TRANSPORT and ROAD
RESEARCH LABORATORY

Department of the Environment

TRRL REPORT LR 512

THE DESIGN AND CONSTRUCTION OF JOINTS IN CONCRETE PAVEMENTS

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Crowthorne, Berkshire
1973

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ABSTRACT

This Report reviews the various types of joints used in concrete pavements in Great Britain, and gives recommendations on their design, which is related to the method of pavement construction employed.

The recommendations are based on the results obtained from a comprehensive programme of laboratory tests and site studies carried out jointly by the Transport and Road Research Laboratory and the Cement and Concrete Association. Standards for the rigidity of transverse joint assemblies are discussed, and a relaxation in the tolerances for alignment of dowel bars is suggested.

The report also discusses simple procedures for site tests on joint assemblies before concreting to ensure satisfactory performance both during the construction and the subsequent life of the road.

1. INTRODUCTION

Joints are provided in concrete roads to reduce the stresses induced in the slab by its expansion, contraction and warping brought about by changes in the temperature and moisture content of the concrete; they also serve as a link between successive periods of construction and enable the road to be laid in lanes of convenient width.

Both in construction and in performance, a joint must provide sufficient relief from induced stresses to limit the possibility of cracking. In so doing it must:

(a) preserve the surface alignment

(b) be effectively sealed to exclude grit and stones and as far as possible water

(c) interfere as little as possible with the construction of the pavement

(d) cause the minimum possible weakening of the road in the vicinity of the joint

(e) make the minimum possible contribution to the surface irregularity of the road.

An overall assessment of the role of joints in concrete roads must equate the benefit of improved performance resulting from the inclusion of satisfactorily designed and constructed joints to the increased initial cost of their inclusion. Load-transfer devices such as dowel bars form an important part of transverse joints. Although the omission of such devices facilitates pavement construction and cheapens initial cost, the provision of such devices improves the in-service performance of the road.

The main benefits derived from load-transference are:

(1) a reduction of the effects of impact from moving loads, particularly when the slab is subjected to warping stresses due to the influence of a temperature gradient through the slab

(2) the limitation of differential settlement between adjacent slabs.

The need for good workmanship in joint construction is all important; probably more defects have been caused in concrete roads by faulty joint construction than by any other factor and these defects often create a particularly unsatisfactory impression on the road user. The introduction of wider paving machines, working at higher speeds, not only emphasised existing problems associated with the construction of joints, but also created new problems.

Experience showed that the joint assemblies which had been used successfully with single-lane construction were unstable under the action of the wider concrete-laying machines, particularly in the case of expansion joints. It was also found difficult to install dowel bars in transverse joints so that their position and alignment were not disturbed by the placing and compaction of the concrete.

In March 1964, a small Working Group of engineers from the Transport and Road Research Laboratory and the Cement and Concrete Association was formed with the object of examining existing methods of making joints and to develop improved assemblies suitable for all forms of mechanised construction. The introduction of the slip-form paver lent an added urgency to the solution of the problems and much thought was devoted to this aspect during the trials of this machine in 1965.

More recently, the technique of placing dowel bars by a mechanical method was examined.

This Report describes some of the research and development carried out by this Working Group.

2. TYPES OF JOINT

2.1 Transverse joints

Transverse joints may be classified into expansion, contraction, warping and construction joints.

2.1.1 Expansion joints Expansion joints provide gaps in the concrete to allow the slabs to expand when the temperature rises above that at which the concrete was laid. The gaps are filled with a compressible material. Expansion joints also allow contraction and warping of the slabs.

2.1.2 Contraction joints Contraction joints are essentially breaks in the concrete, permitting it to contract when the temperature falls below the temperature of laying, and accommodating movements caused by moisture movement and shrinkage. Most contraction joints will also permit some release of warping stresses under the effects of temperature gradients.

2.1.3 Warping joints Warping joints are also simply breaks in the continuity of the concrete, but opening of the joints is controlled by tie-bars or reinforcement. Such joints allow a small amount of angular movement between the slabs and so prevent high warping stresses which would otherwise be developed because of temperature gradients in the concrete, but they do not allow for contraction.

2.1.4 Construction joints Construction joints are formed when work has to be interrupted at a point where no joint would otherwise be required, for example, when a plant breakdown occurs during paving operations. Normally construction is planned so that the joint at the end of the day's work occurs at a place where a joint would be required for structural purposes.

2.2 Longitudinal joints

Longitudinal joints in concrete roads are generally designed as warping joints, and are used when the slab width exceeds 4.5 m.

3. LOAD-TRANSFER DEVICES – BRITISH PRACTICE

Worldwide acceptance of the need for load-transfer devices at joints is unlikely because of differences in design philosophy. The importance of such devices depends on the strength of the soil foundation and the climatic conditions. Their function is to limit differential vertical movement of the slabs.

In Great Britain, load-transfer devices are specified for concrete road pavements thicker than 150 mm. The particular methods employed are dowel bars in movement joints, ie expansion and contraction joints, and aggregate interlock in tied joints.

The dowel bar is an obvious method of shear transfer at a joint and compares favourably with all other systems in terms of structural performance. However, its inclusion may still present difficulties in construction, as when a slip-form paver employing front-feeding is being used. It may also be difficult to achieve the alignment required for satisfactory performance at a reasonable cost.

