drops 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 building. The tightness of vertical joints constructed along these principles has been proven in various laboratories in Norway, Poland, Hungary, Rumania, and Germany. Furthermore, this type of joint formation has shown exceptionally good service for over twenty years. 1+3 Long-term failure with this type of joint formation is actually impossible, since the tightness of the joint depends entirely on the formation of the lateral wall edges and on the permanence of the rain barrier. 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.

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

Fig. 4 shows a two-stage joint in a precast concrete wall, in which the profiling necessary for the joint has been made directly in the concrete. Fig. 5 and 6 also show 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 sections embedded in the concrete during 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 long production runs as there is for the type of construction shown in Fig. 4, and the danger of damaging the wall elements during transportation and assembly is greatly reduced. In the case of horizontal joints, a flexible section (water threshold) is emplaced on the building site in the concrete-embedded PVC seal. The junction points of this seal are bonded or are closed by another special plastic profiled member. In the area of the vertical joint, the rain barrier is inserted storeywise from the last-installed floor slab without any requirement for special equipment.
Figures 7 and 8 show details with joint sections.
The behaviour of the plastic seals embedded in the

walls (Fig. 5) has been tested in a "carousel" (Fig. 9).

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

THERMAL PROTECTION

Introduction

Heat exchange between a heated interior and outside air takes place 1) through conduction (heat transmission) and 2) by means of air escaping through gaps in the joints (heat convection).

Heat Loss through Transmission (conduction)

As a rule exterior joints are filled with insulating material. The influence of compression on the heat conduction value λ is diagrammed in Figure 10. From this curve we may conclude that for all practical cases, the influence of joints on heat loss by conduction is generally so small as to be negligible (Fig. 11).

Heat Loss through Joints

The wind permeability of joints is important when considering heat loss and drafts.
The entry of cold air must be stopped by means of a wind barrier (Fig. 4 or 5). The cold air can pass the wind barrier in two ways: through the material of the wind barrier, or 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 German Industrial Standard DIN 18055, sheet 2 (corresponding to EN 86).

$$a = \frac{V}{l.(\Delta p)^n} \qquad \left[\frac{m^3}{h.m.(Pa)^n}\right]$$

With:

V = quantity of air passing the wind barrier, in m^3/h
h = unit of time
l = joint length, in m

Δp = pressure difference between outside air and the building interior [Pa]

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 / 1m)

The relationships shown in Fig. 12 were determined by the evaluation of the test results and the determination of the a-value characteristic of the joint construction. Linearity (Fig. 12, 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.

With "rigid", closed-celled wind barriers as well as with "rough" lateral wall surfaces, nonlinearity (Fig. 12, 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 ($a \leq 0.5$) that an expecially 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 in 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 $a \leq 0.25\ m^3/(h\ m\ kp/m^2)$ 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. 13 was calculated according to German Industrial Standard 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.

INFLUENCE OF JOINTS ON SOUNDPROOFING OF EXTERIOR WALLS

The sound-insulating characteristics of an exterior wall depend on both wall materials and joints. The following factors influence the sound-insulating characteristics of joints:

a. Width of joint (b = 5 - 30 mm)

b. Number of joint seals (n = 1 or 2)

c. Compression of joint seals

d. Material of joint seals

Figure 14 shows the sound-insulating characteristics of a 20 mm wide joint with respect to frequency; of interest here is the sudden drop that occurs at a frequency of 1000 Hz (3). The curves shown in Figure 14 are evaluated in the following figure, in which sound-insulation values are plotted against compression (Figure 15). Here it is obvious that sound insulation improves with increasing compression of the seal, whereas at a constant compression, sound insulation decreases with increasing joint width.

The improved sound-insulating qualities that can be gained by the use of two joint seals rather than one are illustrated in Figure 16. Here the favorable influence of compression is particularly obvious.

The acoustic influence of a continuous joint on the overall sound-insulation value of a wall with an area of A = 4 x 2.5 = 10 sq.m. is given in Figure 17. When seals of high soundproofing value are used (K = 1:4), the influence of joints on walls with low insulating values (R_o = 40 and 45 dB) is inconsiderable, since the insulating value of the joint approaches that of the wall. The greater the difference between the insulation values of wall and joints, the more influence the joints will have on overall sound insulation.

FIRE PROTECTION

The influence of joints on the fire resistance of exterior walls can be determined by experiments of the type described in the ISO 834 standard, or by those set forth in national norms. A number of experiments in the past have shown that joints plugged with asbestos rope or foam do not adversely affect the fire resistance times of fire-resistant walls (F 90). When applying such test results in practice it is particularly important that the joint-seal compression figures used in the test be held to during construction. Figure 18 represents a joint that is filled with asbestos foam.

EVALUATION OF THE VARIOUS SEALING PRINCIPLES

It is difficult to recommend joint types and seals which optimally satisfy all the demands placed on them. According to the latest results, however, it can be claimed that two-stage joints come closest to fulfilling the requirements. Judging from experience already gained, they in addition provide the greatest longterm protection against lateral rain penetration. Research conducted in Germany by manufacturers of two-stage joints in which they collected data on project location, extent of damage, and cause of such damage, resulted in the finding that of 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 of Berlin is fifteen years old. It must be emphasized, however, that aging has practically no effect on the tightness of two-stage joints.

