

ACI 224.3R-95
(Reapproved 2013)

Joints in Concrete Construction

Reported by ACI Committee 224



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Joins in Concrete Construction

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www.concrete.org
ISBN 978-087031-328-8

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Joints in Concrete Construction

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This report reviews the state of the art in design, construction, and maintenance of joints in concrete structures subjected to a wide variety of use and environmental conditions. In some cases, the option of eliminating joints is considered. Aspects of various joint sealant materials and jointing techniques are discussed. The reader is referred to ACI 504R for a more comprehensive treatment of sealant materials, and to ACI 224R for a broad discussion of the causes and control of cracking in concrete construction. Chapters in the report focus on various types of structures and structural elements with unique characteristics: buildings, bridges, slabs-on-grade, tunnel linings, canal linings, precast concrete pipe, liquid-retaining structures, walls, and mass concrete.

Keywords: bridges, buildings, canal linings, canals, **concrete construction**, construction joints, contraction joints, design, environmental engineering concrete structures, isolation joints, **joints**, parking lots, pavements, runways, slabs-on-grade, tunnel linings, tunnels, walls.

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ACI 224.3R-95 became effective August 1, 1995.
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Joints are necessary in concrete structures for a variety of reasons. Not all concrete in a given structure can be placed continuously, so there are construction joints that allow for work to be resumed after a period of time. Since concrete undergoes volume changes, principally related to shrinkage and temperature changes, it can be desirable to provide joints and thus relieve tensile or compressive stresses that would be induced in the structure. Alternately, the effect of volume changes can be considered just as other load effects are considered in building design. Various concrete structural elements are supported differently and independently, yet meet and match for functional and architectural reasons. In this case, compatibility of deformation is important, and joints may be required to isolate various members.

Many engineers view joints as artificial cracks, or as means to either avoid or control cracking in concrete structures. It is possible to create weakened planes in a structure, so

cracking occurs in a location where it may be of little importance, or have little visual impact. For these reasons, ACI Committee 224—Cracking, has developed this report as an overview of the design, construction, and maintenance of joints in various types of concrete structures, expanding on the currently limited treatment in ACI 224R. While other ACI Committees deal with specific types of structures, and joints in those structures, this is the first ACI report to synthesize information on joint practices into a single document. Committee 224 hopes that this synthesis will promote continued re-evaluation of recommendations for location and spacing of joints, and the development of further rational approaches.

Diverse and sometimes conflicting guidelines are found for joint spacing. Table 1.1 reports various recommendations for contraction joints, and Table 1.2 provides a sampling of requirements for expansion joints. It is hoped that, by bringing the information together in this Committee Report, recommendations for joint spacing may become more rational, and possibly more uniform.

Aspects of construction and structural behavior are important when comparing the recommendations of Tables 1.1 and 1.2. These recommendations may be contrary to usual practice in some cases, but each could be correct for particular circumstances. These circumstances include, but may not be limited to: the type of concrete and placing conditions; characteristics of the structure; nature of restraint on an

Table 1.1—Contraction joint spacings

Author	Spacing
Merrill (1943)	20 ft (6 m) for walls with frequent openings, 25 ft (7.5 m) in solid walls.
Fintel (1974)	15 to 20 ft (4.5 to 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 to 30 ft (6 to 9 m) for walls
PCA (1982)	20 to 25 ft (6 to 7.5 m) for walls depending on number of openings.
ACI 302.1R	15 to 20 ft (4.5 to 6 m) recommended until 302.1R-89, then changed to 24 to 36 times slab thickness.
ACI 350R-83	30 ft (9 m) in sanitary structures.
ACI 350R	Joint spacing varies with amount and grade of shrinkage and temperature reinforcement.
ACI 224R-92	One to three times the height of the wall in solid walls.

Table 1.2—Expansion joint spacings

Author	Spacing
Lewerenz (1907)	75 ft (23 m) for walls.
Hunter (1953)	80 ft (25 m) for walls and insulated roofs, 30 to 40 ft (9 to 12 m) for uninsulated roofs.
Billig (1960)	100 ft (30 m) maximum building length without joints. Recommends joint placement at abrupt changes in plan and at changes in building height to account for potential stress concentrations.
Wood (1981)	100 to 120 ft (30 to 35 m) for walls.
Indian Standards Institution (1964)	45 m ($\approx$ 148 ft) maximum building length between joints.
PCA (1982)	200 ft (60 m) maximum building length without joints.
ACI 350R-83	120 ft (36 m) in sanitary structures partially filled with liquid (closer spacings required when no liquid present).

individual member; and the type and magnitude of environmental and service loads on the member.

1.2—Joint terminology

The lack of consistent terminology for joints has caused problems and misunderstandings that plague the construction world. In 1979 the American Concrete Institute Technical Activities Committee (TAC) adopted a consistent terminology on joints for use in reviewing ACI documents:

Joints will be designated by a terminology based on the following characteristics: resistance, configuration, formation, location, type of structure, and function.

Characteristics in each category include, but are not limited to the following:

Resistance: Tied or reinforced, doweled, nondoweled, plain.

Configuration: Butt, lap, tongue, and groove.

Formation: Sawed, hand-formed, tooled, grooved, insert-formed.

Location: Transverse, longitudinal, vertical, horizontal.

Type of Structure: Bridge, pavement, slab-on-grade building.

Function: Construction, contraction, expansion, isolation, hinge.

Example: Tied, tongue and groove, hand-tooled, longitudinal pavement construction joint.

The familiar term, “**control joint**,” is not included in this list of joint terminology, since it does not have a unique and universal meaning. Many people involved with construction have used the term to indicate a joint provided to “control” cracking due to volume change effects, especially shrinkage. However, improperly detailed and constructed “control” joints may not function properly, and the concrete can crack adjacent to the presumed joint. In many cases a “control joint” is really nothing more than rustication. These joints are really trying to control cracking due to shrinkage and thermal contraction. A properly detailed contraction joint is needed.

An additional problem with joint nomenclature concerns “isolation” and “expansion” joints. An isolation joint isolates the movement between members. That is, there is no steel or dowels crossing the joint. An expansion joint, by comparison, is usually doweled such that movement can be accommodated in one direction, but there is shear transfer in the other directions. Many people describe structural joints without any restraint as expansion joints.

1.3—Movement and restraint in concrete structures

Restrained movement is a major cause of cracking in concrete structures. Internal or external restraint can develop tensile stresses in a concrete member, and the tensile strength or strain capacity can be exceeded. Restrained movement of concrete structures includes the effects of settlement; compatibility of deflections and rotations where members meet, and volume changes.

Volume changes typically result from shrinkage as hardened concrete dries, and from expansion or contraction due to temperature changes.

A detailed discussion of volume change mechanisms is beyond the scope of this report. Evaluate specific cases to determine the individual contributions of temperature change and loss of moisture to the environment. The potential volume change is considered in terms of the restraint that results from geometry, as well as reinforcement.