Friberg[1] investigated, both theoretically and in the laboratory, the behaviour of correctly aligned and misaligned dowel bars in joints. Loe extended the work.[2] The effects of dowel-bar diameter, spacing and length were studied and both authors demonstrated that, when the joint moved, misaligned bars would cause substantial shear stresses in the bars and in the surrounding concrete. Although the shear stresses generated in the bars were shown to be unlikely to cause their failure the load-transfer efficiency of the joint would be reduced. It is upon these studies that the original specification for bar diameter, length and spacing was based, using Loe's criterion for maximum allowable dowel-bar misalignment of 0.5 per cent. Friberg recommended a less conservative criterion of 1 per cent. The requirement of 0.5 per cent was relaxed slightly when the Ministry of Transport Specification for Road and Bridge Works[3] was revised in 1969. Dowel bars are now required to be provided at approximately mid-depth of the slab, parallel to the finished surface of the slab and to the centre line of the carriageway, within the following tolerance:

(1) two-thirds of the bars shall be within 0.5 per cent

(2) the remaining third, less one per 3.6 m length of joint, shall be within 1.0 per cent

(3) no bar shall differ in alignment from an adjoining bar by more than 1.0 per cent.

It was not specifically stated whether these tolerances referred to dowel-bar alignment before or after concreting. However the publication of Technical Memorandum H10/71[4] by the Department of the Environment in 1971 made it clear that these tolerances referred specifically to the position before concreting.

The requirements of both the 1969 and the original specifications have been widely criticised by supervising and contracting engineers who claimed that the tolerances could not be achieved even before concreting except at considerable expense. The need for such narrow limits has also been questioned in view of the lack of evidence of damage which can be attributed to overstressing the dowel bar or the surrounding concrete. The Working Party recognised the problems and undertook a further programme of research into the effects of dowel-bar misalignment, combining laboratory studies with measurements made in the field.

The measurement of alignments of dowel-bars in the joints of five roads which had a reasonable overall standard of construction and subsequent performance, (built to the 1957 or 1963 specification) are discussed later in this Report. Also included are the results of measurements made on sites where the alignments were required to conform to the 1969 Edition of the specification.

4. DESIGN REQUIREMENTS OF TRANSVERSE JOINT ASSEMBLIES

4.1 Purpose

Associated with each transverse joint is a joint assembly which is normally prefabricated and placed in advance of concreting. The main purpose of such assemblies is to hold the dowel-bars in position during construction.

A further purpose of the joint assembly is to position the joint filler of expansion joints so that the sealing groove may be accurately located above it. Failure to do so may lead to spalling and cracking of the concrete at the ends of the slabs.

In a similar manner, the joint assembly assists in positioning the crack inducer at contraction joints, which is fixed to the sub-base immediately under the centres of the dowel-bars.

4.2 Practical requirements

The provision of transverse joints must interfere as little as possible with the construction of the pavement if paving is to proceed continuously. Every stoppage of the paver can lead to surface irregularities which may result in the formation of an uneven surface profile, and which will be objectionable to the road user.

Difficulties in meeting the requirements of the then current British specification for concrete pavement construction were experienced when the slip-form paver was first introduced into Great Britain in 1965. The provision of dowelled expansion and contraction joints presented a problem which had not been encountered in slip-form construction abroad. A solution was sought during trials with the machine at Al

Cromwell By-pass in Nottinghamshire, and a form of joint assembly was developed which resulted in the requirements of the specification being met without interference to the lorries end-tipping concrete into the front of the paver.[5]

Whatever construction method is used, either a conventional train of machines or a slip-form paver, the design of the joint must be such that it can withstand considerable thrust from the concrete being placed by the machines without being displaced or distorted. Types of joint assembly which had been used successfully for hand-laid, single-lane, construction were found to be unstable under the wider concrete-laying machines. Thought was given to improving the design of assemblies, but it was first necessary to consider the magnitude of the loads being imposed on joints during concreting operations.

4.3 Forces acting on joint assemblies during concreting

The loads imposed on expansion joints are very much greater than those on contraction joints because of the presence of the joint filler in the former. For this reason the measurement of pressures was confined to expansion joints.

Tests were made by setting pressure gauges into holes drilled in joint fillers at different heights above the base and at different distances from the edges of the slab. The gauges were as wide as the joint filler so that their outer faces were flush with the surfaces of the filler. Electrical-resistance strain gauges were cemented to the faces of the pressure gauges, the output being displayed on an ultra-violet recorder.

4.3.1 Conventional paving train With this form of construction, the concrete is usually spread by means of a power-operated box hopper with bottom-gate discharge. The tests have shown that, when concrete is discharged from the hopper as it moves transversely and therefore approximately along the line of the joint filler, it distributes concrete on either side of the assembly simultaneously and the difference in pressure between the faces of the filler, ie the 'out-of-balance' pressure, is normally less than 0.007 N/mm^2. Such pressures occur only over a length of about 0.6 m at any instant and, as long as the assembly is rigid, the unloaded portion on either side of the length under load will give support. Concrete thrown at the filler, from a hopper travelling at right-angles to the joint assembly, may however produce impact pressures three or four times greater.

During compaction of the concrete, the 'out-of-balance' pressures recorded were not great, with a maximum of about 0.005 N/mm^2 recorded on the approach side of the assemblies.

