ARCHITECTURAL PRECAST CONCRETE JOINT DETAILS

Reported by

PCI Committee on Architectural Precast Concrete Joint Details

Raymond J. Schutz
Chairman

James Engle
James G. Gross
Abraham Gutman
J. A. Hanson
Kai Holbek
Felix Kulka
Albert Litvin
R. L. Pare
John S. Parrish
Irwin J. Speyer
Ivan L. Varkay
Lloyd Wright

Correct joint design and proper selection of materials and installation are vital for the successful performance and esthetic appeal of precast concrete wall systems. This report recommends the proper precast concrete joint details and sealants for specific situations. In writing these recommendations, architectural treatment and economy in mold design were considered but are not included, since these are covered in the PCI Manual on Architectural Precast Concrete. Following these recommendations will result in a good design and a durable, waterproof, and economical joint.

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CHAPTER 1—JOINT DESIGN

1.1 Scope

The design of joints must be executed as an integral part of the total wall design. Some specific guidelines for joints do govern their ultimate success. This chapter highlights and illustrates several cases of interdependence with other wall design criteria.

In all cases, the designer should assess his requirements for joints realistically with respect to both performance and cost. If joint designs and details are contemplated which differ from those normally used in the area where the project *is* located, local producers should be consulted.

The following discussion will deal mainly with joints which are designed to accommodate local wall movements only, rather than an accumulation of such movements which would require properly designed expansion joints.

1.2 Types of joints

Joints between precast wall panels may be divided into two basic types:

1. One-stage joints
2. Two-stage joints

A cavity wall design is considered a further application of the two-stage joint.

1.2.1 *One-stage joints.* As the name implies, this joint has one line of defense for its weatherproofing ability. This occurs normally in the form of a sealant close to the exterior surface. The advantage of this type of joint is that it generally provides the lowest first cost, and it is suitable for use between precast panels as shown in Figs. 3.2.1 to 3.2.6.

The success of one-stage joints depends on the quality of materials and proper installation at the building site. This type of joint is in common use in most of North America. One-stage joints should be regularly inspected and may demand fairly frequent maintenance to remain weathertight.

1.2.2 *Two-stage joints.* These joints have two lines of defense for weatherproofing. The typical joint consists of a rain barrier near the exterior face and an air seal normally close to the interior face of the panels. The rain barrier is designed to shed most of the water from the joint and the air seal is the demarcation line between outside and inside air pressures. Between these two stages is an equalization or expansion chamber which must be vented and drained to the outside. Section 3.3 gives typical details of two-stage joints. It can be seen that the simplest form of a horizontal two-stage joint is the well proven shiplap joint.

The rain barrier prevents most of the rain and airborne water from entering the joint. If airborne water (wind-driven rain) penetrates this barrier, it will drain off in the expansion chamber as the kinetic energy is dissipated and the air loses its ability to carry the water. Any water which penetrates the rain barrier should be drained out of the joint by proper flashing installations.

In order to avoid vertical movement of the air in the expansion chamber (stack effect) caused by wind or outside air turbulences, it is advisable to use these flashing details as dampers and provide them at regularly spaced intervals along the height of the vertical joints. Such flashing is sometimes installed at each floor level, but a greater spacing (two or three stories) may be sufficient for low-rise buildings and in areas with moderate wind velocities.

Since the air seal is the plane where the change in air pressures between the outside and inside atmospheres occurs, it would normally be subject to water penetration through capillary action. Inasmuch as the outside air reaching this seal has lost its water content, no moisture can enter by such action.

The danger of humidity traveling from inside the building and through the air seal should be investigated for buildings with relatively higher interior humidity, and for tall buildings, where the interior air pressure may occasionally be substantially higher than the outside atmospheric pressure. This condition is normally solved by using a cavity wall design.

A cavity wall (Fig. 3.4.1) is the most effective wall for the optimum separation and control of both outside and inside air and humidity conditions. When precast concrete wall panels are used in cavity wall designs, they will normally serve as the rain barrier. An air space is maintained between the precast exterior and the interior wall. Insulation, when required, is applied to the outside face of the interior wall, eliminating condensation problems and, thereby, making the inner wall subject only to the relatively constant interior temperature. Cavity wall construction is normally expensive when compared with conventional walls. On the basis of their lower maintenance costs and their excellent performance records, they may well be justified for specific types and locations of buildings.

The two-stage joint is gaining acceptance particularly for buildings subject to severe climatic exposure or temperature and humidity control.

A disadvantage of the two-stage joint for concrete wall panels is the higher cost. For projects with good repetitive joint design properly integrated with other panel details, and having efficient production and erection procedures, it may well approach the cost of one-stage joint installations. In these instances, the safety factors and lower maintenance costs should also be considered.

A minimum precast wall panel thickness of 4 in. (10.2 cm) (with field-molded sealants), preferably 5 in. (12.7 cm) (with gaskets and compression seals), is required to accommodate both the rain barrier and the air seal. For two-stage joints with compression seals, connection detail allowance should be made for slight horizontal movements of the panels after initial fastening for air seal compression.[5] The joints must be fully accessible from the inside of the panels for later installation of the air seal. The simplest form of a horizontal two-stage joint is the shiplap joint.

1.3 General design concepts for joints

The purpose of joint design is to provide weathertightness of the joint consistent with the exposure of the joint. In addition, as part of the overall performance requirements of the building, the purpose for which the building is built will also determine design requirements for the joint.

Thus, joint design will be governed by its exposure (orientation and climatic conditions), the purpose of the building, and appearance. The following guidelines must all be evaluated in relation to the relative importance of these criteria.

1.4 Number of joints

It is generally advantageous to plan for the fewest number of joints, due to the lower overall joint cost, potentially lower maintenance cost, and the economy of large panel erection.

Optimum panel sizes must, however, also be determined from erection conditions and established limitations of weight and sizes for transportation.[7]

If the desired appearance requires additional joints, this may be achieved through the use of false or dummy joints. In order to match the appearance of both false and real joints, an applied finish should be chosen to simulate sealants or gaskets in the real joints. Caulking of the false joints adds an unnecessary expense.

1.5 Location of joints

Joints are easier to design and execute if they are located where maximum panel thickness occurs. Except for one-stage joints and joints in precast panels performing as rain barriers in cavity walls, the minimum panel thickness at joints should be 4 in. (and preferably 5 in.) for panels which can be manufactured and erected to close tolerances. Hence, it is recommended that joints be placed in any ribbed projections of panels.

If ribs are too narrow to accommodate joints, the full rib may be located in one panel only (Fig. 3.2.6). Another solution is to design every second panel with ribs at both edges using the balance as infill units.

An important factor in locating and detailing joints is a proper assessment of the predicted weathering pattern for the structure. To limit weathering effects on the building, it is advisable to emphasize the joints by making them wide and recessed from immediately adjacent surfaces.[8] Joints in forward sloping surfaces are difficult to weatherproof, especially where they may collect snow or ice. When these surfaces cannot be avoided, the architect should include a second line of defense against water penetration. This may be achieved by sealing the front of the surface and using a two-stage joint. If a one-stage joint is used, the owner must accept regular inspection of such joints and be prepared to perform frequent maintenance.

CHAPTER 2—PLANNING CHECK LISTS

2.1 Definitions

Joint planning is recognition of, and provision for, movement or isolation of movement in a building or other structure based on an analysis of esthetic, structural and mechanical requirements.

Water runoff planning is the visualization of the paths that moisture may take, or its entrapment, and the provisions of safe channels for its flow and discharge.

2.2 Joint planning

1. Determination of amount of movement that can be anticipated.
    - A. Initial movement
        1. Shrinkage
        2. Foundation
        3. Elastic deflection
        4. Other
    - B. Life of structure movement
        1. Temperature
        2. Moisture
        3. Wind

        4. Earthquake or other foundation movement
        5. Live load deflections
        6. Creep
        7. Other

2. Architectural (esthetic) considerations
    - A. Accentuated jointing
    - B. Hidden joints
    - C. Spacing (a few large or many small)
    - D. Environmental needs
        1. Water control
        2. Air control (circulation)
        3. Temperature control
        4. Noise (vibration control)

3. Structural considerations
    - A. Elimination of stress in structural materials through relief of allowed movement.
    - B. Design to resist movement through the accumulation of stress.
    - C. Location of expansion-contraction joints to maintain the structural integrity.
        1. Expansion-contraction joints
        2. Construction joints
        3. Articulating joints

4. Mechanical considerations
    - A. Differential movement potential
        1. Differing coefficients of expansion
        2. Differing heat absorption rates
        3. Differing moisture absorption qualities
        4. Differing exposure to heat or moisture
    - B. Isolation of vibrations
        1. Internal (machinery or activity)
        2. External
    - C. Other

5. Material considerations
    - A. Field-molded sealants
        1. Mastics
        2. Thermoplastics
        3. Thermosetting
        4. Accessory materials
    - B. Preformed sealants
        1. Rigid waterstops
        2. Flexible waterstops
        3. Gaskets
    - C. Other

6. Tolerances
    - A. Production
    - B. Erection
    - C. Adjacent construction

2.3 Water runoff planning

1. Resistance to penetration
    - A. Seal
    - B. Shape of joint

2. Channelization of moisture and discharge
    - A. Planned channelizing joints (two-stage system)
    - B. Channelization of inadvertent or seepage penetration (one-stage system)

CHAPTER 3—JOINT DETAILS

3.1 General

This chapter shows typical details for one-stage and two-stage joints, for floor and roof slab joints, for precast concrete parapets, and for windows in precast concrete panels. The committee recognizes that other details can be developed within the recommendations of this report that will provide satisfactory service. Thus, it is not intended that these details be used to the exclusion of all others, but rather that they be taken to illustrate the features of good joint planning and design.

