THE FORMATION OF TWO-STAGE JOINTS

PROF. DR. E. CZIESIELSKI
Technical University Berlin

1. Methods of joint sealing for exterior walls

The problem of the formation and the sealing of joints has become increasingly significant due to the application of industrial construction methods, especially in the area of exterior wall structures. The demands placed on such joints are essentially the following:

1. The joint sealing must permanently prevent the penetration of precipitation water and wind.
2. It must represent a connection between the walls which is aesthetically, practically, technically, and economically satisfactory.
3. The joint sealing must be resistant over a long period of time.
4. The joint sealing must be able to be performed independently of weather conditions.
5. The joint design must allow movements due to temperature variations, moisture changes, and ground deformations.
6. It must be able to compensate for production and assembly tolerances, as well as for tolerances between precast members and components manufactured at the building site.

Independently of the type of construction and of the building materials used, the following methods for sealing of joints are employed today in the area of exterior walls in aboveground construction (see fig. 1):

a. Sealing joints with mastic (fig. 1a)

Advantages: universally applicable, minimal demands placed on the wall structure.

Disadvantages: sensitive to tolerances, dependence on weather conditions during emplacement, short lifetime.

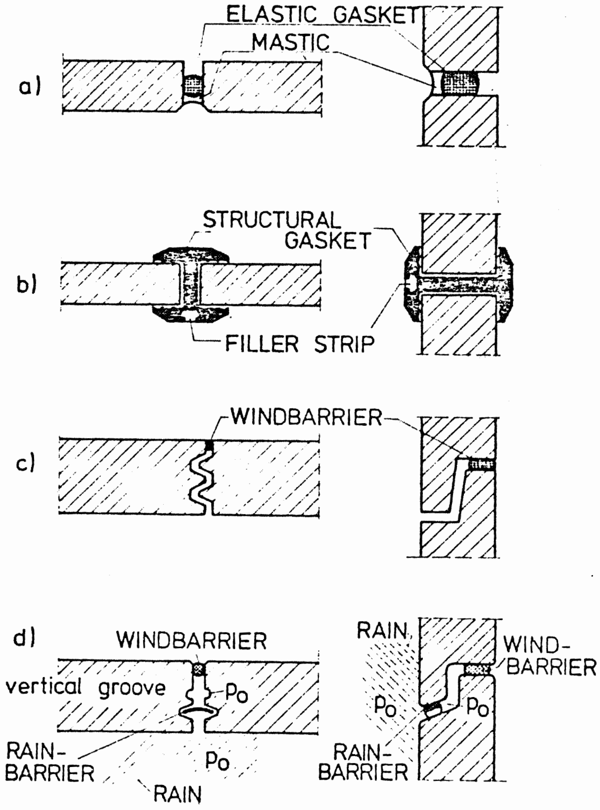

Fig. 1 Principal methods of joint sealing

a. Sealing with mastic
b. Sealing with structural gasket
c. Sealing by specially-shaped walls
d. Two-stage joints

b. Sealing joints with structural gaskets (fig. 1b)

Advantage: emplacement not dependent on the weather.

Disadvantages: sensitive to tolerances, not universally applicable.

c. Formation of joints without sealing compounds--for joints that eliminate the entry of precipitation water by means of their mode of construction alone (fig. 1c).

Advantages: long lifetime, emplacement not dependent on the weather.

Disadvantages: difficult form of the lateral wall edges (especially with precast concrete construction); problems due to damages to the lateral wall edges during transportation and emplacement; the impracticability of formation of vertical joints due to the necessity of directionally-dependent assembly (the horizontal joints, on the other hand, are practicable and are therefore of importance in construction).

d. Two-stage joints (fig. 1d)

Characteristics of the two-stage joints: a profiling of the lateral wall edges, in groove form, is performed. Once the wall elements have been assembled, a rain barrier is placed in the vertical grooves on each floor. This is performed at the construction site. The rain barrier prevents the direct entry of rainwater into the interior of the rooms. It is emplaced in the wall grooving in such a way that it can move and thereby allow for an unhindered movement of the walls themselves. Depending on the constructional formation of the joint, a space created by the profiling of the wall is located behind the rain barrier (fig. 1d), or at the level of the rain barrier (fig. 3)--the pressure equalizing space. In the area of the open horizontal joint, the vertically running pressure equalizing space leads to the outdoor air. By means of this connection between the space and the outside, a pressure difference Δp is prevented between the space behind the rain barrier and the outdoor air. Without a pressure difference, however, rainwater cannot be driven around the rain barrier to the interior of the rooms. The joint is therefore impervious to precipitation water.

