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NEW WAYS WITH WEATHERPROOF JOINTS

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Tests have been carried out, primarily using a natural exposure rig, on a number of designs of vertical and horizontal joints employing labyrinths to separate the air and water entering the joint. Results obtained under a limited range of conditions show that it is possible, with suitable designs, to prevent penetration of water without necessarily making a joint airtight.

A number of potential applications are put forward, including a prototype window.

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NEW WAYS WITH WEATHERPROOF JOINTS

by M R M Herbert and H W Harrison

INTRODUCTION

Many weatherproof joints place reliance on a seal of some form to prevent the entry of both air and water. Most seals, however, are made of materials which have a shorter effective life than that of the components which they join. They are also susceptible to indifferent installation practices, and adequate inspection is often omitted. Variations in joint sizes and relative movements of the components make predictions as to their cost and effective life uncertain. From this it follows that joints which can function without seals, and which can tolerate movements and inaccuracies, have much to commend them.

Methods of jointing which allow the passage of air but prevent water penetration have therefore been under investigation at the Building Research Station.

The purpose of this paper is to describe that part of the work which has been carried out in a natural exposure rig at Plymouth, in order to establish and demonstrate the value and principles of labyrinth joint design, and to draw attention to some possible applications. Although the work has benefited from some laboratory studies, these have been limited in the main to obtaining qualitative data under a limited set of conditions. Consequently the design data which can be derived are presented only in broad terms, serving as guidelines should designs need to be prepared in the immediate future. In the meantime, further laboratory studies of a more detailed nature are in progress.

DATA FROM PREVIOUS WORK

Previous experiments to those reported here, for example those in references 1 and 2, have shown that the majority of water reaching a vertical joint flows sideways from adjacent surfaces and, on entering the joint, drains downwards. Other water entering the joint is in the form of driving rain or droplets torn from the sides of the joint by the airstream passing through it. Additionally, water bridging the joint can be forced into it in the form of a 'plug'.

Penetration of driving rain can be prevented by the use of baffles, as in the BRE open drain joint, and the amount of water entering a vertical joint is effectively reduced if the side flow from surfaces adjacent to it is obstructed or diverted. Vertical and outward drainage within the joint can be encouraged by sharp-edged arrises or inclined grooves, while wide joints prevent bridging by water and the consequent formation of 'plugs'.

The problem of horizontal joints has always been less tractable than that of vertical joints; indeed, quantities of run-off from surfaces can be such as completely to fill narrow horizontal joints, especially at positions where the water load is increased by drainage from vertical joints above.

The results of previous experimental work and observations of a few joints under natural exposure test suggested that if a labyrinth configuration were used, the momentum of the water droplets travelling in the airstream through the joint could be utilised to deposit them in areas of the joint away from the fast airstream, where vertical drainage could then take place. Alternatively penetration could be reduced or prevented by designing the joint so that the air velocity through it was kept below that which would transport water droplets.

These theories are now discussed in relation to the natural exposure tests carried out at Plymouth[1] on vertical labyrinth joints and to a detailed qualitative examination in the laboratory of the mechanism of penetration through horizontal joints.

CONDITIONS OF TEST

Both vertical and horizontal joints were exposed on the Plymouth rig for a period of about four months, during which time a variety of driving rain intensities was experienced, and a variety of wind speeds and directions occurred. Continuous records were kept of the meteorological conditions, whilst the performance of the joints was recorded by measuring quantities of catch collected over 24-hour periods.

Laboratory tests were conducted by means of a simple pressure box of the type used for BS 4315 : Part 2 using cone sprays instead of a sparge pipe. The intention here was to examine the mechanism of penetration in a qualitative fashion for which relatively large quantities of water have to be used, rather than specifically to acquire quantitative data; although records were kept for rough comparison, these do not reach the usual standards for reproducibility of results.

The results obtained, together with a discussion of the main points arising from these, are now described in turn for each of the three main categories under study, namely, vertical labyrinths, inclined fin labyrinths, and horizontal labyrinths.

VERTICAL LABYRINTHS

The types of vertical fin joints, and some of the results obtained for unsealed cavities, are shown in Figures 1 and 2. Under both natural exposure and laboratory tests no water penetrated through the joints and virtually no penetration was recorded beyond the third fin overlap, although the odd drop came deeper occasionally. Both in the laboratory and under natural exposure, sealing the back of the joint confined the depth of water penetration to the region of the first fin overlap. Since quantities were minute there is little purpose in providing catch results in this paper.

