1.5 MOVEMENT AND MEMBRANES

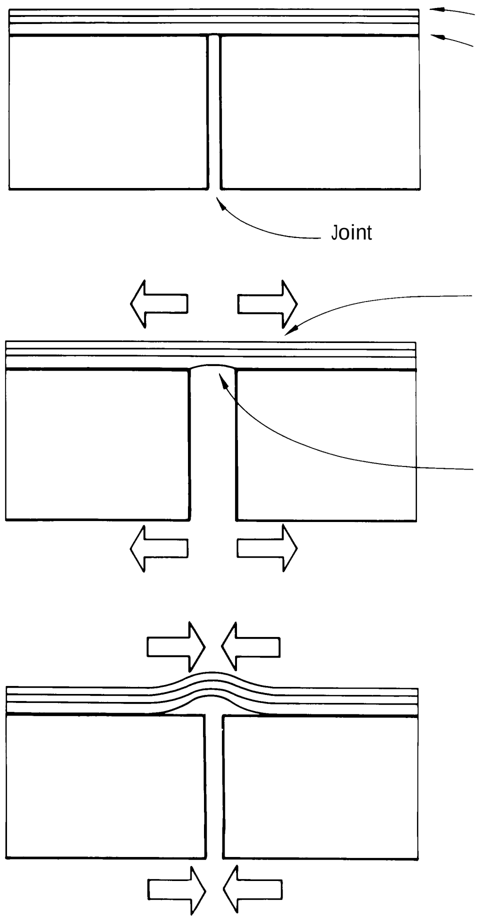
INTRODUCTION

All flat roofs comprise a number of elements which expand, contract or move in relation to each other and therefore subject the waterproofing element to stress. Failure of roofs due to the action of movement has been a principal cause of roofing problems in the past and in almost all cases has been the result of membranes with a low tear strength and a failure to isolate the waterproofing specification from movement. An understanding of joint movement and the advent of modern membranes with high tear strength and fatigue resistance has all but eliminated failure caused by joint movement.

Movement in roofs is primarily caused by thermal expansion and contraction of the roof structure or insulation, or in the case of hygroscopic materials, their expansion and contraction as a result of wetting and drying.

Thermal movement cycles may occur daily or even hourly as the sun is obscured by clouds or as rainfall causes sudden drops in temperature. On the other hand, moisture movement is usually infrequent and occurs in relation to longer spells of wet or dry weather, although a more rapid cycle of moisture movement can occur as a result of the changing conditions inside a building which may involve large amounts of water vapour generated over short periods.

These cyclic movements must be allowed for in the design of the structural deck and in the selection and form of attachment of the insulation and waterproofing.



BUILT-UP ROOFING

It is essential for the designer to have an understanding of the effect of joint movement in order to select specifications which eliminate the risk of movement being transmitted to the waterproofing covering.

RIDGING

The properties of bitumen can allow a measure of slip under load which does not fully recover when the load is released. In the case of built-up roofing bonded to a deck or insulation with joints which move significantly, the slip of the bitumen adhesive and the stretch of the membrane can build up from cycles of movement to form loose material above the joint in the form of a ridge.

The build-up of loose material arises as a result of the non-recovery of the slip or stretch in what is termed a ratchet effect, and is generated by temperature cycling or moisture cycling. For example, ridges over joints between precast concrete units are likely to be due to temperature cycling, whilst the ridges over joints between wood fibre insulating board or chipboard decking are usually due to moisture cycling.

After a ridge has formed, continual joint movement will stress and flex the ridge and the membrane must have sufficient strength and flexibility to prevent damage due to fatigue.

Stress may also occur when there is no local ridging of the membrane. This is usually when a membrane is fully bonded on tightly butted joints where cyclic movement is small. The membrane does not become significantly stretched and the bond does not break down or slip locally to the joint, but a stress is transmitted into the membrane. The mechanism is again one of fatigue.

Continual joint movement can lead to fatigue failure

Before the advent of polyester and other high performance roofing, severe ridging and stress would cause splits in the roofing and failures were widespread. The newer materials and methods of attachment have compensated very adequately. This aspect, more than any other, has lead to the current highly successful performance of modern flat roofs.

DECK MOVEMENTS

When built-up roofing is applied direct to the structural deck, movement of the deck will be transmitted directly into the membrane. This can be a single event, such as the initial curing and shrinkage of concrete, or repeated movements from the thermal or moisture cycling of prefabricated deck units. Differential movements may also occur as a result of a change in direction of deck or at a change of deck material and from differential deflection between adjacent units.