1.3.1 Shrinkage volume changes—While many types of shrinkage are important and may cause cracking in concrete structures, drying shrinkage of hardened concrete is of special concern. Drying shrinkage is a complicated function of parameters related to the nature of the cement paste, plain concrete, member, or structural geometry and environment. For example, building slabs shrink about 500×10^{-6} , yet shrinkage of an exposed slab on grade may be less than 100×10^{-6} . A portion of drying shrinkage also may be reversible. A large number of empirical equations have been proposed to predict shrinkage. ACI 209R provides information on predicting shrinkage of concrete structures. If shrinkage-compensating concrete is used, it is necessary for the structural element to expand against elastic restraint from internal reinforcement before it dries and shrinks (ACI 224R).

1.3.2 Expansion volume changes—Where a shrinkage-compensating concrete is used, additional consideration of the expansion that will occur during the early life of the concrete is necessary. Unless a shrinkage-compensating concrete is allowed to expand, its effectiveness in compensating for shrinkage will be reduced.

1.3.3 Thermal volume changes—The effects of thermal volume changes can be important during construction and in service as the concrete responds to temperature changes. Two important factors to consider are the nature of the temperature change and the fundamental material properties of concrete.

The coefficient of thermal expansion for plain concrete α describes the ability of a material to expand or contract as temperatures change. For concrete, α depends on the mixture proportions and the type of aggregate used. Aggregate properties dominate the behavior, and the coefficient of linear expansion can be predicted. Mindess and Young (1981) discuss the variation of the expansion coefficient in further detail. Ideally, the coefficient of thermal expansion could be computed for the concrete in a particular structure. This is seldom done unless justified by unusual material properties or a structure of special significance. For concrete, the coefficient of thermal expansion α can be reasonably assumed to be $6 \times 10^{-6}/\text{F}$ ($11 \times 10^{-6}/\text{C}$).

During construction, the heat generated by hydrating portland cement may raise the temperature of a concrete mass higher than will be experienced in service. Contraction of the concrete as the temperature decreases while the material is relatively weak may lead to cracking. ACI 224R, ACI 207.1R, and ACI 207.2R discuss control of cracking for ordinary and mass concrete due to temperature effects during construction.

In service, thermal effects are related to long-term and nearly instantaneous temperature differentials. Long-term

shrinkage has the same sense as the effect of temperature drops, so overall contraction is likely to be the most significant volume change effect for many structures.

For some components in a structure, the longer term effects are related to the difference of hottest summer and lowest winter temperature. The structure also may respond to the difference between temperature extremes and a typical temperature during construction. In most cases the larger temperature difference is most important.

Daily variations in temperature are important, too. Distortions will occur from night to day, or as sunlight heats portions of the structure differently. These distortions may be very complicated, introducing length changes, as well as curvatures into portions of the structure. An example is the effect of “sun camber” in parking structures where the roof deck surface becomes as much as 20 to 40 F (10 to 20 C) hotter than the supporting girder. This effect causes shears and moments in continuous framing.

1.4—Objectives and scope

This report reviews joint practices in concrete structures subjected to a wide variety of uses and environmental conditions. Design, construction, and maintenance of joints are discussed, and in some cases, the option of eliminating joints is considered. Chapter 2 summarizes aspects of various sealant materials and jointing techniques. However, the reader is referred to ACI 504R for a more comprehensive treatment. Chapters 3-10 focus on various types of structures and structural elements with unique characteristics: buildings, bridges, slabs-on-grade, tunnel linings, canal linings, precast concrete pipe, liquid-retaining structures, walls, and mass concrete. Many readers of this report will not be interested in all types of construction discussed in Chapters 3-10. These readers may wish to first study Chapter 2, then focus on a specific type of structure.

While not all types of concrete construction are addressed specifically in this report, the Committee feels that this broad selection of types of structures can provide guidance in other cases as well. Additional structural forms may be addressed in future versions of this report.

ACI 224R provides additional detailed discussion of both the causes of cracking and control of cracking through design and construction practice.

CHAPTER 2—SEALANT MATERIALS AND JOINTING TECHNIQUES

2.1—Introduction

A thorough discussion of joint sealant materials is found in ACI 504R. This Chapter summarizes the pertinent facts about joint sealants. The reader is cautioned that this Chapter is only an introduction.

2.2—Required properties of joint sealants

For satisfactory behavior in open surface joints the sealant should:

- Be relatively impermeable
- Deform to accommodate the movement and rate of movement occurring at the joint

- Sufficiently recover its original properties and shape after cyclical deformations
- Remain in contact with the joint faces. The sealant must bond to the joint face and not fail in adhesion, nor peel at corners or other local areas of stress concentration. An exception is preformed sealants that exert a force against the joint face
- Not rupture internally (fail in cohesion)
- Not flow because of gravity (or fluid pressure)
- Not soften to an unacceptable consistency at higher service temperatures
- Not harden or become unacceptably brittle at lower service temperatures
- Not be adversely affected by aging, weathering, or other aspects of service conditions for the expected service life under the range of temperatures and other environmental conditions that occur
- Be replaceable at the end of a reasonable service life, if it fails during the life of the structure

Seals buried in joints, such as waterstops and gaskets, require generally similar properties. The method of installation may, however, require the seal to be in a different form and, because replacement is usually impossible, exceptional durability is required.

In addition, depending on the specific service conditions, the sealant may be required to resist one or more of the following: intrusion of foreign material, wear, indentation, pickup (tendency to be drawn out of joint, as by a passing tire), and attack by chemicals present. Additional requirements may be that the sealant has a specific color, resists changes in color, and is nonstaining.

Sealant should not deteriorate when stored for a reasonable time before use. It also should be reasonably easy to handle and install, and be free of substances harmful to the user, the concrete, or other material that may come in contact.

2.3—Commercially available materials

No material has properties perfect for all applications. Sealant materials are selected from a large range of materials that offer a sufficient number of the required properties at a reasonable cost.

Oil-based mastics, bituminous compounds, and metallic materials were the only types of sealants available for many years. However, for many applications these traditional materials do not behave well. In recent years there has been active development of many types of “elastomeric” sealants whose behavior is largely elastic rather than plastic. These newer materials are flexible, rather than stiff, at normal service temperatures. Elastomeric materials are available as field-molded and preformed sealants. Though initially more expensive, they usually have a longer service life. They can seal joints where considerable movements occur and that could not possibly be sealed by traditional materials. This latitude in properties has opened new engineering and architectural possibilities to the designer of concrete structures.

No attempt has been made here to list or discuss the tribute of every available sealant. Discussion is limited to those

features considered important to the designer, specifier, and user, so that claims made for various materials can be evaluated and a suitable choice made for the particular application.