3.2 One-stage joints

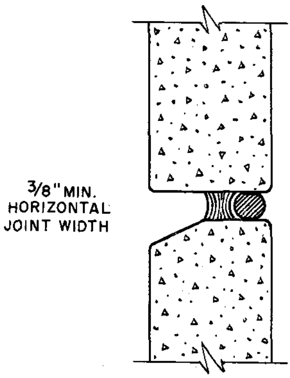


Fig. 3.2.1. Recessed vertical butt joint

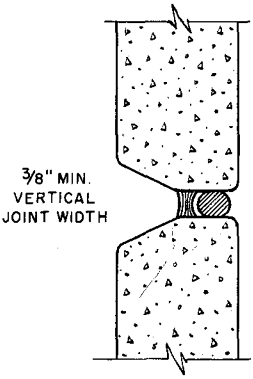


Fig. 3.2.2. Recessed horizontal butt joint

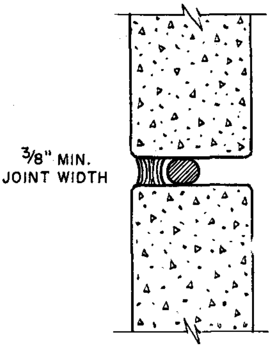


Fig. 3.2.3. Flush butt joint

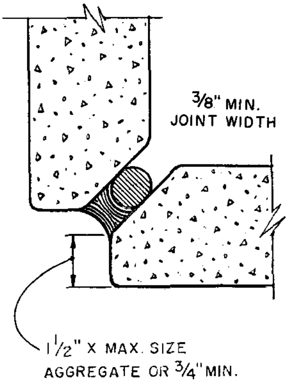


Fig. 3.2.4. Recessed corner joint

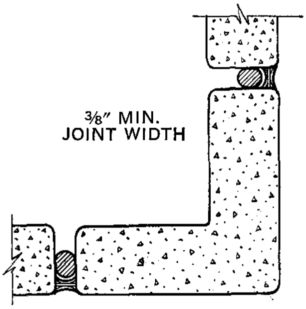


Fig. 3.2.5. Corner joint detail

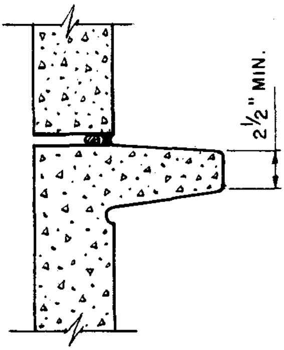


Fig. 3.2.6. Joints in panels with narrow ribs

3.3 Two-stage joints

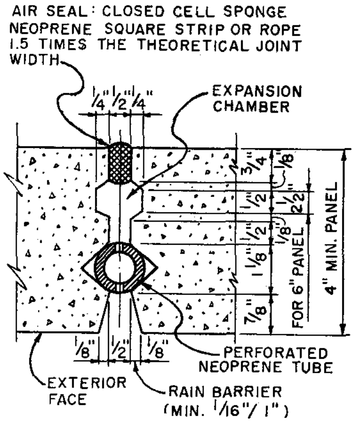


Fig. 3.3.1. Two-stage joint vertical gaskets

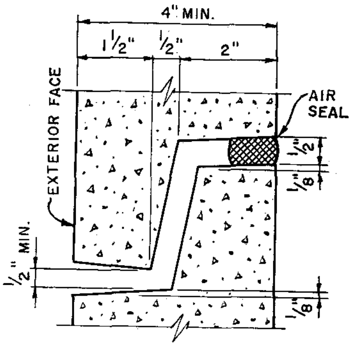


Fig. 3.3.2. Two-stage joint horizontal gasket

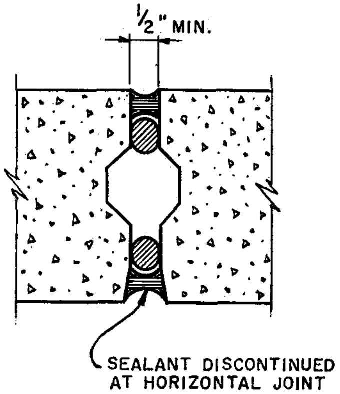


Fig. 3.3.3. Two-stage joint vertical sealants

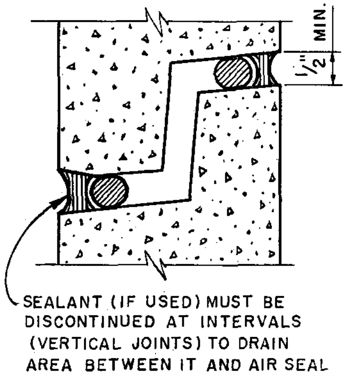


Fig. 3.3.4. Two-stage joint horizontal sealants

3.4 Cavity wall

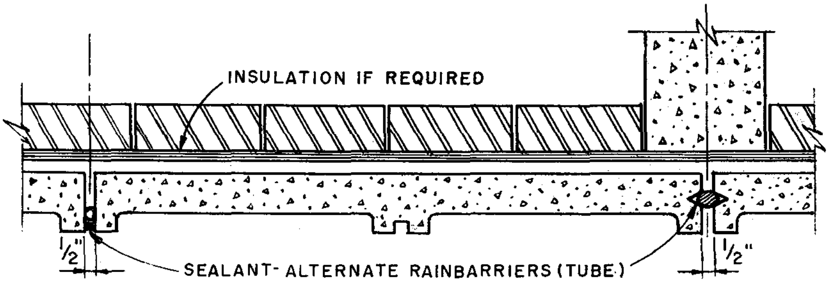


Fig. 3.4.1. Horizontal section through cavity wall

3.5 Floor and roof slab joints

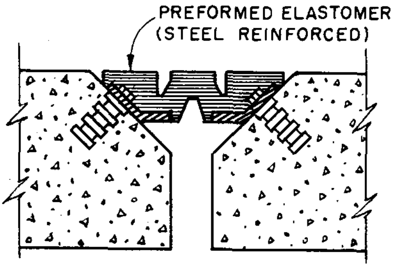


Fig. 3.5.1

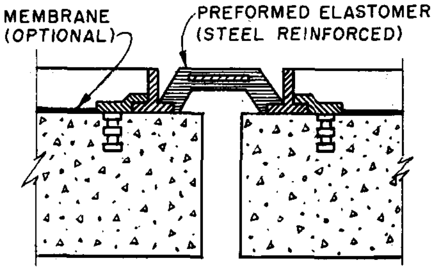
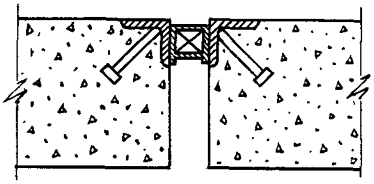


Fig. 3.5.2



PREFORMED COMPRESSION SEAL
(SOMETIMES COMBINED WITH P.V.C.
OR SHEET NEOPRENE SECONDARY
SYSTEMS.)

