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Guide to Sealing Joints in Concrete Structures

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Most joints, and some cracks in concrete structures, require sealing against the adverse effects of environmental and service conditions. This report is a guide to better understanding of the properties of joint sealants and to where and how they are used in present practice.

Described and illustrated are: The functioning of joint sealants; required properties, available materials and applicable specifications for field-molded sealants and preformed sealants such as waterstops, gaskets, or compression seals; determination of joint movements, widths, and depths; outline details of joints and sealants used in general structures, fluid containers, and pavements; methods and equipment for sealant installation including preparatory work; performance of sealants; and methods of repairing defective work or maintenance resealing. Finally, improvements needed to insure better joint sealing in the future are indicated.

New developments in field-molded and preformed sealants and their use are described together with means of measuring joint movements. Appendix C provides a list of specifications and their sources.

Keywords: bridge decks: bridges (structures); buildings; compression seals; concrete construction; concrete dams; concrete panels; concrete pavements; concrete pipes; concrete slabs; concretes; construction joints; control joints; cracking (fracturing); gaskets; isolation joints; joint fillers; joint scalers; joints (junctions); linings; mastics; parting agents; precast concrete; reinforced concrete; repairs; sealers; specifications; tanks (containers); thermoplastic resins; thermosetting resins; walls.

CONTENTS

This supercedes ACI 504R-77.

CHAPTER I-GENERAL

1.1-Background

This report is an update of the committee report originally issued in 1970 and revised in 1977.[1]

Nearly every concrete structure has joints (or cracks) that must be sealed to insure its integrity and serviceability. It is a common experience that satisfactory sealing is not always achieved. The sealant used, or its poor installation, usually receives the blame, whereas often there have been deficiencies in the location or the design of the joint that would have made it impossible for any sealant to have done a good job.

1.2-Purpose

The purpose of this guide is to show that by combining the right type of sealant with proper joint design for a particular application and then carefully installing it, there is every prospect of successfully sealing the joint and keeping it sealed. This report is a guide to what can be done rather than a standard practice, because in most instances there is more than one choice available. Without specific knowledge of the structure, its design, service use, environment, and economic constraints, it is impossible to prescribe a "best joint design" or a "best sealant". The information contained in this guide is, however, based on current practices and experience judged sound by the committee and used by one or more of the many reputable organizations consulted during its compilation. It should therefore be useful in making an enlightened choice of a suitable joint sealing system and to insure that it is then properly detailed, specified, installed, and maintained.

No attempt has been made to reference the voluminous literature except for those papers necessary to an understanding of the subject background. The present state of the art of joint sealing and identification of needed research may be found in the proceedings of the 1st and 2nd World Congresses on Joint Sealing and Bearing Systems held in 1981 and 1986.[2,3] A glossary of terms that may not be generally familiar is provided in the appendix.

1.3-Why joints are required

Concrete normally undergoes small changes in dimensions as a result of exposure to the environment or by the imposition or maintenance of loads. The effect may be permanent contractions due to, for example: initial drying, shrinkage, and irreversible creep. Other effects are cyclical and depend on service conditions such as environmental differences in humidity and temperature or the application of loads and may result in either expansions or contractions. In addition, abnormal volume changes, usually permanent expansions, may occur in the concrete due to sulfate attack, alkali-aggregate reactions, and certain aggregates, and other causes.

The results of these changes are movements, both permanent and transient, of the extremities of concrete structural units. If, for any reason, contraction movements are excessively restrained, cracking may occur within the unit. The restraint of expansion movement may result in distortion and cracking within the unit or crushing of its end and the transmission of unanticipated forces to abutting units. In most concrete structures these effects are objectionable from a structural viewpoint. One of the means of minimizing them is to provide joints at which movement can be accommodated without loss of integrity of the structure.

There may be other reasons for providing joints in concrete structures. In many buildings the concrete serves to support or frame curtainwalls, cladding, doors, windows, partitions, mechanical and other services. To prevent development of distress in these sections it is often necessary for them to move to a limited extent independently of overall expansions, contractions and deflections occurring in the concrete. Joints may also be required to facilitate construction without serving any structural purpose.

1.4-Why sealing is needed

The introduction of joints creates openings which must usually be sealed in order to prevent passage of gases, liquids [illegible] into or through the openings.

In buildings, to protect the occupants and the contents, it is important to prevent intrusion of wind and rain. In tanks, most canals, pipes and dams, joints must be sealed to prevent the contents from being lost.

Moreover, in most structures exposed to the weather the concrete itself must be protected against the possibility of damage from freezing and thawing, wetting and drying, leaching or erosion caused by any concentrated or excessive influx of water at joints. Foreign solid matter, including ice, must be prevented from collecting in open joints; otherwise, the joints cannot close freely later. Should this happen, high stresses may be generated and damage to the concrete may occur.