4.3.2 Slip-form paver Concrete is fed into the hopper of the slip-form paver either by end-tipping lorries or from a side-loading machine. The concrete is deposited on the approach side of the joint assembly and then pushed over it as the paver moves forward. Pressure on the joint assembly thus occurs mainly on the approach side, and varies with the amount of concrete in the front receiving hopper. The maximum average pressure on a joint filler recorded was about 0.017 N/mm^2 on the approach side, but values of about 0.010 N/mm^2 were also recorded on the departure side caused by the action of the conforming plate and back screed.

4.4 Forces acting on joint assemblies after concreting

4.4.1 Base fixings The joint assemblies must be fixed to the sub-base with sufficient rigidity to withstand the forces imposed on them during construction. Once the concrete has set, linear movement of the slabs occurs caused by thermal expansion and contraction and also by changes in their moisture content. Warping movement also occurs because of vertical temperature gradients in the concrete. At this stage, the base fixings serve no useful purpose, but they tend to resist the longitudinal movement of the slab. Thus, if the fixings are too rigid, movement at the joint will be restrained, and cracking may occur in the concrete a short distance from the joint. Failures of this kind are more likely in the first few days after concreting when the tensile strength of the concrete is low, particularly if the forces causing linear movement are great.

These forces depend upon many factors and their magnitude cannot be precisely determined; hence the only practical solution is to design the base fixings such that they have only the minimum strength required to withstand the pressure likely to be imposed on them during construction.

4.4.2 Bond breaking Restraint will be imposed on slabs unless the sliding ends of the dowel bars are free to slide. The importance of the selection of a suitable material to prevent bonding between the concrete and the dowel bar has been emphasised by Weaver.[6] He carried out comparative studies on a number of different materials and showed that certain quick-drying bituminous paints gave greater bond than that between an uncoated bar and the concrete. Bituminous compounds based on a bitumen with a penetration of 100 to 200 blended with solvent naphtha performed satisfactorily. Mineral grease was not considered to be a suitable alternative because it severely retarded the setting of the concrete around the dowel-bar. Polythene sleeves, although effective as bond-preventing devices, are difficult to apply to the dowel-bar if tight-fitting, whereas an oversize sleeve could not be tolerated as this would lead to the formation of pockets in the concrete around the dowel with a resultant loss in the efficiency of load-transfer.

4.5 Preformed joint filler

When expansion joints are used in pavement construction, the specification requires that the expansion space between adjacent slabs is filled with a preformed joint filler.

Air-gap joints have been used in the past, and have the advantage that they can be narrower than joints containing filling material as the whole of the gap may be used to accommodate the expansion of the slabs. However, forming the gap and sealing the groove proved to be difficult operations.

When materials other than knot-free softwood are used for expansion-joint fillers, they must comply with the requirements of Clause 2630 of the Ministry of Transport Specification in respect of weathering, compression-and-recovery, and extrusion tests.

Compression-and-recovery tests carried out by the Cement and Concrete Association on three joint-filler materials have been described by Weaver.[7] The recovery of all three materials, a softwood, a medium-density chipboard, and a fibreboard, was satisfactory, though the fibreboard was the only material which satisfied the compressibility requirement of the specification.

However, in the same series of experiments by Weaver, the nature of the joint filler was found to have a significant effect on the overall stiffness of the assembly and on the distortion of the assembly when it was subjected to non-uniform loading. There was seen to be little difference between the stiffnesses of assemblies containing softwood and chipboard, but the use of fibreboard reduced the stiffness of the assembly by about 40 per cent. As a consequence fibreboard, unlike the other materials, lacked the ability to spread the restraint forces at points of base fixings to the whole assembly. This deficiency may result in flexural failure in the joint filler and permanent distortion in the cradles at the higher loads.

Experience of the wide use of knot-free softwood has shown that no damage has resulted from the greater loads necessary to compress it. The exemption of this material from the need to show compliance with the clause in the Specification regarding compression and recovery in fact allows its use for carriageway expansion joints, for which purpose it is the most widely used material.

Spalling at some expansion joints has occurred where softwood joint fillers of low initial moisture content have been used and where the sealing grooves were sawn in the hardened concrete. Damage has resulted from the upward expansion of the filler board as it absorbs water from the plastic concrete surrounding it, causing incipient cracking from the top corners of the filler in the concrete bridging over the joint. The concrete thus affected is unlikely to be completely removed in the subsequent joint-sawing operation.

The moisture content of timber stored under cover in a warm, dry atmosphere has been quoted at about 12 per cent, whereas that of air-seasoned timber is generally between 17 to 23 per cent.[8] Tests by Weaver[9] have shown that, where a joint filler is restrained at mid-depth and the initial moisture content of the timber is above 21 per cent, the risk of cracking is small. In practice the filler can be easily brought to this condition by soaking.

4.6 Crack inducers

To ensure complete formation of contraction and warping joints, the specification requires that a vertical plane of weakness is formed in the structural continuity of the slab. Part of the reduction of slab thickness takes the form of a crack-inducing filler, of timber, steel or synthetic material, securely fixed to the sub-base along the line of the joint. Experience has shown that the combined depth of discontinuity provided by the crack inducer and the sealing groove at the top of the slab should be at least one-quarter of the thickness of the slab.

4.7 Sealing grooves

The specification requires that all joints, however made, should be provided with a groove to accommodate a sealing material, an important function of which is to keep out grit.

Grooves may be formed in the surface of the plastic concrete or alternatively they may be sawn after the concrete has set.

Grooves over expansion joints are required to be located over the joint filler to such a depth and with such accuracy that the upper surface of the filler is contained within the groove.