Fig. 3.5.3

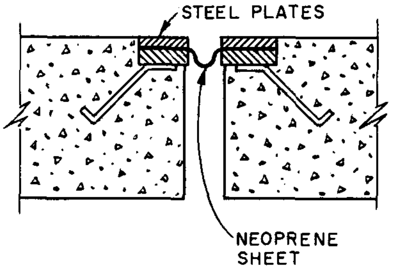
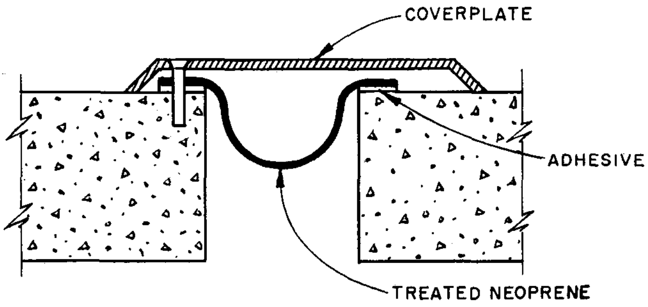


Fig. 3.5.4



WIDTH OF NEOPRENE OR HYPALON SHEET SHALL
EQUAL JOINT WIDTH PLUS ANTICIPATED MOVEMENT
PLUS I INCH PLUS BOND AREA

Fig. 3.5.5

3.6 Precast parapets

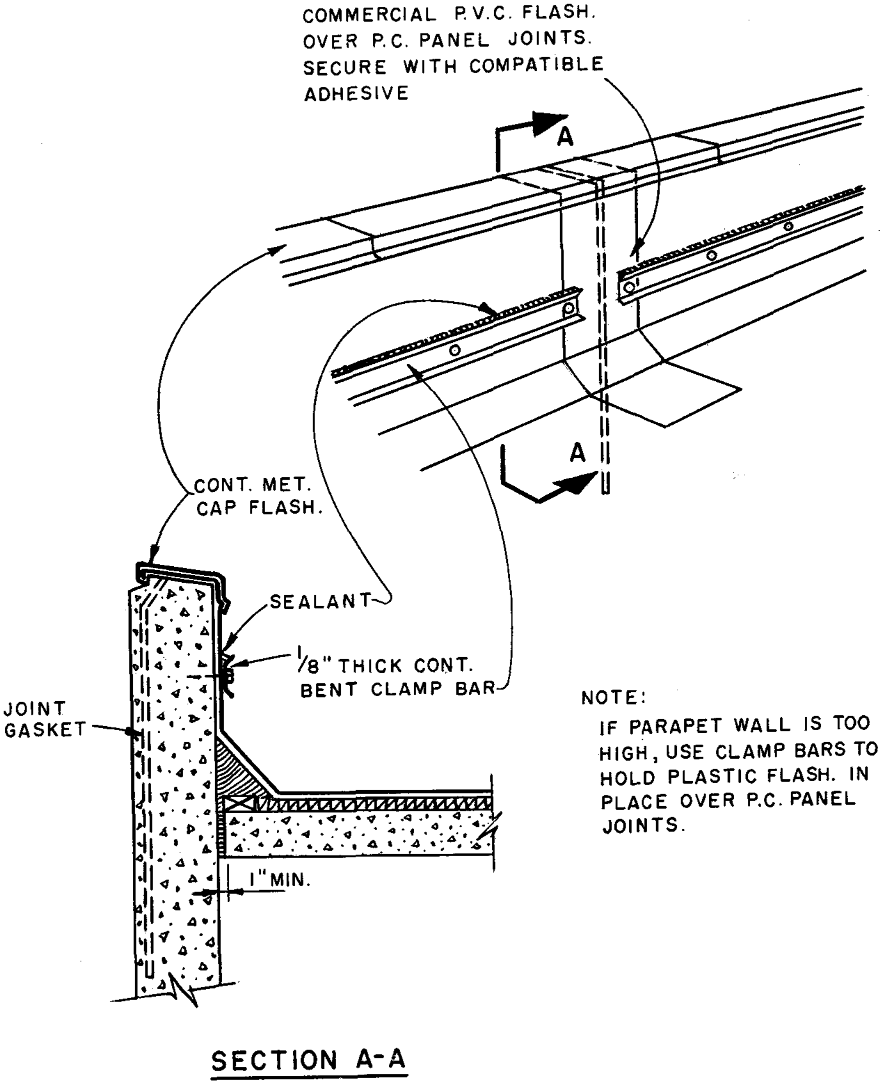


Fig. 3.6.1. Precast parapet joint with cap flashing

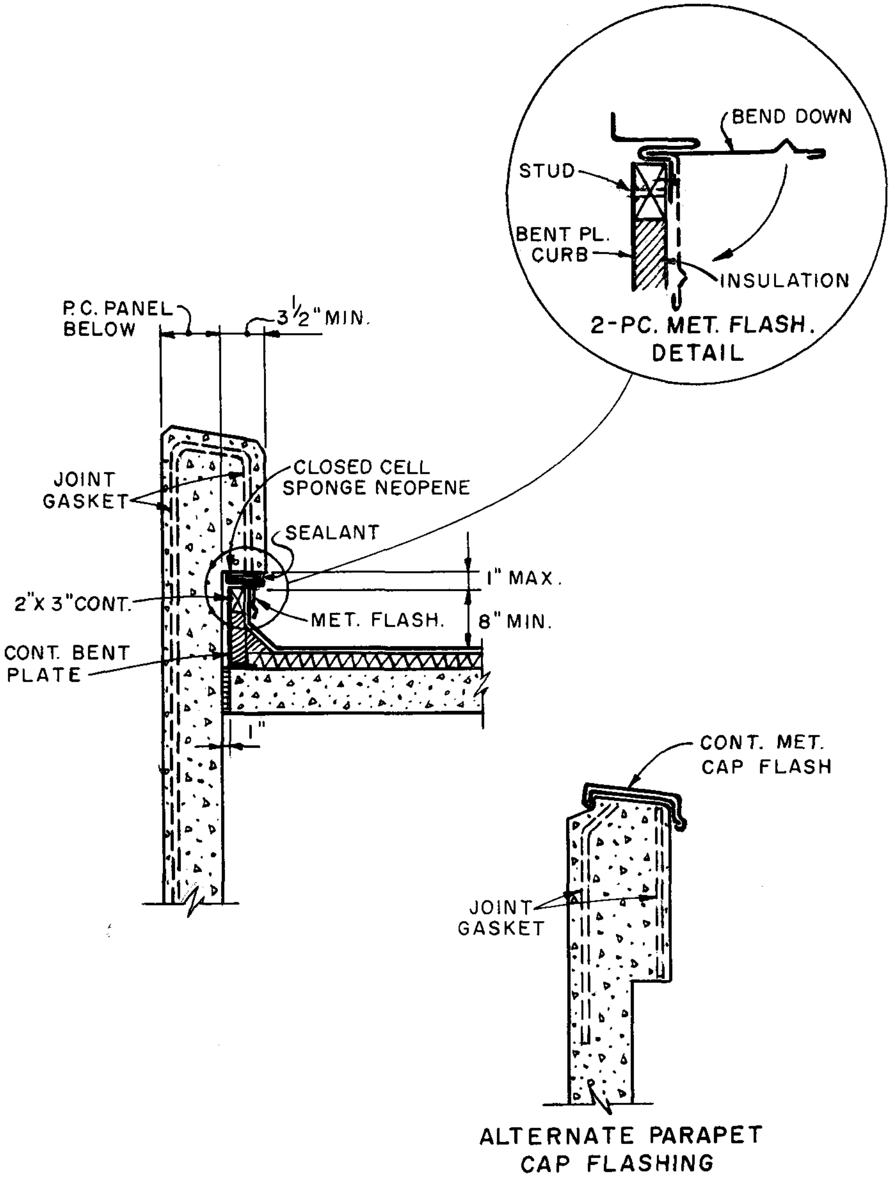


Fig. 3.6.2. Precast parapet with guarded roof flashing

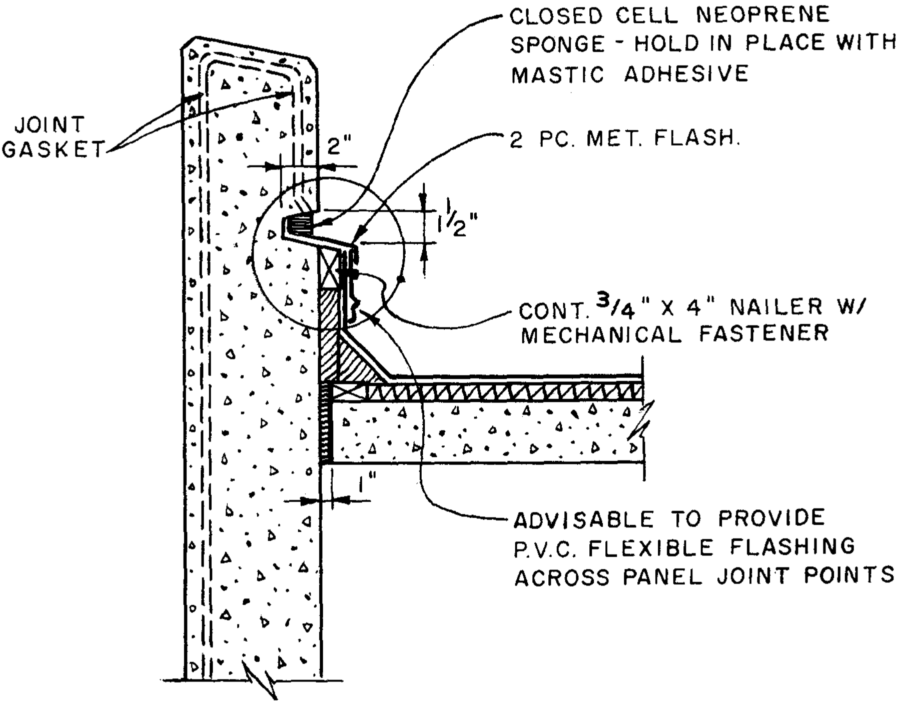


Fig. 3.6.3. Precast parapet with flush roof flashing

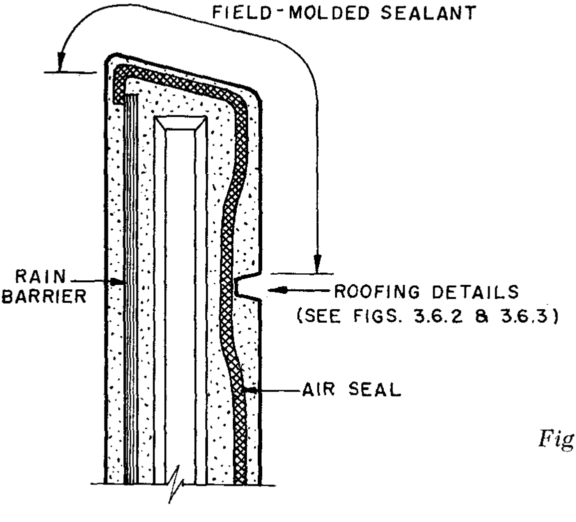


Fig. 3.6.4. Precast parapet two-stage joint

3.7 Precast panel windows details

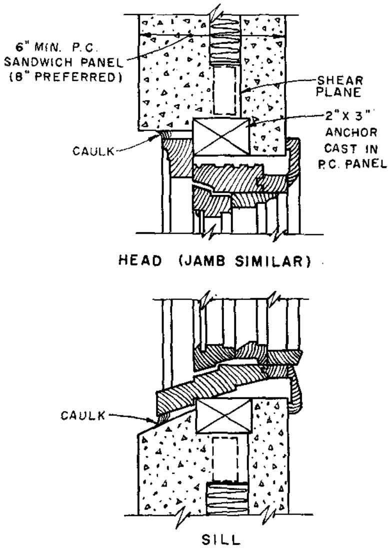


Fig. 3.7.1. Wood casement in precast concrete panel

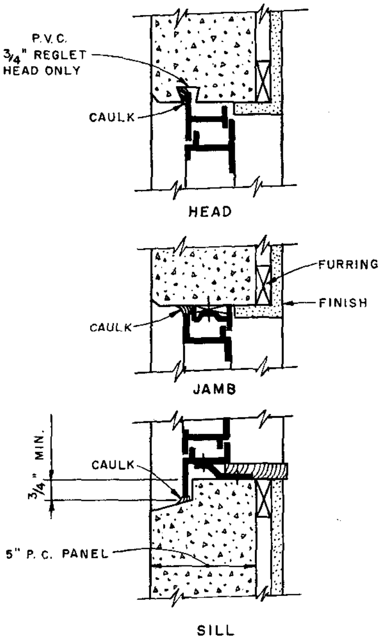


Fig. 3.7.2. Aluminum sash in precast concrete panel

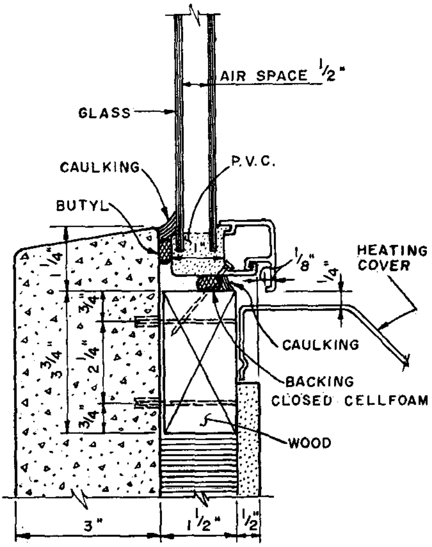


Fig. 3.7.3. Fixed window in precast panel

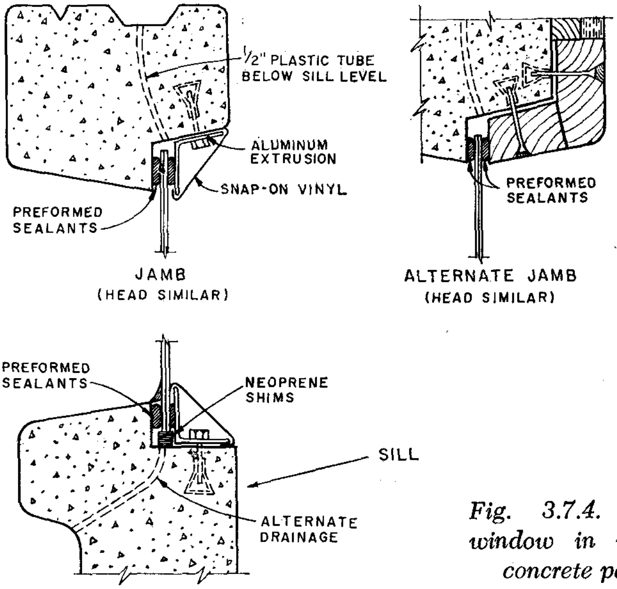


Fig. 3.7.4. Fixed window in precast concrete panel

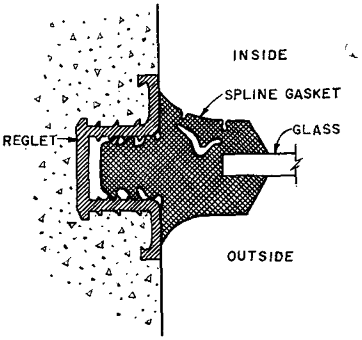


Fig. 3.7.5. Panel with PVC reglet and spline gasket

CHAPTER 4—SEALANT MATERIALS

4.1 General

No one material has the perfect combination of properties necessary to fully meet each and every one of the requirements for each and every application. If there were, and its price were reasonable, obviously it would be in universal use. It therefore is a matter of selecting, from among a large range of materials, a particular material that offers the right properties at a reasonable price to satisfy the job requirements.

For many years oil-based mastics or bituminous compounds and metallic materials were the only sealants available. For many applications these traditional materials do not perform well and in recent years there has been active development of many types of elastomeric sealants whose behavior is largely elastic, rather than plastic, and which are flexible rather than rigid at normal service temperatures. Elastomeric materials are available as field-molded and preformed sealants. Though initially more expensive, they may be more economical over an extended period due to longer service life. Furthermore, as will be seen, they can seal joints where considerable movements occur which could not have been sealed by the traditional materials. This has opened up new engineering and architectural possibilities to the designer of concrete structures.