2.4—Field-molded sealants

2.4.1 Mastics—Mastics are composed of a viscous liquid rendered immobile by the addition of fibers and fillers. They do not usually harden, set, or cure after application, but instead form a skin on the surface exposed to the atmosphere. The vehicle in mastics may include drying or nondrying oils (including oleoresinous compounds), polybutenes, polyisobutylenes, low-melting point asphalts, or combinations of these materials. With any of these, a wide variety of fillers is used, including fibrous talc or finely divided calcareous or siliceous materials. The functional extension-compression range of these materials is about ± 3 percent.

Mastics are used in buildings for general caulking and glazing where very small joint movements are anticipated and economy in first cost outweighs that of maintenance or replacement. With time, most mastics tend to harden in increasing depth as oxidation and loss of volatiles proceeds, thus reducing their serviceability. Polybutene and polyisobutylene mastics have a somewhat longer service life than do the other mastics.

2.4.2 Thermoplastics, hot applied—These are materials that become soft on heating and harden on cooling, usually without chemical change. They are generally black and include asphalts, rubber asphalts, pitches, coal tars, and rubber tars. They are usable over an extension-compression range of ± 5 percent. This limit is directly influenced by service temperatures and aging characteristics of specific materials. Though initially cheaper than some of the other sealants, their service life is relatively short. They tend to lose elasticity and plasticity with age, to accept rather than reject foreign materials, and to extrude from joints that close tightly or that have been overfilled. Overheating during the melting process adversely affects the properties of compounds containing rubber. Those with an asphalt base are softened by hydrocarbons, such as oil, gasoline, or jet fuel spillage. Tar-based materials are fuel and oil resistant and these are preferred for service stations, refueling and vehicle parking areas, airfield aprons, and holding pads. However, noxious fumes are given off during their placement.

Use of this class of sealants is restricted to horizontal joints, since they would run out of vertical joints when installed hot, or subsequently in warm weather. They have been widely used in pavement joints, but they are being replaced by chemically curing or thermosetting field-molded sealants or compression seals. They are also used in building roofs, particularly around openings, and in liquid-retaining structures.

2.4.3 Thermoplastics, cold-applied, solvent, or emulsion type—These materials are set either by the release of solvents or the breaking of emulsions on exposure to air. Sometimes they are heated up to 120 F (50 C) to simplify application, but they are usually handled at ambient temperature. Release of solvent or water can cause shrinkage and increased hardness with a resulting reduction in the permis-

sible joint movement and in serviceability. Products in this category include acrylic, vinyl, and modified butyl types that are available in a variety of colors. Their maximum extension-compression range is ± 7 percent. However, heat softening and cold hardening may reduce this figure.

These materials are restricted in use to joints with small movements. Acrylics and vinyls are used in buildings, mainly for caulking and glazing. Rubber asphalts are used in canal linings, tanks, and as crack fillers.

2.4.4 Thermosetting, chemical curing—Sealants in this class are either one- or two-component systems. They are applied in liquid form and cure by chemical reaction to a solid state. These include polysulfide, silicone, urethane, and epoxy-based materials. The properties that make them suitable as sealants for a wide range of uses are resistance to weathering and ozone, flexibility and resilience at both high and low temperatures, and inertness to a wide range of chemicals, including, for some, solvents and fuels. In addition, the abrasion and indentation resistance of urethane sealants is above average. Thermosetting, chemically curing sealants have an extension-compression range of up to ± 25 percent, depending on the particular sealant, at temperatures from -40 to $+180$ F (-40 to $+82$ C). Silicone sealants remain flexible over an even wider temperature range. They have a wide range of uses in buildings and containers for both vertical and horizontal joints, and also in pavements. Though initially more expensive, thermosetting, chemically-curing sealants can stand greater movements than other field-molded sealants and generally have a much longer service life.

2.4.5 Thermosetting, solvent release—Another class of thermosetting sealants cure by the release of solvent. Chlorosulfonated polyethylene and certain butyl and neoprene materials are included in this class. Their characteristics generally resemble those of thermoplastic solvent release materials. They are, however, less sensitive to variations in temperature once they have “setup” on exposure to the atmosphere. Their maximum extension-compression range does not exceed ± 7 percent. They are used mainly as sealants for caulking and joints in buildings, where both horizontal and vertical joints have small movements. Their cost is somewhat less than that of other elastomeric sealants, and their service life is likely to be satisfactory.

2.4.6 Rigid—Where special properties are required and movement is negligible, certain rigid materials can be used as field-molded sealants for joints and cracks. These include lead (wool or molten), sulfur, modified epoxy resins, and polymer-concrete type mortars.

2.5—Accessory materials

2.5.1 Primers—Where primers are required, a suitable proprietary material compatible with the sealant is usually supplied along with it. For hot poured field-molded sealants, these are usually high viscosity bitumens or tars cut back with solvent. To overcome damp surfaces, wetting agents may be included in primer formulations, or materials may be used that wet such surfaces preferentially, such as polyamide-cured coal tar-epoxies. For decorative finishes, shellac can be used.

2.5.2 Bond breakers—Many backup materials do not adhere to sealants and thus, where these are used, no separate bond breaker is needed. Polyethylene tape, coated papers, and metal foils are often used where a separate bond breaker is needed.

2.5.3 Backup materials—These materials serve a variety of purposes during application of the sealant and in service. Backup materials limit the depth of the sealant; support it against sagging, indentation, and displacement by traffic or fluid pressure; and simplify tooling. They may also serve as a bond breaker to prevent the sealant from bonding to the back of the joint. The backup material should preferably be compressible so that the sealant is not forced out as the joint closes, and it should recover as the joint opens. Care is required to select the correct width and shape of material, so that after installation it is compressed to about 50 percent of its original width. Stretching, twisting, or braiding of tube or rod stock should be avoided. Backup materials and fillers containing bitumen or volatile materials should not be used with thermosetting chemical curing field-molded sealants. They may migrate to, or be absorbed at joint interfaces, and impair adhesion. In selecting a backup material to ensure compatibility, it is advisable to follow the recommendations of the sealant manufacturer.

Preformed backup materials are used for supporting and controlling the depth of field-molded sealants.

2.6—Preformed sealants

Traditionally, preformed sealants have been subdivided into two classes; rigid and flexible. Most rigid preformed sealants are metallic; examples are metal water stops and flashings. Flexible sealants are usually made from natural or synthetic rubbers, polyvinyl chloride, and like materials, and are used for waterstops, gaskets, and miscellaneous sealing purposes. Preformed equivalents of certain materials, e.g., rubber asphalts, usually categorized as field molded, are available as a convenience in handling and installation. Compression seals should be included with the flexible group of preformed sealants. However, their function is different. The compartmentalized neoprene type can be used in most joint sealant applications as an alternative to field-molded sealants. They are treated separately in this report.