At contraction and warping joints, the sealing groove should be made at a position vertically above the crack-inducing filler to within a tolerance of ± 12 mm.

5. STANDARDS OF RIGIDITY AND ALIGNMENT

For dowelled joints to perform satisfactorily four main conditions must be satisfied. These are:

(1) joint assemblies must not move bodily forward under the action of the paving machines,

(2) local deformations and deflections must be small,

(3) joint fillers must remain substantially vertical,

(4) dowel bars must remain parallel to one another and to the surface of the slab.

Failure in meeting the requirements (1) and (2) would create difficulties in positioning the sealing groove correctly in relation to the joint filler or to the crack inducer. The joint filler must remain vertical in order to preserve dowel-bar alignment and also to prevent compressive loads being transmitted on inclined faces at the joint.

Following the formation of the Working Party in 1964, the Road Research Laboratory carried out a number of studies on different contracts to ascertain the general standards of rigidity and alignment being achieved in joint assemblies under site conditions.

At that time, the Ministry of Transport Specification for Road and Bridge Works required that dowel bars should be aligned within 0.5 per cent (ie ± 3 mm in a 600 mm bar) in both the vertical and the horizontal direction, although it was apparent that little checking for compliance in fact took place. There was then no standard for rigidity.

The first results obtained from the contracts visited during these preliminary studies tended to be poor, with dowel-bar misalignments far in excess of the specified tolerance and with little attention being paid to the stability of the joint assemblies. It was felt that much of this poor quality was due to a lack of previous experience among engineers and workmen in the construction of concrete pavements.

As a result, a number of simple tests were devised to enable measurements of the alignment of dowel bars and the rigidity of joint assemblies to be made in the field. A provisional note relating to the inspection and testing of assemblies was drafted, setting out the requirements for alignment of dowel bars, and in addition, giving recommended acceptance limits for the rigidity of the joint filler and for the rigidity of dowel bars. The limits were based on the results of the work on measurement of pressures on joint assemblies during concreting, and also on data obtained from a programme of laboratory tests on the stability of expansion-joint assemblies carried out by the Cement and Concrete Association.[7]

The provisional note was circulated to a number of major concrete construction jobs commencing in 1965, and formed the basis for discussion between site engineers and Road Research Laboratory staff on problems of joint construction. Each site was supplied with the equipment required for the testing procedure, the measurements being made by the Resident Engineer's staff or by Road Research Laboratory personnel. Principles of the test methods employed are given below and full details of the preferred procedure are given at the end of the Report in Part 10.

5.1 Rigidity of the joint filler

The rigidity of the joint filler in expansion joints was measured by the application of a force, perpendicular to the vertical face of the joint filler, at its mid-depth. The load was distributed over a length of 600 mm by means of softwood packing, and the deflection at the top of the filler measured. After removal of the load, the residual displacement was also recorded. The apparatus for testing the rigidity of the joint filler is shown in Plate 1.

In the preliminary site investigations a force of 250 N was applied to the filler and even at this magnitude joints were moved bodily or suffered severe distortion.

Subsequently, in order to standardise methods of test to be used by the Cement and Concrete Association and the Road Research Laboratory, a force of 1.33 kN was chosen as that thought to approximate to the force exerted on the filler by a loaded spreader box. On removal of the load, it was considered that the maximum permissible residual displacement of the filler should be fixed at 3 mm so that any dowel bar misalignment resulting from the pressures imposed on the filler remained within acceptable limits. A limit of 12 mm was fixed as the maximum deflection of the filler under load. Joint fillers which deflected more than this amount were considered unlikely to recover to within 3 mm of the original position.

The Cement and Concrete Association laboratory tests showed that satisfactory performance could be obtained from cradle assemblies under the loads applied from conventional paving plant, provided that base fixings are sufficiently frequent. A number of other modifications were shown to benefit the stability of assemblies: for example, the splicing of discontinuities in the joint filler, the use of cradles made from 6.4 mm diameter wire instead of the 5.4 mm previously used and the adjustment of the hole diameters in the filler so that the dowel bars made a "push-fit".

When these recommendations were put into practice on construction sites, considerable improvements were made in the compliance with the requirements given in the provisional note. The results, taken from five sites, are shown in Columns 5 and 6 of Table 1.

It was evident from the laboratory tests that the type and frequency of base fixing is of major importance in reducing the movement of the assembly. At the sites referred to in Table 1 cradle assemblies were fastened to the base either by nailing or by setting in a mortar bed. Nailed base fixings were used in pairs at 600 mm centres, one on either side of the assembly, using long wire nails in granular base materials and large diameter masonry nails in lean concrete. With the cradle assembly, the residual displacement of the joint filler was much larger when fixed to the base by nailing than when set in a mortar bed, but, on the basis of the criteria given above, all the joints were satisfactory. Nailed base fixings are shown in Fig 1 and the mortar-bed method of fixing is given in Fig 15.

Cradle assemblies cannot be used with slip-form construction when front-feeding methods of supplying concrete to the paver are used, and alternative forms of joints were examined. During the slip-form paver trials at Cromwell[5] the welded assembly illustrated in Fig 2, developed for the trials, proved to be most satisfactory and was used for most of the carriageway laid during the trials. After some modifications, it was also used on M.74 Hamilton By-pass and on A.1 Tuxford By-pass. The results of rigidity tests on both these latter sites are included in Table 1.

