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REPAIR AND REPLACEMENT OF SEALED JOINTS IN EXTERIOR CLADDINGS.

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PREFACE

The repair of sealed joints in exterior claddings is an ongoing item of commercial building maintenance. Until recently there has been little in the way of published information on the best ways to carry out such repairs. This paper is a summary of current available information.

ACKNOWLEDGEMENTS

The time and willingness of a number of sealing contractors and sealant manufacturers and suppliers in discussing current repair methods is gratefully acknowledged.

This report is intended for building owners, maintenance managers, and designers.

REPAIR AND REPLACEMENT OF SEALED JOINTS IN EXTERIOR CLADDINGS

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REFERENCE

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ABSTRACT

Current repair and replacement methods for one-stage sealed joints in exterior claddings are described. Design, workmanship and material factors causing failure are discussed, how they are identified, and the steps necessary to ensure a successful repair.

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INTRODUCTION

Both past and current construction methods for large buildings such as office blocks involve the use of large, often prefabricated cladding elements which require joints between them to be sealed on site. Common New Zealand practice is for such joints to be one-stage, with the sealant in the joint being the sole barrier to weather penetration. Those sealants considered the most durable have estimated lifetimes of only 30 years, considerably less than the design life of most commercial buildings. Repair and replacement of sealed joints has been and will continue to be an important item of building maintenance. The purpose of this paper is to summarise the methods of joint repair available for one-stage cladding joints, and to outline the steps which should be taken to ensure successful repair. Edwards (1986b) outlines steps necessary for the repair of two-stage joints.

Technical terms used are described in the glossary (Appendix 1).

CAUSES OF FAILURE

Once the decision has been made to repair or replace a sealed joint, it is necessary to try to work out why the joint failed in the first place, so that the same mistake is not repeated. Failure types are shown in Figure 1. Reasons for failures are summarised in Table 1, which can be used as a checklist. Failures can usually be attributed to design, workmanship or material selection errors. The best approach is to look at design first, to make sure that the joints should have worked. If that aspect seems all right, then workmanship should be checked. Materials are the final aspect to be considered. Very often there will be a number of causes contributing to failure, and they must all be coped with in repair.

Design

A common fault is having too few joints or joints that are too small to accommodate the movement occurring. There are a number of reasons why this may have come about, and failure may be due to combinations of reasons.

Tolerances

Preserving aesthetics (avoiding wide joints which become a prominent feature of the building) is sometimes a reason. More often it is a lack of allowance for tolerances in manufacture, and site deviations as constructed cause problems. Every manufactured building component has slightly different dimensions, and it is very important that the joint design allows for this. Some of the dimensional variations that can occur in manufactured components are shown in Figure 2. For example, having joints designed nominally as 10 mm wide to accommodate components which may vary dimensionally by ±10mm means that some joints will be 0mm wide as installed. Alternatively, if the joint has been designed at 20mm, the same ± 10mm nominal variation could mean that some joints could be 30mm wide as installed, and this may cause the sealant to slump out of the joint when it is placed.

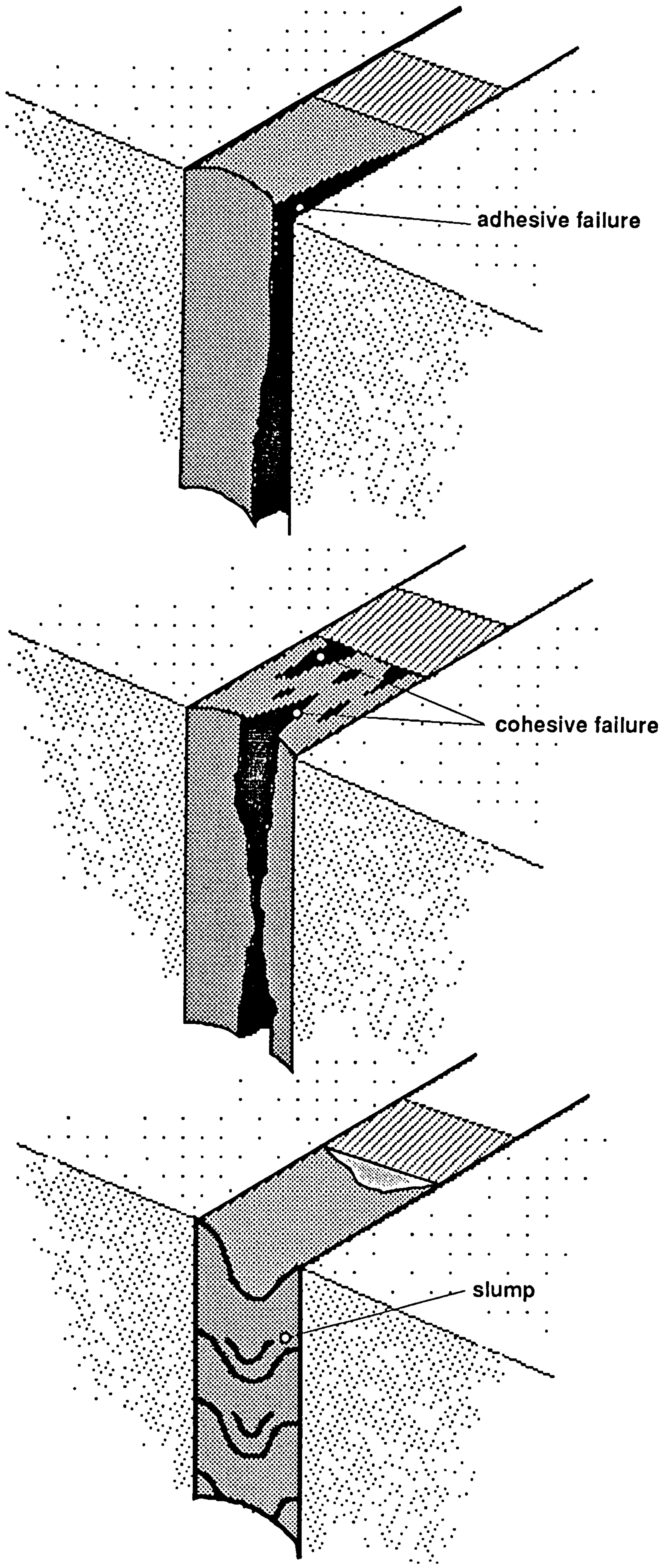

Figure 1 : Definition of joint failure types.

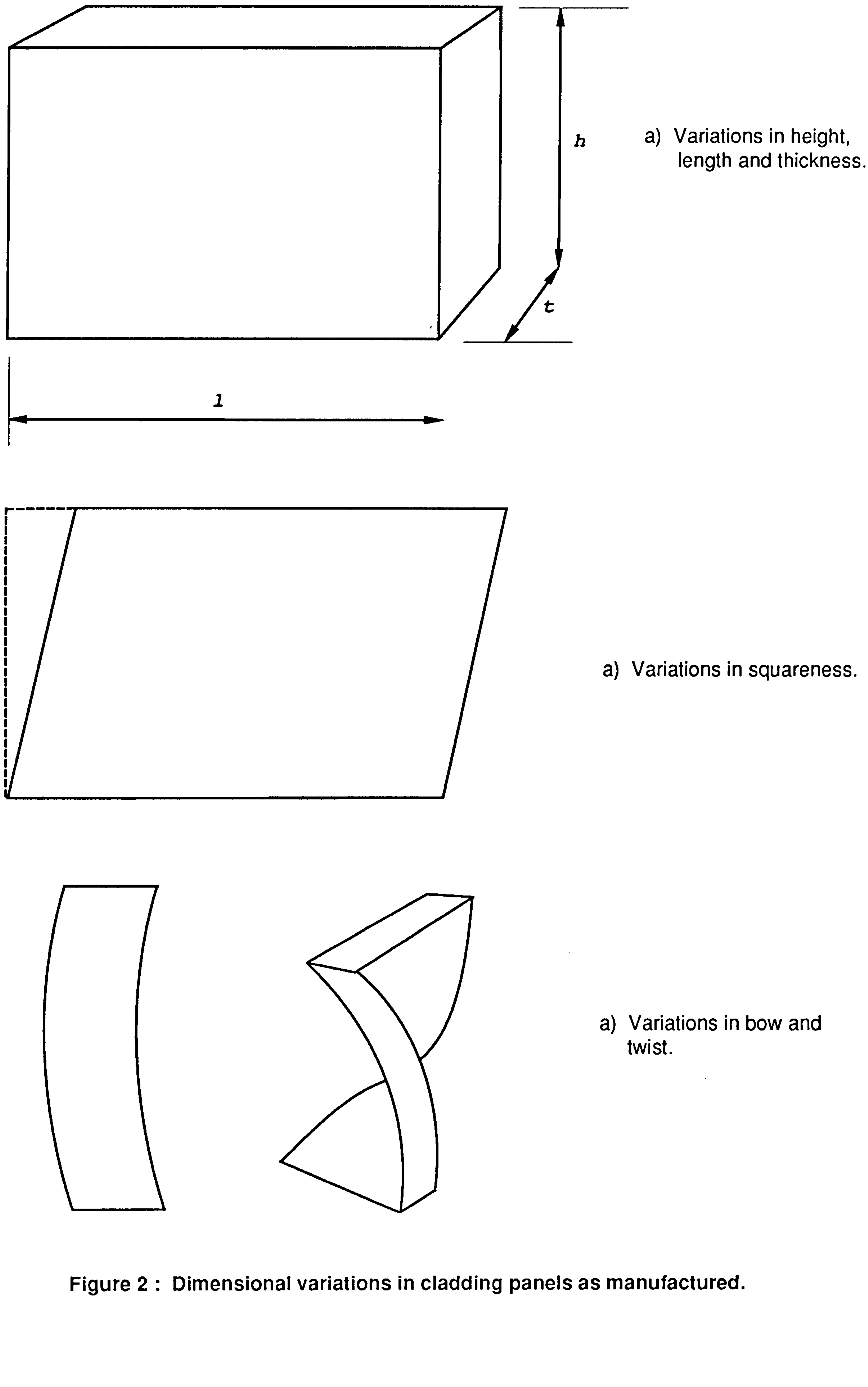

Figure 2 : Dimensional variations in cladding panels as manufactured.