No attempt has been made in this chapter to list or discuss every attribute of every sealant on the market. Discussion is limited to those features considered important to the designer, specifier, and user so that the claims made for various materials can be assessed and a suitable choice for the application can be made.

4.2 Field-molded sealants and their uses

The following types of materials listed in Table 1 are currently used as field-molded sealants:

4.2.1 *Mastics.* Mastics are composed of viscous liquid rendered immobile by the addition of fibers and fillers. They do not usually harden, set or cure after applications, 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 asbestos fiber, fibrous talc or finely divided calcareous or siliceous materials. The functional extension-compression range for these materials is approximately ± 3 percent.

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

4.2.2 *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 to a temperature not exceeding 120 F (49 C) to facilitate application but usually they are handled at ambient temperature. Release of solvent or water can cause shrinkage and increased hardness with a resulting reduction in the permissible joint movement and in serviceability. Products in this category include acrylic, vinyl and modified butyl types which are available in a variety of colors. Their maximum extension-compression range is ± 7 percent. Heat softening and cold hardening may, however, reduce this figure.

These materials are restricted in use to joints with small movements. Acrylics and vinyls are used in buildings primarily for caulking and glazing.

4.2.3 *Thermosetting (chemically curing).* Sealants in this class are either one- or two-component systems which cure by chemical reaction to a solid state from the liquid form in which they are applied. They 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 expansion-compression range of up to ± 25 percent depending on the one used, at temperatures from –40 F to +180 F (–40 C to +82 C). Silicone sealants remain flexible over an ever wider temperature range.