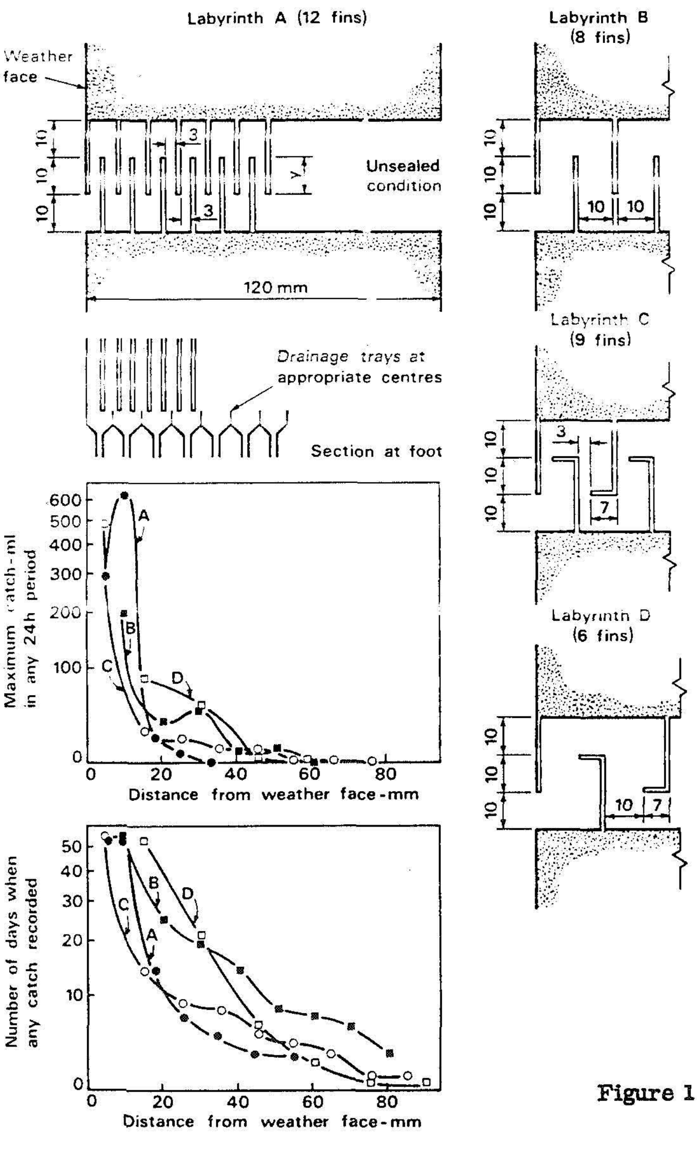

Figure 1 Details of vertical labyrinth joints and summarised test results

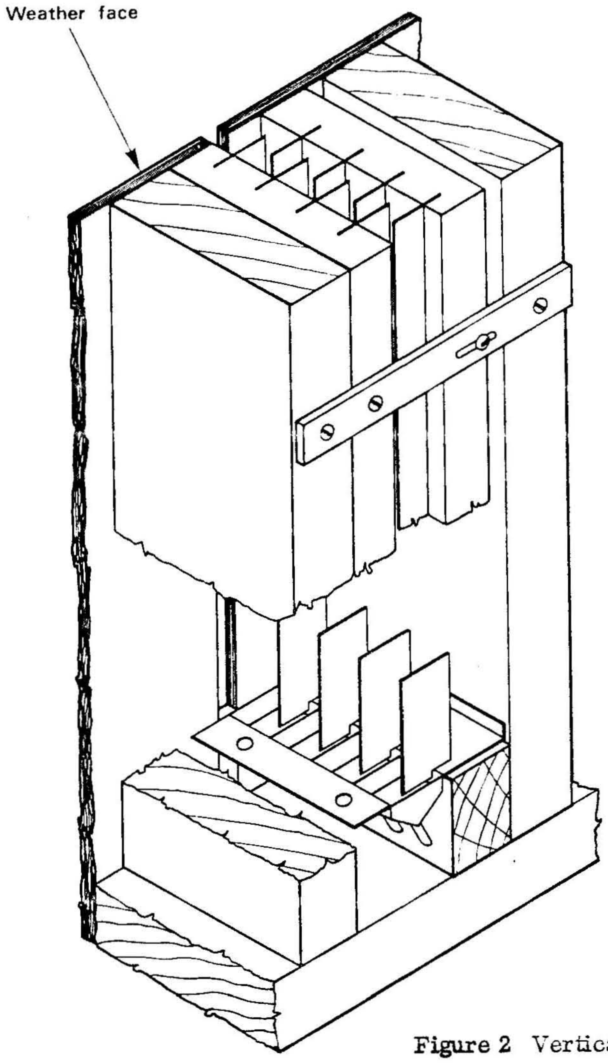

Figure 2 Vertical labyrinth joint

The way in which these joints achieved weather protection was studied in detail in the laboratory and was found to be similar for all four configurations. Observations showed that a proportion of the water running down the first fins was swept sideways by the airstream and carried around the edge of the fin and onto its back face where it spread across the fin to the sides of the joint and drained downwards. When high concentrations of water occurred, on and adjacent to the fin edges, some water in the form of droplets was torn from the fin edge by the fast moving airstream and carried into the labyrinth. The majority of these droplets struck the side of the joint and were drained away in areas free from the fast-moving airstream. Any droplets which remained airborne were carried on to the next or subsequent fins.

There was little difference in the pattern of behaviour of the four configurations tested. Varying the amount of fin overlap between 1 mm and the maximum possible produced no changes in the pattern of behaviour or the extent of the protection afforded, although clearly it cannot be concluded from this that the fins could always be shallow.

These observations clearly demonstrate that separation of water from the air can be achieved in this form of joint by shaping the labyrinth path so as to direct airborne droplets of water into regions of low air velocity where natural drainage can take place.