As well as the variation in size of building components as manufactured, an additional factor complicating fit is that the the gaps to receive cladding panels on site will also not be of uniform size, because there are 'as built' deviations to allow for. The space into which the cladding panel is to fit can also show variations in size in the same ways as the panels shown in Figure 2.

It is better if joints are designed to be relatively wide so that manufacturing tolerances and site deviations result in minimum and maximum joint widths which will still allow the joints to perform as intended.

Movement

Movement may not necessarily occur at every joint. If some joints stick, or are wedged open by incompressible material, movement may be concentrated at specific joints, which have thus to contend with much more movement than originally intended. Movement of components due to thermal or moisture expansion and contraction may be greater than anticipated.

Incompatibility

Incompatibility between sealant and substrate may cause failure. For example, the use of acid-cured silicone on cement based materials, or limestone or marble, or the use of formwork release agents on concrete components will result in poor adhesion between sealant and substrate. A listing of substrates and possible contaminants is given in Table 2. The substrate may become contaminated after the sealant is installed, for instance where porous materials become saturated with water disrupting the sealant bond. Incompatibility may occur with one material if a sealant has to bond to two different types of material.

Different subtrades (e.g., sealing contractors and window installers) may use different types of sealant which can prove incompatible. The designer should specify sealant brand and type, and allow no substitutions unless compatibility checks have been made available. It is futile to have specified a high performance durable sealant for cladding panel joints if equal control has not been exercised over the sealant used as a perimeter seal for window frames.

Access

Designers sometimes do not allow for good access for sealant application. Panel/column or beam junctions have often been an example of this. (See Figure 3). The joint edges should have been designed to be clean and true, not ragged and uneven, as can occur with exposed aggregate panels.

Feedback

Unless failure is sudden and drastic, there is little feedback between design and long term success or failure. Sometimes a specific joint design simply cannot cope with the conditions of exposure: the height of the horizontal airseal upstand in two-stage joints is an example. Unless the upstand is of adequate height, the detail will not work.

Any building design aimed at minimal capital cost of construction including joints can leave the client coping with the consequences of a short design life.

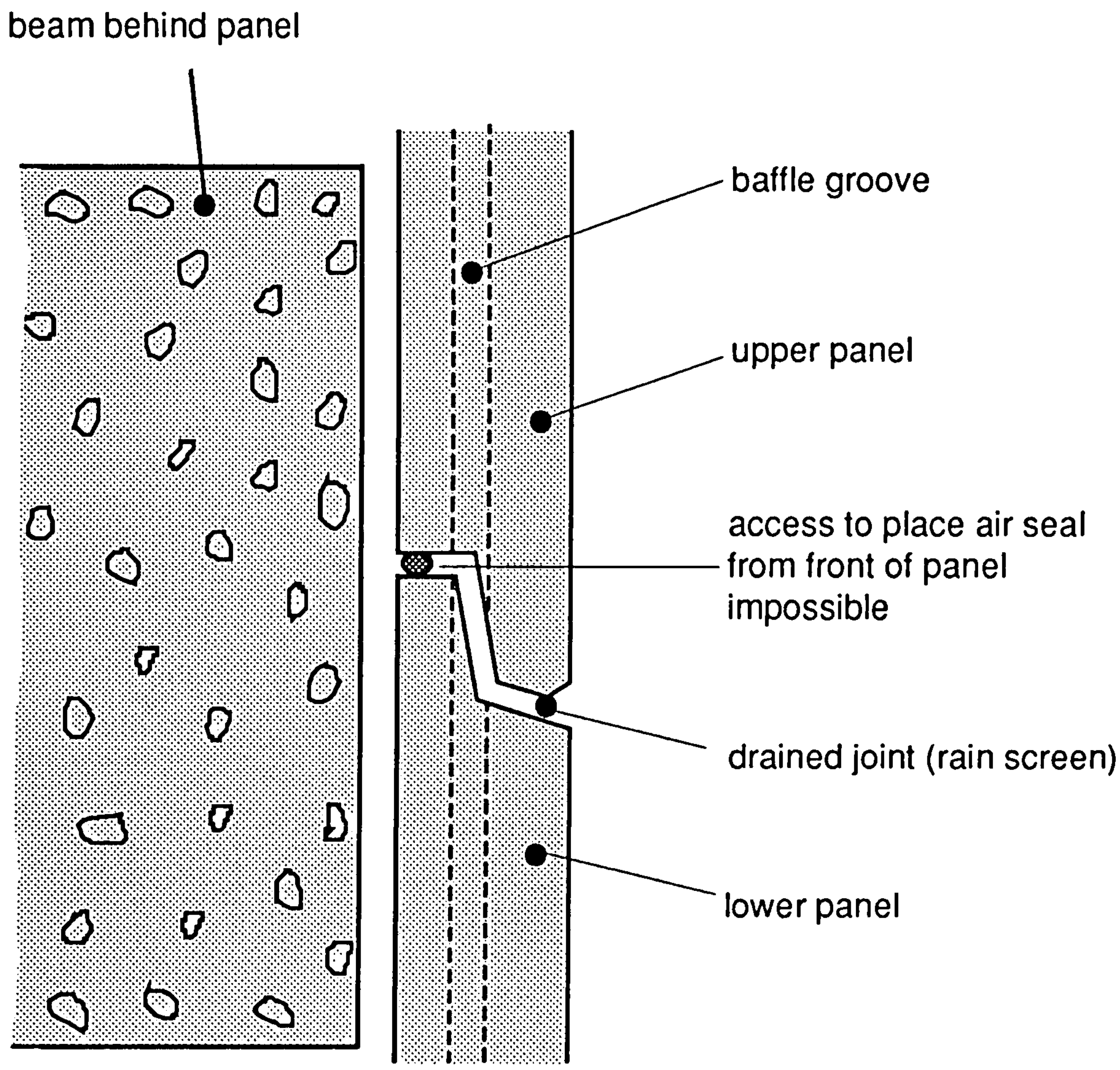

Figure 3 : Seal placement access problem - horizontal drained joint.

Workmanship

Some failures attributed to workmanship have in fact been caused by design shortcomings. Nevertheless, workmanship plays a big part in a successful joint: both design and execution must be well carried out.

Substrate and Priming

Causes of failures from faulty workmanship include failure to clean and dry out the joint thoroughly before placing the sealant. If the substrate is dusty, oily or wet the sealant will not adhere well to the sides of the joint. On many substrates, manufacturers state that a primer should be used with their sealant. There are several reasons for this, including improving the bond between sealant and substrate, and preventing water penetration which will disrupt bonding in the long term. Omission of a primer results in inferior bonding.

Backup Material

Failure to use any or the appropriate backup material will cause problems, and the backup material must be inserted to a uniform depth into the joint. The depth of insertion must result in the required sealant profile (usually width:depth 2:1 see Figure 11 of Appendix 1). In addition to a backup material, a bond breaker must be installed to prevent the sealant sticking to the bottom of the joint and then tearing when the joint opens. The bond breaker may be incorporated in the backup material. Figure 4 shows a section of sealant removed from a failed joint. As well as the backup material having been either poorly positioned for depth, or inadequately held so that it moved when the sealant was applied, no bond breaker had been incorporated and the sealant was firmly bonded to the open cell foam backup strip. The result was a sealant having a very poor and highly variable cross-sectional conformation to accommodate movement, coupled with little actual movement capacity anyway, because of bonding to the backup material.

Mixing

Failure to properly mix two-part sealants, or using them after the end of their potlife also contributes to failures. Incomplete mixing was a particular problem with two-part polyurethane sealants in the past. Even if design and material are correct, poor or uneven application may cause failure.

Materials

Failures caused by design and/or workmanship shortcomings are often blamed on the material. There are some failures caused by material-specific properties, and these are summarised below.

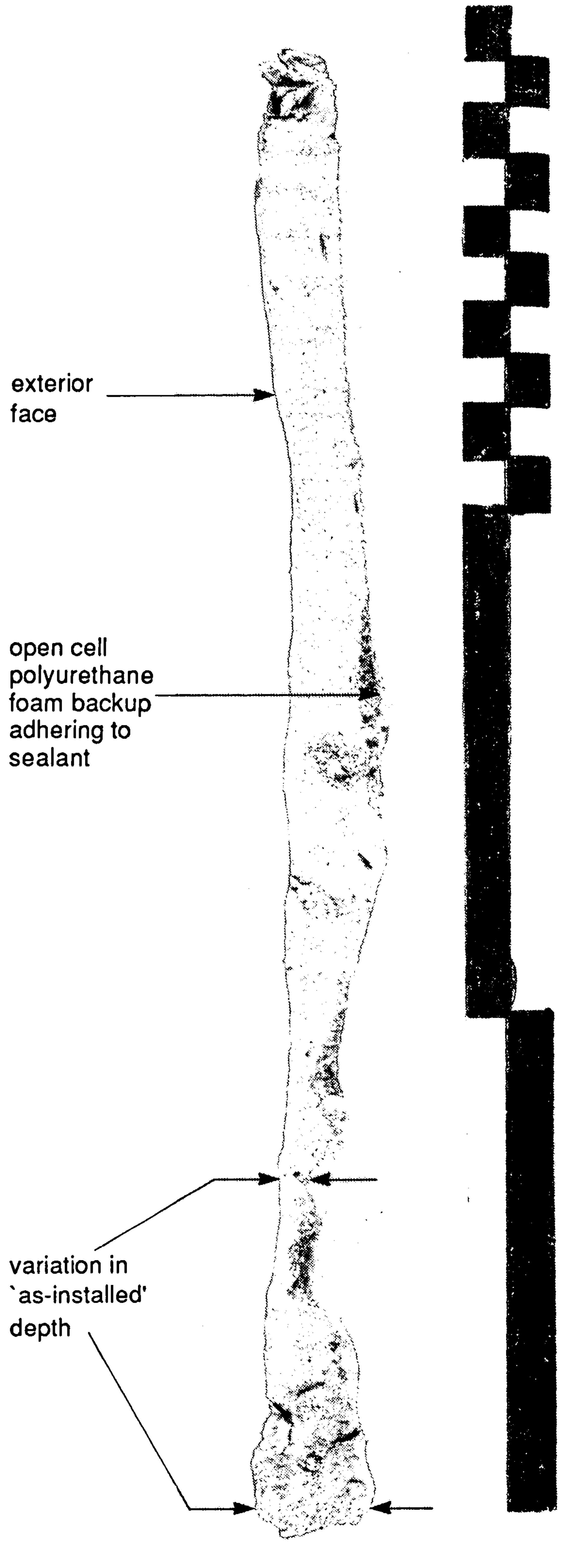

Figure 4 : Section of sealant as installed. (Removed after failure. Scale bar 10mm/100mm)

Sealant Types

A description of sealant types and general properties is given in the Building Research Association of New Zealand's Building Information Bulletin 239 (1985). The earliest sealants available, oleoresinous and butyls, were not very durable and became hard, shrunken and cracked within 10 years or so of installation where they were exposed to the weather. (Butyls are still widely used as bedding compounds in glazing, where they are in a protected position.)