These sealants have a wide range of uses in buildings and containers for both vertical and horizontal joints, and may be used in pavements. Though initially more expensive, thermosetting, chemically curing sealants can accommodate greater movements than other field-molded sealants, and generally have a much greater service life.

4.2.4 *Thermosetting (solvent release).* Another class of thermosetting sealants are those which cure by the release of solvent. Chlorosulfonated polyethylene and certain butyl and neoprene materials are included in this class and their performance characteristics generally resemble those of thermoplastic solvent release materials (see Section 4.2.2). They are, however, less sensitive to variations in temperature once they have set up on exposure to the atmosphere. Their maximum extension-compression range does not, however, exceed ± 7 percent. They are primarily used as sealants for caulking and for horizontal and vertical joints in buildings which have small movements. Their cost is somewhat less than that of other elastomeric sealants, and their service life is likely to be satisfactory, though for some recent products this has not yet been established by experience.

4.2.5 *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 portland cement mortar and modified epoxy resins.

4.3 Accessory materials

4.3.1 *Primers.* Where primers are required, a suitable proprietary material compatible with the sealant is usually supplied with it. To overcome damp surfaces, wetting agents may be included in primer formulations, or materials may be used that preferentially wet such surfaces, such as polyamide-cured coal tar epoxies. For oleoresinous mastics, shellac can be used.

4.3.2 *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.

4.3.3 *Backup materials.* These materials serve to limit the depth of the sealant; support it against sagging, indentation, and displacement by traffic, fluid pressure, and other forces; facilitate tooling; and may serve as a bond breaker to prevent the sealant from bonding to the back of the joint. Suitable materials are listed in Table 2. The backup material should preferably be compressible so that the sealant is not forced out as the joint contracts, and it should recover as the joint expands. Care must be taken to select the correct width and shape of material so that, after installation, it is in approximately 50 percent compression. 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, chemically curing field-molded sealants, since these additives migrate to and/or are absorbed at joint interfaces, thus impairing adhesion. In the selection of a backup material, it is advisable to follow the recommendations of the sealant manufacturer to insure compatibility. Backup materials necessary to control the depth of field-molded sealants or provide support are usually preformed.

4.4 Preformed sealants and their uses

Strictly speaking, compression seals should be included with the flexible group of preformed sealants. However, because their functional principle is different and because the compartmentalized neoprene type can be used in almost all joint sealant applications as an alternate to field-molded sealants, it is included in Table 1 and treated separately.

4.4.1 *Gaskets and miscellaneous seals.* Gaskets and tapes are widely used sealants between glazing and its frame, around window and other openings in buildings, and at joints between precast concrete panels in curtain walls. Suitable materials and their uses are listed in Table 3. Sealing action is obtained either because the sealant is compressed between the joint faces (gaskets) or because the surface of the sealant, as in the case of polyisobutylene, is pressure sensitive and thus adheres.

4.5 Compression seals and their uses

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

4.5.1 *Compartmentalized.* Neoprene extruded to the required configuration is currently used for most compression seals (see Tables 1 and 3). For this application, the neoprene formulation used must have special properties.[14] For effective sealing, sufficient contact pressure must be maintained at the joint face. This requires that the seal experiences some degree of compression. Good resistance to compression set (that is, the material must recover sufficiently when released) is required. In addition, the neoprene must be crystalization-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 neoprene is not fully cured, the interior webs may adhere together during service, often permanently, when the seal is compressed.

To facilitate installation of compression seals, liquid neoprene based lubricants are used. For machine installations, additives to make the lubricant thixotropic have been found necessary. Special lubricant adhesives, which both prime and bond, have been formulated for use where improved seal to joint face contact is required. Neoprene compression seals are effective joint sealants over a wide range of temperature in almost all applications.

Table 1. Materials used for sealants in joints open on at least one surface

Group	Field-molded				Preformed
Type	Mastic	Cold-applied thermoplastics	Thermosetting		Compression seal
			Chemically-curing	Solvent release	
Composition	(A) Drying oils (B) Nondrying oils (C) Polybutenes (D) Polyisobutylenes or combination of C & D All used with fillers such as asbestos fiber or siliceous materials. All contain 100 percent solids, except C & D which may contain solvent.	(E) Acrylics Contain 75-90 percent solids and a solvent	(F) Polysulfide (G) Polyurethane (H) Silicones (F) (H) Contain 95-100 percent solids (G) Contains 75-100 percent solids May be either one or two component system	(J) Neoprene (K) Butadiene styrene (L) Chlorosulfonated polyethylene (J) (L) Contain 80-90 percent solids (K) Contains 85-90 percent solids	(M) Neoprene rubber
Colors	(A) (B) Varied (C) (D) Limited	Varied	(F) (H) Varied (G) Limited	(J) Limited (L) Varied	Black Exposed surfaces may be treated to give varied colors.
Setting or Curing	Noncuring, remains viscous A and B form skin on exposed surface.	Noncuring, sets on release of solvent or evaporation of water; remains soft except for surface skin.	Two component system-catalyst. One component system-moisture pickup from the air.	Release of solvent	
Aging and weathering resistance	Low	Moderate	High	High	High
Increase in hardness in relation to (1) Age	High	High	Moderate	High	Low
or (2) Low temperature	High	High	Low	High	Low
Recovery	Low	Low	(F) Moderate (G) (H) High	Low	High
Resistance to wear	Low	Moderate	(G) (H) High (F) Moderate	Moderate	High
Resistance to indentation and intrusion of solids	Low	Low at high temperatures	High	Low	High
Shrinkage after installation	High	High	Low	High	None
Resistance to chemicals	High except to solvents and fuels.	High except to alkalis and oxidizing acids	(F) (G) Low to solvents, fuels, oxidizing acids (H) Low to alkalis	Low to solvents, fuels and oxidizing acids	High
Modulus at 100 percent elongation	Not applicable	Low	(F) (G) Low (H) High	Moderate	
Allowable extension and compression	± 3 percent	± 7 percent	± 25 percent	± 7 percent	Must be compressed at all times to 45-85 percent of its original width.
Other properties	(A) (B) (C) (D) Nonstaining (C) (D) Pick up dirt; use in-concealed location only.		Nonstaining	(K) (L) Nonstaining (L) Good vapor and dust sealer	
Unit first cost	(A) (B) Very low (C) (D) Low	High	Very high	Low	High

Table 2. Preformed materials used for fillers and backup

Composition and type	Uses and governing properties	Installation
Natural rubber (a) Sponge (b) Solid	Expansion joint filler. Readily compressible and good recovery. Closed cell. Non-absorptive. Solid rubber may function as filler but primarily intended as gasket.	High pliability may cause installation problems. Weight of plastic concrete may precompress it. In construction joints attach to first placement with adhesive.
Neoprene or butyl sponge tubes	Backup Where resilience required in large joints. Check for compatibility with sealant as to staining.	Compressed into joint with hand tools.
Neoprene or butyl sponge rods	Backup Used in narrower joints. Check for compatibility with sealant as to staining.	Compressed into joint with hand tools or roller.
Expanded polyethylene, polyurethane, polyvinyl chloride, or polypropylene flexible foams	(a) Expansion joint fillers. Readily compressible, good recovery, non-absorptive. (b) Backup. Compatible with most sealants.	Must be rigidly supported for full length during concreting. Compressed into joint with hand tools.
Expanded polyethylene, polyurethane or polystyrene rigid foams	Expansion joint filler. Useful to form a gap after significant compression will not recover.	Support in place during concreting. In construction joints attach to first placement. Sometimes removed after concreting where no longer needed.
Glass fiber or mineral wool	(a) Expansion joint filler. Made in board form by impregnating with bitumen or resins. Easily compressed. (b) Backup. Insert without impregnation so as not to damage sealant.	Installed as for wood or fiberboard materials. In mat form, packed loose material or yarn.
Oakum, jute, or manila yarn and rope	The traditional material for packing joints before installing sealant. Where used as backup should be untreated with oils, etc.	Packed in joint to required depth.
Portland cement grout or mortar	Used at joints in precast units and pipes to fill the remaining gap when no movement is expected and sometimes behind waterstops.	Bed (mortar) Inject (grout)

4.6 Joint design

The location and width of joints that require sealing can only be specified by considering whether a sealant is available which will take the anticipated movement, and what shape factor or, in the use of preformed sealants, what size is required. If the sealants can not take the anticipated movement, then the joint system for the structure must be redesigned to reduce the movement at the joints. Sealing systems currently available can accommodate (at increasing cost) movements up to about 15 in. (38.8 cm) and are presently being designed for even greater movements. With due forethought it should, therefore, be possible to design and specify a suitable sealed joint for almost any type of concrete structure.