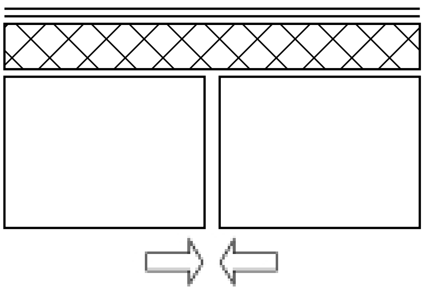
Most prefabricated deck materials will move too much to allow a fully bonded specification. There are two methods employed to isolate the movement of the deck from the membrane. The first method is a partial bonded first layer and the second method is to introduce an isolating insulation layer between the deck and the waterproofing.

The most common partially bonded system is by the use of BS 747 type 3G perforated venting felt. The perforations produce a controlled part bond and the mineral granules on the lower surface prevent self-adhesion and ensures that no seal is formed by heat from the sun in service.

A partial bitumen bond is used to attach built-up roofing to substrates of precast concrete, lightweight concrete screeds, sand / cement screeds, woodwool slabs and timber based products such as plywood and particleboard.

Partial bonding is also usual when laying built-up roofing direct to an in-situ cast concrete slab, even though there is little movement. In this case, however, the primary purpose is to provide a release zone for vapour pressures which may build up as a result of trapped air and moisture beneath the waterproofing.

The alternative and often preferred method of isolating movement is to use an insulation layer which must break joint with the deck and will prove wholly effective in isolating the membrane from deck joint movements. If an underlay or vapour check is required, this would be bonded to the deck, before



Membrane isolated from movement by insulation

application of the insulation.

Timber boarded decks present a large number of closely spaced joints, and the traditional method of accommodating the deck movement is to nail the first layer of roofing.

INSULATION MOVEMENT

The movement characteristics of insulation materials vary considerably and determine whether the waterproofing membrane is to be fully bonded, partially bonded or protected from movement by using a more stable insulation as an overlay to the main insulation board before applying the waterproofing.

Fibrous insulating materials such as wood fibreboard, cork, mineral wool, or perlite board suffer little movement from temperature and it is usual to fully bond the membrane to these insulants. Some ridging of the membrane above the joints in the insulation may be evident, but this should not be regarded as a cause for concern.

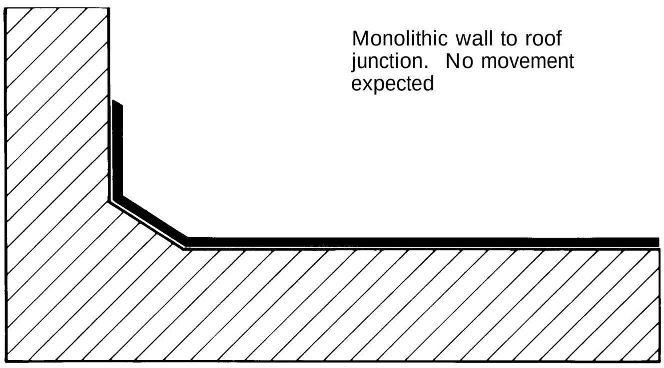
The high efficiency foam insulants, however, have high coefficients of expansion and rapid response to temperature change. They will absorb deck movements, but will also impose their own range of movements which must be taken into account when designing the specification.

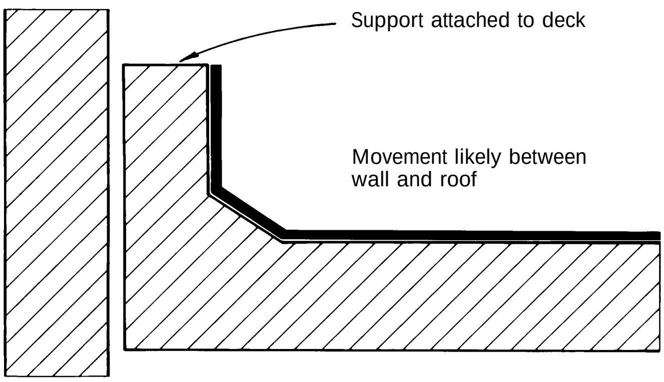
Expanded polystyrene moves substantially as a result of temperature changes and new material has a tendency to shrink permanently during curing which is in addition to any thermal movement. An overlay of a more stable insulating material is required to prevent movement of the expanded polystyrene being transmitted directly into the membrane.

