkage and temperature reinforcement in such specialized structures stipulated by ACI 350 is shown in Figure 17.5 and tabulated in Table 17.4, based on provision of full contraction joints in the walls and the slab foundation. If partial contraction joints as described in Section 17.3 are used, a maximum 50% of wall reinforcement is permitted to cross the contraction joint (ACI Committee 350, 2006). The spacing of these joints is permitted to be up to 30 ft by ACI 350; yet, it is preferable not to exceed 20- to 25-ft spacing to reduce the width and extent of volumetric change cracking. Although the maximum percentage in Figure 17.5 and Table 17.4 is given as 0.5% for 40-ft movement joints, the high rigidity of the foundation slab at the wall joint renders this percentage inadequate. The relative lower flexibility of the wall as compared to the stiff foundation slab at the lower wall segment renders the joint totally rigid with a low magnitude of rotation at the joint, because the wall is almost fixed at the base and free at the top. As a result, vertical cracking, and wide cracks develop, and the liquid-retaining structure becomes heavily permeable. To prevent vertical cracking at the lower quarter segment of the wall, more than 0.5% reinforcement would be needed for walls with expansion joints spaced in excess of 40 to 50 ft. It is the opinion of the author that a percentage ratio in the range of 1.0 to 1.25% for horizontal reinforcement at the lower 15 to 20% of the wall height is necessary to prevent the often excessive cracking at lower segments of a wall. This need arises because the flexible wall element is rigidly held by its monolithically supporting rigid foundation, so as to eliminate the consequent leakage of the retained liquid and its environmentally hazardous effects.

17.4.4.3 Expansion Joint Stops and Fillers

Liquid-tightness is vitally necessary in environmental structures to maintain their long-term integrity. A joint sealant at the liquid face and a suitable water stop made of high-quality rubber or plastic is necessary. As described in ACI 224 (ACI Committee 224, 1995), liquid stops and sealants can be chosen from a variety of alternatives. Rubber water stops allow more joint movement than polyvinylchloride (PVC) water stops. Either type should be at least 9 in. (225 mm) wide to provide adequate concrete embedment, and they should be 3/8 to 1/2 in. (9 to 12 mm) thick. To allow movement at the joint, a preformed joint filler should ideally be able to compress to half of its original width and be able to re-expand to fill the

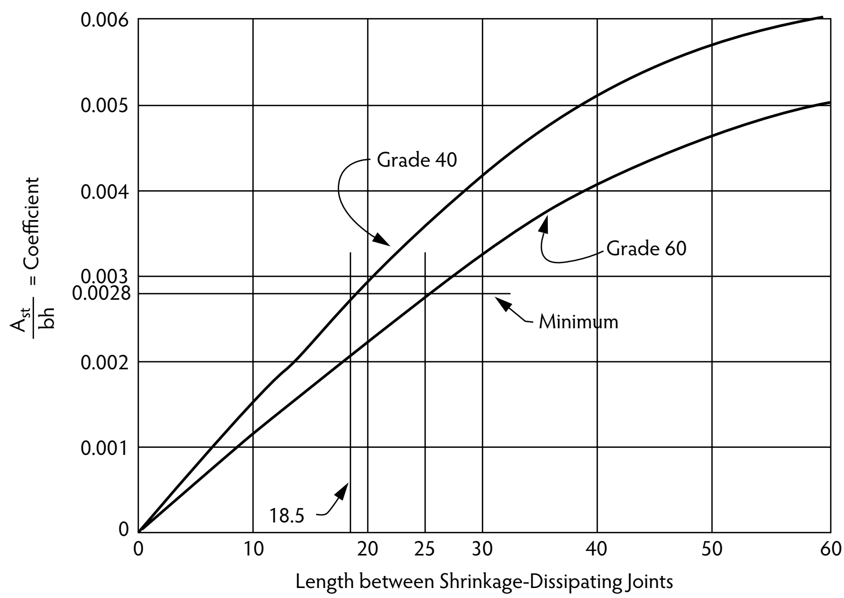

FIGURE 17.5 Shrinkage and temperature reinforcement for environmental engineering concrete structures. (From ACI Committee 224, *Joints in Concrete Construction*, ACI 224.3R-95, American Concrete Institute, Farmington Hills, MI, 1995, pp. 1–44; ACI Committee 350, *Code Requirements for Environmental Engineering Concrete Structures and Commentary*, ACI 350, American Concrete Institute, Farmington Hills, MI, 2006.)