It is clear from these results that rain-tight joints of the form illustrated can operate satisfactorily up to 3 metres in height, since this was the height under test. It is possible that above this height the performance may deteriorate because of water accumulating within the joint. However, it is known[2] that four-fifths of the water entering a vertical joint comes from surfaces adjacent to the joint. This suggests that continuous vertical labyrinth joints would operate satisfactorily up to a height of 15 m provided that most of the side-flowing water on the facade was prevented from entering the joint by such features as projecting fins or ribs.

INCLINED LABYRINTHS FOR VERTICAL JOINTS

Three inclined fin labyrinth joints were also included in the natural exposure tests. The design of these joints is based on two observations made by Bishop[2]. These were: that a horizontal joint having an upstand of 100 mm or more provided considerable protection, and that inclined grooves on the vertical joint meeting faces drained most of the water entering the joint to the weather face. These two features have been combined in one joint to produce an inclined fin labyrinth.

The inclined labyrinth joints illustrated in Figures 3, 4 and 5 were tested under natural exposure and their performance compared with that of a 13 mm wide plain-sided vertical control joint fabricated from stainless steel sheet. The results are plotted on the same horizontal scale,

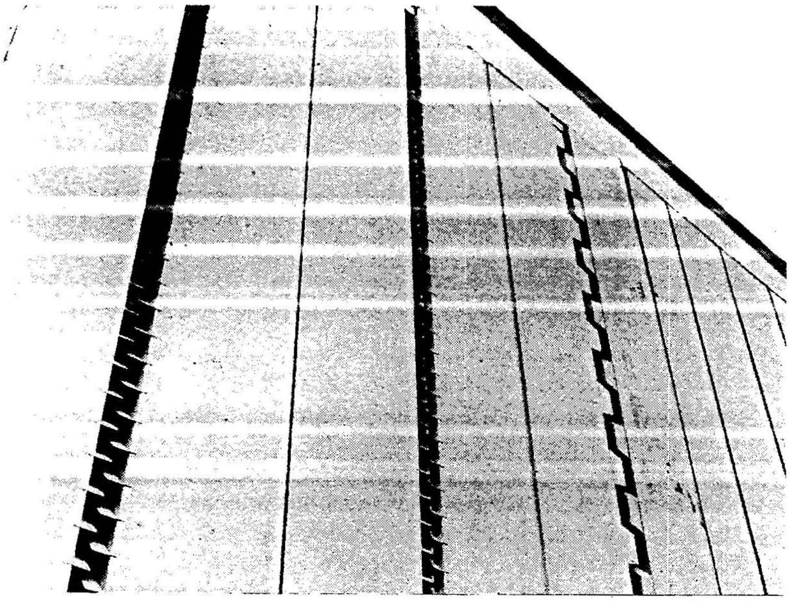

Figure 3 External view of inclined labyrinth joints on the Plymouth natural exposure rig

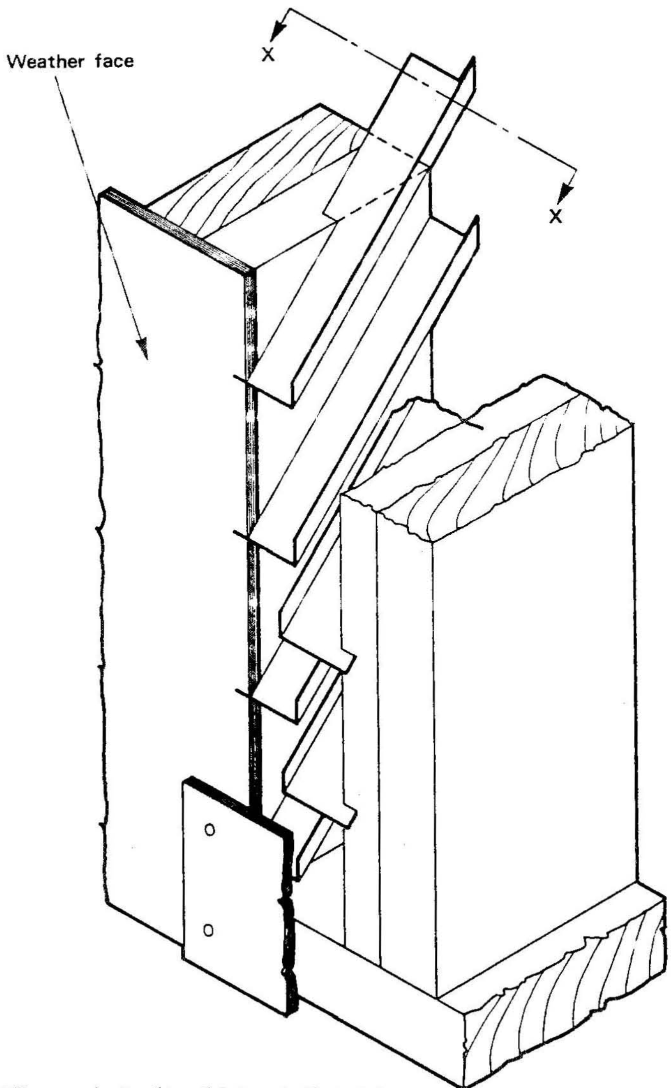

Figure 4 Inclined labyrinth joint
(For sections on plane X-X, see Figure 5)