The 1.33 kN force applied in the tests corresponds to an average pressure of 0.010 N/mm^2 on the joint filler. It is greater than the average pressure of 0.007 N/mm^2 which was subsequently measured under a conventional paving train, but less than the maximum average pressure of 0.017 N/mm^2 recorded under the slip-form paver. However, as described in 4.3.2, pressures were also recorded on the departure side of joint assemblies caused by the conforming plate and back screed of the slip-form paver, and these assist recovery and reduce the residual displacement of the joint. It is the final position of the joint filler which is the important criterion, and practice has shown that joints which complied with the test conditions have behaved satisfactorily during construction.

TABLE 1

Results from rigidity tests on joint filler and on dowel bars

Paving equipment	Site	Type of joint		Rigidity of joint filler: Maximum displacement under 1.33 kN force mm	Rigidity of joint filler: Residual displacement after removal of force mm	Force required to cause failure of base fixings kN	Rigidity of dowel bars % within tolerance* under 100 N force before concreting: Vertical	Rigidity of dowel bars % within tolerance* under 100 N force before concreting: Horizontal
1	2	3	4	5	6	7	8	9
Slip-form paver	A.1 Cromwell By-pass	Welded assembly on lean concrete base	Expansion	7.6 to 8.9	0 to 2.5	not measured	75	100
		Cradle assembly nailed to granular base	Expansion	10.9	0.8	”	75	100
		Cradle assembly mortared to granular base	Expansion	1.7	0	”	100	100
Slip-form paver	M.74 Hamilton By-pass	Welded assembly on processed steel slag base	Expansion	7.1 to 10.3†	2.0 to 3.5	”	76	100
Slip-form paver	A.1 Tuxford By-pass	Welded assembly on lean concrete base	Expansion	2.2 to 8.0	0 to 3.6	”	87	not measured
Conventional train	M.1 Southern Extension	Cradle assembly mortared to lean concrete base	Expansion	5.6 to 11.1†	0.8 to 2.4	”	98	100
Conventional train	A.1 Long Bennington By-pass	Cradle assembly with ½ width mortar on lean concrete base	Expansion	2.8 to 4.0	0.4	3.38	100	100
			Contraction	N/A	N/A	not measured	100	100
		Cradle assembly mortared to granular base	Expansion	3.6 to 5.6	0.8	3.20	100	100
			Contraction	N/A	N/A	not measured	100	100
		Cradle assembly nailed to lean concrete base	Expansion	8.3 to 9.9	1.6 to 2.0	2.45	100	85
			Contraction	N/A	N/A	not measured	100	100
		Cradle assembly nailed to granular base	Expansion	10.3 to 14.3	1.6 to 4.0	2.56	97	100
			Contraction	N/A	N/A	not measured	100	100

* Displacement not to exceed 0.5 per cent (3 mm in 600 mm)

† Force applied as point load on filler

Reference was made in 4.4.1 to the fact that, once the concrete has set, the base fixings serve no useful purpose, but tend to resist the linear movement of the slabs caused by thermal expansion and contraction. Tests were therefore carried out with cradle assemblies, fastened to lean concrete and to granular bases, both by nailing and by mortar bed, to determine the force required to produce failure of the fixings. Failure of nailed fastenings was considered to have occurred if the fixing moved more than 3 mm on the loaded side of the assembly at the point of application of the load. Failure of mortar-bed fastenings was defined as shear failure between the bed and the road base, or cracking in the mortar. The results of these tests, carried out at Long Bennington, are given in Table 1, Column 7.

One objection to the welded assembly joint was the uncertainty of freedom of movement. In its initial form, the assembly was fitted with square stalk feet sliding in square sockets and it was felt that cement grout might penetrate into the sockets, thereby locking the joint. The objection was substantially reduced by improvements made to the assembly during the course of the Cromwell trials. The square stalk feet and sockets were replaced by round bars sliding in round tube sockets, and wooden plugs and rubber collars used to preserve slab movement relative to the sockets. Fig 2 shows the final form of the assembly.

The test for the rigidity of the joint filler was incorporated into the revision of the Ministry of Transport Specification,[3] the criterion being that set out above. In addition, a requirement was added to the effect that failure of the base fixings should occur under the application of a 2.67 kN force.

5.2 Rigidity of dowel bars

The rigidity of individual dowel bars in the vertical plane is a measure of the rigidity of the assembly and its fixings to the base. In expansion joints, dowel-bar rigidity is greatly assisted by the joint filler, provided that the holes drilled in the filler are of such diameter to give the dowel bars a "push-fit".

Contraction joints lack the stiffening effect of the filler and depend much more on the strength of the base fixings.

Rigidity in the horizontal direction is mainly a measure of the efficiency of the wire ties fastening the dowel bars to the cradle assembly.

In the preliminary site studies, dowel-bar rigidity was expressed as the force required to deflect the bar by 3 mm in the 600 mm length, the load being applied in the upwards, downwards and sideways directions at either end of the dowel bar. The dowel bars in cradle assemblies which had been poorly fastened to the base were deflected by very small forces of less than 40 N, but later tests on joints which had been modified to improve the overall stability showed that forces in excess of 200 N were required to cause this degree of deflection.

As a result of a large number of measurements and experience generally on the A.1 Cromwell By-pass, it was recommended that the test procedure should be changed to that of measuring the deflection of the dowel bar when a standard force of 100 N was applied in both the vertical and the horizontal direction. It seemed logical to apply the same limits for deflection as was used for dowel bar alignment, ie not more than 3 mm in 600 mm, although this was brought into line with the amended tolerance for alignment in the revision of the specification in 1969.