Polysulphides were the first 'high performance' sealants to come on the market, and have an extensive and successful history of use. They also had some limitations. Early use of polysulphides in glazing resulted in loss of adhesion as the bond of polysulphides to glass is susceptible to UV breakdown. UV-screening primers are now specified for glazing use. Where porous substrates such as concrete became saturated with water in the long term, adhesive and cohesive failure of the polysulphide resulted.

Polyurethanes and silicones appeared in the late 1970s/early 1980s in New Zealand. Although widely used at that time, the performance of polyurethanes in exterior cladding panel joints has not been good. The main problem was failure caused by extensive cohesive cracking of the sealant (e.g., Figure 5). A number of polyurethane sealant installations have been replaced. Failures in adhesion to aluminium, possibly due to the use of no or the wrong primer, have also occurred. Polyurethanes are also susceptible to loss of adhesion to glass caused by UV radiation passing through the glass. The more recently introduced polyurethane sealants available since the mid 1980s are claimed to be formulated to overcome the earlier problems. UV screening primers are available for use on glass.

The earliest silicone sealants used were the acid-cured types. Silicone sealants installed prior to 1980 will be of the acid-cured type, although the numbers of such installations are small. Numbers of known failures of both acid- and neutral-cured silicone sealants appear small, the principal problem is dirt pick-up caused by the silicone oil plasticisers used in them. Long term, silicones are expected to fail in adhesion on porous substrates if the substrates become saturated with water. Translucent silicones are transparent to UV radiation which means that plastic or wood-based substrates to which they are attached may suffer UV-induced breakdown with subsequent adhesion loss.

Adverse reactions occurring between different types of sealants was mentioned under design. Known examples of this are polyurethanes, whose dioctyl phthalate type plasticisers are incompatible with some other sealant formulations, and the cure systems of polyurethanes and silicones which are mutually incompatible (one retards the other).

Backup Material

Although open-celled polyurethane foam has been used as a backup material in the past (because of its lower cost, or unavailability of closed cell foam), it should not be used. Only a closed cell foam backup is suitable. Open-celled foam has been stated to allow moist air to penetrate, which aids the curing of one-part sealants. However, they also require a bond breaker to stop the sealant sticking to the foam. The bond breaker is impermeable, and thus nullifies moist air penetration. Closed cell foams incorporating a bond breaker still allow sufficient moisture to pass the

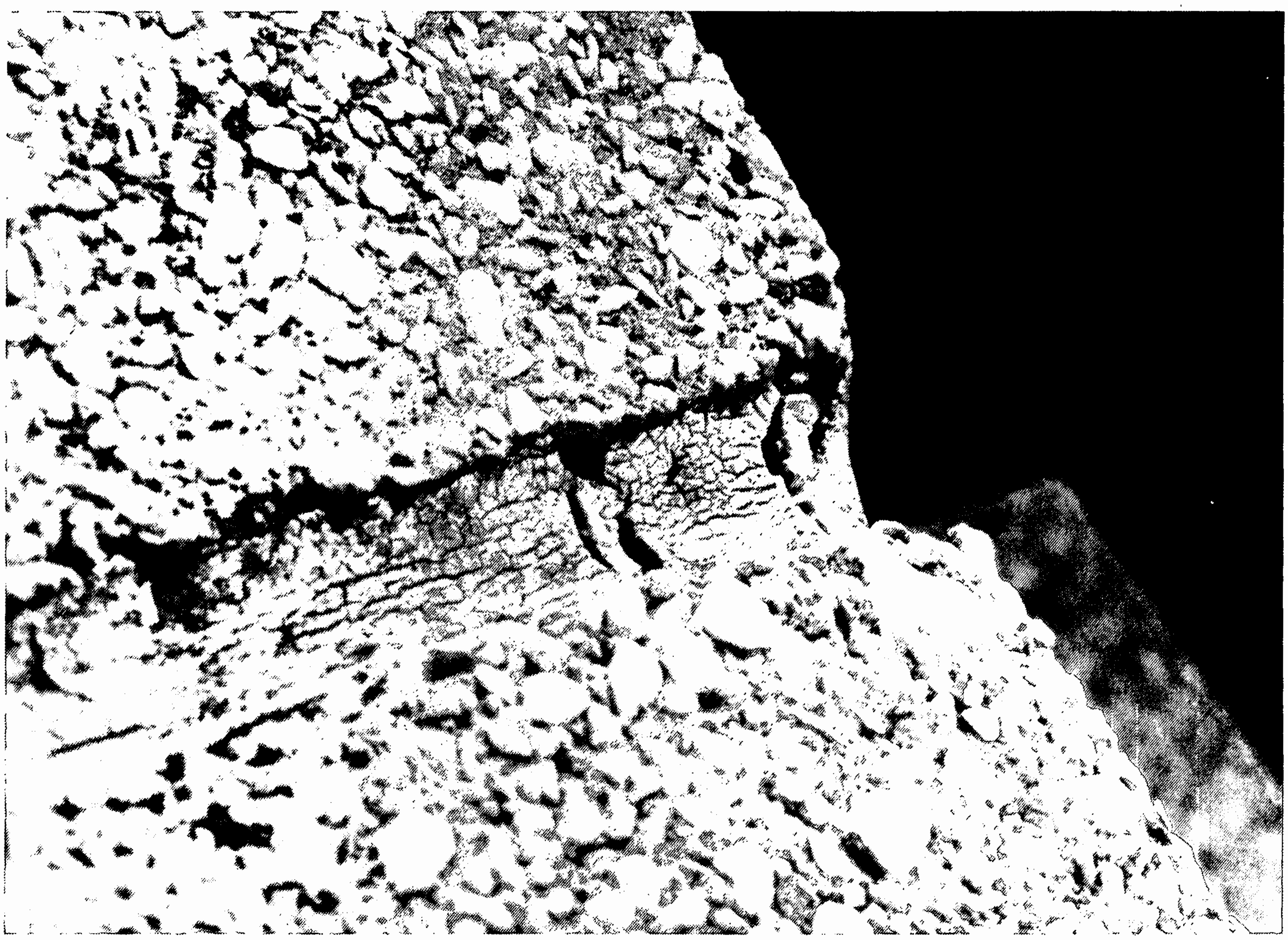

Figure 5 : Polyurethane joint sealant showing cohesive cracking failure.

foam to activate cure. Open cell foams are usually rectangular in cross-section, which results in a less suitable sealant shape in the joint than the use of a closed cell foam rod. Open cell foams can act as a conduit for water, making it extremely hard to trace leaks. If the sealant fails a closed cell foam backup is a much better last line of defence in resisting liquid water penetration through the joint. Closed cell foams should be installed with a blunt tool, such as a piece of wood. Screwdrivers may rupture the foam, and if sealant is installed over ruptured foam, outgassing on warm days will cause bulging and sometimes failure of the sealant.

Colour

As with the durability of all building materials, colour is an important consideration. Dark-coloured sealants, such as dark bronzes, and sealants on dark-coloured substrates will get much hotter than lighter-coloured ones. Heat, as well as UV radiation and moisture, is important in sealant breakdown, and is more important than UV in the breakdown of opaque sealants. The initial hardening reactions of sealants do not cease once the sealant becomes rubbery, but continue slowly for the life of the sealant - and other hardening reactions also occur, with oxygen in the air for instance. The harder the sealant gets, the less it is able to cope with deformation and movement. The hotter the sealant is, the faster these breakdown reactions occur.

Painting

The effect of painting over a sealant is worth noting. If a sealant will accept a paint or coating system, and is coated, then some staining or stickiness of the coating system should be expected. The coating may also seriously restrict the sealant's ability to accept movement, and contribute to failure in the same way as if the sealant were bonded to the backup material.

Other

If the sealant has been installed at too low (or too high) a temperature, failure may also occur. If installed at too high a temperature when cladding panels are at their maximum size, the sealant will be placed into the joint when the joint is at its narrowest. When the joint opens the stress imposed on the sealant will be much higher than the design stress. Conversely, if the joint is filled when conditions are cold, then cure will be slow - allowing more time for the sealant to be damaged - and the sealant will bulge out of the joint when it closes.

One-part sealants cure and develop strength very slowly over the course of two to three weeks. During this time their ability to resist loss of adhesion or cohesive tearing is much less than when they are fully cured. In the ideal situation the sealant would be installed at a temperature corresponding to the midpoint of its operating range. In practice this is seldom possible due to contractural pressures, or urgency of repairs. When the joint is designed or repair work planned, the additional effect of application temperature must be allowed for - by making sure the sealant can withstand a joint movement of +15%, -5% for example, rather than $\pm$10%, and checking minimum and maximum joint widths.