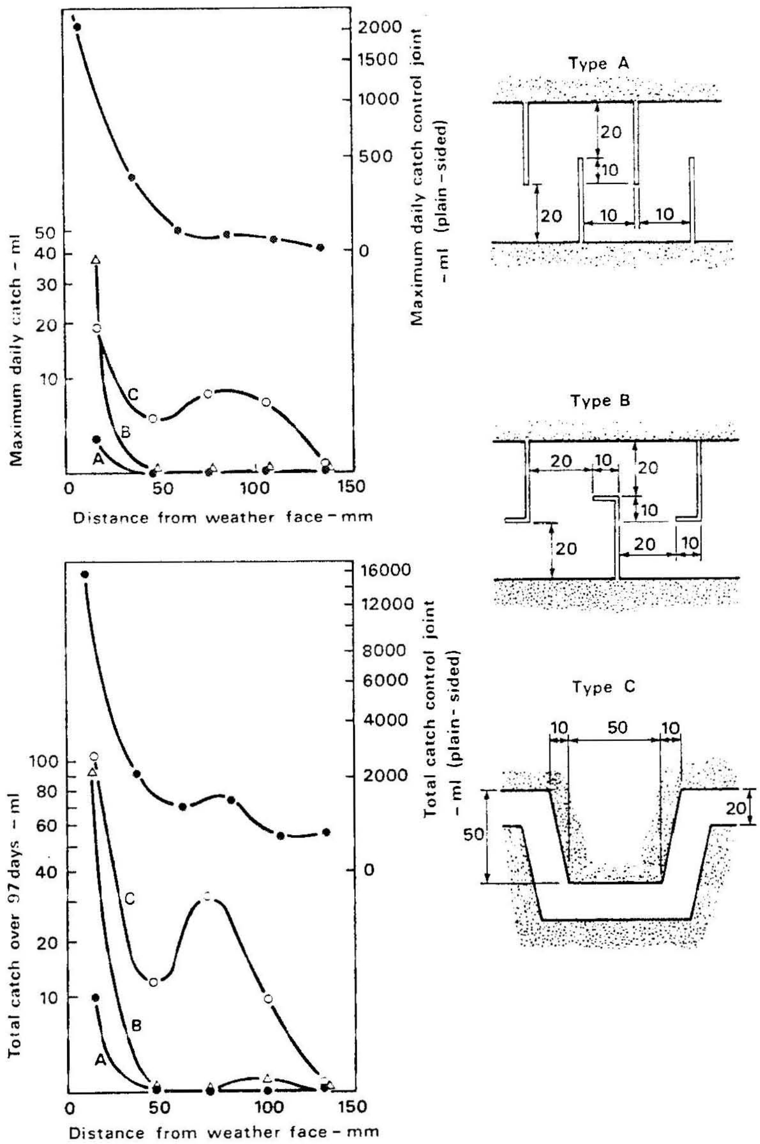

Figure 5 Details of inclined labyrinth joints and summarised test results

but with a different vertical scale. Comparison of the catches in the compartmented tray at the base of each joint (see Figure 5) show that except for type C no water penetrated deeper than the first compartment and that this was very small compared with the catch in the control joint. All joints performed very much better than the control joint, and the performance of the metal finned joints was superior to the simulated concrete joint made from wood.

In the joints tested the fins overlapped by 10 mm. Observations suggest that this should be preserved as a minimum lap and that increasing the lap would improve the performance of the joint still further. In designing a joint therefore the protrusion of the fins will be dictated by the anticipated variations in joint size and movement of the joints. From other ad hoc tests not reported here, variation in the slope of the fins does not appear to be critical provided it is greater than about 30 degrees and provided that a vertical lap is maintained. These joints were not tested in the laboratory, and it is not easy to observe the detailed behaviour of joints under natural exposure. However such observations as have been made show that the majority of water enters from the side of the joints and travels diagonally downwards towards the back until it is intercepted by an inclined fin. The water is then encouraged to drain outwards to the weather face by the fin. The action is confirmed by the pattern of dirt deposition within the joints which also suggests that the patch of water entering the joint rarely rises above the horizontal.

Whichever is the case it is clear that this form of overlapping inclined fin labyrinth joint provides a high degree of protection to any seal at the back of the joint and also creates a very diminished water flow at the intersections when compared with a conventional open drain joint. This last attribute could prove of considerable value in jointing systems where the provision of flashings at the joint intersection is difficult.

HORIZONTAL JOINTS WITH AND WITHOUT LABYRINTHS

A few short lengths of horizontal joint were exposed in the rig at Plymouth, and observed over a period of about a year. They consisted of simple small chambers protected by upstands of 6 to 25mm in height such as may sometimes be employed for permanent ventilators in windows, and capable of being vented or sealed at the back (Figure 6). Although normally very small catches were recorded, even in the vented condition there were a few unexplained very large ones. In total, insufficient reliable data were gathered to enable conclusions to be drawn. In subsequent laboratory work it was discovered that the 6mm distance between the faces could be bridged under certain conditions by water plugs which behaved erratically.

Figure 6 Horizontal joints under test on Plymouth natural exposure rig

Most of the following observations stem from laboratory work.

A series of different sections was modelled in perspex (Figure 7) so that the mechanism of failure could be studied. Different variations of gaps, upstands and fins were used. Most joints had a 12mm wide opening, though a few joints with 6 and 18mm wide openings were also included. The type designs are illustrated in Figure 8, and the full list with dimensions is included in Table 1.