The results from the tests made at Cromwell and at 4 other sites are given in Table 1, Columns 8 and 9. In the vertical direction, the best results were achieved with cradle assemblies mortared to the base, the welded assembly being the least strong. In the horizontal direction the welded assembly was very rigid, as might be expected because the dowel bars are welded to the main rib. The cradle assemblies also showed 100 per cent compliance when the dowel bars were securely fastened by wire ties to all intersections on the cradle.

As with the test for rigidity of the joint filler, this test was incorporated into the revision of the Ministry of Transport specification in 1969.

5.3 Alignment of dowel bars

5.3.1 Alignment before concreting Reference has already been made in 3.2 to the work of Friberg and Loe which resulted in the requirement that the dowel bars be aligned within 0.5 per cent both in the vertical and in the horizontal directions being included in the Ministry of Transport Specification (prior to the 1969 revision). A simple method of checking the vertical alignment of dowel bars relative to the finished surface of the slab was adopted by the Road Research Laboratory. A spirit-level fitted with adjustable feet (shown in Plate 2) was first set to the level of the road. This level was taken off the guide wires in slip-form work or from the rails or banquettes in the case of conventional construction. The spirit-level was fitted with a scale, graduated into units of misalignment of 1.5 mm in 300 mm, so that when transferred from bar to bar, readings could be easily and rapidly taken.

Checking the horizontal alignment of dowel bars relative to the centre line of the carriageway was more difficult. Measurements were made by stretching two tapes, parallel to one another and 600 mm apart, across the line of dowel bars with the tapes set to a common datum (shown in Plate 3). The misalignment of any given bar over 300 mm is given by half the difference between the readings on the two tapes.

As was found in the early measurements of rigidity, the results obtained from the preliminary studies were poor, with misalignments of up to 4.0 per cent being recorded. By drawing attention to the need for some degree of precision in joint construction in the provisional note, and by introducing test procedures for checking compliance, the results obtained on later sites showed considerable improvement. These are given in Figs 3, 4 and 5; the values in Fig 5 were however only obtained after considerable adjustment had been made to the bars as a result of a first inspection.

A number of contractors found that the adjustable spirit-level was a useful tool in setting up assemblies on site and thereby eliminated the need for a great deal of vertical adjustment prior to concreting.

The horizontal alignment of dowel bars in the welded assembly joints, shown in Figs 3 and 4, were particularly good, as might be expected from a jig-welded fabrication.

The results obtained all showed a normal distribution of misalignment. At none of the sites was there 100 per cent compliance with the specified tolerance, and the need for such strict limits was questioned. An analysis of the results obtained from Cromwell showed that, for all the 26 dowel bars in a joint to be within compliance, a standard deviation of 0.3 (in terms of limit of tolerance of ± 3 mm in 600 mm) was necessary, but in practice this figure was unobtainable. Evidence gathered from surveys of concrete roads in service, described in detail in 5.3.4, suggested that the tolerances were perhaps too severe and could be relaxed. It was proposed that a standard deviation of 1.0 be accepted, which would require 65 per cent of the dowel bars in any one joint to be within ± 3 mm in 600 mm. The remaining third, less one bar per 3.6 m length of joint could be within ± 6 mm in 600 mm. As two adjacent badly aligned bars may cause local failure in the concrete with a consequent loss of load-transfer efficiency, a requirement that no bar should differ in alignment from an adjoining bar by more than 1.0 per cent was also proposed.

These proposals were incorporated into the contract documents for trials on joint construction on A.1 Long Bennington By-pass in 1968. The results, given in Figs 6 and 7, are those taken during the first inspection after the joints had been set in position. The vertical alignment of dowel bars in joints which are fastened to the base by mortar needs to be of high standard before the mortar is placed, because little correction can be carried out afterwards. In this respect, the joints at Long Bennington were satisfactory, but some minor adjustments were required in the horizontal direction before concreting commenced.

These proposals for a slight relaxation in the tolerances for the alignment of dowel bars were incorporated into the 1969 revision of the specification.

5.3.2 Alignment after concreting A major difficulty in devising tests for joints in concrete pavements is that such testing can conveniently be carried out only before concreting takes place. It is highly probable that the alignment of dowel bars would be affected by the passage of the concreting plant across the joint and it is the condition of the joint after construction which is important in influencing the performance of the joint in service. There was therefore a need to establish a relationship between the condition of joints before concreting and that after concreting to enable more confidence to be placed in acceptance criteria applied to measurements made on the joint before concreting.

At Cromwell, concrete was carefully removed from around a number of joints after laying of the concrete and the alignment of the dowel bars remeasured. Burks and Maggs[5] reported that, in the majority of cases, the alignments had worsened as expected: this was largely attributed to the construction process although there could have been some adverse effect caused by the digging-out operation itself.

Another method was used to investigate the alignment of dowel bars at two further sites. Cores, 100 mm in diameter, were cut at both ends of the dowel bars in the hardened concrete. Drilling was continued down to the level of the dowel bars and the concrete above the bars broken off. Measurements were taken on the exposed ends of the dowel bars in both the vertical and horizontal directions and these were compared with readings taken on the same bars before concreting. On both sites, M1 Southern Extension and A40 between Mitchel Troy and Raglan, the cradle-assembly joints were carefully checked and were found to be constructed to a high standard before concreting. The expansion joints on M1 were fastened to a lean-concrete base using mortar, whereas the contraction joints were fixed with masonry nails. Wire-nail fastenings were used for the joints on A40 where the base was of granular material. The results from these sites, given in Fig 8, indicate that in the vertical direction some displacement of the dowel bars took place during construction, but a major proportion of the bars were still within the specified limits. Similarly, in the horizontal direction some displacement of the bars occurred during concreting but all final positions were within twice the limits of tolerance given in the 1963 Specification. The maximum movement during concreting in both the vertical and the horizontal direction was 6 mm in 600 mm ie 1 per cent.