By contrast, research conducted by Grunau (z)for the years 1958 to 1965 resulted in determination of a failure rate of joints sealed with sealing compound (mastic) at the extremely high level of 31%. Though the failure rate for the years 1970 to 1975 decreased, it still remained at a level of 11%. The relatively high occurrence of such failures resulting in damages, despite advances made in sealing compound composition, can be traced to the difficulties involved in fitting the seal, and to sensitivity to the unavoidable tolerances encountered in the construction business. This drawback can be effectively countered by sealing joints with tapes cemented to the wall surfaces. In this type of seal wear and tear due to expansion and compression is largely avoided, thus increasing the durability of the joint considerably.

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(2) Grunau, E. 1976. Lebenserwartung von Dichtstoffen im Hochbau. Das Baugewerbe. Issue 5.

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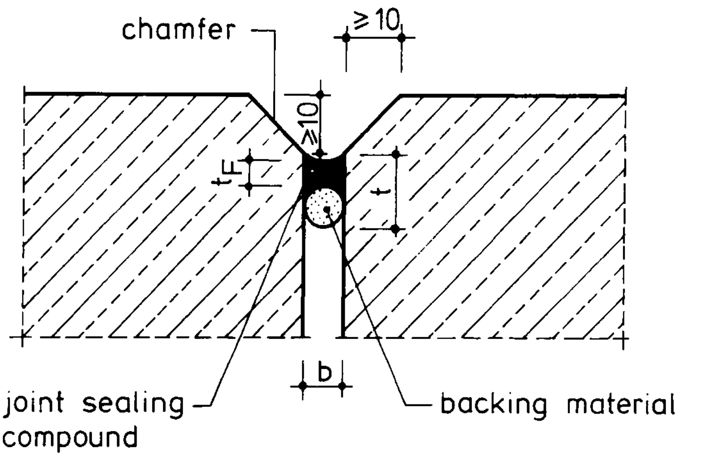
Table 1

Dimension of Joint Seals

Sealing Compound and Prefabricated Concrete Walls

Joint interval in m	Nominal value for b (planning) in mm	Req. min. joint width in mm	Thickness of seal t_f in mm
up to 2 m	15	10	8
2-4	20	15	10
4-6	25	20	12
6-8	30	25	15



t_F in the thickness of the joint sealing compound

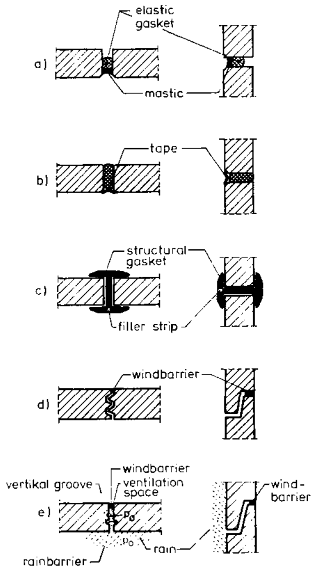


Fig. 1--Principal methods of joint sealing
(a) Mastic seal
(b) Tape seal
(c) Sealing by means of structural gaskets
(d) Sealing by means of special wall profiles
(e) Two-stage joint