TABLE 17.4 Minimum Shrinkage and Temperature Reinforcement

Length between Movement Joints (ft)	Minimum Temperature and Shrinkage Reinforcement Ratio	
	Grade 40	Grade 60
Less than 20	0.0030	0.0030
20 to less than 30	0.0040	0.0030
30 to less than 40	0.0050	0.0040
40 and greater	0.0060[a]	0.0050[a]

[a] Maximum shrinkage and temperature reinforcement where movement joints are not provided.

Note: When using this table, the actual joint spacing should be multiplied by 1.5 if no more than 50% of the reinforcement passes through the joint.

Source: Data from ACI Committee 350, *Code Requirements for Environmental Engineering Concrete Structures and Commentary*, ACI 350, American Concrete Institute, Farmington Hills, MI, 2006.

joint as the joint enlarges. According to ASTM Standards D 994, D 1751, and D 1752, cork, rubber, foam, and other products conforming to these standards should perform satisfactorily in permitting such levels of movement. Figure 17.6 presents optimal expansion joint water stop detail and illustrates a typical expansion joint for a non-liquid-retaining structure.

17.4.5 Seismic Joints

Seismic joints are wide expansion joints intended to separate portions of buildings that are dissimilar in mass and stiffness. They are designed to allow adjacent units to respond to a seismic wave without the structural units banging against each other. The width of the joint should be equal to the sum of the total displacement at the particular affected level from the base of the two adjacent units, but no less

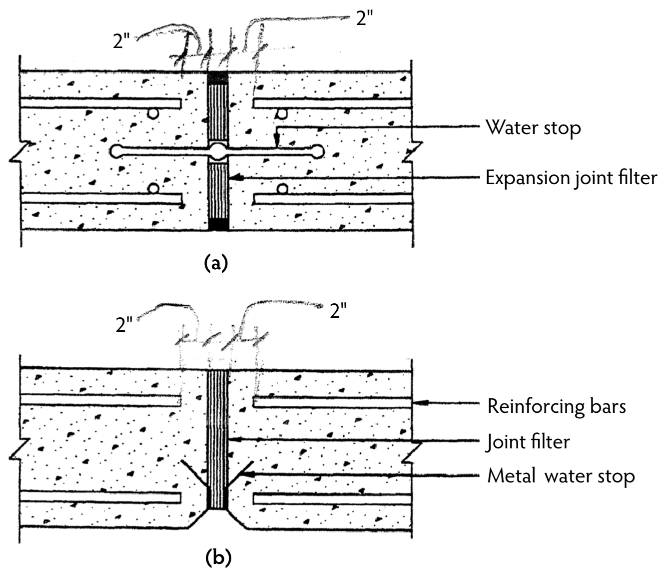

FIGURE 17.6 Expansion joint details: (a) liquid-retaining structures, (b) non-liquid-retaining structures. (From ACI Committee 224, *Joints in Concrete Construction*, ACI 224.3R-95, American Concrete Institute, Farmington Hills, MI, 1995, pp. 1–44; ACI Committee 302, *Guide for Concrete Floor and Slab Construction*, ACI 302.1R-89, American Concrete Institute, Farmington Hills, MI, 1989.)

than 1 in. for the first 20 ft of height and 1/2 in. for each additional 10 ft of height. The details of the joint should permit a doubling of the joint opening as a minimum when subjected to the seismic wave (Fintel, 1974). Because a seismic joint as a separation joint is normally wider than 2 in. (50 mm), it has to be adequately and aesthetically covered. Figure 17.7 provides suggested configurations for the plate closure at the floor and at the wall–slab separation.

17.5 Joints in Slabs on Grade and Pavements

17.5.1 Slabs on Grade

Slab movements are the result of four actions: volumetric change due to drying or shrinkage, temperature changes, stresses due to applied stationary or moving loads, and slab settlement. When movement is restrained, the slab will have to crack when the tensile stress in the concrete exceeds its modulus of rupture. The ensuing cracks may appear at any time and at any location; hence, joints become necessary to ensure that cracks form at the imposed, prescribed locations. A slab on grade with the minimum initial construction cost is unreinforced and with closely spaced joints, but unreinforced concrete may not be economical over the long term and would often require a larger thickness of the slab. Yet, joint construction and maintenance usually increase costs and must be considered in the design of joint spacing. It is always important to consider the relationship between initial construction costs and recurring costs, including slab reinforcement, use of shrinkage-compensating cement in the concrete, post-tensioning, and special-use considerations of the finished slab, such as flat slabs (ACI Committee 224, 1995). Typical placement of joints in slabs on grade in a typical structure with columns is shown in Figure 17.8 and discussed in the following sections.