In addition, the pressure equalizing space functions similarly to a labyrinth waterstop. Individual raindrops that manage to pass the rain barrier (for example, by means of their kinetic energy) are led off vertically downward in the pressure equalizing space. They pass off in the area of the open horizontal joint.

A wind barrier (heat insulation) must be located in the area of the joint, in proximity to the interior of the rooms. The wind barrier prevents cold air from entering into the interior of the rooms. The tightness of vertical joints constructed along these principles has been proven in the various and different laboratories of Norway, Poland, Hungary, Rumania, and Germany. Furthermore, this type of joint formation has shown exceptionally good service for over twenty years (1, 2). Long-term failure with this type of joint formation is therefore impossible, since the tightness of the joint depends entirely on the formation of the lateral wall edges and on the permanence of the rain barrie Resistant plastic material is employed for the construction of the easily-exchangeable rain barriers (neoprene, etc.).

Advantages: not sensitive to tolerances, not sensitive to unforeseen movements of the building mass (ground settling, earthquakes, etc.); emplacement not dependent on the weather; long life.

Disadvantage: labor necessary for the preparation of the lateral wall edges.

2. The practical constructional emplacement of two-stage joints

2.1 Evaluation of the various sealing principles

It is difficult to recommend joint formation and sealing which optimally satisfy all the demands placed on them. According to the latest in technology, however, it can be claimed that two-stage joints come closest to fulfilling the requirements placed. Judging from experience already gained, they in addition provide the greatest long-term protection against lateral rain penetration. Research conducted in Germany by manufacturers of two-stage joints with information tabulated on project location, extent of damage occurring, and cause of such damage, resulted in the finding that from approximately 1,000 km of joint length installed, not even one meter of damage due to rain penetration could be determined. The oldest joint construction independently tested by random sample by the Technical University in Berlin is fifteen years old. It must be emphasized, however, that aging influences on the tightness of two-stage joints are practically nonexistent.

In contrast, research conducted by Grunau (2) for the years 1958 to 1965 resulted in determination of a failure rate with joints sealed with sealing compound (mastic) at the extremely high level of 31%. The failure rate for the years 1970 to 1975 decreased, to be sure, but remained at a level of 11%. The relatively high occurrence of such failures resulting in damages continuing at this level despite advances made in sealing compound composition can be traced to the difficulties involved in emplacement of the sealing, and to sensitivity to the unavoidable tolerances encountered in the construction business.

2.2 Examples of two-stage joint employment

The following method of forming joints has proved reliable in the construction business: the vertical joints are carried out in the two-stage mode, and the horizontal joints are formed as open, sill-type joints (see fig. 1c).

Fig. 2 shows a two-stage joint in a precast concrete exterior wall, in which the profiling necessary for the joint has been made dirctly in the concrete. Fig. 3 also shows a two-stage joint for a concrete sandwich wall, in which the forming of the lateral wall edges has been accomplished by means of plastic profile pieces embedded in the concrete. The plastic profiles are emplaced in the precast concrete walls during their manufacture. In this manner, expensive form work can be avoided in the manufacture of the precast concrete walls. The formwork can be removed sooner from the wall elements, there is no necessity for a larger series of element production as with construction corresponding to fig. 2, and the danger of damaging the wall elements during transportation and assembly is greatly reduced.