2.6.1 Rigid waterstops and miscellaneous seals—Rigid waterstops are made of steel, copper, and occasionally of lead. Steel waterstops are primarily used in dams and other heavy construction projects. Ordinary steel may require additional protection against corrosion. Stainless steels are used in dam construction to overcome corrosion problems. Steel waterstops are low in carbon and stabilized with columbium or titanium to simplify welding and retain corrosion resistance after welding. Annealing is required for improved flexibility, but the stiffness of steel waterstops may lead to cracking in the adjacent concrete.

Copper waterstops are used in dams and general construction; they are highly resistant to corrosion, but require careful handling to avoid damage. For this reason, in addition to considerations of higher cost, flexible waterstops are often used instead. Copper is also used for flashings.

At one time lead was used for waterstops, flashings, or protection in industrial floor joints. Its use is now very limited. Bronze strips find wide application in dividing, rather than sealing, terrazzo and other floor toppings into smaller panels.

2.6.2 Flexible waterstops—The types of materials suitable and in use as flexible waterstops are butyl, neoprene, and natural rubbers. These have satisfactory extensibility and resistance to water or chemicals and may be formulated for recovery and fatigue resistance. Polyvinyl chloride (PVC) compounds are, however, probably now the most widely used. This material is not quite as elastic as the rubbers, recovers more slowly from deformation, and is susceptible to oils. However, grades with sufficient flexibility (especially important at low temperatures) can be formulated. PVC has the advantage of being thermoplastic and it can be spliced easily on the job. Special configurations can also be made for joint intersections.

Flexible waterstops are widely used as the primary sealing system in dams, tanks, monolithic pipe lines, flood walls, swimming pools, etc. They may be used in structures that either retain or exclude water. For some applications in either precast or cast-in-place construction, a flexible waterstop containing sodium bentonite may also act as an internal joint sealant. Bentonite swells when contacted by water, and forms a gel, blocking infiltration through the structure.

2.6.3 Gaskets and miscellaneous seals—Gaskets and tapes are widely used as sealants at glazing and frames. They are also used around window and other openings in buildings, and at joints between metal or precast concrete panels in curtain walls. Gaskets are also used extensively at joints between precast pipes and where mechanical joints are needed in service lines. The sealing action is obtained either because the sealant is compressed between the joint faces (gaskets) or because the surface of the sealant, such as of polyisobutylene, is pressure sensitive and thus adheres.

2.7—Compression seals

These are preformed compartmentalized or cellular elastomeric devices that function as sealants when in compression between the joint faces.

2.7.1 Compartmentalized—Neoprene (chloroprene) or EPDM (ethylene propylene diene monomer) extruded to the required configuration is now used for most compression seals. For effective sealing, sufficient contact pressure is maintained at the joint face. This requires that the seal is always compressed to some degree. For this to occur, good resistance to compression set is required (that is, the material recovers sufficiently when released). In addition, the elastomer should be crystallization-resistant at low temperatures (the resultant stiffening may make the seal temporarily ineffective though recovery will occur on warming). If during the manufacturing process the elastomer is not fully cured, the interior webs may adhere together during service (often permanently) when the seal is compressed.

To simplify installation of compression seals, liquid lubricants are used. For machine installation, oils are used to make the lubricant thixotropic are necessary. Special lubricant

adhesives that both prime and bond have been formulated for use where improved seal-to-joint face contact is required.

Neoprene compression seals are satisfactory for a wide range of temperatures in most applications.

Individual seals should remain compressed at least 15 percent of the original width at the widest opening. The allowable movement is about 40 percent of the uncompressed seal width.

Compression seals are manufactured in widths ranging from 1/2 to 6 in. (12 to 150 mm); therefore, they are excellent for use in both expansion and contraction joints with anticipated movements up to 3 in. (75 mm).

2.7.2 Impregnated flexible foam—Another type of compression seal material is polybutylene-impregnated foam (usually a flexible open cell polyurethane). This material has found limited application in structures such as buildings and bridges. However, its recovery at low temperature is too slow to follow joint movements. Also, when highly compressed, the impregnant exudes and stains the concrete. This generally limits application to joints where less than ± 5 percent extension-compression occurs at low temperature or ± 20 percent where the temperature is above 50 F (10 C). The material often is bonded to the joint face.

2.8—Jointing practice

Four primary methods are available for creating joints in concrete surfaces: forming, tooling, sawing, and placement of joint formers.

2.8.1 Formed joints—These are found at construction joints in concrete slabs and walls. Tongue and groove joints can be made with preformed metal or plastic strips, or built to job requirements. These strips can serve as a screed point. They need to be fastened securely so they do not become dislodged during concrete placement and consolidation.

Prefabricated circular forms are available for use at column isolation joints. They are one-piece elements that latch together in the field, and are left in place. This allows placement of concrete inside the isolation blockout when the slab concrete is placed, if desired.

2.8.2 Tooled joints—Contraction joints can be tooled into a concrete surface during finishing operations. A groove intended to cause a weakened plane and to control the location of cracking should be at least 1/4 the thickness of the concrete. Often, tooled joints are of insufficient depth to function properly. A joint about 1/2 to 3/4 in. (10 to 15 mm) deep is nothing more than rustication. In concrete flatwork, cracks may occur within such a groove, but they are also quite likely to occur at adjacent locations or wander across the groove. Grooving tools with blades of 1-1/2 to 2 in. (40 to 50 mm) deep are available.

At a tooled contraction joint, the reinforcement in the concrete element should be reduced to at least one-half the steel area or discontinued altogether. As the distance between tooled contraction joints increases, the volume of steel reinforcement should be increased to control tension stresses that are developed.

2.8.3 Sawed joints—Use of sawed joints reduces labor during the finishing process. Labor and power equipment are required within a short period of time after the concrete has

hardened. The most favorable time for sawing joints is when the concrete temperature (raised because of heat of hydration) is greatest; this may often be outside of normal working hours. In any event, joints should be sawed as soon as practical. The concrete should have hardened enough not to ravel during cutting. If there is a delay in cutting the slab, and a significant amount of shrinkage has already occurred, a crack may jump ahead of the saw as tensile stresses accumulate and reach a rupture level. As with tooled joints, saw-cut grooves at least 1/4 of the depth of the member are recommended to create a functional plane of weakness.

A variety of sawing techniques and equipment is available. Blades may be diamond-studded, or made of consumable, abrasive material. If abrasive blades are used it is important to set a limit on the wear used to determine when the blade will be replaced. If this is not done, the depth of cut will be variable, and may be insufficient to force cracking within the cut. The resulting shallow cut is ineffective as a contraction joint, just like the shallow tooled joint. Cutting may be dry, or wet, with water used to cool the blade. Equipment may be powered by air, a self-contained gasoline engine, or an electric motor. A variety of special floor-cutting saws and other frames and rollers are available, depending on the application. Air-powered saws are lighter and lessen fatigue where workers hold them off the ground. Wet cutting prolongs blade life but produces a slurry and may be unsafe with electrical equipment. Diamond blades are more expensive than abrasive blades, but can be cost-effective on large projects when considering labor time lost in changing blades.

