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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.

CHAPTER 1—INTRODUCTION

1.1—Joints in concrete structures

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 (≈ 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 6×10^{-6}/F (11×10^{-6}/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