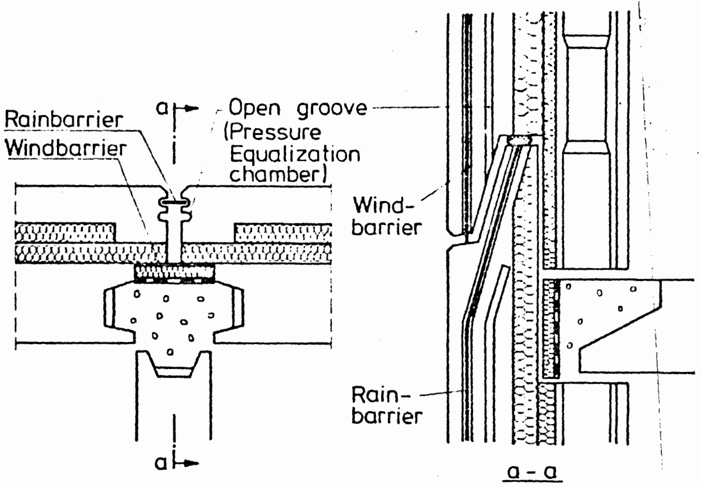

Fig. 2 Employment of two-stage joints with concrete sandwich walls. The profiling is performed directly on the concrete.

Fig. 4 shows a joint construction for ventilated cladding of aluminium.

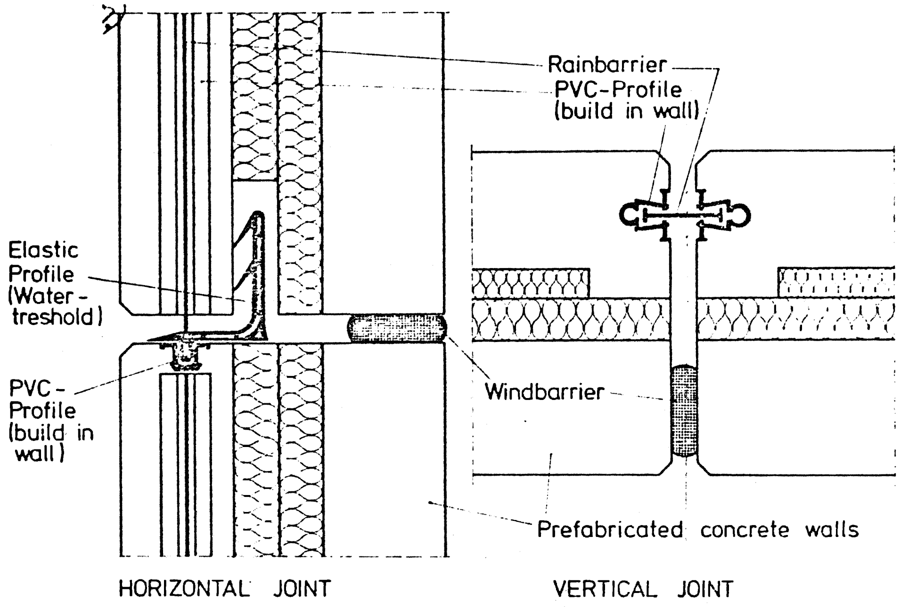

Fig. 3 Two-stage joint construction in a concrete sandwich wall element, with embedded plastic profile pieces.