17.5.1.1 Contraction Joints

Contraction joints should be provided in slabs on grade to accommodate shrinkage and temperature expansion and contraction, as well as to relieve the resulting internal stresses. As discussed in ACI Committee 224 (1995), a concrete slab on grade does not dry uniformly throughout its depth because

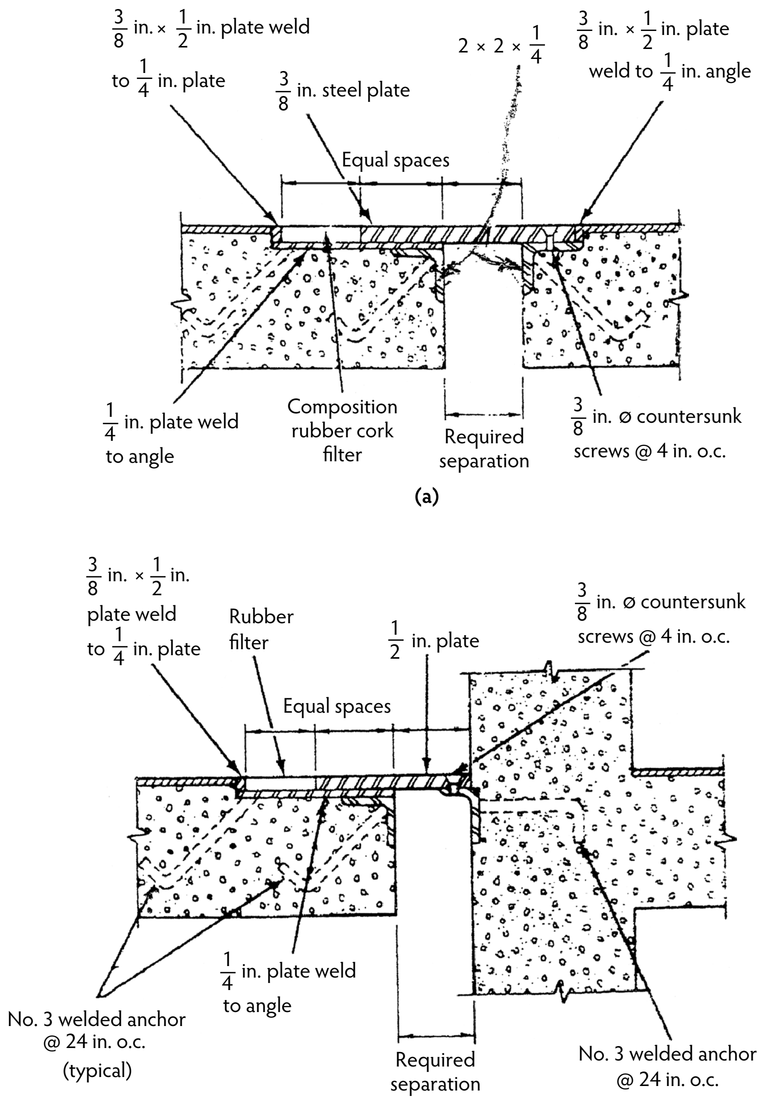

FIGURE 17.7 Seismic separation joints in concrete structures: (a) isolated floor plate closure, (b) building separation floor plate closure at the structure wall. (Adapted from Fintel, M., Ed., *Handbook of Concrete Engineering*, Van Nostrand Reinhold, New York, 1974, pp. 94–110.)

the temperature gradient is different at the slab top and bottom surfaces. The top surface of the slab dries faster than the lower surface, resulting in warping of the slab and intense curling at corners and at some joint boundaries. Use of dowelled joints, proper distribution and an adequate percentage of reinforcement, or thickening of the slab edges can reduce the level of deformation and possibly eliminate cracking in the slab on grade. Additionally, it is advisable to provide contraction joints at locations of change in subgrade slab support to reduce the possibility of cracking in those transition areas, in addition to providing contraction joints at column lines. It is recommended that joints be spaced in such a manner that the slab on grade is divided into small rectangular areas, preferably squares, but the recommended ratio of the long to short side should not exceed a value of 1.25 to 1.5. As a general guideline, the spacing of contraction joints in slabs on grade should be 24 to 36 times the slab thickness in both directions