Identification of the Cause of Failure

A summary of possible reasons for failure is given in Table 1.
In order to avoid simply duplicating in repair the reasons for the original failure occurring, it is useful to try to analyse the cause(s) of the failure. There are three questions which should be asked:

a) Is the failure widespread?
If so, the flow chart in Figure 6 may help to find the cause.

b) Is the failure isolated?
This could be due to variations in the size of a particular joint, or movement at a specific point. It may be a defect in application at that particular point: shape, bubbles, tooling etc. It may also be an indication of the onset of general failure.

c) Is the joint designed for movement?
Many joints (perimeter seals around windows for example) are gaps that have been plugged rather than joints designed for movement. Accordingly, the sealant may be installed in a way which will not allow any movement that does occur to be accommodated (no bond breaker, for example).

Table 1: Summary of Reasons for Sealant Failure

DESIGN	- too few joints/joints not wide enough/joints too wide (slump) - movement not occurring at every joint - sealant/substrate incompatible - sealant/sealant incompatible - multiplicity of sealant types (varying durability) - poor provision for sealant application
WORKMANSHIP	- substrate not clean and dry - no/wrong primer - no/wrong/poorly inserted backup material - no/wrong/poorly inserted bondbreaker - two part sealant inadequately mixed - poor application
MATERIALS	- nondurable type (oleoresinous/butyl) - sealant/substrate incompatible - sealant/sealant incompatible
SUBSTRATE	- substrate contaminated - substrate failure
OTHER	- sealant installed at climatic extreme (hot/cold)

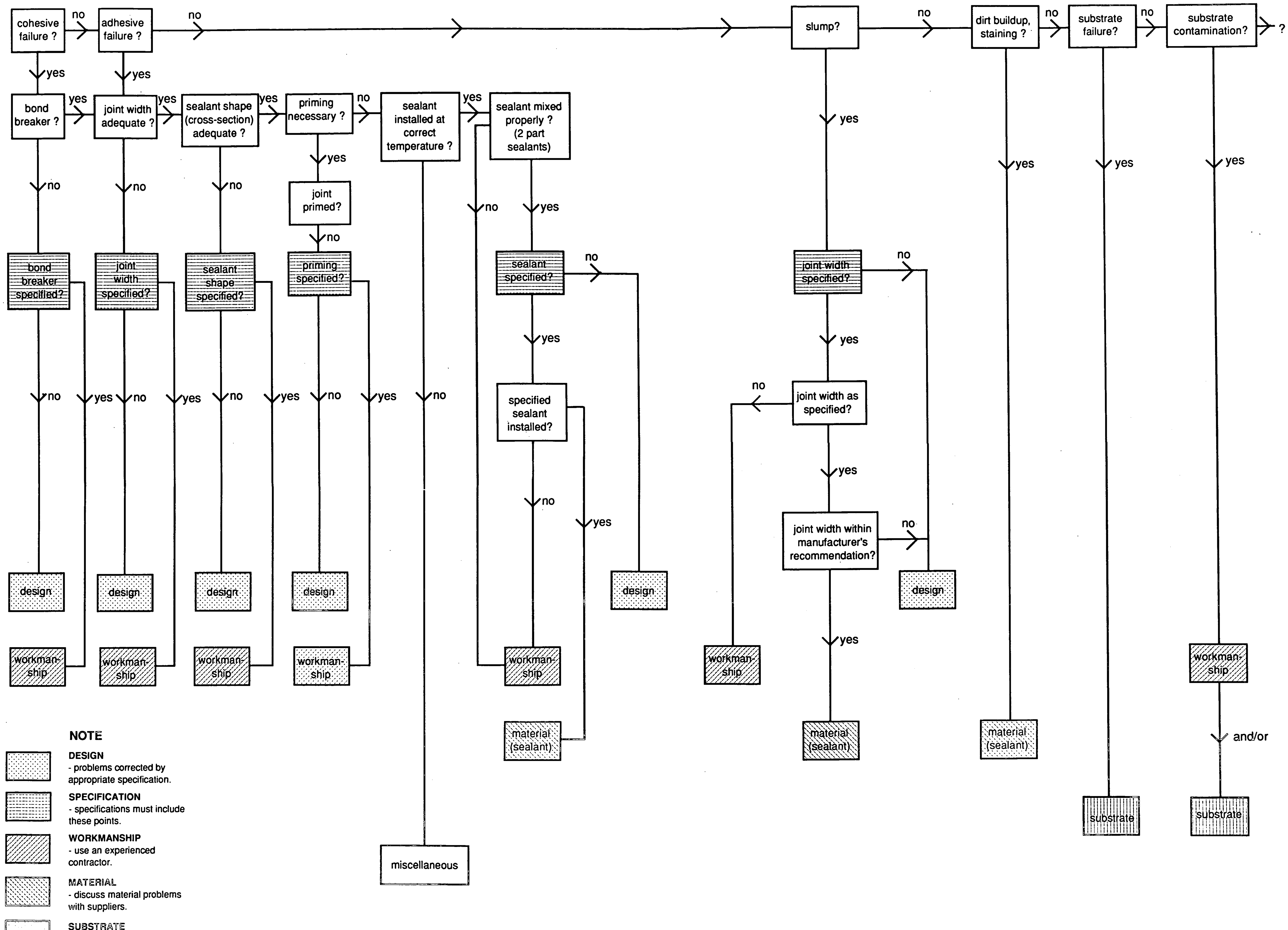

Figure 6 : Identification of the cause of a widespread failure.

Table 2. Substrates and Contaminants

Substrate	Contaminants
- anodised aluminium	- a wide variety of types and finishes available*. (often difficult to get good adhesion)
- coil coated aluminium	- a wide variety of types and finishes available*.
- mill finished aluminium	- mill contaminants; oil, graphite, carbon residues.
concrete (including block)	- laitence, release agents, curing compounds, moisture. Acid curing silicones should not be used with concrete or any other cement-based material
grc	- see concrete
galvanised steel	- oil, white rust.
coil coated galvanised steel	- a wide variety of types and finishes available*.
grp (glass fibre reinforced polyester)	- wax
stainless steel	- oil.
wood, unpainted	- moisture, oils (paint wood to reduce these effects).
wood, painted	- a wide variety of types and finishes available*.
* Because of the wide range of coatings and paints available, compatibility between a specific sealant and a specific paint or coating should be checked.	

Table 3. Composition of Typical Joint Sealant

Component	Use
prepolymer	binder
plasticisers	control of hardness, elasticity
extenders	cheapens sealant
reinforcing fillers	strengthening of cured sealant, mechanical control thixotropy (slump resistance)
fillers	packing (cheapens sealant)
pigments	colouring
adhesion promoters	better bond to substrate
antioxidants	resist heat and weathering
accelerators/retarders	speed up or slow down cure
crosslinkers	build up three-dimensional structure

Identification of Sealant Type

Although sealants are commonly referred to by type such as 'polyurethane' or 'acrylic', there are in fact a wide range of formulations and properties available within a particular type. The constituents of a typical sealant are shown in Table 3. By altering the relative proportions, or the actual constituents themselves, sealant properties including cost can be accentuated or de-emphasised. Some of the constituents can be found in more than one sealant type, which makes type identification particularly difficult.

Unless there is a strong indication that the sealant used was a definite type and brand, and can therefore be referred back to its original manufacturer for analysis and confirmation, it is impossible to identify the specific brand of sealant used in a joint. Since formulations are confidential to each manufacturer, a detailed chemical analysis will not establish brand unless the original formulation details are available. It is difficult to even establish generic type such as silicone or polyurethane from chemical analysis, and there is little published information available on how to do this. Table 4 gives a listing of appearance and simple physical tests which can be used to tentatively identify the generic type of sealant used in a joint.

Distinguishing between acid-cured and neutral-cured silicone sealants is not easy, although silicones installed before 1980 are likely to be acid-cured. Acid-cured silicone has a high tensile modulus (650-1050 kPa at 150% elongation), neutral-cured sealants are medium or low (less than 650 kPa). These can be checked on strips of sealant if they can be removed intact from the joint and have a uniform cross-section.

Pyrolysis (reducing to ash in a laboratory furnace) of silicone sealant samples is also useful, since the ash corresponds to the original filler content of the sealant, although fumed silica used as a filler may be lost during pyrolysis. The presence of CaO as a residue indicates neutral silicone sealant, since $CaCO_3$ would not be present in acid-cured types. This distinction is not available in the case of clear silicone sealants. Acid-cured silicones usually contain less than 15% filler, neutral-cured 5 to 40 per cent.

REPAIR METHODS

Design

Design of a successful repair depends firstly on having correctly identified the cause of failure. Secondly, there must be conservative design with some built-in overcapacity to allow for deterioration in sealant properties with age, and for the fact that not every joint may move which increases the amount of movement at other joints.

Preparation

Treatment of the sealant in the existing joint depends on what type it is, and its existing condition. If the failed sealant is a polyurethane and removal rather than the bandage approach (see below) has been decided

Table 4. Identification of Sealant Type

oleoresinous - surface skin, extremely hard and wrinkled. - may have very soft interior, or very hard and brittle right through.
butyl - very sunken, hollow surface due to shrinkage. - wrinkled surface.
acrylic (solvent) - tough, but not resilient, when stretched stays stretched. Often dirty and soiled, usually found around windowframes.
polysulphide - surface chalking (whitish dust which will rub off). - freshly cut piece smells faintly of sulphur. - not truly elastic, if a length is removed and left stretched overnight and the tension is then removed, does not go back to original length.
polyurethane - surface crazed (see Figure 4). - truly elastic, stretched length goes back to original when released. - no sulphur smell when freshly cut.
silicone - no chalking or surface crazing. - elastic and rubbery, full recovery when stretched. - tear resistance is usually low. - failure is usually adhesive due to material incompatibility. - often bad staining and dirt pickup adjacent to joint in porous substrates. - a high level of dirt pickup on the sealant.

upon, it is necessary to remove all traces of it. If this is not done, the adhesion of the new sealant to the joint sides may fail since silicones and polysulphides will not stick to polyurethanes and many polyurethanes will not stick to each other. All traces of oil-based sealants must likewise be removed - very difficult on porous substrates, unless the edges of the joint are cut or ground out. If permitted by the local authority, sand-blasting is also an option.