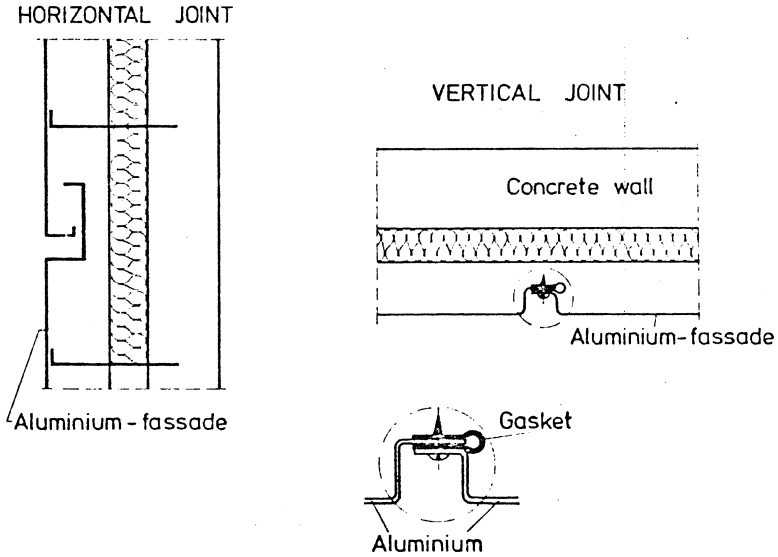

Fig. 4 Joint formation for ventilated cladding

2.3 Rain tests

Joint permeability to rain is measured in rain tests. It is difficult to conduct the tests in such a way that actual, natural climatic conditions are exactly simulated. At the present, there are two basic test methods used for checking of permeability to rain (see fig. 5):

a. the static method;
b. the dynamic method.

New test methods are at present being worked out in England as well as in Germany for the preparation of ISO standards, in order that methods are available for the conduction of tests which simulate the natural weather conditions.

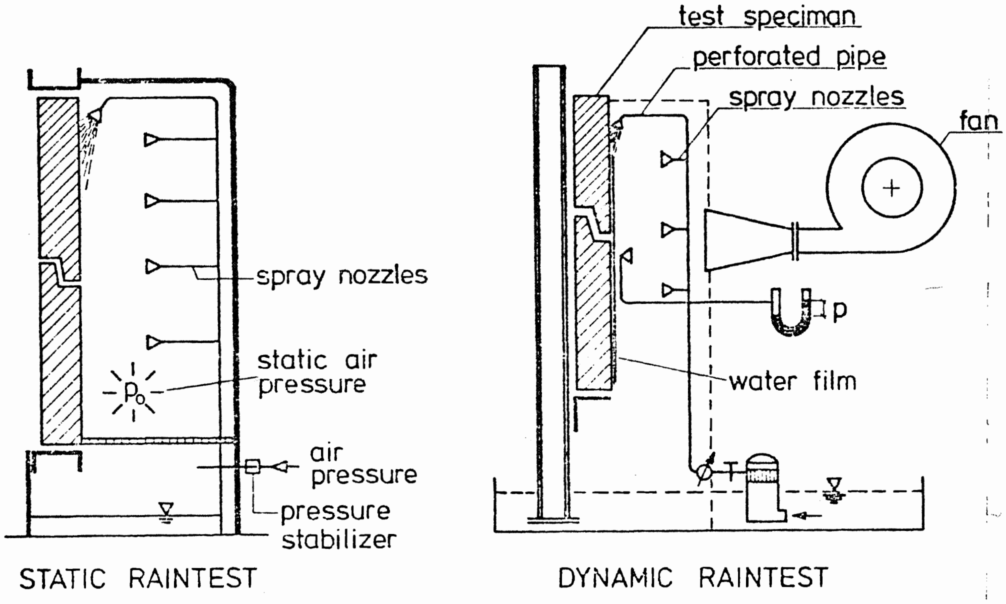

Fig. 5 Rain tests for two-stage joints

a. static method
b. dynamic method

The permeability of the joint construction depicted in figs. 2-4 has been tested by experiments according to the dynamic method as well as the static method. The positive test results from the laboratories have been confirmed by similar positive experience after years of practical use.- In order to check the effectiveness of individual constructional configurations, it has proven useful and valid to build plexiglass models of joint constructions to the scale of 1:1 for laboratory testing. Permeation of water into the joints could be observed exactly, especially for the testing according to the dynamic method. On the basis of such observations, the plastic profile piece shown in fig. 3, for example, was developed for use in the area of the horizontal joint. It was conclusively proven by the tests that the two horizontal seals effectively prevent entry of rainwater, and that the otherwise necessary sill height (see fig. 2) of $h \geqq 100$ mm could be reduced.

The behavior of the plastic profile pieces embedded in the walls (fig. 3) has been tested in a "rain test carrousel"(fig. 6).