A final drawback to the use of sawed joints is equipment clearance. In sawing a concrete slab, it is impossible with most equipment to bring the saw cut to the edge, say, where a wall bounds the slab. Where the kerf terminates 2 to 3 in. (50 to 75 mm) from the wall, an irregular crack will form in the unsawed concrete as shrinkage occurs. The depth of cutting can be increased at a wall to improve the behavior of the weakened plane at the slab edge.

2.8.4 Joint formers—Joint formers can be placed in the fresh concrete during placing and finishing operations. Joint formers can be used to create expansion or contraction joints. Expansion joints generally have a removable cap over expansion joint material. After the concrete has hardened, the cap is removed and the void space caulked and sealed. Joint formers may be rigid or flexible. One flexible version has a strip-off cap of the same expansion material and is useful for isolation joints and joints curved in plane. Contraction joints are made by forming a weakened plane in the concrete with a rigid plastic strip. These are generally T-shaped elements that are inserted into the fresh concrete, often with the use of a cutter bar. After the contraction joint former is inserted to the proper depth, the top or cap is pulled away before final bullfloating or troweling. If a rounded edge is desired, an edging tool can be used.

CHAPTER 3—BUILDINGS

3.1—Introduction

Volume changes caused by changes in humidity and temperature should be accounted for in the design of reinforced

concrete buildings. The magnitude of the forces developed and the amount of movement caused by these volume changes are directly related to building length. Contraction and expansion joints limit the magnitude of forces and movements and cracking induced by moisture or temperature change by dividing buildings into individual segments. Joints can be planes of weakness to control the location of cracks (contraction joints), or lines of separation between segments (isolation or expansion joints).

At present, there is no universally accepted design approach to accommodate building movements caused by temperature or moisture changes. Many designers use “rules of thumb” that set limits on the maximum length between building joints.

Although widely used, rules of thumb have the drawback that they do not account for the many variables that control volume changes in reinforced concrete buildings. These include variables that influence the amount of thermally induced movement, including the percentage of reinforcement; the restraint provided at the foundation; the geometry of the structure; the magnitude of intermediate cracks; and provisions for insulation, cooling, and heating.

In addition to these variables, the amount of movement in a building is influenced by materials and construction practices. These include the type of aggregate, cement, mix proportions, admixtures, humidity, construction sequence, and curing procedures. While these variables can be addressed quantitatively, their consideration is usually beyond the scope of a typical design sequence and will not be considered here. Many of these parameters are addressed by Mann (1970).

The purpose of this chapter is to provide guidance for the placement of construction, contraction, isolation, and expansion joints in reinforced concrete buildings. Joints in slabs on grade within the buildings are covered in Chapter 5. Additional information on joints in buildings is available in an annotated bibliography by Gray and Darwin (1984), and reports by PCA (1982) and Pfeiffer and Darwin (1987).

Once joint locations are selected, the joint should be constructed so that it will act as intended. The weakened section at a contraction joint may be formed or sawed, either with no reinforcement or a portion of the total reinforcement passing through the joint. The expansion or isolation joint is a discontinuity in both reinforcement and concrete; therefore, an expansion joint is effective for both shrinkage and temperature variations. Both joints can be used as construction joints, as described in the following section.

3.2—Construction joints

For many structures, it is impractical to place concrete in a continuous operation. Construction joints are needed to accommodate the construction sequence for placing the concrete. The amount of concrete that can be placed at one time is governed by batching and mixing capacity, crew size, and the amount of time available. Correctly located and properly executed construction joints provide limits for successive concrete placements, without adversely affecting the structure.

For monolithic concrete, a good construction joint might be a bonded interface that provides a watertight surface, and allows for flexural and shear continuity through the interface. Without this continuity, a weakened region results that may serve as a contraction or expansion joint. A contraction joint is formed by creating a plane of weakness. Some, or all, of the reinforcement may be terminated on either side of the plane. Some contraction joints, termed “partial contraction joints,” allow a portion of the steel to pass through the joint. These joints, however, are used primarily in water-retaining structures. An expansion joint is formed by leaving a gap in the structure of sufficient width to remain open under extreme high temperature conditions. If possible, construction joints should coincide with contraction, isolation, or expansion joints. The balance of this section is devoted to construction joints in regions of monolithic concrete. Additional considerations for contraction, isolation, or expansion joints are discussed in the sections that follow.

3.2.1 Joint construction—To achieve a well-bonded watertight interface, a few conditions should be met before the placement of fresh concrete. The hardened concrete is usually specified to be clean and free of laitance (ACI 311.1R). If only a few hours elapse between successive placements, a visual check is needed to be sure that loose particles, dirt, and laitance are removed. The new concrete will be adequately bonded to the hardened green concrete, provided that the new concrete is vibrated thoroughly.

Older joints need additional surface preparation. Cleaning by an air-water jet or wire brooming can be done when the concrete is still soft enough that laitance can be removed, but hard enough to prevent aggregate from loosening. Concrete that has set should be prepared using a wet sand blast or ultra-high pressure water jet (ACI 311.1R).

ACI 318 states that existing concrete should be moistened thoroughly before placement of fresh concrete. Concrete that has been placed recently will not require additional water, but concrete that has dried out may require saturation for a day or more. Pools of water should not be left standing on the wetted surface at the time of placement; the surface should just be damp. Free surface water will increase the water-cement ratio of new concrete at the interface and weaken the bond strength. Other methods may also be useful for preparing a construction joint for new concrete.

Form construction plays an important role in the quality of a joint. It is essential to minimize the leakage of grout from under bulkheads (Hunter 1953). If the placement is deeper than 6 in. (150 mm), the possibility of leakage increases due to the greater pressure head of the wet concrete. Grout that escapes under a bulkhead will form a thin wedge of material, which must be cut away before the next placement. If not removed, this wedge will not adhere to the fresh concrete, and, under load, deflection in the element will cause this joint to open.

3.2.2 Joint location—Careful consideration should be given to selecting the location of the construction joint. Construction joints should be located where they will least affect the structural integrity of the element under consideration, and be compatible with the building's appearance.

Placement of joints varies, depending on the type of element under construction and construction capacity. For this reason, beams and slabs will be addressed separately from columns and walls. When shrinkage-compensating concrete is used, joint location allows for adequate expansion to take place. Details are given in ACI 223.

3.2.2.1 Beams and slabs—Desirable locations for joints placed perpendicular to the main reinforcement are at points of minimum shear or points of contraflexure. Joints are usually located at midspan or in the middle third of the span, but locations should be verified by the engineer before placement is shown on the drawings. Where a beam intersects a girder, ACI 318 requires that the construction joint in the girder should be offset a distance equal to twice the width of the incident beam.