Unfaced polyurethane foam has similar expansion characteristics to expanded polystyrene, but boards used for roofing are restrained by facings which are designed to stabilise the board. A glass fibre tissue facing is adopted by most manufacturers and this produces a stable board with no undue thermal movement. The facing takes the stress and provides a good surface for part bonding, so that the membrane is substantially freed from stresses which could otherwise be induced by the movement of the insulation.

MOVEMENT AT DETAILS

Most common is differential movement or differential deflection between the roof structure and the wall. Typically movement occurs at the junction of timber, woodwool, or metal deck roofs and independent brick walls. However, the junction between metal deck and vertical metal cladding is not at risk of joint movement because the structural curb is normally formed of pressed metal sections connected firmly to the deck and to the structural frame.





A sure sign of differential movement between the roof structure and the wall

Differential movement can also arise because the roof and walls act as separate single plates. In this case, the stresses are normally towards the end of the skirting and may be accompanied by shear deformations in the waterproofing upstand. These show as slanting ruckles and are a sure sign of differential movement between the roof structure and the wall.

It is usually possible to predict movements at skirtings, and effective precautions in the form of independent or reinforced upstands are easy to arrange.

MEASUREMENT OF JOINT MOVEMENT

Various fatigue test programmes on roofing materials and specifications have been carried out, including tests by the Building Research Establishment. These tests simulate roof movement under controlled conditions and record the number of movement cycles which can be withstood by a membrane before failure occurs.

The tests demonstrate that classic fatigue failure as experienced on site with low strength roofing materials can be reproduced in the laboratory showing that the form of failure is normally by formation of a ridge and subsequent flexural fatigue at the base of the ridge.

The results of the tests can be expressed in a number of ways, but they relate to the gap movement and the number of cycles.

A difficulty in comparing the best materials with the worst arises because of the inherent weakness of the old traditional rag, asbestos and glass base roofings. These only withstand small movement in the order of 1mm for a limited number of cycles. The best high performance roofings cannot be taken to failure with only a 1mm gap opening, even after many thousands of cycles and these materials are therefore tested at a greater gap opening, commonly 3mm or more.

The results of the fatigue testing relate to the form of apparatus used, the speed and form of movement cycling and the test temperature. The most useful common yardstick is the performance of traditional BS 747 felts, particularly a three-layer specification comprising type 3B glass base roofing. This specification is no longer widely used but it still forms a useful yardstick for comparing performance.

Tests indicate that the majority of high performance roofings are so good that it is clear they will not suffer fatigue failure as long as the original properties of the material are retained in service. It is this aspect which will prove critical to the long term fatigue resistance. Favourable ageing characteristics are more likely to influence the life of the waterproofing than the fatigue test performance.

A method of obtaining an indication of the long term durability is to heat a sample of the roofing in an oven for 56 days at 80°C. Samples thus treated were used for the fatigue test figures given in the table below, which shows that a ranking order can be established between various known roofings. This was the subject of work carried out at the Princes Risborough Laboratory and was covered in a paper presented at the International Symposium of Roofs and Roofing in Brighton in September 1981. The results are still broadly valid today.

Fatigue resistance x 100

TABLE 1.14

	New	Aged
BS 747 type 3B	2	1
Polyester (oxidised bitumen)	20	10
Polyester (modified bitumen)	1500	200

STRENGTH AND ELONGATION

Whilst fatigue testing gives information on the ability of a specification to resist repeated stresses in service, it does not give information on the ultimate strength of the membrane, the elasticity or the elongation.

BS 747 type 3 felts with a glass tissue base are relatively weak and fail in tension at an elongation in the order of 2%. Polyester based roofings are considerably stronger and fail in tension at an elongation in the order of 40%. It is therefore hardly surprising that polyester based roofings should show a greatly increased order of fatigue resistance over glass base felts.

Strengths and elongations of British Standard and proprietary roofings are available from most manufacturers, but the following properties are typical:

TABLE 1.15

	Tensile strength in machine direction (N/50mm)	Elongation at break in machine direction (%)
BS 747 type 3B	200	2
Polyester (oxidised bitumen)	600	40
Polyester (modified bitumen)	600	60

MASTIC ASPHALT

When designing with mastic asphalt, it is necessary to consider the movement of the membrane as a separate structure as well as the movements which are imposed on it by movement of the substrate.