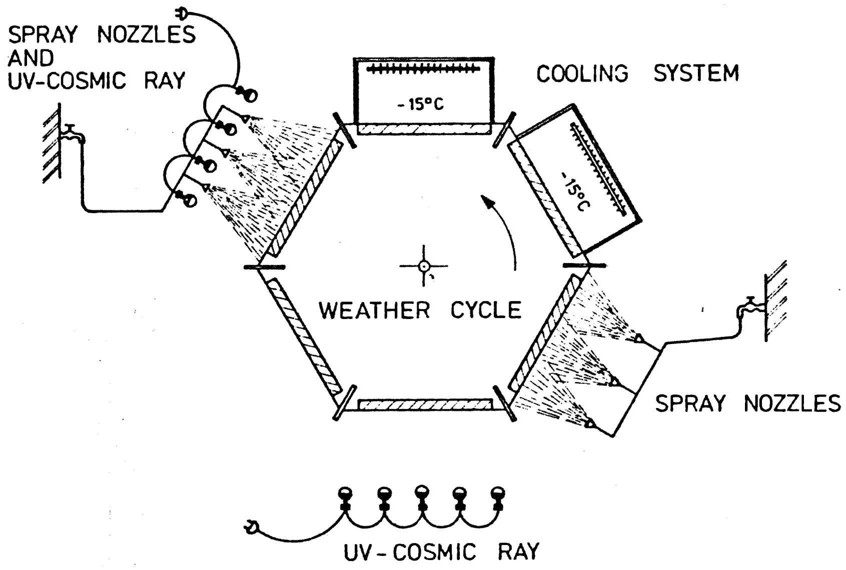

Fig. 6 Weathering cycles to check weather resistance of joint designs.

After 50 weathering cycles with harsh variations from frost to thaw, no aging of the PVC plastic profiles was observed. There was likewise no observation made of any structural loosening, nor of any reduced adhesion between the joint profiles and the concrete.

2.4 Wind permeability of two-stage joints

The wind permeability of joints is important when consideration is made of heat loss and drafts. As a rule, joints are formed in such a way that a wind-tight construction is located behind the joints, to the side of the room interior (see figs. 2 and 4). In industrial construction, however, one often finds construction of joints to correspond to fig. 3, in which the entry of cold air must be stopped by means of a wind barrier alone. The cold air can pass the wind barrier in two ways: a. through the material of the wind barrier, or b. at the contact points between wall and wind barrier. In order to examine the influence of various parameters on wind permeability, the a-value of constructional joints between precast concrete elements was tested according to DIN 18055, sheet 2 (German Industrial Standards, corresponding to EN 86).

$$a = \frac{V}{l \cdot (\Delta p)^n} = \left[\frac{m^3}{h \cdot m \cdot (N/m^2)^n} \right]$$

with:

V quantity of air passing the wind barrier, in $[m^3/h]$

h unit of time

l joint length, in

Δp pressure difference between outside air and the building interior $[N/m^2]$

The following parameters were varied in the course of the trials:

1. Material of the wind barrier (PU foam, PE foam, rock wool, foamed plastic sealing impregnated with wax)
2. Roughness of the wall surfaces (smoothed, exposed concrete; washed concrete with particle sizes 2-4 mm, 4-8 mm, and 8-16 mm)
3. Joint width (b = 10 mm, 15 mm, and 20 mm)
4. Conical joints (taper: 10 mm/1 m)

The relationships shown in fig. 7 were determined by the evaluation of the test results and the determination of the a-value characteristic of the joint construction. Linearity (fig. 7, curve a) was observed for smooth or for only very slightly rough concrete, and for "elastic" wind barriers, which fit tightly against the concrete surfaces. In this case, the air transit took place primarily through the wind barrier.

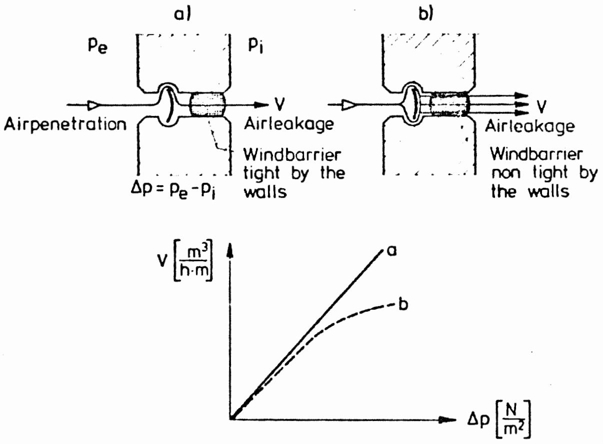

Fig. 7 Air transit in the area of the wind barrier

a. air transit through the wind barrier alone

b. air transit through the wind barrier and at the points of contact between wind barrier and wall