For purposes of comparison, Table 1 adopts a criterion of the pressure at which droplets began to pass the ventilation slot. Relative amounts of catch, while meaningful in long-term site studies, are not a useful indication in these tests, since in the laboratory only minute air pressure differences separate initial from total failure, that is to say the difference between a few drops and the entire quantity of run-off being driven through the slot.

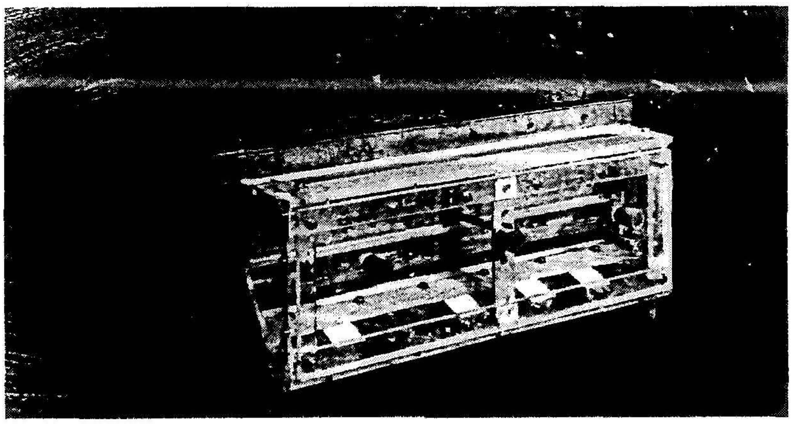

Figure 7 Close up of perspex box containing experimental joint

Table 1 Pressure categories at which water penetrated joints (to be read in conjunction with Figure 8)

Type	No	Dimensions in mm						No of fins	Ventilation gap		
									1.5 mm	3.0 mm	6.0 mm
		a	b	c	d	e	f		Pressure category	Pressure category	Pressure category
I	1	12	0	3	12	-	-	-	B	A	A
	2	12	0	6	12	-	-	-	B	B	-
	3	12	0	12	12	-	-	-	C	B	A
II	1	12	6	6	18	-	-	-	C	B	A
	2	12	6	12	18	-	-	-	D	B	A
III	1	12	13	3	25	-	-	-	A	A	A
	2	12	13	6	25	-	-	-	B	B	A
	3	12	13	12	25	-	-	-	D	C	B
	4	12	13	18	25	-	-	-	E	C	B
IV	1	12	38	6	50	-	-	-	B	B	-
	2	12	38	12	50	-	-	-	D	C	B
	3	12	38	18	50	-	-	-	D	C	B
V	1	12	38	18	50	-	6	1	D	C	B
	2	12	38	18	50	-	3	1	D	C	B
	4	12	38	18	50	-	6	1 cranked	D	C	B
VI	1	12	38	18	50	12	5	2	E	C	B
	2	12	38	18	50	26	5	2	E	C	B
VII	1	12	38	18	50	-	6	1	E	C	B
VIII	1	12	38	18	50	2	4.5	2	E	E	E
	2	12	38	18	50	6	4.5	2	E	D	C
	3	12	38	18	50	8	4.5	2	E	D	C
	4	12	38	18	50	16	4.5	2	D	D	C
	5	12	38	18	50	26	4.5	2	D	C	C
	7	12	38	18	50	8	4.5	3	E	D	C
	8	12	38	18	50	8	4.5	4	E	D	D
IX	1	12	38	36	50	8	4.5	2	D	C	C
	2	12	38	36	50	8	4.5	3	D	D	C
	3	12	38	36	50	8	4.5	4	E	D	D
X	1	18	38	6	56	-	-	-	B	A	A
	2	18	38	12	56	-	-	-	E	C	B
	3	18	38	18	56	-	-	-	E	D	B
XI	1	18	38	18	56	8	4.5	3	E	E	E
	2	18	38	18	56	8	4.5	4	E	E	E

Key to water gauge pressure categories at failure:

A = 0 to 10 mm

B = 10 to 25 mm

C = 25 to 50 mm

D = 50 to 75 mm

E = no penetration at 75 mm

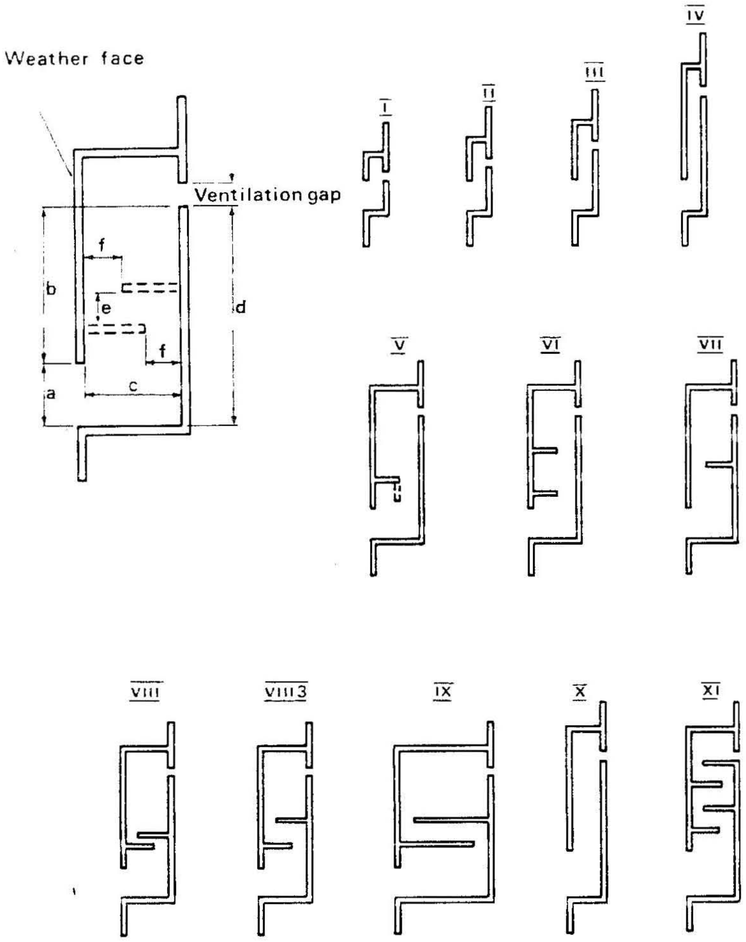

Figure 8 Horizontal joints tested

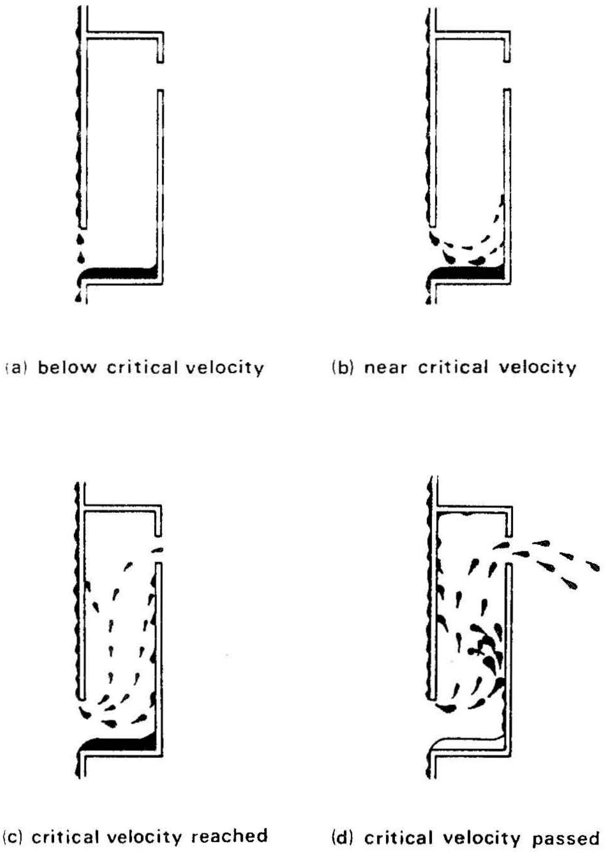

Figure 9 The stages in water penetration due to 'critical air velocity'

An attempt was also made to obtain air velocity readings; although these are not given in this report it did become clear that at the opening on the weather face (Figure 8, dimension a), there existed for all joints a critical velocity of the order of 5 metre/second, at which individual droplets would be carried through in the airstream. This mechanism is illustrated in Figure 9. Where lower velocities at penetration were recorded, these were usually associated with the formation of water plugs.

It was found with the 6 mm joints that water droplets entering the joint caused a water plug to form at the weather face of the joint. This water plug rose between the joint faces as the pressure was increased. When the pressure was approximately 20 mm water gauge large air bubbles were forced through the water plug causing penetration. This was experienced on all types of joint configurations tested. It appears from the results that it was not necessary to keep joint openings small; in fact a 12 mm joint opening provides much better protection than a 6 mm joint.

It is not known how far these results depend on the test method employed, but they probably broadly indicate one commoner type of failure under natural conditions.

The pattern of penetration was similar for all joint configurations tested. The water droplets produced by run-off passed across the face of the joint opening and as the pressure was increased so did the air velocity through the joint. This gradually turned the water droplet into the joint opening. The characteristic turning under of the water droplets was recorded just before penetration occurred, that is just before the critical air velocity was reached (Figure 9). Once the critical air velocity was reached, water droplets were then carried in the airstream through the joint. Some of the heavier droplets were deposited on the sides of the joint while others were carried further through the joint and out of the ventilation gap. In the plain overlapping joint some droplets were driven up the back of the plate on the weather face of the joint. These were also eventually driven out of the ventilation gap.

Once the labyrinth joint had been penetrated, water droplets which had been deposited on the sides of the joint drained on to the projecting fins in areas where the movement of air is below the critical air velocity required to transport water droplets. Only when the build-up caused overflowing did the droplets again enter the airstream and pass through the joint.

In most of the tests carried out the ventilation gap was placed over the top of the joint. Sufficient further tests were carried out to establish that penetration occurred at the same pressure, wherever in the upper chamber the ventilation gap was positioned.