4.7 Determination of joint movements and locations

The anticipated length (volume) changes within the structure must be determined and translated into joint locations and movements that not only fit the structural design and maintain the integrity between the individual structural units, but also consider the fact that each type of sealant currently available imposes specific limitations on both the shape of joint that can be sealed and the movement that can be accommodated. When using the applicable structural design codes and standards for these calculations, it should be remembered that the sources of movement and the nature of the movement, both long and short term, can be very complex in other than simple structures. Both experience and judgment are necessary in the design of joints that function satisfactorily. A more complete discussion of this is beyond the scope of this report. The following simple facts will, if properly considered, result in good joint seal performance:

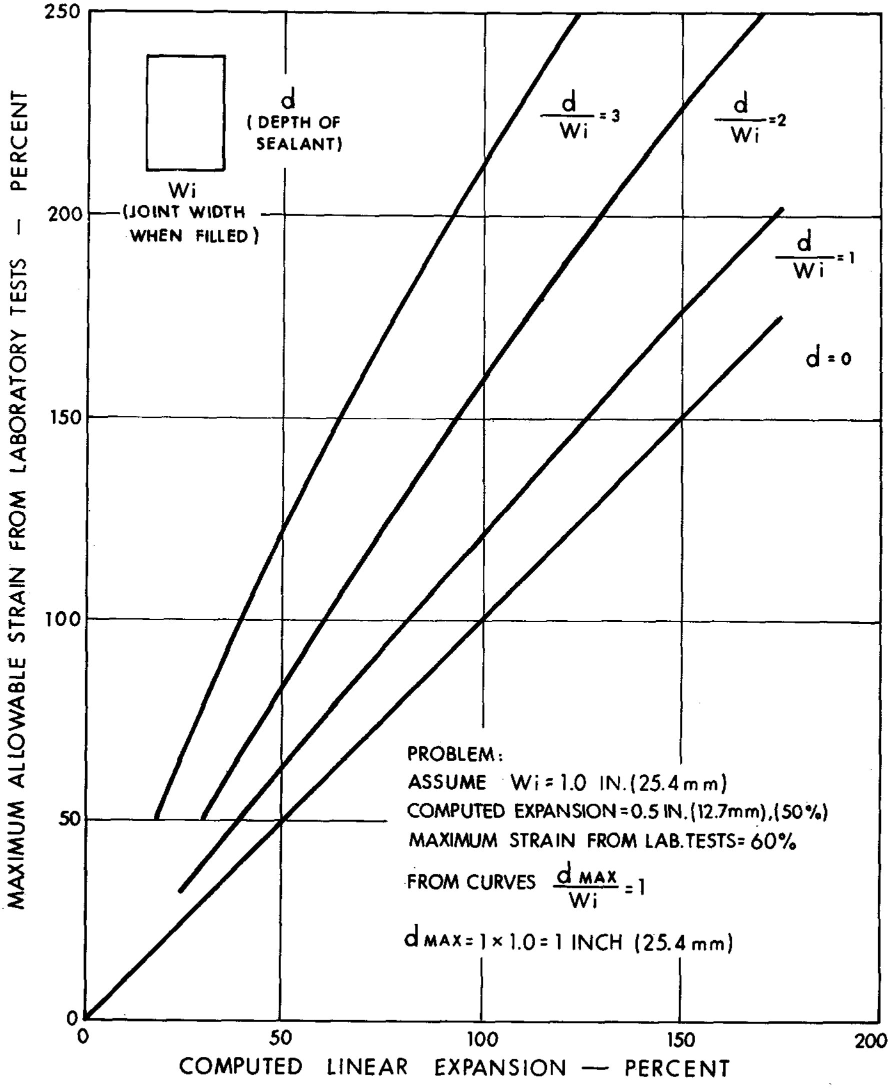
1. The movement of the end of a unit depends on its effective length, that is, on the length of that part of the unit that is free to move in the direction of the joint.
2. Except where a positive anchor is a feature of the design, experience shows that the only safe assumption is that a joint between two units may be called upon to take the total movement of both units. Based on joint movement measured on actual buildings, the Building Research Station in England calculated that movement of each joint should be multiplied by two for design purposes. Egon Tons of the University of Michigan suggests[15] a multiplication factor of 1.7.
3. The actual service temperatures of the materials being joined, not the ambient range, must be used in calculating joint movements.
4. Where units to be joined are of dissimilar materials, they may not be at the same surface temperature and the appropriate coefficient for each material must be used in calculating its contribution to the joint movement. Differential movements resulting from this may, depending on the joint configuration, result in secondary strains in the sealant.
5. Where knowledge exists of actual movements that have occurred in similar joints in similar structures under similar service conditions, these should be used in the new design to supplement those indicated by theory alone.
6. Allowance must be made for the practical tolerances that can be achieved in constructing joint openings and positioning precast units.
7. In butt joints, the movement to which the sealant can properly respond is that at right angles to the plane of joint faces.
8. The width of the joint sealant reservoir must always be greater than the movement that can occur at the joint.
9. When viewing a structure, the joints, either sealed or unsealed, are readily noticeable. It is, therefore, desirable to either locate and construct them as a purposeful feature of the architectural design or to conceal them by structural or architectural details.

4.8 Selection of butt joint widths for field-molded sealants

The selection of the width and depth of field-molded sealants, for the computed movement in a joint, is based on

Table 3. Preformed materials used for waterstops, gaskets, and miscellaneous sealing purposes

Composition and type	Properties significant to application	Available in	Uses
Butyl—conventional rubber cured	High resistance to water, vapor and weathering. Low permanent set and modulus of elasticity formulations possible, giving high cohesion and recovery. Tough. Color—black, can be painted.	Beads, rods, tubes, flat sheets, tapes and purpose-made shapes.	Waterstops. Combined crack inducer and seal. Pressure sensitive dust and water sealing tapes for glazing and curtain walls.
Butyl—raw, polymer-modified with resins and plasticisers	High resistance to water, vapor and weathering. Good adhesion to metals, glass, plastics. Moldable into place but resists displacement. Tough and cohesive. Color—black, can be painted.	Beads, tapes, gaskets, grommets.	Glazing seals, lap seams in metal cladding. Curtain wall panels.
Neoprene—conventional rubber cured	High resistance to oil, water, vapor and weathering. Low permanent set. Color—basically black but other surface colors can be incorporated.	Beads, rods, tubes, flat-sheets, tapes, purpose-made shapes. Either solid or open or closed cell sponges.	Waterstops, glazing seals, insulation and isolation of service lines. Tension-compression seals. Compression seals. Gaskets.
PVC (polyvinyl chloride) Extrusions or moldings	High water, vapor, but only moderate chemical resistance. Low permanent set and modulus of elasticity formulations possible, giving high cohesion and recovery. Tough. Can be softened by heating for splicing. Color—pigmented black, brown, green, etc.	Beads, rods, tubes, flat sheets, tapes, gaskets, purpose-made shapes.	Waterstops, gaskets, combined crack inducer and seal.
Polyiso-butylene-non-curing	High water, vapor resistance. High flexibility at low temperature. Flows under pressure, surface pressure sensitive, high adhesion. Sometimes used with butyl compounds to control degree of cure. Color—black, grey, white.	Beads, tapes, grommets, gaskets.	Gaskets, glazing seals. Curtain wall panels. Acoustical partitions.
SBR (styrene butadiene rubber) NBR (nitrile butadiene rubber) and polyisoprene—polydiene—conventional rubber cured	High water resistance. NBR has high oil resistance.	Beads, rods, flat sheets, tapes, gaskets, grommets, purpose-made shapes. Either solid or cellular sponges.	Waterstops.