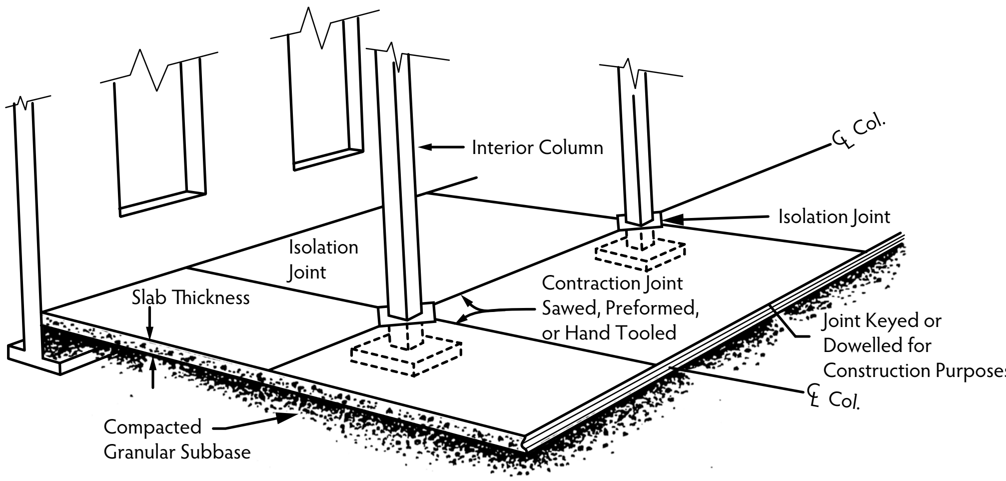

FIGURE 17.8 Location of types of joints in slabs on grade. (From ACI Committee 224, *Joints in Concrete Construction*, ACI 224.3R-95, American Concrete Institute, Farmington Hills, MI, 1995, pp. 1–44; ACI Committee 350, *Code Requirements for Environmental Engineering Concrete Structures and Commentary*, ACI 350, American Concrete Institute, Farmington Hills, MI, 2006.)

unless intermediate cracks are acceptable (ACI Committee 302, 1989). A greater spacing is permitted for low-slump concrete with aggregate size larger than 3/4 in. (20 mm).

Several types of contraction joints can be used, such as sawed joints, hand-tooled or preformed joints, keyed joints, or dowelled joints. Figure 17.2 illustrates these types of joints. Sawed joints are the most common method of making contraction joints in slabs on grade by saw-cutting the hardened concrete. Hand-tooled joints are produced by hand-tooling or by inserting plastic strips before finishing. If floor slabs are so thick that insertion of preformed strips or hand tooling becomes cumbersome, premolded inserts can be placed at the bottom of the slab. Sometimes it is preferable to use keyed joints to ensure full load transfer. In such cases, a full-depth premolded joint can be inserted in the slab on grade. This process is required in cases where movement between sections of the slab exceeds the level of movement chosen for adequate load transfer through aggregate interlock. Load transfer in keyed joints can also be accomplished through the insertion of full-depth preformed keys at the time of concrete placement so the slab will have a tongue-and-groove joint when the concrete is cast on both sides of the joint. The keyway can be formed through the use of beveled wood strips with premolded keys or the use of metal forms. Keyed contraction joints should not be used for slabs on grade less than 6 in. (150 mm) thick (ACI Committee 224, 1995).

Dowelled joints are used in heavily loaded slabs on grade with a high percentage of reinforcement for adequate load resistance and crack control requirement. Load transfer at the contraction joint is accomplished through the use of steel dowels, such as the dowel assembly shown in Figure 17.3. The dowels have to be centered at the joint and must not bond to the concrete on at least one side to enable horizontal movement. Greasing the dowels or coating them with a bond-breaker plastic will prevent them from bonding with the concrete. Table 17.5 gives recommended dowel spacing.