MOVEMENT OF THE ASPHALT MEMBRANE

Mastic asphalt has no continuous reinforcement to control the natural movement of the bitumen other than the fine and coarse aggregates which form approximately 85% of its weight and add stiffness and hardness. The properties of the asphalt are therefore primarily influenced by the rheological properties of the bitumen and the grading and proportions of the aggregate.

The ideal formulation for asphalt is one which is not too soft to take traffic at the highest temperatures and not so hard at low temperatures that it would crack from self induced stresses during contraction or become easily damaged by knocks and strains. This requires performance over a temperature range of -20°C to 80°C which are likely extremes of temperature for an exposed roof surface, and it is difficult to formulate traditional asphalt to be plastic over the entire range. The temperature range of the asphalt is reduced by solar reflective treatments, and polymer modified asphalt maintains plastic properties over a wider range of temperatures.

Self-induced stresses in asphalt can be produced by a sharp drop in temperature, known as thermal shock, and in extreme cases the relief of the stress may take the form of cracking of the asphalt rather than plastic flow. Fortunately the weather in the UK is temperate and few problems from thermal shock arise. The greatest risk occurs where asphalt is applied on top of an efficient insulation, but in practice a stone chipping surface or other solar reflective treatment to the asphalt effectively controls this form of shock.

THERMAL EXPANSION AND CONTRACTION

Thermal expansion of asphalt in the horizontal direction is effectively restrained by skirtings and edge details and the major thermal expansion takes place in the vertical direction to give a marginal increase in thickness of the asphalt.

When the sun heats the top surface of the asphalt, the underside remains cooler and the hotter more mobile mastic at the top surface is free to expand upwards. During the cooling of the asphalt, however, the temperature gradient reverses. The upper face of the asphalt will be at a lower temperature than the underside and being stiffer will take up an effectively solid form before the layers below. The solid upper face is not fully restrained by the more plastic lower layers and there is a tendency for the upper layer to contract in the horizontal plane. The contraction movement is non-reversible as it takes place only on the cooling cycle and the tendency to contract, if unrestrained, would continue progressively.

The self-induced stresses during contraction are generally not greater than the strength of the mastic asphalt. The tendency to contract merely results in the slight stressing of the asphalt and this is the key to the design and formation of detail work. It is essential that all edge details are securely bonded into position to restrain the forces of contraction. Skirtings can be pulled away from the vertical if not properly bonded and the asphalt can be drawn back from handrails and outlets if a satisfactory bond is not formed.

CRAZING

Crazing is a secondary effect caused by thermal expansion and contraction. It is a surface effect only and does not prove a cause for concern other than on grounds of appearance.

When asphalt is laid, a surface skin rich in bitumen is formed which is sensitive to photo-oxidation and it is the formation of a thin but hard oxidised skin that results in crazing of the surface, unless suitable precautions are taken.

Crazing can give the appearance of a series of cracks in the asphalt, but it is only a surface effect and there is no danger of complete splitting nor of the waterproofing being impaired. The crack is seldom deeper than the height of the ridge in which it is formed and the effective thickness of the mastic asphalt is not normally reduced by crazing. The raised and crazed portion can often be totally removed by rubbing the surface of the asphalt with a coarse abrasive, for example by rubbing with a brick.

Crazing is controlled at the time of laying the hot asphalt by rubbing clean coarse sand into the surface with a float. This reduces the richness of the surface and reduces the differential expansion between the surface and the main body of the asphalt.

ALLOWING FOR MOVEMENT

Horizontal surfaces

On horizontal areas a complete separation of asphalt from the roof deck is necessary to isolate the asphalt from joint movement in the substrate. This is achieved by the use of sheathing felt, or by glass tissue when the asphalt has to accept heavy loading and sheathing felt would be too compressive. Many alternative separating layers have been tried but sheathing felt has particular qualities which are not matched by the alternatives. Being a loose mat of fibres bound together with bitumen of similar properties to that of the asphalt, the felt introduces no stresses or strains to the system. It effectively prevents the bond of the asphalt to the deck but at the same time presents a close, rough contact resulting in a fairly high level of friction. The sheathing therefore provides a measure of lateral restraint to the asphalt. This is an advantage in cold weather when the friction acts to restrain the contraction of the asphalt, but at the same time it will allow differential joint movement in the substrate without transmitting stress into the asphalt.