Note: (i) *if dmax is less than ½ in. (12.7 mm.) sealant may, with age lose extensibility. Redesign joint system.*

(ii) *sealant free to assume parabolic shape on both faces.*

(iii) *factor of safety of 4 should be used in applying this chart*

Fig. 4.8.1. Selection of dimensions for field-molded sealants in butt joints (Courtesy: American Concrete Institute)

the maximum allowable strain in the sealant. This occurs in the outer fibers, usually when the sealant is extended, though in some cases maximum strain may occur while the sealant is compressed. The part of the total movement which extends the sealant is that which increases the width of the joint at the time the sealant is installed to the width of the joint at its maximum opening. The temperature difference between that at installation and at maxi-

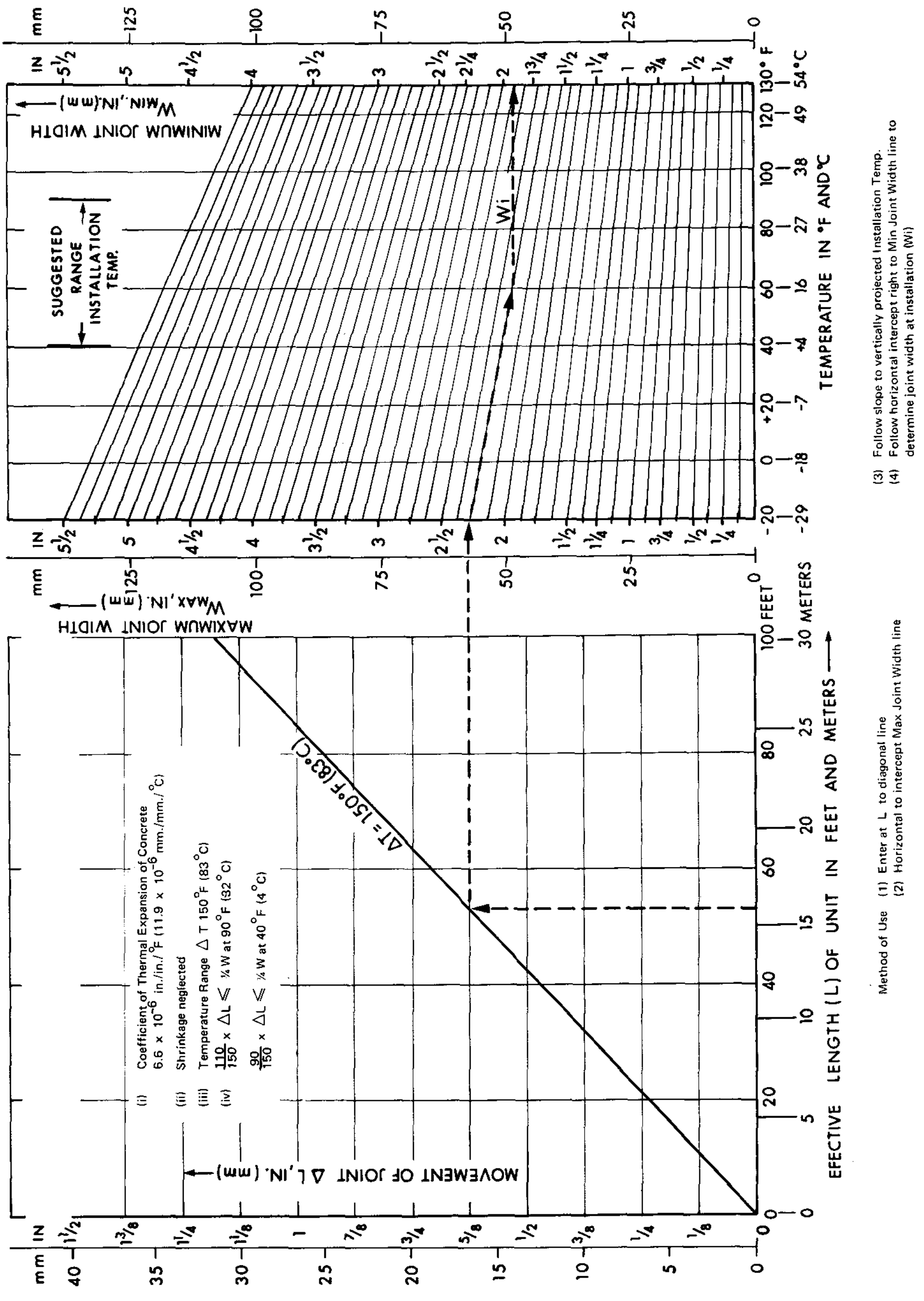


Fig. 4.8.2. Chart for determining joint movements and width; field-molded sealants (Courtesy: American Concrete Institute)

mum opening is the main contribution to the extension of the sealant; but any residual drying shrinkage of the concrete that has yet to occur, and shrinkage in the sealant as it sets or cures, will also impose additional extension on the sealant.

When the suitability of a new joint sealant is first being considered, and a precise determination of the dimensions of the sealant reservoir is required, the approach using Fig. 4.8.1 may be followed. The curves relate the maximum allowable strain in a sealant to an assumed joint width and various shape factors. First, the maximum allowable strain for the sealant under consideration must be determined by testing at a specified temperature. Usually this temperature is 0 F (−18 C) and the test is performed in accordance with the requirements of Federal Specification SSR-406-C. Next, a likely approximation to the joint width is assumed, and the linear extension and compression that the sealant will experience, as related to the installed width, are then calculated.

The various curves then permit the computed extension and shape factor to be interrelated so that the maximum allowable strain will not be exceeded. More than one solution is usually possible and, where the upper limits of the curves are approached, a wider assumed joint width should be tried. In practice, a safety factor of four should be applied in using this chart to allow for unforeseen circumstances.

The detailed procedure of Fig. 4.8.1 is simplified for practical use by using the percentage extension-compression shown in Table 1 for each group of sealants. This figure has been developed through consideration of the maximum allowable strains for materials in the group and application of the suggested safety factor. The percentage extension-compression of the sealant is the percentage increase or decrease of the installed width of the sealant that can be safely accommodated as the joint subsequently opens and closes. The width of the joint to be formed, which becomes the sealant mold and thus determines the sealant width as installed, can then be obtained by a simple calculation so that the permissible extension-compression range is not exceeded in service. This calculation should, of course, consider the anticipated temperature at the time of forming the joint, the temperature at sealant installation, and any additional joint opening caused by drying shrinkage of the abutting concrete units as well as by the extremes of service temperature.

When the joint width is designed, a precise installation temperature cannot usually be known or specified; otherwise, an intolerable restriction would be placed on the installation operation. Normally a general installation temperature range is specified. This can be done safely by checking the dimensional range under the worst temperature circumstances for installation; for extension the top of the range is used, and for compression the bottom of the range. A practical range of installation temperatures is assumed for this and other factors, such as moisture condensation at low temperatures and reduced working life at high temperatures, to be from 40 to 90 F (4 to 32 C). Generally, because the tension condition, as the joint opens with a decrease in temperature, is the most critical in sealant behavior, joint sealants installed at the low end of this range may be expected to perform best. A warning note should be included on the plans that, if sealing must take place for any reason at temperatures above or below the specified range, then a wider than specified joint may have to be formed, or changes in the type of sealant or shape factor may be required to secure greater extensibility.

Detailed calculations for selection of

the joint width for sealants with an expansion-compression range of ± 25 percent (which is the most common one for the widely used class of thermosetting, chemically curing sealants) can be dispensed with by the use of Fig. 4.8.2. Where a reasonable joint width (see Section 4.11) is not possible by either of the above considerations or by those that follow in Section 4.9 as to sealant depth, the proposed joint layout for the structure must be redesigned to produce movements tolerable to sealant.

4.9 Selection of butt joint shape for field-molded sealants

When a suitable joint width has been established (see Section 4.8), the appropriate depth for the sealant reservoir must be determined so that the sealant has a good shape factor.[16] Fig. 4.8.1 can be used for this purpose. Curves for depth-to-width ratios of 1:1, 2:1, and 3:1 are shown on this chart. Any depth-to-width ratio may be used provided that the maximum allowable strain is not exceeded at the computed extension or compression expected in the sealant. The benefits in both better performance and economy of material by using the smallest possible depth-to-width ratio have already been discussed in the preceding section. In general, the depth of sealed joints should not exceed joint width and that on wide joints (up to say 4 in.) depth at midwidth should not exceed ½ in., with concave shape giving greater thickness at panel faces. The depth of sealant is controlled by using a suitable backup material as described in Section 4.3.3. To obtain full benefit of a well-designed shape factor, a bond breaker must be used behind the sealant (see Section 4.3.2).