Assessing Joint Width Range

The failed joints should be extensively surveyed to work out the existing range of joint widths. For each type of joint to be replaced (e.g., panel/panel horizontal and vertical joints) the width of the narrowest joint should be measured at its narrowest point, and the widest joint at its widest. The width of the widest joint sets the upper limit - can this joint be filled without the sealant slumping out? Is the narrowest joint wide enough to cope with the calculated movement? It is possible to grind or cut narrow joints out if necessary.

Sealant Selection

Use the width of the narrowest and widest joints to set the range of joint widths to be filled. Estimate the likely range of service temperature and likely movement. Table 5 gives typical temperature ranges for building materials depending on colour and components, Table 6 lists thermal and

Table 5: Estimated extreme temperatures on buildings

Building Element	Temperature °C	
	Maximum	Minimum
Precast concrete, light-coloured masonry wall (outer 75 mm), exposed concrete eaves, edges of floor slab	50	−10
Similar construction, but dark coloured	65	−10
Black glass, ceramic tiles,or metal, insulated behind	80	−15
White glass, ceramic tiles, or metal, insulated behind	60	−15
Black metal panel, exposed behind clear glass and insulated behind	130	−5
Clear glass in front of dark insulated background such as panel above	80	−15
Aluminium mullion in a curtain wall (natural colour or white)	50	−5

Table 6: Thermal and moisture movement of building materials (adapted from BRE Digest 228, 1979)

Material Type	Coefficient of linear thermal expansion per $^{o}C \times 10^{-6}$	Typical movement, mm per m for $60^{o}C$ change	Moisture Movement, % of length (change wet to oven dry)	
			Reversible	Irreversible (Shrinkage)
granite	8 – 10	0.50		
limestone	3 – 4	0.24	0.01	
marble	4 – 6	0.36		
slate	9 – 11	0.66		
cement mortar	10 – 13	0.78	0.02 – 0.06	0.04 – 0.10
concrete (normal)	10 – 14	0.84	0.03 – 0.10	0.03 – 0.08
cellulose cement sheet	8 – 12	0.72	0.10 – 0.15	
GRC	7 – 12	0.72	0.15 – 0.25	0.07
concrete block				
– normal	6 – 12	0.72	0.02 – 0.04	0.02 – 0.66 0.6
– lightweight	8 – 12	0.72	0.03 – 0.06	0.02 – 0.06
bricks (clay)	5 – 8	0.48	0.02	
cast iron	10	0.60		
mild steel	12	0.72		
stainless steel				
– austenitic (304, 316)	18	1.1		
– ferritic (444)	10	0.60		
aluminium	24	1.4		
aluminium alloys	24	1.4		
copper	17	1.0		
bronze	20	1.2		
aluminium bronze	18	1.1		
brass	21	1.3		
zinc	23 – 33	1.4 – 2.0		
lead	30	1.8		
acrylic	50 – 90	3.0 – 5.4		
GRP	20 – 35	1.2 – 2.1		
polycarbonate	60 – 70	3.6 – 4.2		
PVC	40 – 70	2.4 – 4.2		
glass (plain or tinted)	9 – 11	0.66		
radiata pine	4 – 6 with grain	0.36	negligible with grain	
	30 – 70 across grain	4.2	2.5 across grain*	
particleboard				
– urea-formaldehyde	30 – 40	1.8 – 2.4	0.07 – 0.19*	
– tannin	30 – 40	1.8 – 2.4	0.11 – 0.21*	
plywood	20	1.2	0.10 – 0.15* (UK data)	
hardboard	10	0.6	0.06 – 0.12*	

* change from 65% to 90% RH

Table 7: Selection guide for sealants used with external claddings (adapted from Beech, 1981 and BS 6213 : 1982)

Chemical classification	Substrate suitability: asphalt/bitumen	brick	cellulose cement	concrete	GRC	glass, glazed ceramics	metals	plastics	wood	Maximum recommended movement % of installed sealant width	Type	Expected service life (years)	Comments	Typical uses
bituminous rubber/bituminous	X	X	X	X	X		X		X	10	P	5	Poor durability in external joints.	In contact with bituminous materials.
oleoresinous		X	X	X	X		X		X	5	P	10	Regular maintenance necessary.	Pointing around window and door frames.
butyl rubber			X	X		X	X		X	10	P	10	Properties very dependent on individual formulations.	Pointing and bedding, particularly in glazing.
acrylic latex											P–E		Not suitable for exterior use in moving joints.	Interior pointing.
acrylic solvent		X	X	X	X		X		X	15	P–E	15	Good adhesion. May retain dirt and support mould growth.	Pointing around wooden door and window frames.
one-part polysulphide		X	X	X	X	X	X		X	25	E–P	20	Takes up to 3 weeks to cure; vulnerable to damage by moving joint until cured. Priming necessary on most substrates.	Movement joints in heavy structures.
one-part polyurethane		X	X	X	X	X	X	X	X	20	E	20	Takes up to 3 weeks to cure; vulnerable to damage by moving joint until cured. Priming necessary on most substrates.	Movement joints with light (e.g. metal) components.
two-part polysulphide		X	X	X	X	X	X	X	X	30	E–P	20	Mix on site. Priming necessary on most substrates.	Fast moving joints in light structures; slow moving joints in heavy structures.
two-part polyurethane		X	X	X	X	X	X	X	X	20	E	20	Mix on site. Priming necessary on most substrates.	Fast moving joints in light structures; slow moving joints in heavy structures.
silicone – low modulus		X	X	X	X	X	X	X	X	50	E	20	Priming necessary on most substrates. Careful surface preparation essential. High initial cost.	Joints between plastic and metal components; joints having large movement.
silicone – medium modulus		X	X	X	X	X	X	X	X	25	E	20	Priming necessary on most substrates.	General purpose construction sealant.
silicone – high modulus		X				X	X	X	X	20	E	20	Priming necessary on most substrates. Unsatisfactory on porous surfaces.	Glazing, structural glazing, fast moving joints, sanitaryware. Do not use on cementitious materials, coil-coated steel, galvanised steel, lead, zinc or copper without checking suitability/need for priming.

X = suitable
P = plastic
P–E = plastoelastic
E–P = elastoplastic
E = elastic

moisture movement figures for building materials. Calculation methods are given in Appendix 2. From Table 7 select the generic sealant type which can cope with the anticipated movement for the minimum joint width. These are general guidelines only. Movement capacity will still vary depending on the specific brand of sealant selected, and therefore needs to be checked. The depth of sealant in the joint must be at least 6 mm.

From manufacturer's data find a specific sealant of the appropriate generic type, and make sure that it will not be subject to slumping when used to fill the widest joints. From the practical viewpoint, if one-part sealants are used in the ideal 2:1 width-to-depth ratio then the maximum width is 30 mm since maximum depth for adequate cure of one-part sealants is 15 mm. In fact, for many one-part sealants a 30 mm wide joint will cause slumping and 20 mm is a more realistic maximum width. With two-part sealants wider joints can be used but may not have the optimum cross-section. Only a sealant with a life expectancy of 20 years or more should be used (see Table 7). Where the type and brand of sealant originally used is known from records, the same sealant should be used again if it is of reasonable quality (polysulphide or silicone), and not considered to be the cause of the failure. Although, in theory, polyurethanes can be replaced with the same type again, once the failed joint has been thoroughly cleaned out, current industry practice is to replace with silicone. In discussions prior to the preparation of this report, sealant contractors indicated their distrust of polyurethanes following failures in the mid- and late 1970s. However, as noted under 'Materials' above, the polyurethane sealants currently marketed are stated as being improvements on those of the 1970s. Where the substrate is weak, the use of a low modulus silicone or polysulphide sealant will place the least tensile stress on it.

Specification and Trial Repairs

Make sure that the repair specification includes sealant type and brand name, and also the manufacturer's recommendation for cross-section, backup material, bond breaker, and primer - without permitting substitution of any items. It is a good idea to check compatibility of the old and new systems by a small scale trial of cleaning out and replacement. After an adequate cure time of a month or so, the ease of removal of the new sealant can be checked to see, in particular, whether there is good adhesion to the sides of the joint. Trials can also give some idea of likely cost.

Generally look out for:

joint width	if less than 12 mm for concrete panels wider than 4 m, then cohesive or adhesive failure of the sealant is likely.
perimeter seals around windows	if the depth of the joint is less than 6 mm then adhesion failure (to aluminium) is likely.
joints at corners of buildings	these joints are subject to maximum shear and stress (see Figure 7), and should be designed with a width at least 30 per cent greater than ordinary panel-to-panel joints.