17.5.1.2 Expansion Joints

Expansion joints are isolation joints that allow horizontal and vertical movement between slabs and adjoining structures (e.g., walls, columns, footings) or in especially loaded areas such as heavy machinery foundations. Movement of the structural elements supported by or adjoining the slabs on grade differs from that of the slab itself because of differences in support conditions, in environmental effects, and in the way the stresses develop due to loading, particularly the rigid connections at column and wall joints. Lack of adequate isolation or separation joints in these areas of stress concentration result in cracking. The joints in their different categories separate the reinforcement, mechanical connection, or keyways

TABLE 17.5 Dowel Length and Spacing for Slabs on Grade

Slab Thickness		Dowel Diameter		Total Dowel Length[a]	
in.	mm	in.	mm	in.	mm
5	125	3/4	20	16	400
6	150	3/4	20	16	400
7	175	1	25	18	450
8	200	1	25	18	450
9	225	1-1/4	30	18	450
10	250	1-1/4	30	18	450
11	275	1-1/4	30	18	450

[a] Allowance made for joint openings and minor errors in positioning dowels.

Note: Recommended dowel spacing is 12 in. (300 mm) on-center. Dowels must be carefully aligned and supported during concreting operations. Misaligned dowels cause cracking.

Source: Data from ACI Committee 224, *Joints in Concrete Construction*, ACI 224.3R-95, American Concrete Institute, Farmington Hills, MI, 1995, pp. 1–44; ACI Committee 302, *Guide for Concrete Floor and Slab Construction*, ACI 302.1R-89, American Concrete Institute, Farmington Hills, MI, 1989.

across the entire joint and ensure that no bond interaction between adjacent segments is present. An example of a dowel bar assembly for isolation joints is shown in Figure 17.3, and a typical isolation (or, more correctly, expansion joint) is shown in Figure 17.4. The isolation material filling the joint between the slab on grade and the adjoining structural element has to be wide enough to permit both vertical and horizontal movement (ACI Committee 224, 1995; PCA, 1982). It is important to emphasize that joints have to be adequately sealed to improve joint performance. Sealing joints prevents water and deleterious materials from entering the joints and causing damage through corrosion of reinforcement or freezing, for example. ACI 302.1R (ACI Committee 302, 1989) stipulates that joints in industrial and flat floors subject to hard-wheeled traffic have to be adequately filled with a durable hard material such as epoxy to give adequate support for the joint and provide good resistance to wear and tear. The joint material should have an elongation of at least 6% and should be applied in joint locations where further movements are unlikely. It is recommended that the filling epoxy be applied from 3 to 6 months after slab placement (ACI Committee 224, 1995). In summary, it is extremely important for the subgrade to be stable and that soils such as silts and clays are removed to sufficient depths before a stabilized subgrade is placed; otherwise, failure of joints develops and accelerates with time.

17.5.1.3 Special Considerations

17.5.1.3.1 Shrinkage-Compensating Cement Concrete

Concrete made with shrinkage-compensating cement is sometimes used in large slab areas or slabs on grade with a reduced number and enlarged spacing of joints. The use of such a concrete could significantly improve the performance of these slabs by offsetting shrinkage through expansion of the concrete. Gulyas (1984) noted that the use of shrinkage-compensating cement causes greater expansion in the top half of the slab depth than in the bottom half. As a result, less curling is noticed as compared to slabs constructed of normal Portland cement concrete. This difference in shrinkage level between the top and bottom of the slab concrete section seems to be caused by differences in the restraint imposed by the subgrade on the lower surface of the slab. The reduced curling leads to better long-term performance of slabs on grade; in such cases, the additional costs incurred by the use of shrinkage-compensating cement would be justified over the long term.

17.5.1.3.2 Post-Tensioning

Post-tensioning is a technique that can eliminate cracking of slabs on grade or significantly control the extent of cracking caused by restrained drying shrinkage and temperature variations normally occurring during the initial few days after concrete placement. This technique is used for the construction of large areas of slabs without any joints—for example, 100 to 250 ft (30 to 60 m) of slab length without separation