Horizontal construction joints in beams and girders are usually not recommended. Common practice is to place beams and girders monolithically with the slab. For beam and girder construction where the members are of considerable depth, Hunter (1953) recommends placing concrete in the beam section up to the slab soffit, then placing the slab in a separate operation. The reasoning behind this is that cracking of the interface may result because of vertical shrinkage in a deep member if the beam and slab concrete are placed monolithically. With this procedure, there is a possibility that the two surfaces will slip due to horizontal shear in the member. ACI 318 requires that adequate shear transfer be provided.

The main concern in joint placement is to provide adequate shear transfer and flexural continuity through the joint. Flexural continuity is achieved by continuing the reinforcement through the joint with sufficient length past the joint to ensure an adequate splice length for the reinforcement. Shear transfer is provided by shear friction between the old and new concrete, or dowel action in the reinforcement through the joint. Shear keys are usually undesirable (Fintel 1974), since keyways are possible locations for spalling of the concrete. The bond between the old and new concrete, and the reinforcement crossing the joint, are adequate to provide the necessary shear transfer if proper concreting procedures are followed.

3.2.2.2 Columns and walls—Although placements with a depth of 30 ft (10 m) have been made with conventional formwork, it is general practice to limit concrete placements to a height of one story. Construction joints in columns and bearing walls should be located at the undersides of floor slabs and beams. Construction joints are provided at the top of floor slabs for columns continuing to the next floor; column capitals, haunches, drop panels, and brackets should be placed monolithically with the slab. Depending on the architecture of the structure, the construction joint may be used as an architectural detail, or located to blend in without being noticeable. Quality form construction is of the highest importance in providing the visual detail required (PCA 1982).

The placement of fresh concrete on a horizontal surface can affect structural integrity of the joint. Although it is not always necessary, common practice has been to provide a bedding layer of mortar, of the same proportions as that in

the concrete, before placement of new concrete above the joint. ACI 311.1R recommends using a bedding layer of concrete with somewhat more cement, sand, and water than the design mix for the structure. Aggregate less than 3/4 in. (20 mm) can be left in the bedding layer, but larger aggregate should be removed. This mixture should be placed 4 to 6 in. (100 to 150 mm) deep and vibrated thoroughly with the regular mixture placed above.

The concrete in the columns and walls should be allowed to stand for at least two hours before placement of subsequent floors. This will help to avoid settlement cracks in slabs and beams due to vertical shrinkage of previously placed columns and walls.

The location of vertical construction joints in walls needs to be compatible with the appearance of the structure. Construction joints are often located near re-entrant corners of walls, beside columns, or other locations where they become an architectural feature of the structure. If the building architecture does not dictate joint location, construction requirements govern. These include production capacity of the crew and requirements for reuse of formwork. These criteria will usually limit the maximum horizontal length to 40 ft (12 m) between joints in most buildings (PCA 1982). Because of the critical nature of building corners, it is best to avoid vertical construction joints at or near a corner, so that the corner will be tied together adequately.

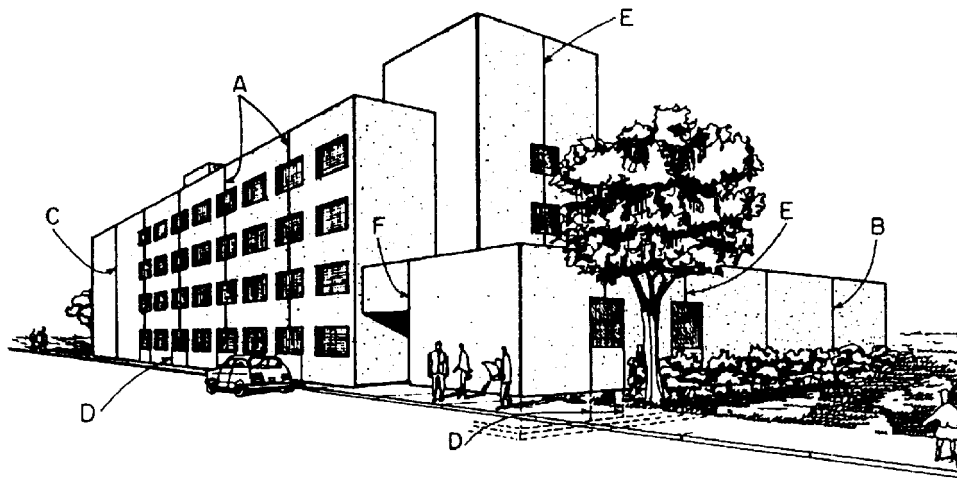
Shear transfer and bending at joints in walls and columns should be addressed in much the same way it is for beams and slabs. The reinforcement should continue through the joint, with adequate length to ensure a complete splice. If the joint is subject to lateral shear, load transfer by shear friction or dowel action is added. Section 8.5 provides additional information on construction joints in walls.

3.2.3 Summary—Construction joints are necessary in most reinforced concrete construction. Due to their critical nature, they should be located by the designer, and indicated on the design drawings to ensure adequate force transfer and aesthetic acceptability at the joint. If concrete placement is stopped for longer than the initial setting time, the joint should be treated as a construction joint. Advance input is required from the designer on any additional requirements needed to ensure the structural integrity of the element being placed.

3.3—Contraction joints

Drying shrinkage and temperature drops cause tensile stress in concrete if the material is restrained. Cracks will occur when the tensile stress reaches the tensile strength of the concrete. Because of the relatively low tensile strength of concrete [$f_t' \sim 4.0 \sqrt{f_c'}$] for normalweight concrete, f_c' and f_t' in psi (ACI 209R)], cracking is likely to occur. Contraction joints provide planes of weakness for cracks to form. With the use of architectural details, these joints can be located so that cracks will occur in less conspicuous locations. Sometimes they can be eliminated from view (Fig. 3.1). Contraction joints are used primarily in walls, addressed in this chapter, and in slabs-on-grade, discussed in Chapter 5.

For walls, restraint is provided by the building structure. For slabs-on-grade, restraint is provided by the structural forces due to volume change. The magnitude of these forces increases as the distance



- A. 20 ft (6m) apart in walls with frequent openings.
- B. Never more than 20 ft (6m) apart, walls with no openings.
- C. Within 10 to 15 ft (3 to 5m) of a corner, if possible.
- D. In line with each jamb at first-story level.
- E. Above first story at centerline of opening
- F. Jamb lines are preferable.

Fig. 3.1—Locations for contraction joints in buildings as recommended by the Portland Cement Association (1982).

between contraction joints increases. To resist these forces and minimize the amount of crack opening in the concrete, reinforcement is increased as the distance between joints and the degree of restraint increases. Increased reinforcement generally results in more, but finer, cracks.