Trial tests carried out using simulated wind gusting have shown that the joint configurations behaved the same as under static pressures, that is to say, the gusting did not have any effect on the joint until penetration had occurred; once this had happened and the surfaces of the joint were wetted, penetration would then occur at a slightly lower pressure than before, especially with labyrinth joints where water would lie on the projecting fins, and be torn off into the airstream.

With massive increases in run-off there is some indication that failure occurs at a lower pressure, almost certainly due to the joint partly filling with water. This suggests that, in situations experiencing heavy run-off therefore, dimension a could be increased with advantage.

The results also show that careful selection of the dimensions of simple lap joints can considerably improve their performance, although they remain sensitive to increases of ventilation rate and air velocity through the joint. This sensitivity is however very considerably reduced by the introduction of overlapping fins between the meeting faces of the joint. Consequently simple horizontal lap joints of the form shown in type X can provide considerable protection against rain penetration if the ventilation gap is small and can be controlled.

The tests on the labyrinth configurations suggest that these can be designed to maintain their performance over a wide range of gap sizes while at the same time accepting large movements in the plane of the joint and limited movements at right angles to it.

APPLICATION: GENERAL DISCUSSION

This work has shown that rain-proof horizontal and vertical joints can be designed which are not dependent for their performance on air or water seals. Air seals can of course be used to reduce air leakage if required, but their function is solely that of an air seal, and the rain-tightness performance of the joint is not dependent on them. If used they should be positioned on the inner part of the joint (Figure 10).

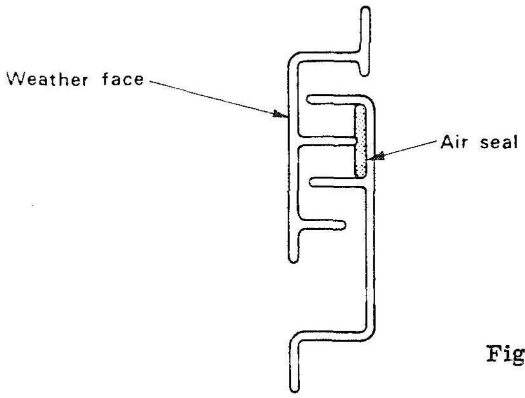

Figure 10 Section through typical labyrinth joint showing one way of positioning an air seal

There is a wide variety of situations and materials to which these labyrinth jointing methods can be applied, the edge profiles being either formed integrally with the component or attached by non-working sealed joints. It should be noted here that the joints tested are not intended as finished designs, their purpose being to establish the way in which this type of joint behaves and to derive design principles.

As with all weatherproof jointing systems care must be taken with the design of the intersections. Generally the arrangement must be such as to allow free drainage of the vertical joint without ooding the horizontal joint, and air paths through the intersections which allow high velocities to develop must be avoided.

To illustrate one of the ways in which the labyrinth joint (UK Patent Application No 47674/73) principle can be applied, a prototype top-hung open-out window has been made. It is illustrated in Figure 11. One significant advantage with windows designed on this principle is that they will remain watertight under quite severe conditions even when left slightly open for ventilation purposes.

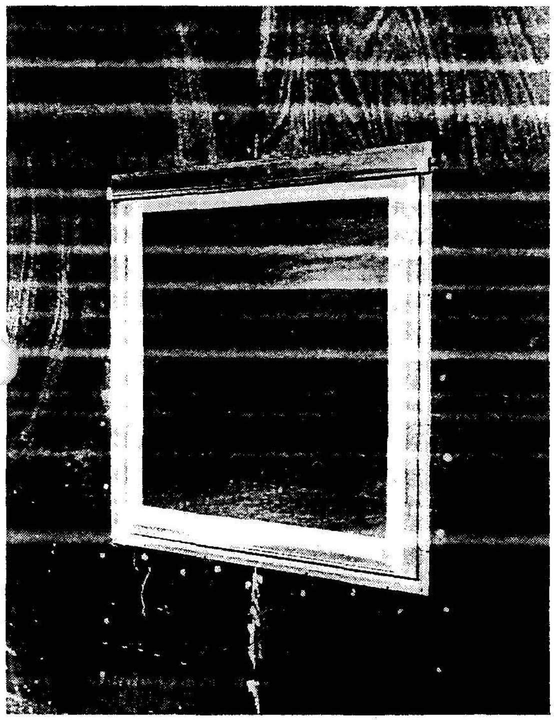

Figure 11 Labyrinth jointed window under natural exposure tests

The prototype was laboratory tested to BS 4315:Part 1 procedures. In both the closed position, and open 2 mm, there was no initial leakage at up to 80 mm water gauge. When open 5 mm, initial leakage occurred at 25 mm wg, but there was no gross leakage at up to the fan capacity (producing 45 mm wg) When the test was changed to the use of cone sprays delivering 500 mm of driving rain/hour, ie extremely large quantities of water not likely to occur under natural conditions, there was no leakage in the closed position, but initial leakage occurred at 30 mm wg at the lower corners when open 3 mm. The horizontal lower joint was filling with water, and this failure mechanism has been described. The prototype, opened 2 mm, was also installed on the Plymouth rig for a period of five weeks during which conditions occurred with winds giving rise to pressures of 30 mm wg, together with driving rain of about 5 mm/h; no leakage occurred. There are indications therefore that a successful design could eventually emerge.