With "rigid", closed-celled wind barriers as well as with "rough" lateral wall surfaces, nonlinearity (fig. 7, curve b) was observed. The type of relationships characterized by curve a are, however, generally the rule observed in construction work.

With respect to the materials investigated for the wind barrier, it was determined that all materials proved suitable for such use. For joint widths greater than 20 mm, however, the proportion of air passing through the wind barrier of rock wool was so great ($a \geq 0.5$) that an especially thick plugging had to be performed in the joint to increase the resistance to the air stream. The advantage enjoyed with the rock wool lies in the relatively easy emplacement and the fire protection achieved in the area of the joint.

The following influences are significant for the wind permeability of a joint:

a. The volume of the material employed (resistance to the air stream);

b. Compression of the material (tightness at the points of contact between wall and wind barrier).

An a-value of $a \leq 0.25\ m^3/(h \cdot m \cdot kp/m^2)$ can also be assumed for conical joint configurations (building tolerances) up to joint widths of 20 mm and with conventionally smooth joint walls. As a rule, this value includes a sufficient safety factor against building tolerances and improper procedures. For joint widths up to $b = 30$ mm, a value of $a \leq 0.25$ can be employed only with closed-cell PE foam with compression to 75% of its original width. Without consideration of further factors, an a-value of $a \leq 0.50$ can be assumed for joint widths $b > 20$ mm. The width of the emplaced and compressed wind barrier must hereby be greater than 2.5 times the width of the joint.

In order to estimate the influence of the wind permeability on heat requirements, the total heat requirement for the building shown in fig. 8 was calculated according to DIN 4701. If the total heat requirement without consideration of the exterior wall joints is set at 100%, then the heat loss of the exterior wall joints with respect thereto (with $a \leq 0.25$) amounts to approximately 1%. This result confirms basically the practised convention in calculating heat requirements, of disregarding the influence of wind permeability of two-stage joints.

Horizontal and vertikal joints see illustration 3

Heat requirement: Without joints $Q = 100\%$
With joints $Q' = 1{,}01\ Q$ ($a = 0{,}25$ kcal/h·m kp/m^2)

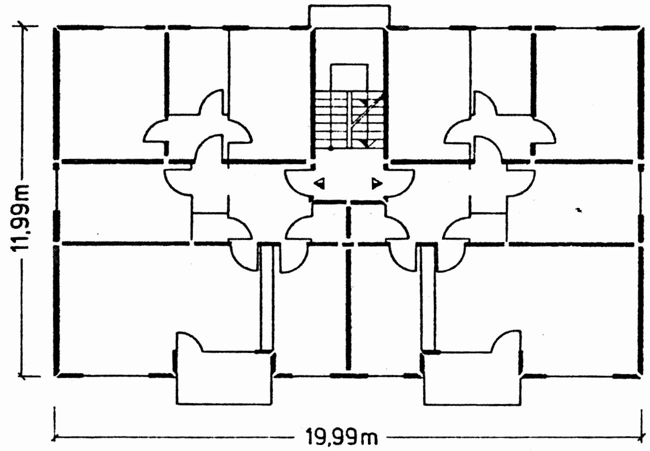

Fig. 8 Layout of a three-story building

3. Summary

It is difficult to find an optimal joint construction for the building industry. Based on experience gained to date, however, the two-stage joint seems to offer the greatest advantages. These are long life, lack of need for maintenance, lack of sensitivity to tolerances, extensive lack of sensitivity to faulty installation practice, and installation independent of the weather.

Typical implementation examples of two-stage joint construction are represented in figs. 2-4.

Tests confirm that the wind permeability of two-stage joints can be practically disregarded in the determination of heat requirements.

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