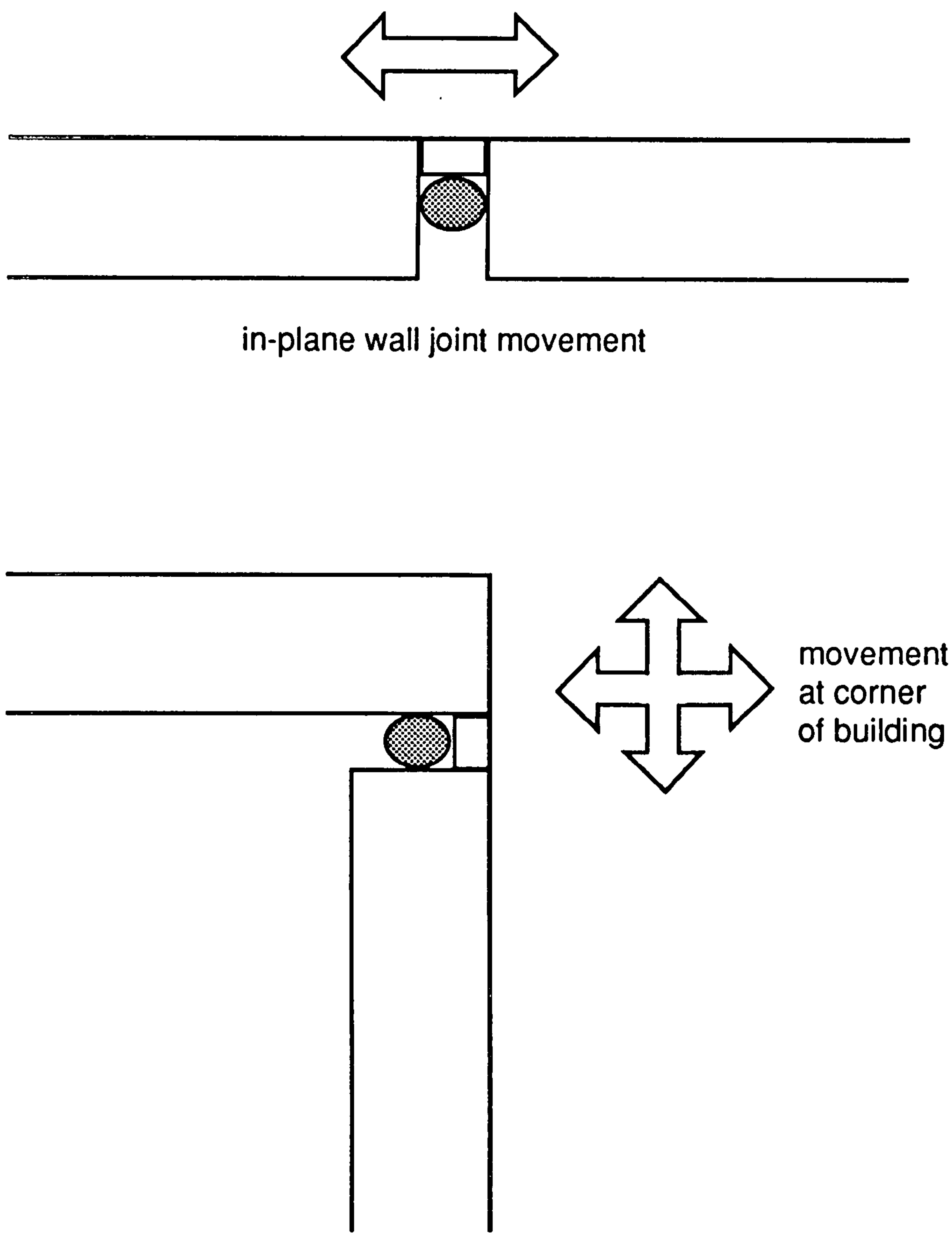

Figure 7 : Joint movement at building corner.

Workmanship

Preparation

The existing sealant should be mechanically removed. As much as possible should be cut out with a knife, and the edges of the joint cleaned up by hand or mechanical wire brushing, grinding or sand-blasting to remove all traces of the previous sealant. To avoid scratching non-absorbent substrates such as glass, aluminium, glazed ceramic tiles, fibreglass reinforced polyester, coated steel or aluminium, solvents may be used to remove the final traces of sealant. Solvents should not be used on porous substrates such as concrete, glass-fibre-reinforced cement, wood, unglazed ceramic tiles or brick. Such substrates will absorb solvent and contaminants which may then give trouble later. Where oleoresinous or other sealants have released oil or contaminants into a porous substrate, the joint edges should be cut or ground away to remove them. Figures 8 and 9 show the edge of a precast concrete panel joint being ground after the sealant has been cut out, and the cleaned joint.

An alternative to removal is the bandage approach, which is discussed after the next section. Although this saves on preparation costs, the resealed joint is more likely to fail again.

Total Replacement Method

Once the sealant has been removed, and the joint thoroughly cleaned out, the backup material is installed first to the required depth, making sure that it is firmly held and will not be dislodged by the pressure of the sealant being applied on top of it. If a bond breaker is not included as an integral part of the backup, then a separate bond breaker should be carefully applied on top of the backup material.

Primers are usually necessary on most substrates to achieve maximum adhesion. Primers can serve several functions. They are of low viscosity, and so wet out and penetrate porous substrates readily. They may prevent penetration of moisture from the substrate to the sealant, which can cause loss of adhesion, or penetration of UV radiation through glass which can have the same effect. They may also protect the substrate from being stained by the sealant. Primers are specially formulated so that they bond to specific substrates as well as the sealant, and so different primers are required for different substrates. It may be necessary to mask the edges of the joint to prevent the primer staining the substrate.

When the joint is to be filled with sealant, the edges of the joint should be masked, and the masking tape removed immediately after tooling. It must be ensured that the sealant completely fills the joint to the required design depth, that the backup material is not dislodged, that the sealant is in full contact with the walls of the joint and that there is no air trapped by the sealant. The gun should be pushed in the direction in which the sealant is applied. Finally, tooling forces the sealant into the joint and gives the surface the correct contour for maximum movement accommodation.

Figure 8 : Grinding the edges of a joint after sealant removal.

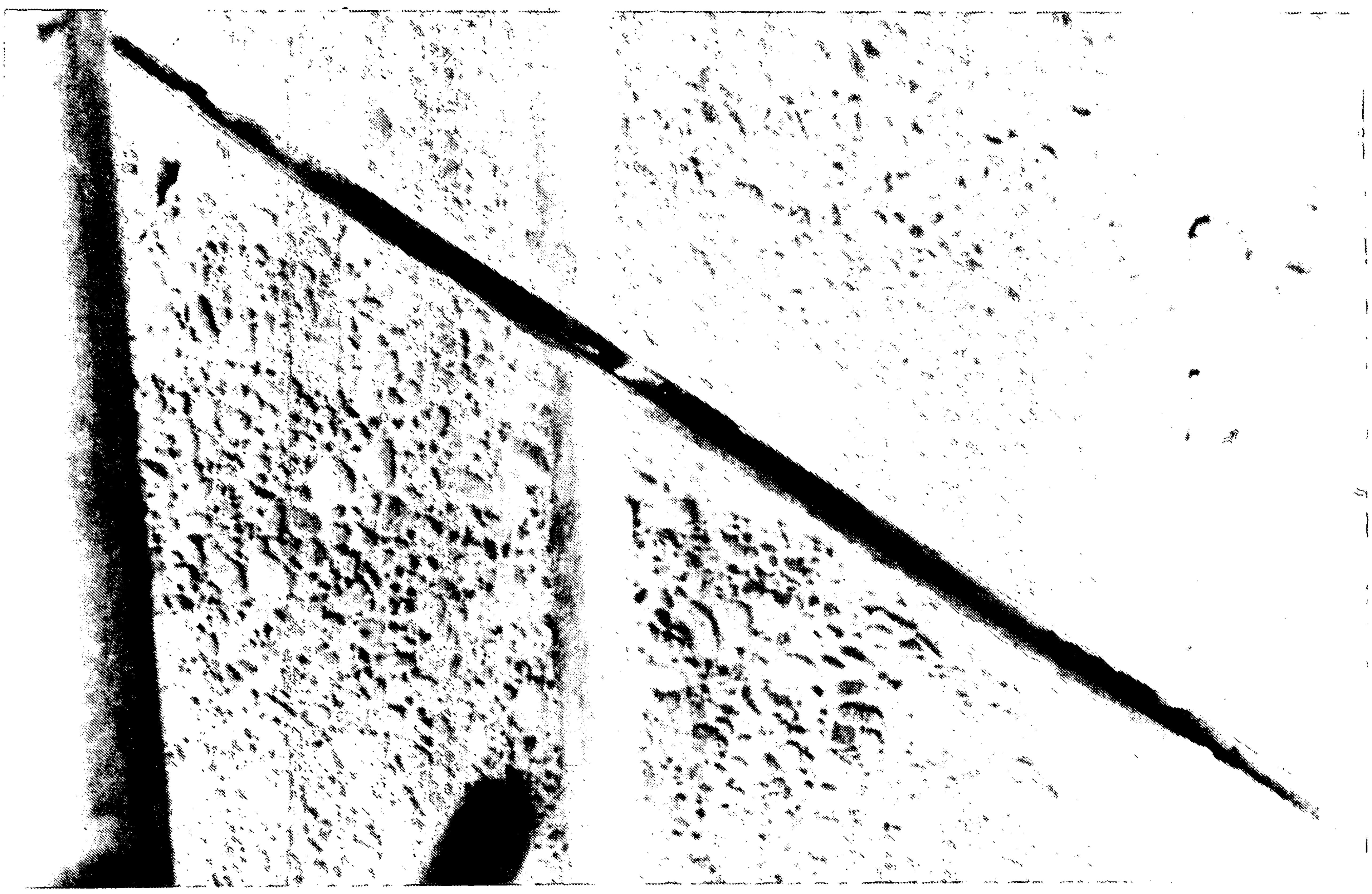

Figure 9 : Cleaned joint after grinding.

Bandage Repair Method

The bandage repair method is considered likely to be less successful than total removal and replacement of the sealant in a failed joint. Nevertheless, it is a viable alternative, particularly when it is desired to extend the life of a building for a comparatively short time (say 10-15 years), or where it is considered that the chance of removing all traces of sealant and associated contaminants from the existing joint is slight.

In the bandage method, a new capping layer of sealant is simply applied over the existing sealant in the joint, i.e. the failed sealant is not removed (see Figure 10). Debonding between new and old sealant is achieved by deliberately selecting a new sealant which will not stick to the old one (see Table 8). This implies two requirements, that the sides of the joint to which the new sealant will adhere are clean and dry and totally free of traces of the old sealant. The old sealant must also be clean and free of any dirt or irregularities to which the new sealant can stick. In practice, the sealant is applied as a relatively thin layer usually not in the ideal width to depth ratio. Any interactions between the old sealant and the new may not become apparent for some time.

Selecting and Testing a Repair Method

Once a repair method has been decided upon in principle, it is a very good idea to carry out a small scale trial on joints which are representative of those to be repaired. This will prove the appropriateness or otherwise of the methods chosen, and a number of different alternatives can be tried. Some information on the likely cost of full-scale repairs will also be obtained, and trials are the most reliable way of obtaining cost information. Sealant contractors, and manufacturers/suppliers can supply information and sometimes specifications for methods which they think will have a good chance of success.

Costs

Limits on the amount of money available for repair are often the principal factor in deciding on a repair method. The intended useful life of the building is also a factor. Where there is some degree of choice, solutions which initially seem expensive may in fact be cheaper in the long term because of the reduced cost of ongoing maintenance.