3.3.1 Joint configuration—Contraction joints consist of a region with a reduced concrete cross section and reduced reinforcement. The concrete cross section should be reduced by a minimum of 25 percent to ensure that the section is weak enough for a crack to form. In terms of reinforcement, there are two types of contraction joints now in use, “full” and “partial” contraction joints (ACI 350R). Full contraction joints, preferred for most building construction, are constructed with a complete break in reinforcement at the joint. Reinforcement is stopped about 2 in. (50 mm) from the joint and a bond breaker placed between successive placements at construction joints. A portion of the reinforcement passes through the joint in partial contraction joints. Partial contraction joints are also used in liquid containment structures and are discussed in more detail in Section 9.2. Waterstops can be used to ensure watertightness in full and partial contraction joints.

3.3.2 Joint location—Once the decision is made to use contraction joints, the question remains: What spacing is needed to limit the amount of cracking between the joints? Table 1.1 shows recommendations for contraction joint spacing. Recommended spacings vary from 15 to 30 ft (4.6 to 9.2 m) and from one to three times the wall height. The Portland Cement Association (1982) recommends that contraction joints be placed at openings in walls, as illustrated in Fig. 3.1. Sometimes this may not be possible.

Contraction and expansion joints within a structure should pass through the entire structure in one plane (Wood 1981). If the joints are not aligned, movement at a joint may induce cracking in an unjointed portion of the structure until the crack intercepts another joint.

3.4—Isolation or expansion joints

All buildings are restrained to some degree; this restraint will induce stresses with temperature changes. Temperature-induced stresses are proportional to the temperature change. Large temperature variations can result in substantial stresses to account for in design. Small temperature changes may result in negligible stresses.

Temperature-induced stresses are the direct result of volume changes between restrained points in a structure. An estimate of the elongation or contraction caused by temperature change is obtained by multiplying the coefficient of expansion of concrete α [about $5.5 \times 10^{-6}/F$ ($9.9 \times 10^{-6}/C$)] by the length of the structure and the temperature change. A 200-ft- (61-m-) long building subjected to a temperature increase of 25 F (14 C) would elongate about 3/8 in. (10 mm) if unrestrained.

Expansion joints are used to limit member forces caused by thermally-induced volume changes. Expansion joints permit separate segments of a building to expand or contract without adversely affecting structural integrity or serviceability. Expansion joints also isolate building segments and provide relief from cracking because of contraction of the structure.

Joint width should be sufficient to prevent portions of the building on either side of the joint from coming in contact. The maximum expected temperature rise should be used in determining joint size. Joints vary in width from 1 to 6 in. (25 to 150 mm) or more, with 2 in. (50 mm) being typical. Wider joints are used to accommodate additional differential building movement that may be caused by settlement or seismic loading. Joints should pass through the entire structure above the level of the foundation. Expansion joints should be covered (Fig. 3.2) and may be empty or filled (Fig. 3.3). Filled joints are required for fire-rated structures.

Expansion joint spacing is dictated by the amount of movement that can be tolerated, and by permissible stresses

or capacity of the members. As with contraction joints, rules of thumb have been developed (Table 1.2). These rules are generally quite conservative and range from 30 to 200 ft (9 to 60 m) depending on the type of structure. In practice, spacing of expansion joints is rarely less than 100 ft (30 m). As an alternative to the rules of thumb, analytical methods may be used to calculate expansion joint spacing. This section presents two of these methods (Martin and Acosta 1970; National Academy of Sciences 1974).

Pfeiffer and Darwin (1987) used those two procedures along with a third by Varyani and Radhaji (1978) to obtain expansion joint spacings for two reinforced concrete frames. Pfeiffer and Darwin include sample calculations and a discussion of the relative merits of the methods. The methods of Martin and Acosta and the National Academy of Sciences are not rational, but are easy to use and produce realistic joint spacings. The method of Varyani and Radhaji has a rational basis, but gives unrealistic results.

3.4.1 Single-story buildings: Martin and Acosta—Martin and Acosta (1970) presented a method for calculating the maximum spacing of expansion joints in one-story frames with nearly equal spans. The method assumes that with adequate joint spacing, the load factors for gravity loads will provide an adequate margin of safety for the effects of temperature change. Martin and Acosta developed a single expression for expansion joint spacing L_j in terms of the stiffness properties of a frame and the design temperature change ΔT . This expression was developed after studying frame structures designed with ACI 318-63. The expansion joint spacing is

$$L_j = \frac{12,000}{R\Delta T} \text{ ft, } \Delta T \text{ in } ^\circ\text{F}$$

or

$$L_j = \frac{12.24}{R\Delta T} \text{ m, } \Delta T \text{ in } ^\circ\text{C} \quad (3-1)$$

In the above expressions:

$$R = 144 \frac{I_c}{h^2} \frac{(1+r)}{(1+2r)} \quad (3-2)$$

where:

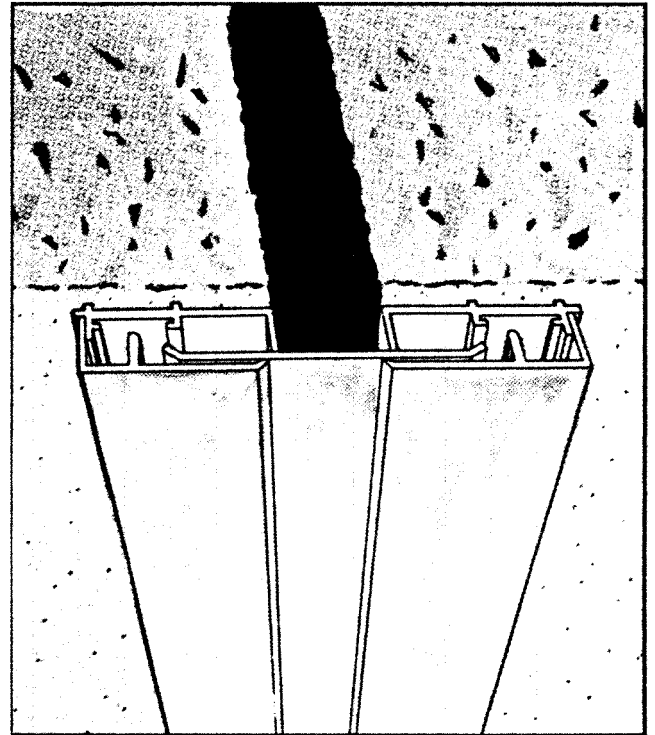


Fig. 3.2—Wall expansion joint cover (courtesy Architectural Art Mfg., Inc.).