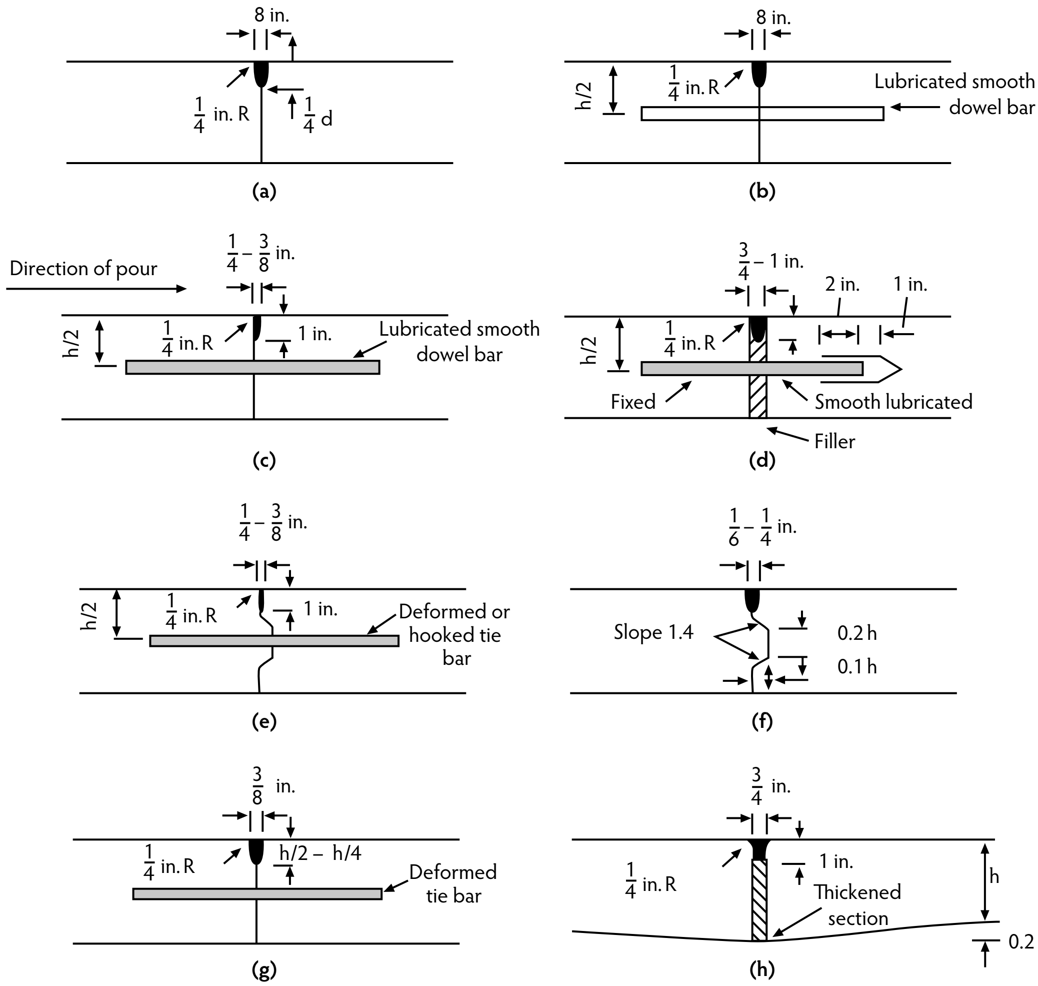

FIGURE 17.9 Various types of pavement joints. (From ACI Committee 224, *Joints in Concrete Construction*, ACI 224.3R-95, American Concrete Institute, Farmington Hills, MI, 1995, pp. 1–44.)

joints. Prestressing induces large compressive forces in the longitudinal direction and prevents any developing cracks from opening. The construction joints in such slabs on grade will open wider than slabs reinforced with conventional steel reinforcement.

17.5.2 Pavements

Pavements are usually thick rigid slabs that have to carry heavy vehicular loads. As in the case of slabs on grade, cracks in pavements are generated as a result of restrained drying shrinkage and temperature variation. They also occur primarily during the first few days after the concrete is placed, namely while the initial curing is taking place. Sometime, blow-ups can occur if the open joint is full of debris and traffic loads are present. The differential temperature gradient through the slab thickness and the restraint imposed by the subgrade on the bottom surface of the slab result in curling of the slab, particularly at the joint. The weight of the pavement slab itself can cause the slab to be subjected to tensile stresses at its lower face that are magnified by additional tensile stresses due to vehicular traffic loads. Such tensile stresses are expected to result in transverse and longitudinal cracks that generate from the lower surface of the slab in contact with the yielding subgrade, with longitudinal cracks developing from warping, curling, ambient temperature changes, and moisture loss (ACI Committee 224, 1995).