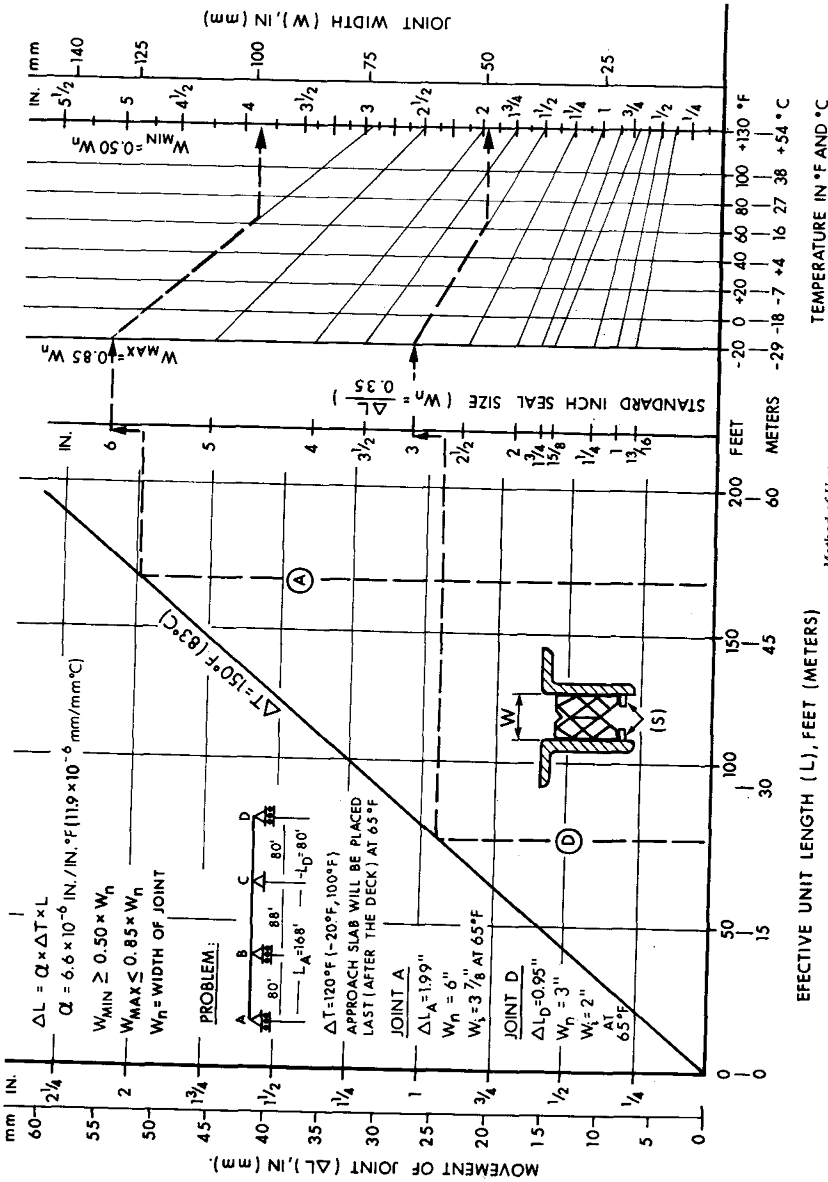
4.10 Selection of size of compression seals for butt joints

A positive contact pressure must be exerted against the joint faces at all times for compression seals to function properly. The development of suitable seal configurations to achieve this, while following the principles explained by Dreher,[18] has been largely based on the results of trial and error laboratory and field experiments in both America and Europe.[17,19] Neoprene compression seals must remain compressed approximately 15 percent of the uncompressed seal width at maximum joint opening to maintain sufficient contact pressure for sealing and to resist displacement; generally, not more than 55 percent of the uncompressed seal width is permitted at maximum closing to prevent overcompression. For larger sizes of compression seals, the 55 percent value may be exceeded. The allowable movement is thus approximately 40 percent of the uncompressed seal width. The allowable movement for impregnated foams is much less, about 5 to 20 percent.

The critical condition exists when the joint is fully open at low temperature since compression set or lack of low temperature recovery may adversely affect sealant performance. The principle of size selection is similar to that for field-molded sealants in that the original uncompressed width of seal is required to maintain the seal within the specified compression range considering the installation temperature, width of formed opening, and the expected movement. A simplified chart applicable to the conditions specified in this section is shown in Fig. 4.10.1.

4.11 Limitations on butt joint widths and movements for various types of sealants

Field-molded sealants generally require a minimum joint width of ¼ in. (6.4 mm) to provide an adequate reserve against loss of material due to extrusion or to accommodate unexpected service conditions.



Notes:

(1) Based on compression range of 15 to 50 percent of uncompressed seal width (may vary with seal size and manufacturer).

(2) Depth of seal governed by specific manufacturer's design. This and inset required for the seal below the open surface of the joint, determines position of support shoulders (S) to underside of seal.

Method of Use:

(1) Enter at Effective Length L to Diagonal Line.

(2) Horizontal to intercept standard inch seal size line.

(3) Vertical to next standard seal size (no direct metric equivalent).

(4) Follow slope to vertically projected installation temperature.

(5) Horizontal intercept at right gives joint width into which selected size of seal should be installed to maintain specified compression range.

Fig. 4.10.1. Chart for determining joint movements and width, or for selecting seal size; compression seals (Courtesy: American Concrete Institute)

The upper limit of joint width and permissible movement varies with the type of material used. Mastic, thermoplastic, and thermosetting, solvent release sealants may be used in joints up to 1½ in. (3.8 cm) wide with a permissible movement not exceeding ¼ in. (6.4 mm). Thermosetting, chemically-curing materials have been used in joints up to 4 in. (10.2 cm) wide with movements in the order of 2 in. (5.1 cm), though it is more usual to confine them to joints of half that size to ensure good performance and economy in materials. In wide joints, increasing care with sealant installation is necessary and, where subject to traffic, protection of the upper surface against damage with a steel plate or other means is required.

4.12 Lap joint sealant thickness

Shear governs sealant behavior in lap joints and its magnitude is related to both the movement that occurs and the thickness of the sealant between the two faces. For installations made at normal temperatures of 40 to 90 F (4 to 32 C), the thickness of the sealant should be at least one half the anticipated movement and, where higher or lower temperatures prevail at installation, the thickness of the sealant should be equal to the anticipated movement. Where there will be no movement, the sealant thickness can be as little as 1/16 in. (1.6 mm). However, in assembling concrete units, a minimum thickness of ½ in. (12.7 mm) is desirable to compensate for casting tolerances or any irregularities in the faces.

REFERENCES

1. "Weathertight Joints for Walls," CIB Symposium, Oslo, Norway, Norwegian Building Research Institute, 1967.
2. Bishop, D., "Weatherproofing Joints Between Precast Concrete Panels," Building Research Station, United Kingdom, *The Builder,* Jan. 5, 1962.
3. Latta, J. K., "Precast Concrete Walls–A New Basis for Design," *Canadian Building Digest #93,* National Research Council, Ottawa, Canada, September 1967.
4. Garden, G. K., "Rain Penetration and its Control," *Canadian Building Digest #40,* National Research Council, Ottawa, Canada, April 1963.
5. Garden, G. K., "Look at Joint Performance," *Canadian Building Digest #97*, National Research Council, Ottawa, Canada, January 1968.
6. Malstrom, P. E., "Jointing Problems in Facades," Fifth International Congress of the Precast Concrete Industry, London, England, British Precast Concrete Federation, May 1966.
7. *PCI Design Handbook, Precast and Prestressed Concrete,* Prestressed Concrete Institute, Chicago, Illinois, 1971.
8. "Aspects of Design in Concrete," Seminar for Architects, Cement & Concrete Association, London, England, 1971.
9. "The Weathering of Concrete," *Proceedings,* Symposium, Royal Institute of British Architects, The Concrete Society, London, England, 1971.
10. "Guide to Joint Sealants for Concrete Structures," ACI Committee 504, *ACI Journal,* Proceedings, Vol. 67, No. 7, July 1970, pp. 489-536.
11. Karpati, Klara K., "Literature Survey of Sealants," *Journal of Paint Technology,* Vol. 40, No. 523, Aug.

1968, pp. 337-347.

12. de Courcy, J. W., "Movement in Concrete Structures," *Concrete* (London), Vol. 3, No. 6, June 1969, pp. 241-246; No. 7, July 1969, pp. 293-297; and No. 8, August 1969, pp. 335-338.
13. "Causes, Mechanism, and Control of Cracking in Concrete," SP-20, American Concrete Institute, Detroit, Michigan, 1968, 246 pp.
14. Hall, Kenneth F., Ritzi, Jack H.; and Brown, Delmont D., "Study of the Factors Governing Contact Pressure Generating in Neoprene Preformed Compression Seals," *Highway Research Record 200,* Highway Research Board, 1967.
15. Tons, Egon, "A Theoretical Approach to Design of a Road Joint Seal," *Bulletin No. 229,* Highway Research Board, 1959, pp. 20-44.
16. Schutz, Raymond J., "Shape Factor in Joint Design," *Civil Engineering,* Vol. 32, No. 10, October 1962, pp. 32-36.
17. Watson, Stewart C., "Compression Seals for Bridges," *ACI Journal,* Proceedings, Vol. 65, No. 9, September 1968, pp. 721-729.
18. Dreher, D., "A Structural Approach to Sealing Joints in Concrete," *Highway Research Record 80,* Highway Research Board, 1965, pp. 57-73.
19. *PCI Manual on Architectural Precast Concrete,* Prestressed Concrete Institute, Chicago, Illinois, 1973.

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