Because labyrinth joints can be designed to accept movements without reducing their resistance to rain penetration they are ideally suited for so-called 'expansion' joints, especially in curtain walling. Suggestions for their use in this way at critical points are shown in Figure 12. In application to curtain walling where the formation of labyrinth grooves or fins at right angles to the direction of extrusion may be difficult, specially formed sections could satisfactorily be joined on by sealed non-working joints, the design being so arranged that all movements in the members were taken up in the unsealed labyrinth joints.

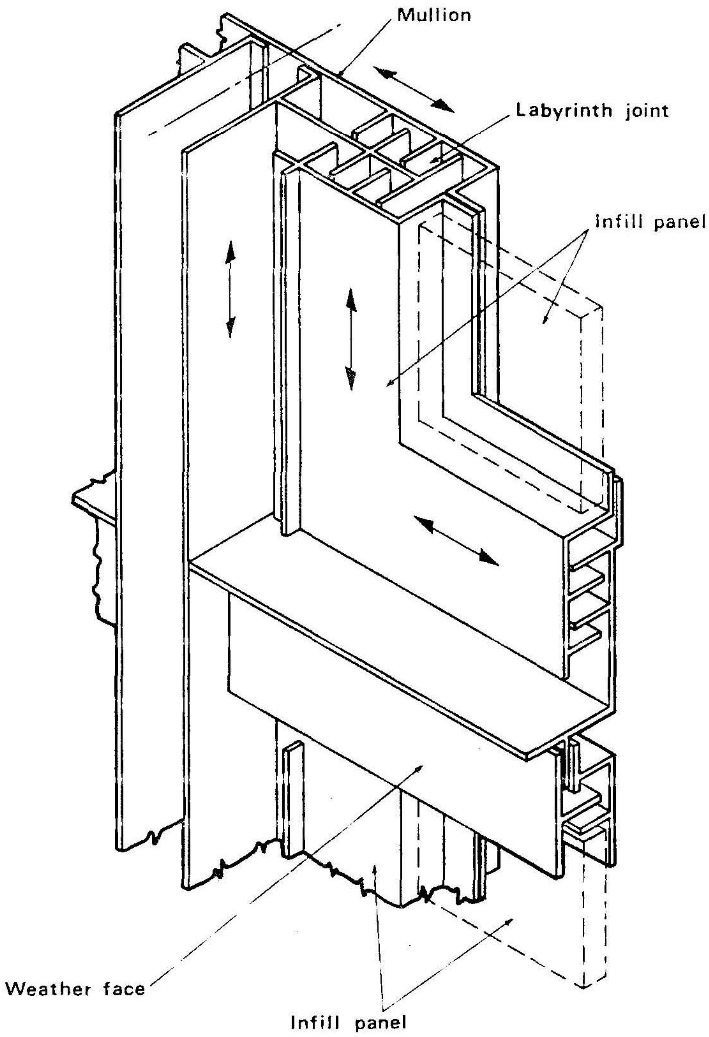

Figure 12 A suggested method of applying labyrinth joint principles to curtain walls

Application of the rather more complex inclined fin joint is difficult to foresee but it might be considered in some forms of construction where a moulded edge is possible, as the first stage of a two-stage drained joint - ie replacing the drainage zone and baffle, perhaps as the edge joint in a moulded window frame.

Only a brief indication has been given here of the potentials for application of the principles of labyrinth joints, and this paper is published in an endeavour to stimulate further application where appropriate. Since only brief details can be given here further information on the profiles used can be obtained on application. Costs will undoubtedly figure largely in any investigations; here it should be remembered that it may be worth while paying a premium for more elaborate designs if they are 'fail safe' in construction, and potentially maintenance free. This will become increasingly important in the future with the tendency to reduce the number of joints, the use of newer materials with larger thermal movements, and consequential increase in the stresses placed on conventional jointing products.

The principles established by these tests are worthy of consideration for application to a variety of jointing problems including large panels, gaskets, and opening lights in windows; and could be used either in addition to conventional joints or in place of them.

The application of all the work mentioned in this paper would appear to be largely confined to those materials in which complex edge profiles are easily formed, such as aluminium, cold rolled steel, plastics and possibly grc, or to materials to which such edge profiles can readily be attached by non-working joints.

SUMMARY OF MAIN RECOMMENDATIONS

The following are the simplified design rules that can be deduced from the work described.

Both vertical and horizontal joints:

1 The amount of ventilation given to any joint was the most important factor that governed at what pressure a joint configuration would fail due to water penetration: ie no ventilation, no penetration.

2 By increasing the number of fins within labyrinth joints it was possible to effectively prevent penetration at very high pressures.

3 No joint should allow the airflow path to narrow too quickly near the joint opening, and the smallest gap within the joint should be kept at the back of the joint.

Vertical joints alone:

4 On unsealed joints probably three overlaps are needed if the fins are plain, and two if they are returned. If the joint is sealed, then one overlap suffices.

5 Above a small minimum, say 5 mm, no significant advantage accrues from increasing the dimension of the overlap. (Dimension y in Figure 1.)

Horizontal joints alone:

6 On joints that rely on an overlap within the profile as a means of preventing penetration, there should be at least a 13 mm overlap, with a minimum 12 mm gap between the meeting faces of the joint. (Dimensions b and c in Figure 8.)

ACKNOWLEDGEMENTS

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