Specific cost figures are difficult to obtain for New Zealand. Estimates suggest that the cost of sealing a new joint is of the order of $25-30 per metre length, and to remove failed sealant, clean out the joint and reseal is approximately three times this figure. Access will play a big part in determining cost. For the sealing of a new joint, scaffolding is already in place. If scaffolding is required for repair work it will constitute a major part of the cost. As noted above, repair of a trial area is the most reliable way of obtaining cost information.

It is well worth bearing in mind that the cost of scaffolding, preparation and application will be much the same whatever sealant is used, and will be much more than the material cost of the sealant. Attempts to save money by using a less expensive (and hence lower performance) sealant should be avoided - they may not prove to be cost savings anyway, and time between maintenance periods will be reduced. The difference in material cost for a sealant is only a factor of two or three times from the cheapest to the

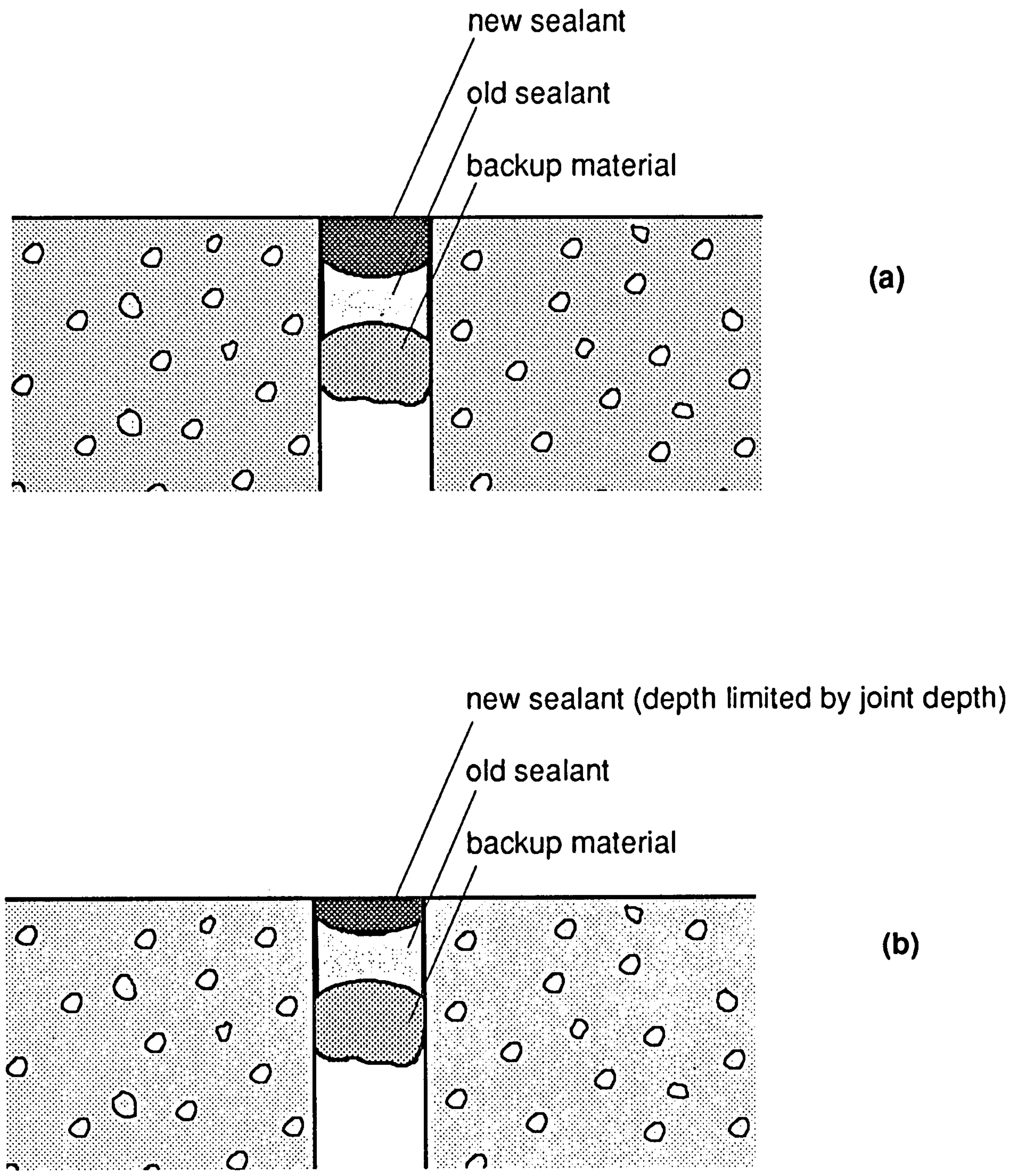

Figure 10 : Bandage repair to failed joint.

a) Ideal

b) More usual

Table 8 : Sealant compatibility in adhesion

new sealant \ old sealant	acrylic (solvent)	butyl	oleoresinous	polysulphide	polyurethane	silicone
acrylic (solvent)	a	n	d	o	n	n
butyl	o	a	d	d	n	n
oleoresinous	o	d	a	a	n	n
polysulphide	o	d	n	a	n	n
polyurethane	n	n	n	d	d	n
silicone	d	d	n	d	n	d

KEY

a - will adhere
o - no information
n - will not adhere
d - specific test required

most expensive. When the differences in movement accommodation from cheapest to most expensive are also taken into account, this cost difference vanishes or may even reverse.

CONCLUDING COMMENTS

As noted initially, current estimates of lifetimes for sealants used in one-stage cladding panel joints and exposed to the weather are much less than the normal lifetimes of most buildings. This means that the sealed joints will need to be repaired and replaced a number of times in the life of a building. A major part of the cost of repair work is likely to be access in terms of scaffolding.

Since repair of the joints is inevitable, it is imperative that the likely repair method, including access, is designed into the building. The designer should pass this information on to his client, along with a suggested schedule of inspections of the jointing system.

Apart from cases of early major failure, there is a lack of feedback between clients and designers on the long term performance of sealed joints, which currently limits refinement of design.

Where the life of the building is not a limiting factor, the repair method should not reduce the sealant cost, and hence quality and performance, as a means of reducing the cost of repair, because of the adverse effects on quality and performance.

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APPENDIX 1: GLOSSARY OF TERMS

Acid-cured	One part silicone sealant which cures by reacting with moisture and releasing acetic acid as a byproduct of the curing reaction.
Adhesive strength	The ability of the sealant to maintain adhesion to the substrate.
Application life	The period within which the sealant can effectively be applied to a joint and tooled before curing starts. Usually refers to two-part sealants (for one-part sealants see skinning time).
Backup material	Compressible closed cell plastic foam material placed behind sealant in a joint to control sealant depth. In most cases the sealant has little or no adhesion to the backup material. Backup material may also be in the form of a plastic or rubber tube.
Bond breaker	A release surface to which the sealant will not adhere. Usually tape or backup material.
Cohesive strength	The ability of the sealant to resist tensile failure within itself.
Modulus	Short for modulus of elasticity. A measure of sealant stiffness. The higher the modulus the stiffer the material (more resistant to deformation). Generally quoted at 100% extension of the sealant.
Neutral-cured	One-part silicone sealant which cures by reacting with moisture and releasing non-acid (neutral or alkaline) byproducts from the curing reaction.
One-part sealant	A sealant supplied ready for use and not requiring mixing. Exposure to moisture in the air after application starts the curing (hardening) reaction.
One-stage joint	A joint in which the sealant provides the sole weather barrier (see Figure 11).
Plasticiser	A material (usually liquid) incorporated in a sealant to increase its flexibility.
Skinning time	For one-part sealants, the time between application into the joint and the formation of a tack free (i.e., non-sticky) skin.
Slump	Flow of uncured sealant out of a filled, overwide joint (see Figure 1 Page 2).
Two-part sealant	A sealant supplied as two components which are mixed on site prior to application. The chemical combination of the two components causes the sealant to cure (moisture is not necessary as it is for one-part sealants).