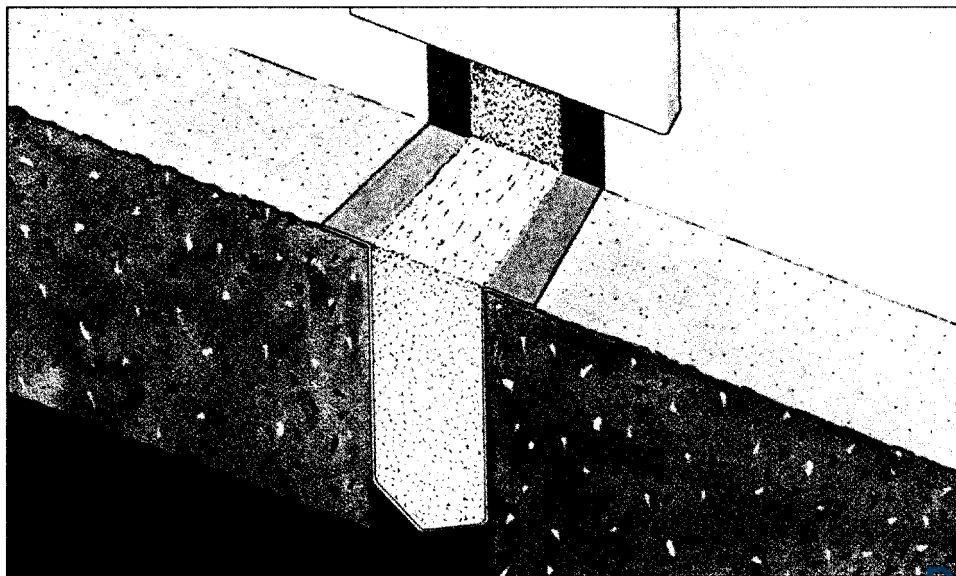


Fig. 3.3—Fire rated filled expansion joint (courtesy Architectural Art Mfg., Inc.).

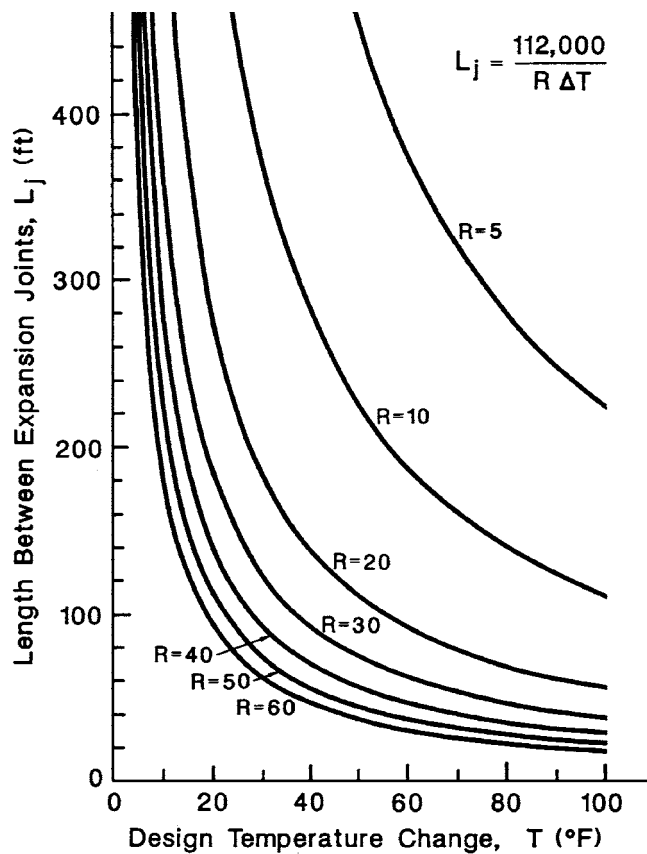


Fig. 3.4—Length between expansion joints versus design temperature change, ΔT (Martin & Acosta 1970).

r = ratio of stiffness factor of column to stiffness factor of beam = K_c/K_b ;

$$\Delta T = \frac{2}{3}(T_{max} - T_{min}) + T_s \quad (3-3)$$

- K_c = column stiffness factor = I_c/h , in.³ (m³)
 K_b = beam stiffness factor = I_b/L , in.³ (m³)
 h = column height, in. (m)
 L = beam length, in. (m)
 I_c = moment of inertia of the column, in.⁴ (m⁴)
 I_b = moment of inertia of the beam, in.⁴ (m⁴)
 T_s = 30 F (17 C)

Values for T_{max} and T_{min} can be obtained from the Environmental Data Service for a particular location (see Table 3.1 for a partial listing). The design temperature change ΔT is based on the difference between the extreme values of the normal daily maximum and minimum temperatures. An additional drop in temperature of about 30 F (17 C) is then added to account for drying shrinkage. Martin (1970) provides site-specific values of shrinkage-equivalent temperature drop. Because of the additional volume change due to drying shrinkage, joint spacing is governed by contraction instead of expansion. L_j from Eq. (3-1) is plotted in Fig. 3.4 for typical values of R .

Table 3.1—Maximum and minimum daily temperatures for selected locations (Martin and Acosta 1970)

Location	Normal daily temperature, F	
	Maximum	Minimum
Anchorage, AK	66.0	4.3
Atlanta, GA	87.0	37.1
Boston, MA	81.9	23.0
Chicago, IL	84.1	19.0
Dallas, TX	95.0	36.0
Denver, CO	88.4	14.8
Detroit, MI	84.7	19.1
Honolulu, HI	85.2	65.8
Jacksonville, FL	92.0	45.0
Los Angeles, CA	75.9	45.0
Miami, FL	89.7	57.9
Milwaukee, WI	78.9	12.8
New Orleans, LA	90.7	44.8
New York, NY	85.3	26.4
Phoenix, AZ	104.6	35.3
Pittsburgh, PA	83.3	20.7
San Francisco, CA	73.8	41.7
San Juan, PR	85.5	70.0
Seattle, WA	75.6	33.0
St. Louis, MO	89.2	23.5
Tulsa, OK	93.1	26.5

Note: C = 5/9 (F – 32).

Martin and Acosta proposed an additional criterion for L_j to limit the maximum allowable lateral deflection, δ to $h/180$ so as to avoid damage to exterior walls. The maximum lateral deflection imposed on a column is taken as

$$\delta = \frac{1}{2} \alpha L_j \Delta T \quad (3-4)$$

where α is the coefficient of linear expansion of concrete (about $5.5 \times 10^{-6}/F$ or $9.9 \times 10^{-6}/C$).

Equation (3-4) is based on the assumption that the lateral deflection of a floor system caused by a temperature change is not significantly restrained by the columns. This assumption is realistic since the in-plane stiffness of a floor system is generally much greater than the lateral stiffness of the supporting columns. Thus, the columns have little effect on δ .

This leads to the limitation on L_j of

$$L_j \leq \frac{166.7h}{\Delta T} \text{ ft; } h \text{ in inches, } \Delta T \text{ in F}$$

or

$$L_j \leq \frac{1111h}{\Delta T} \text{ m; } h \text{ in m, } \Delta T \text{ in C} \quad (3-5)$$

Martin and Acosta state that Eq. (3-1) yields conservative results (adequately low values of L_j) in these cases, but is very conservative for very rigid structures. Because of changes in ACI 318 since 1963, expansion joint spacings