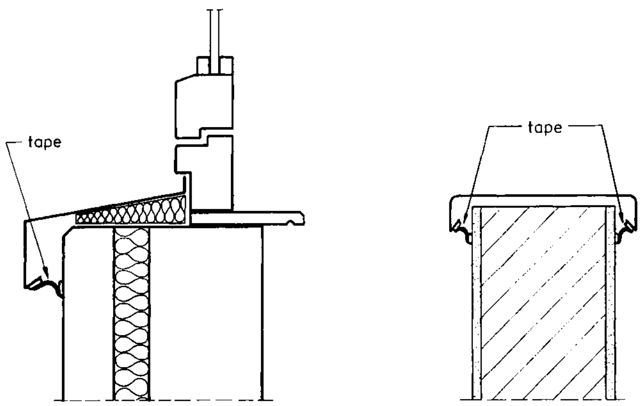


Fig. 2--Types of tape seal
(a) Attic
(b) Window sill

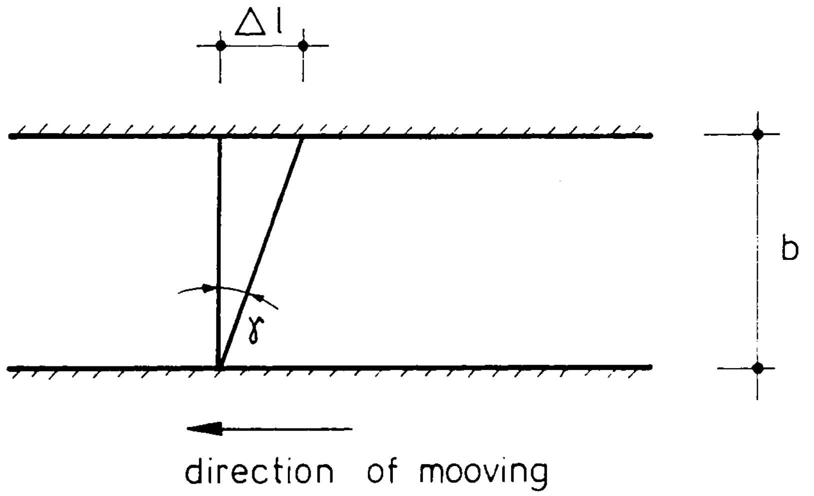


Fig. 3--Shear forces on joint tape

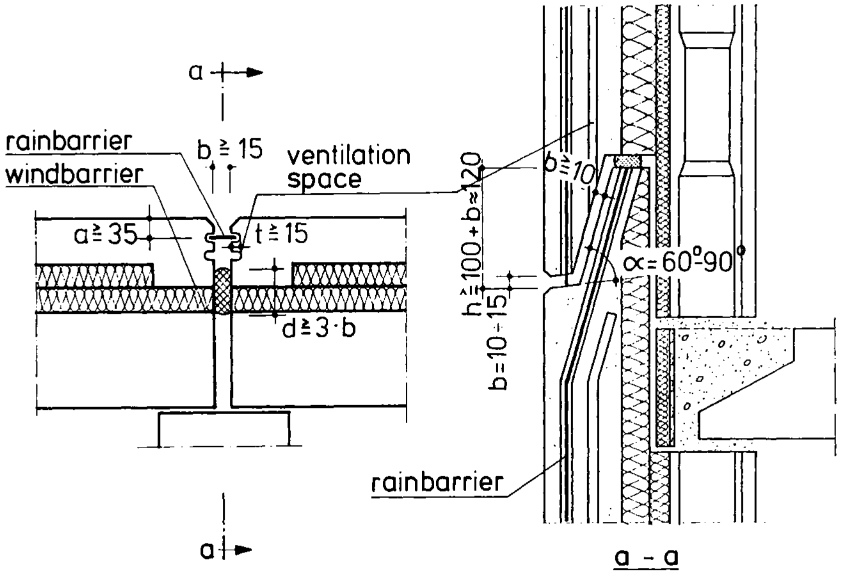


Fig. 4--Two-stage joint in concrete sandwich wall. Profiling is integral to wall

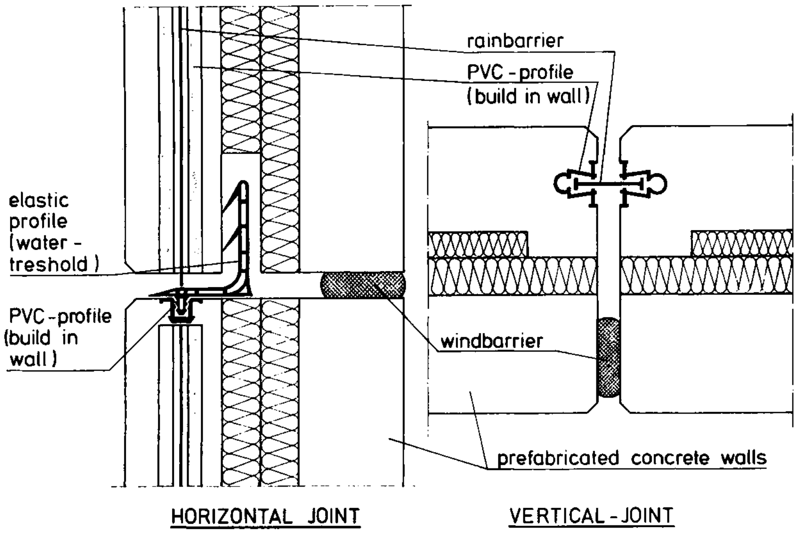


Fig. 5--Two-stage joint in concrete sandwich wall. Plastic gaskets imbedded in wall

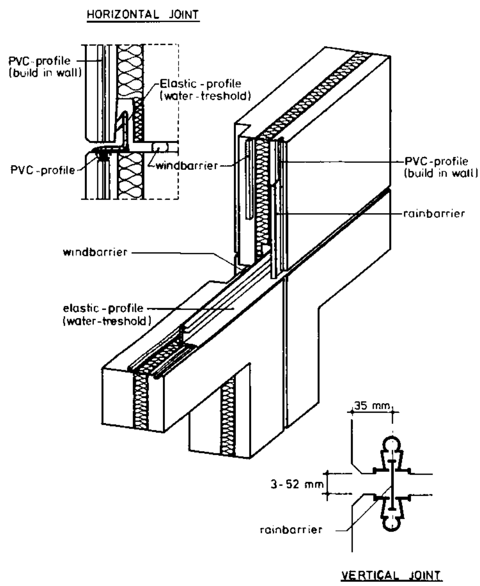


Fig. 6--Two-stage joint. Perspective view