In industrial floors the concrete at the edges of joints often needs the protection of a filler or sealant between armored faces capable of preventing damage from impact of concentrated loads such as steel-wheeled traffic.

In recent years, concern over the spread of flames, smoke and toxic fumes has made the fire resistance of joint sealing systems a consideration, especially in high-rise buildings.

The specific function of sealants is to prevent the intrusion of liquids (sometimes under pressure), solids or gases, and to protect the concrete against damage. In certain applications secondary functions are to improve thermal and acoustical installations, damp vibrations or prevent unwanted matter from collecting in crevices. Sealants must often perform their prime function, while subject to repeated contractions and expansions as the joint opens and closes and while exposed to heat, cold, moisture, sunlight, and sometimes, aggressive chemicals. As discussed in Chapters 2, 3 and 6, these conditions impose special requirements on the properties of the materials and the method of installation.

In most concrete structures all concrete-to-concrete joints (contraction, expansion and construction), and the periphery of openings left for other purposes require sealing. One exception is contraction joints (and cracks) that have very narrow openings, for example, those in certain short plain slab or reinforced pavement designs. Other exceptions are certain construction joints, for example, monolithic joints not subject to fluid pressure or joints between precast units used either internally or externally with intentional open draining joints.

1.5-Joint design as part of overall structural design

In recent years it has become increasingly recognized that there is more to providing an effective seal at a joint than merely filling the "as constructed" gap with an impervious material. The functioning of the sealant, described in Chapter 2, depends as much on the movement to be accommodated at the joint and on the shape of the joint, as on the physical properties of the sealant. Joint design, which broadly covers the interrelationship of these factors, is discussed in some detail in Chapter 4 since it should be an important, sometimes governing, consideration in the design of most concrete structures. It is considered beyond the scope of this guide on sealing joints to venture into the whole field of volume change in concrete and the structural considerations that determine the location and movement of joints. It is, however, pertinent to point out th

trying to keep joints sealed indicate that joint movements may vary widely from those postulated by theory alone.

There are probably as many "typical details" of joints in existence as there are structures incorporating them. Faced with the problem of illustrating, from the viewpoint of how they can be sealed, the various types of joints and their uses, it appeared best to present them in schematic form in Chapter 5 to bring out the principles involved for each of the three major groups of application to concrete:

1. Structures not under fluid pressure (most buildings, bridges, storage bins, retaining walls, etc.).
2. Containers subject to fluid pressure (dams, reservoirs, tanks, canal linings, pipe lines, etc.).
3. Pavements (highways and airfield).

From both the structural and sealant viewpoint, irrespective of design detail and end use, all the joints may be classified according to their principal function and configuration.

1.6-Types of joints and their function

1.6.1 *Contraction (control) joints*-These are purposely made planes of weakness designed to regulate cracking that might otherwise occur due to the unavoidable, often unpredictable, contraction of concrete structural units. They are appropriate only where the net result of the contraction and any subsequent expansion during service is such that the units abutting are always shorter than at the time the concrete was placed. They are frequently used to divide large, relatively thin structuralunits, for example, pavements, floors, canal linings, retaining and other walls into smaller panels. Contraction joints in structures are often called control joints because they are intended to control crack location.

Contraction joints may form a complete break, dividing the original concrete unit into two or more units. Where the joint is not wide, some continuity may be maintained by aggregate interlock. Where greater continuity is required without restricting freedom to open and close, dowels, and in certain cases steps or keyways, may be used. Where restriction of the joint opening is required for structural stability, appropriate tie bars or continuation of the reinforcing steel across the joint may be provided.

The necessary plane of weakness may be formed either by partly or fully reducing the concrete cross section. This may be done by installing thin metallic, plastic or wooden strips when the concrete is placed or by sawing the concrete soon after it has hardened.

1.6.2 *Expansion (isolation) joints*-These are designed to prevent the crushing and distortion (including displacement, buckling and warping) of the abutting concrete structural units that might otherwise occur due to the compressive forces that may be developed by expansion, applied loads or differential movements arising from the configuration of the structure or its settlement. They are frequently used to isolate walls from floors or roofs; columns from floors or cladding; pavement slabs and decks from bridge abutments or piers; and in other locations where restraint or transmission of secondary forces is not desired. Many designers consider it good practice to place such joints where walls or slabs change direction as in L-, T-, Y- and U-shaped structures and where different cross sections develop. Expansion joints in struc- joints because they are intended to isolate structural units that behave in different ways.

Expansion joints are made by providing a space for the full cross section between abutting structural units when the concrete is placed through the use of filler strips of the required thickness, bulkheading or by leaving a gap when precast units are positioned. Provision for continuity or for restricting undesired lateral displacement may be made by incorporating dowels, steps or keyways.