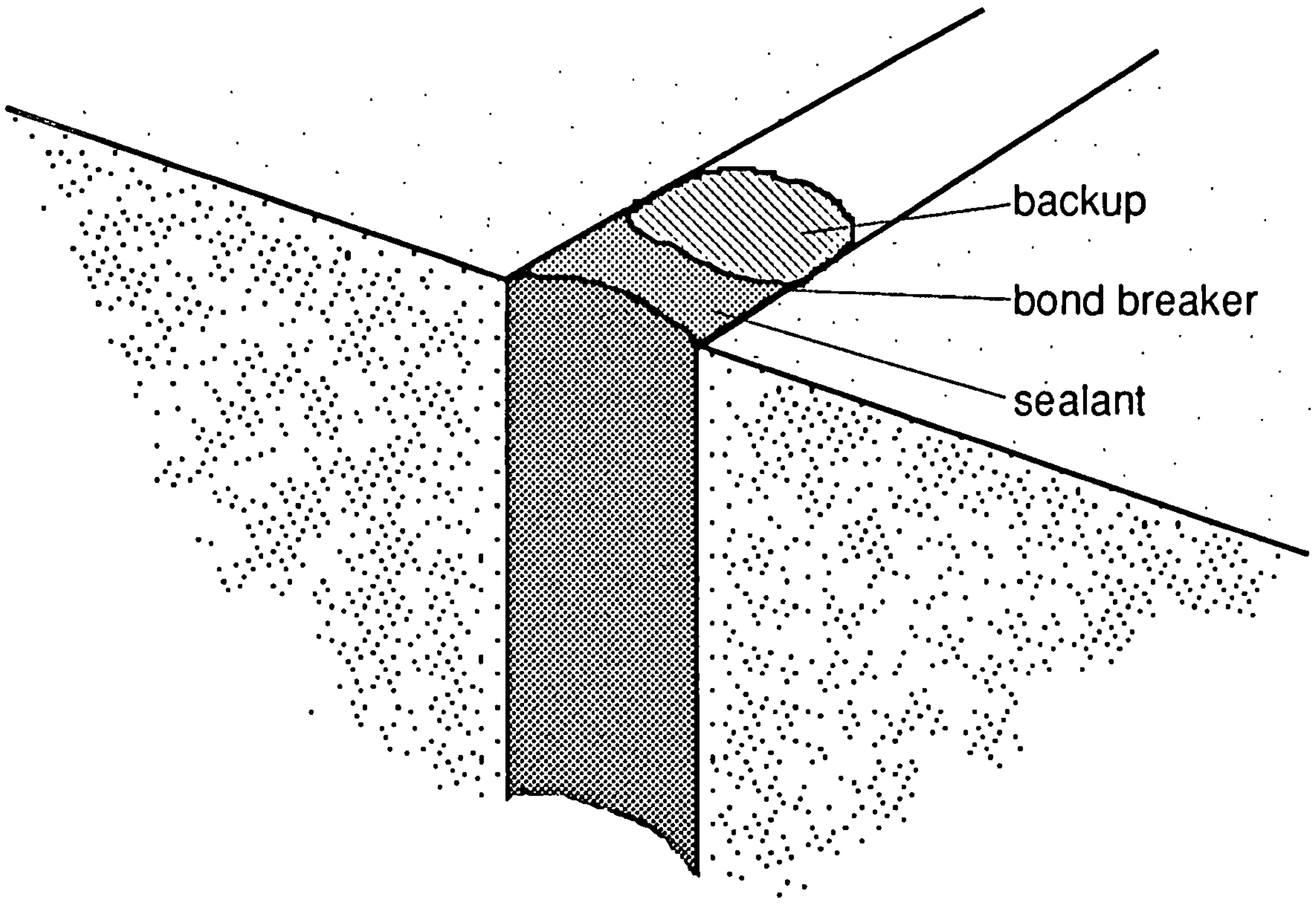
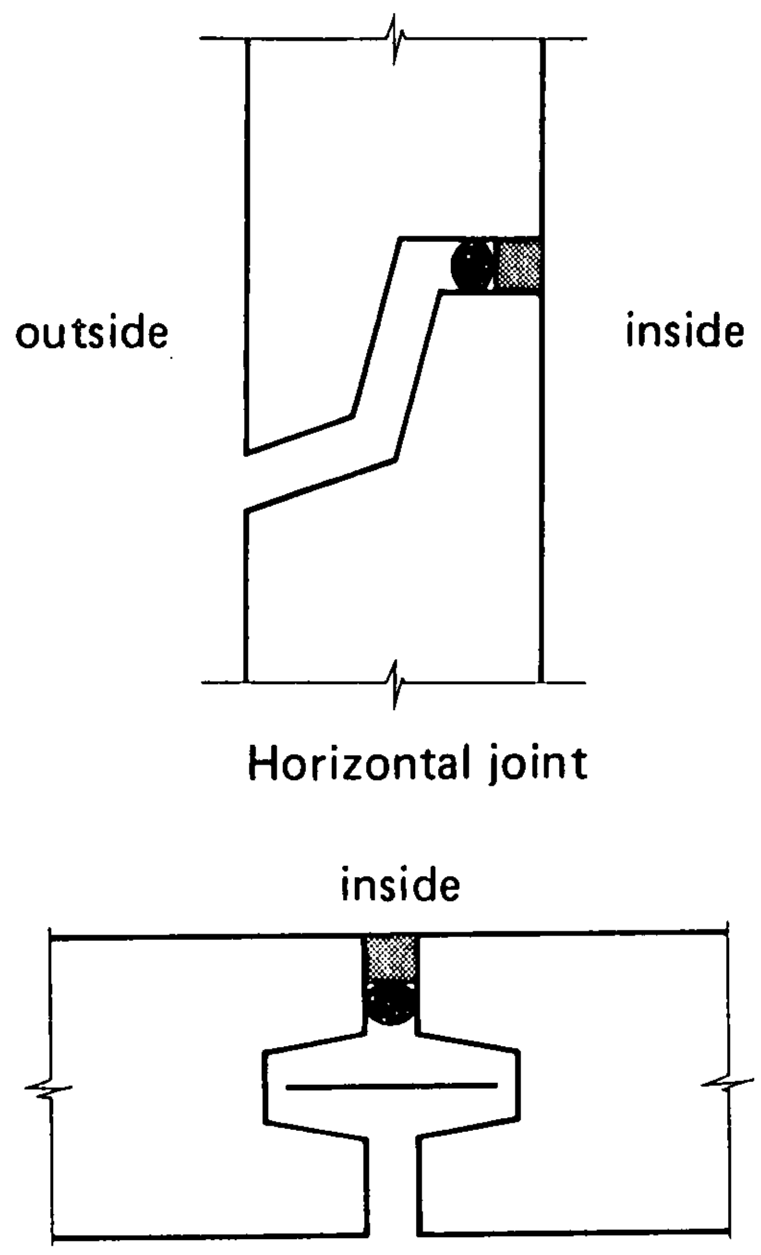
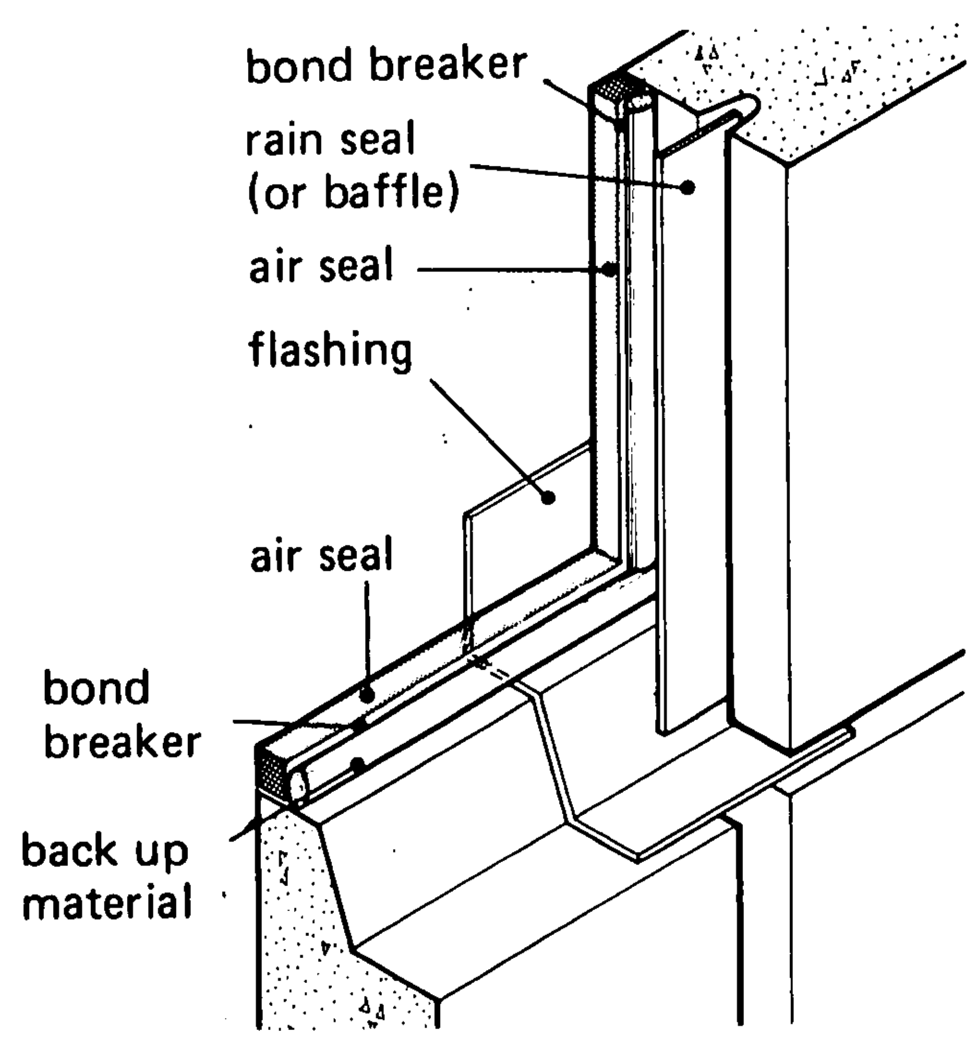


Figure 11 : One - stage joint (vertical and horizontal joints are the same).



a) Vertical joint



b) Intersection of horizontal and vertical joints

Figure 12 : Two stage (drained) joint (schematic).

Two-stage joint Also known as drained joints or rain screen joints. The screen against rain, and the seal against air leakage, are treated as two separate operations. The rain screen need not be airtight, and can be simply an offset in the panel in horizontal joints and a baffle in vertical joints (see Figure 12a and b). The air seal is usually positioned in the back of the joint (Figure 12b).

APPENDIX 2: CALCULATION OF MOVEMENT AT JOINT

Apart from wood based materials where moisture movement predominates, thermal movement of cladding panels is the predominant factor acting on joints. Thermal movement and moisture movement in materials tend to act in opposition, although the long term tendency of concrete to shrink as it cures and dries must also be kept in mind. Table 6 (page 18) lists thermal expansion coefficients of building materials.

The amount of thermal movement can be calculated using the simple formula:

$$A=aLT$$

where A=panel expansion/contraction
a=linear coefficient of thermal expansion
L=length (or width) of panel
T=temperature change

Colour plays an important part. For light-coloured materials the temperature change will be of the order of 60°C, for dark colours it may be well over 100°C (see Table 5, page 17).

Once the movement has been calculated, it is necessary to see whether the existing joint width and proposed sealant combination will be able to cope with the likely movement. From the survey of joint widths the maximum,M, and minimum,m, measured joint widths are known. The maximum and minimum potential joint widths in service are calculated as

$$Max=M+A$$
$$Min=m-A$$

since joint width measurements are unlikely to have been made when the joints were open or closed to their fullest.

Check the manufacturer's literature for the sealant it is proposed to use for the repair job. Make sure that the minimum allowable width is not less than the minimum calculated above. If it is, then the joint will need to be cut or ground out, or another sealant selected. Similarly, make sure the calculated maximum is not above the manufacturer's maximum. Again, if it is, another sealant having better slump resistance must be selected. As far as possible allow for some redundancy in sealant movement capability, i.e., select a sealant that will easily cope with the anticipated movement. As the sealant hardens with age and its movement capability decreases, it will still be able to cope.

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Repair and replacement of
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