Sheathing felt also acts as a form of reinforcement to the asphalt particularly at the lap joints which are welded together by the heat of the asphalt. This provides a continuity of reinforcement which prevents a concentration of stresses or strains in the asphalt above the lap.

The sheathing felt will only be fully effective against joint movement of the deck when applied to a reasonably level deck surface. Irregularities in the deck surface will form a key to the underside of the asphalt and impose local restraints which can cause local stresses from substrate movement or from the cold weather contraction of the asphalt itself. Changes of level between concrete slabs and between insulation boards are examples of localised restraint which can break the efficiency of the separating layer and impose local stresses.

It is also possible to cause restraint by damaging the deck or insulation surface before application of the asphalt. If depressions are formed by such damage, this will lead to an extra thickness over the area of the depression which develops a key to the deck. A restraint will then be formed which can cause stresses, most probably around the edges of the depression. In practice it is the isolated points of restraint which are more likely to give rise to problems. An overall keying from a uniformly rough or indented surface is not likely to cause stresses, as a uniform restraint is imposed on the asphalt.

Vertical surfaces

Having assured adequate separation of the membrane from the flat area by means of sheathing felt, it is also necessary to restrain the natural contraction movement of the mastic asphalt in cold weather. The frictional resistance of the sheathing felt provides a measure of lateral restraint but it is necessary to ensure good edge restraint at the perimeter of the asphalt by forming a strong bond at skirtings or a suitable turndown anchorage at eaves and outlets. This prohibits the use of separating layers on skirtings but fortunately the common forms of building construction for vertical surfaces, other than timber, do not involve panel joints. Direct applications of asphalt are likely to be to brick or in-situ concrete where there is no great risk of joint movement but if brickwork or concrete cracks, it is likely to crack the mastic asphalt bonded to it.

In the case of skirtings to be formed on timber, not only must a secure attachment be formed but it is also necessary to separate the asphalt from direct contact with the timber, because of its moisture content and movement, both of which would act against the asphalt if it was fully bonded. To achieve a secure attachment of asphalt to timber, sheathing felt is first applied to isolate the asphalt from the timber. The sheathing felt is covered with expanded metal lathing nailed at maximum 150mm centres to keep it as tightly attached to the timber as possible and the first coat of asphalt is worked thoroughly into the lathing.

It is sometimes necessary to form vertical work on steel upstands particularly when the roof is of metal decking. In this case, timber is attached to the metal upstands and the asphalt detail is completed as normal for timber using sheathing felt and expanded metal lathing. In some cases, the expanded metal lathing can be welded direct to the steel upstand but only if the runs are short and the metal upstands are continuous with no joints which might give rise to movement. Small rooflight curbs are an example of the possible application of expanded metal lathing direct to steel.

Precast concrete wall, eaves or gutter units can sometimes cause problems. The movement at the joints of the precast units is normally small but can be expected to cause wrinkling of the asphalt surface. There is a slight risk of cracks developing from the movement, however, and it is best to avoid the direct application of asphalt to precast units unless the units are locked together to prevent joint movement. When circumstances permit, an application of sheathing felt and expanded metal lathing will alleviate the situation.

Joint movement at skirtings

Asphalt is bonded tightly to the wall or kerb face and is therefore vulnerable to cracking at the base of the skirtings if there is differential movement between the wall face and the roof. Independent skirtings must be used where the wall and roof are not of an integral construction or not held together at the junction.

All timber, plywood, particleboard and woodwool roof decks butting to brick or concrete walls are likely to suffer sufficient joint movement between the wall and roof to cause cracking at the base of a skirting. Independent upstands are always included for these constructions. Similarly metal decking abutting brick or concrete walls will always call for independent upstands.

As with built-up roofing, internal gutters form a line on which movement can take place and they are best avoided. In the case of mastic asphalt the movement of the material is constrained in the sole of the gutter and wrinkling is common. This should not lead to leakage but it is unsightly and shows that the asphalt is acting under constraint.

An asphalt gutter also forms a heat trap if exposed to continuous sunshine and the sides of a gutter are thus prone to slumping and blistering as well as to substrate movements. If gutters are incorporated in a roof, designers should ensure that joint movements are restrained as much as possible and that the asphalt is firmly supported, and protected by solar reflective treatment.