To minimize cracking in rigid pavements, it becomes necessary to use both transverse and longitudinal joints in reinforced as well as unreinforced concrete slab pavements. The joints should be designed to transfer loads between adjacent segments and to systematically open and close. Also, all joints have to be properly sealed, as for slabs on grade, to prevent liquids and deleterious materials from entering the joint and corroding the reinforcement; trapped water could freeze in cold temperatures and result in continuous deterioration of the pavement and its ultimate failure. It is important for contraction and expansion (isolation) joints to be well designed so they can help maintain the integrity of the pavement. Figure 17.9 gives recommended pavement joints (ACI Committee 224, 2005). As in the case of slabs on grade, contraction joints have to be provided, as shown in Figure 17.9, with a groove of at least 1/4 to 1/3 the slab thickness. For cut grooves, concrete should be sawed as soon as possible after hardening. The load transfer in Figure 17.9a is accomplished by aggregate interlock of the cracked lower portion of the slab. When dowel bars are used for joint interlock, they are usually spaced at 12 in. (300 mm) mid-depth in the pavement slab, as shown in Figure 17.9c. The dowels can be coated with paraffin-based lubricant, asphalt emulsions, form oil, or grease to prevent bonding of the concrete. Expansion joints, on the other hand, are constructed with a clean break as a total separation through the entire depth of the pavement slab (Figure 17.9d). Sometimes, the slab is thickened at the expansion joint as shown in Figure 17.9h. When keyed construction joints are used (Figures 17.9e,f), it is recommended that be placed in alternative lanes. Again, it should be emphasized that all joints in pavement slabs must be sealed with appropriate filler material as described in Section 17.5.1 for slabs on grade.

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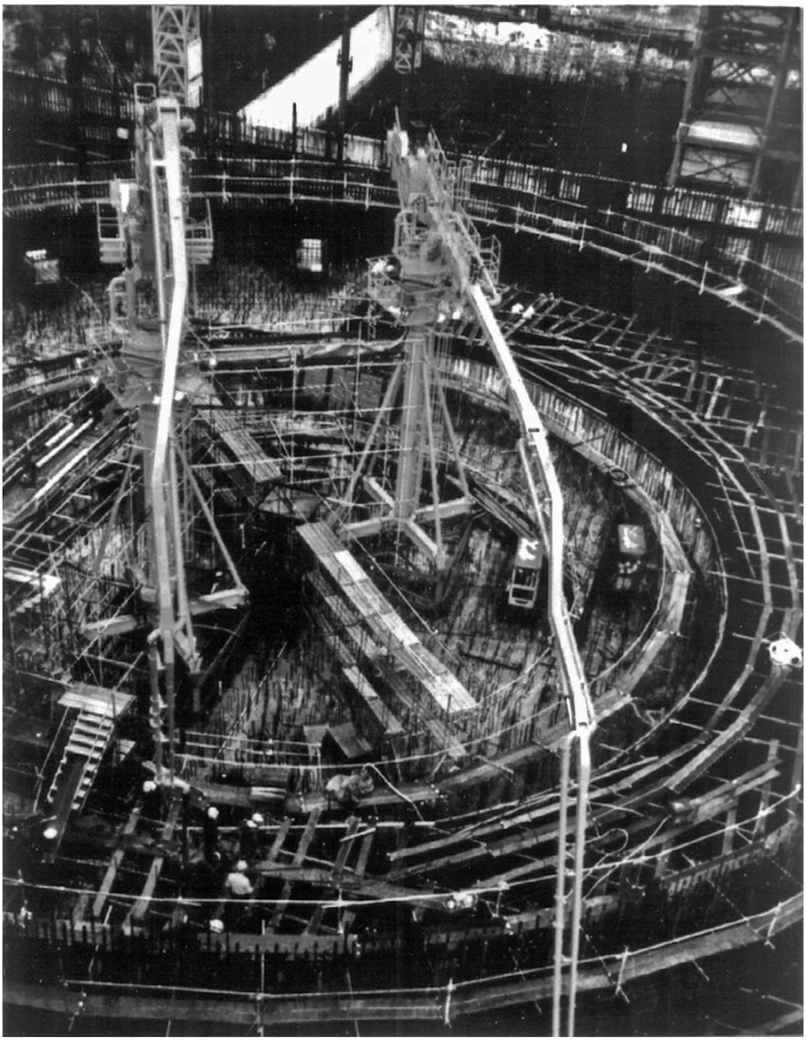

Automation in placement of concrete wall. (Photograph courtesy of Portland Cement Association, Skokie, IL.)