1.6.3 *Construction joints*-These are joints made at the surfaces created before and after interruptions in the placement of concrete or through the positioning of precast units. Locations are usually predetermined by agreement between the design professional and the contractor, so as to limit the work that can be done at one time to a convenient size with the least impairment of the finished structure, though they may also be necessitated by unforeseen interruptions in concreting operations. Depending on the structural design they may be required to function later as expansion or contraction joints having the features already described, or they may be required to be monolithic; that is, with the second placement soundly bonded to the first to maintain complete structural integrity. Construction joints may run horizontally or verticall y depending on the placing sequence required by the design of the structure.

1.6.4 *Combined and special purpose joints*-Construction joints (see Section 1.6.3) at which the concrete in the second placement is intentionally separated from that in the preceding placement by a bond-breaking membrane, but without space to accommodate expansion of the abutting units, also function as contraction joints (see Section 1.6.1). Similarly, construction joints in which a filler displaced, or a gap is otherwise formed by bulkheading or the positioning of precast units, function as expansion joints (see Section 1.6.2). Conversely, expansion joints are often convenient for forming nonmonolithic construction joints. Expansion joints automatically function as contraction joints, though the converse is only true to an amount limited to any gap created by initial shrinkage.

Hinge joints are joints that permit hinge action (rotation) but at which the separation of the abutting units is limited by tie bars or the continuation of reinforcing steel across joints. This term has wide usage in, but is not restricted to, pavements where longitudinal joints function in this manner to overcome warping effects while resisting deflections due to wheel loads or settlement of the subgrade. In structures, hinge joints are often referred to as articulated joints.

Sliding joints may be required where one unit of a structure must move in a plane at right angles to the plane of another unit, for example, in certain reservoirs where the walls are permitted to move independently of the floor or roof slab. These joints are usually made with a bond-breaking material such as a bituminous compound, paper or felt that also facilitates sliding.

1.6.5 *Cracks*-Although joints are placed in concrete so that cracks do not occur elsewhere, it is extremely difficult to prevent occasional cracks between joints. As far as sealing is concerned, cracks may be regarded as contraction joints of irregular line and form, Treatment of cracks is considered in Section 7.2.2.

1.7-Joint configurations

In the schematic joint details for various types of concrete structures shown in Chapter 5, two basic configurations occur from the standpoint of the functioning of the sealant. These are known as butt joints and lap joints.

In butt joints, the structural units being joined abut each other and any movement is largely at right angles to the plan of the joint. In lap joints, the units being joined override each other and any relative movement is one of sliding. Butt joints, and these include most stepped joints, are by far the most common. Lap joints may occur in certain sliding joints (see Section 1.6.4), between precast units or panels in curtainwalls, and at the junctions of these and of cladding and glazing with their concrete or other framing. As explained in Chapter 2, the difference in the mode of the relative movement between structural units at butt joints and lap joints, in part, controls the functioning of the sealant. In many of the applications of concern to this guide, pure lap joints do not occur, and the functioning of the lap joint is in practice a combination of butt and lap joint action.

From the viewpoint of the sealant, two sealing systems should be recognized. First, there are open surface joints, as in pavements and buildings in which the joint sealant is exposed to outside conditions on at least one face. Second, there are joints, as in containers, dams, and pipe lines, in which the primary line of defense against the passage of water is a sealant such as a waterstop or gasket buried deeper in the joint. The functioning and type of sealant material that is suitable and the method of installation are affected by these considerations.

In conclusion, two terms should be mentioned since they are in wide, though imprecise use. Irrespective of their type or configuration, joints are often spoken of as "working joints" where significant movement occurs and as "nonworking joints" where movement does not occur or is negligible.

CHAPTER 2-HOW JOINT SEALANTS FUNCTION

2.1-Basic function of sealants

To function properly, a sealant must deform in response to opening or closing joint movements without any other change that would adversely affect its ability to maintain the seal. The sealant material behaves in both elastic and plastic manners. The type and amount of each depends on: the movement and rate of movement occurring; installation and service temperatures; and the physical properties of the sealant material concerned, which in service is either a solid or an extremely viscous liquid.

2.2-Classification of sealants

Sealants may be classified into two main groups. These are as follows:

1. Field-molded sealants that are applied in liquid or semi: liquid form, and are thus formed into the required shape within the mold provided at the joint opening.

2. Performed sealants that are functionally preshaped, usually at the manufacturer's plant, resulting in a minimum of site fabrication necessary for their installation.

2.3-Behavior of sealants in butt joints

As a sealed butt joint opens and closes, one of three functional conditions of stress can exist. These are:

1. The sealant is always in tension. Some waterstops [Fig. 1 (2A)] function to a large degree in this way though compressive forces may be present at their sealing faces and anchorage areas.