Thus, in joints constructed to a high standard and which complied with the rigidity requirements described above, the displacement of dowel bars under the action of the concreting plant remained within acceptable limits.

5.3.3 Alignment of bars inserted by dowel-bar placer On the Raglan-to-Usk section of the A40 Newport-Worcester Trunk Road, the contractor elected to construct an unreinforced concrete pavement in accordance with revised recommendations issued by the Ministry of Transport in 1969.[10] For work carried out during the summer months, these recommendations also permitted the omission of expansion joints, and on this contract the contractor decided to construct all joints as contraction joints using a dowel-bar placing machine. This was the first occasion that a mechanical method of inserting dowel bars into concrete pavements had been tried in Britain, although the machine had been used in Europe, and the opportunity was therefore taken to carry out some investigations into the alignment of bars placed by this method.

Harris and Zeronian have described the concrete pavement construction in detail.[11] The major proportion of the pavement was constructed in two layers with the dowel bars placed into the bottom layer of compacted concrete. A length of approximately 150 m of carriageway was constructed in a single layer, and here the dowel bars were placed through the compacted surface layer.

The alignment of dowel bars in a number of joints was examined using the technique of cutting cores in the hardened concrete, the results for the two-layer construction being given in Fig 9 and those for the single-layer construction in Fig 10.

Less than 60 per cent of the dowel bars inserted into the bottom compacted course were within ± 1.0 per cent alignment, both in the vertical and the horizontal direction ie the limits of tolerance then specified for conventional joint construction were not met by a wide margin. At the time of construction the Specification made no reference to the alignment of dowel bars placed by mechanical methods but the Technical Memorandum H10/71[4] now requires the accuracy of alignment of these bars to be within twice the tolerances specified for bars supported by cradles before concreting. Further attempts to assess the accuracy of the dowel-bar placer were made by Harris. Measurements taken from dowel bars exposed in the plastic concrete were compared with those taken from cores, and the results showed that there had been a tendency for bars to sink during compaction of the top layer. The average settlement was 18 mm with considerable variation from the mean in individual values.

By placing the dowel bars through the compacted surface layer it was thought that the alignment of the bars would show an improvement over those in the two-course work, as the former would not be affected by further vibration.

There were indications that this was in fact so in a limited investigation by Harris and Zeronian. However, further tests were carried out by the Transport and Road Research Laboratory on 36 dowel bars and the results are given in Fig 10. Analysis of the results shows that compared with the two-layer construction there is a significant difference at the 5 per cent level for alignment in the horizontal direction, but in the vertical direction there is no significant difference detectable at the 5 per cent level. Although the dowel bars were better positioned relative to the mid-depth of the slab in the single-course construction, the distribution of results was not normal about zero. This suggests that, for this short trial length, the machine was not in correct adjustment in the vertical direction.

It was considered unwise to cut cores on every dowel bar across the width of the pavement because of the risk that, by greatly reducing the cross-sectional area of the concrete, a transverse crack might develop at the ends of the dowel bars. Cores were therefore cut on alternate bars and it was not possible to examine the relative alignment of adjoining bars. There is however no reason to assume that the relative misalignment of alternate bars is appreciably different from that of adjacent bars. The difference in alignment, both vertically and horizontally, between alternate bars is shown in Fig 11, the results being plotted for both single and two-layer construction. In only 3 per cent of the results does the difference in alignment between alternate bars exceed 4 per cent. The distribution of relative misalignments is generally similar to that of absolute misalignment.

At each of the joints tested for alignment on this contract, the joint had cracked and was functioning normally. Again, it was considered unwise to cut cores, even at 600 mm centres, at joints which were not already functioning because of the risk of inducing transverse cracks. It was recognised that by omitting from the study, those joints where no movement due to thermal changes had occurred, the sample considered might exclude those bars with the worst alignment. An inspection of the road made 1½ years after opening to traffic showed that there are only two transverse cracks mid-way between contraction joints in the 8 km length of carriageway and there is therefore no reason to suspect that the joints tested were not typical of the overall standard.

During the investigations into the performance of the dowel-bar placer, a number of cores were cut through dowel bars in order to assess the degree of compaction around the bars. In every case, the concrete was in a fully compacted state; this was attributed to the technique of continuing the vibration for about 30 seconds after the bars had reached their final depth.

5.3.4 Alignment of dowel bars in older concrete roads To determine the effect of dowel-bar misalignment on the performance of concrete pavements, the condition of joints in roads which had been in service for a number of years has been investigated. Details of the five sites are given in Table 2. They were selected as having a reasonable standard of construction and subsequent performance.

The ends of alternate dowel bars were exposed by coring in both the expansion and the contraction joints of five roads, and the misalignment in the vertical and horizontal plane was measured. The results are given in Figs 12 and 13. Numerous misalignments of up to 4 per cent, with occasional even higher values, were discovered. These misalignment, gross in terms of any of the Specifications used so far confirmed that the limits for tolerance were unnecessarily severe.