2. The sealant is always in compression. This principle, as illustrated in Fig. 1 (1A, B, C), is the one on which compression seals and gaskets are based.

3. The sealant is cyclically in tension or compression. Most field-molded and certain preformed sealants work in this way. The behavior of a field-molded sealant is illustrated in Fig. 2 (1A, B , C) and an example of a preformed tension-compression seal is shown in Fig. 9 (4).

A sealant that is always in tension presupposes that the sealant was installed when the joint was in its fully closed position so that thereafter, as the joint opens and closes, the sealant is always extended. This is only possible with preformed sealants such as waterstops which are buried in the freshly mixed concrete and have mechanical end anchors. Field-molded sealants cannot be used this way and the magnitude of the tension effects shown in Fig. 2 (1B) would likely lead to failure as the joint opened in service. Most sealing systems used in open surface joints are therefore designed to function under either sealant in compression or a condition of cyclically in compression and tension to take best advantage of the properties of the available sealant materials and permit ease of installation.

2.4-Malfunctions of sealants

Malfunction of a sealant under conditions of stress consists of a tensile failure within the sealant or its connection to the joint face. These are known as cohesive and adhesive failures, respectively.

In the case of preformed sealants that are intended to be always in compression, malfunctioning usually results in failure to generate sufficient contact pressure with the joint faces. This leads to the defects shown in Fig. 3 (1). This figure also shows defects in water stops. Splits, punctures or leakage at the anchorage may also occur with strip (gland) seals.

Malfunctioning of a field-molded sealant, intended to function cyclically in tension or compression, may develop with repetitive cycles of stress reversal or under sustained stress at constant deformation. The resulting failure will then be shown as one of the defects illustrated in Fig. 4.

Where secondary movements occur in either or both directions at right angles to the main movement, including impact at joints under traffic, shear forces occur across the sealants. The depth (and width) of the sealant required to accommodate the primary movement can more than provide any shear resistance required.

2.5 Behavior of sealants in lap joints

The sealant as illustrated in Fig. 2 (2A, B , C) is always in shear as the joint opens and closes. Tension and compression effects may, however, be added in the modified type of lap joint used in many building a

2.6-Effect of temperature

Changes in temperature between that at installation and the maximum and minimum experienced in service affect sealant behavior. This is explained by reference to Fig. 5.

The service range of temperature that affects the sealant is not the same as the ambient air temperature range. It is the actual temperature of the units being joined by the sealant that govern the magnitude of joint movements that must be accommodated by the sealant. By absorption and transfer of heat from the sun and loss due to radiation, etc., depending on the location, exposure, and materials being joined, the difference between service range of temperature and the range of ambient air temperature can be considerable.

For the purpose of this guide, the service range or temperatures has been assumed to vary from -20 to + 130 F (-29 to + 54 C) for a total range of 150 F (83C). In very hot or cold climates or where the joint is between concrete and another material that absorbs or loses heat more readily than concrete, the maximum and minimum values may be greater. This is particularly true in building walls, roofs and in pavements. On the other hand, inside a temperature-controlled building or in structures below ground the range of service temperatures can be quite small. This applies also to containers below water line. However, where part of a container is permanently out of the water, or is exposed by frequent dewatering, the effects of a wider range of temperatures must be taken into account.

The rate of movement due to temperature change for short periods (ie: an hr, a day) is quite as important as the total movement over a year. Sealants generally perform better, that is, respond to and follow joint opening and closing when this movement occurs at a slow and uniform rate. Unfortunately, joints in structures rarely behave this way; where restraint is present, sufficient force to cause movement must be generated before any movement occurs. When movement is inhibited due to frictional forces, it is likely to occur with a sudden jerk that might rupture a brittle sealant. Flexibility in the sealant over a wide range of temperatures is therefore important, particularly at low temperatures where undue hardening or loss of elasticity occurs with many materials that would otherwise be suitable as sealants. Generally all materials perform better at higher temperatures, though with certain thermoplastics softening may lead to problems of sag, flow and indentation.

Furthermore, in structures having a considerable number of similar joints in series, for example, retaining walls, canal linings and pavements, it might be expected that an equal share of the total movement might take place at each joint. However, one joint in the series may initially take more movement than others and therefore the sealant should be able to handle the worst combination.

These considerations are discussed in detail in Chapter 4.

2.7-Shape factor in field-molded sealants

Field-molded sealants should be 100 percent solids (or semi-solids) at service temperatures and as shown in Fig. 2, they alter their shape but not their volume as the joint opens and closes. These strains in the sealant and hence the adhesive and cohesive stresses developed are a critical function

given sealant then, its elastic