The difference in alignment between alternate bars is shown in Fig 14 for the joints investigated on the five sites. In 95 per cent of the results, the relative difference between alternate bars was 4 per cent or less and the distribution of relative misalignments was similar to that of absolute misalignments. Again, as in the case of dowel bars placed by machine, there is no reason for the relative alignment of alternate bars to be appreciably different from that of adjacent bars. Only in an expansion joint of insufficiently stiff construction would systematic differences occur and these would be such as to increase the relative misalignment of alternate bars in relation to that of adjacent ones. The use of alternate bars to judge relative misalignment would therefore be conservative in these conditions.

It was considered unwise to carry out an examination for damage to the concrete around the dowel bars at the joint faces because this would reduce, if not destroy, the load-transfer capacity of the joint. However, there was no evidence of stepping at any of the joints and measurements of the relative vertical movement at the ends of the slabs showed a maximum value of 0.025 mm under normal traffic loading conditions. Longitudinal movements at the joints were not apparently inhibited by the presence of misaligned dowel bars.

TABLE 2

Details of the sites studied for alignment of dowel bars
(selected as having a reasonable standard of construction and subsequent performance)

Site	Date of construction	Date of joint testing	Estimated average daily 24-hour traffic flow (1966/67)	Details of joints tested
M.1 Motorway (Herts)	1959	1966	42,000 vehs	Expansion joints – cradle assemblies
A.1 Grantham By-pass	1961/62	1966	10,000 vehs	Expansion and contraction joints – cradle assemblies
A59 Longton By-pass	1957	1967	17,500 vehs	Expansion and contraction joints – cradle assemblies
A.27 Chichester By-pass	1962	1966	12,500 vehs	Contraction joints – cradle assemblies
B6247 Padiham By-pass	1963	1966	4,300 vehs	Contraction joints – cradle assemblies

5.4 Recommendations for alignment tolerance

It is evident that on many sites there was considerable deviation from the specified limits of tolerance for the alignment of dowel bars: even on the sites where compliance was of the order of 90 per cent or greater, these values were achieved only at the expense of considerable checking and re-setting of dowel bars. However, in none of the cases examined have there been failures, either in the vicinity of the joints or at mid-bay, which could be attributed to misalignment of dowel bars.

The evidence therefore indicates that the recommended tolerances for alignment of dowel bars after concreting are too severe and that misalignments of 3 to 4 per cent would in fact be acceptable.

The effects of dowel-bar misalignment were also examined experimentally over a range of joint widths, misalignments and ages of concrete by the Cement and Concrete Association. As a result of these further laboratory studies and of theoretical comparisons of the effect of misalignment with that of traffic loading a relaxation of the tolerance on alignment to the range 3–4 per cent was suggested by the Association.[12]

For dowel bars inserted into plastic concrete by mechanical methods it is therefore suggested that the dowel bars should be provided at approximately mid-depth of the slab parallel to the finished surface of the slab and to the centre-line of the carriageway, within a tolerance of 4 per cent, ie ± 24 mm in 600 mm. In addition, no bar should differ in alignment from an adjoining bar by more than 4 per cent in either plane. These tolerances refer to the positions of the bars after concreting is completed.

For pre-fabricated joint assemblies it has been shown that, even in well-constructed joints, some displacement of the dowel bars may occur during the concreting operations. Thus for joints in which the dowel bars are positioned in assemblies prior to concreting, it is suggested that the dowel bars be provided at approximately mid-depth of the slab parallel to the finished surface of the slab and to the centre-line of the carriageway, within a tolerance of 2 per cent, ie ± 12 mm in 600 mm. In addition, no bar should differ in alignment from an adjoining bar by more than 2 per cent in either plane. These tolerances refer to the assemblies before concreting.

5.5 Conclusions

Many types of joint assemblies have been designed in attempts to produce satisfactoy load transference combined with unrestrained movement of the slabs, and at the same time to give a practical form of assembly which will maintain the necessary accuracy during construction of the pavement. Since its introduction in 1969, the dowel-bar placer is now used almost exclusively in the construction of joints in pavements laid by conventional plant. However, although developments are in hand, it has not yet been conclusively demonstrated that a completely satisfactory method of mechanically inserting dowel bars into pavements laid by slip-form pavers has been developed. Pre-fabricated assemblies are also required when expansion joints are included in the construction. Research and experience has shown that two basic types of joint – the cradle assembly and the welded assembly – are satisfactory for machine-laid concrete pavements.

Recommendations on the fabrication of these assemblies and on the methods of fastening to different types of base are made (see Section 6), which when associated with simple field tests for rigidity and alignment carried out before concreting, will ensure that the joints will behave satisfactorily both during the construction of the pavement and its subsequent service life.

6. RECOMMENDED FORMS OF EXPANSION AND CONTRACTION JOINTS

6.1 Cradle assemblies

6.1.1 Form of construction The form of construction for expansion and contraction joints is fundamentally the same. The dowel bars should be supported by the cradles to the correct height above the base and should be tied to the cradles at all intersections. Discontinuities in the cradles and the joint filler should be staggered to improve the rigidity of the assembly, and breaks in the joint filler should be spliced to prevent stepping at those points. The dowel bars should be a tight push-fit through holes drilled in the joint filler.

When complete, the assembly should form one rigid structure for the whole width to be concreted at each pass of the paving train.

Cradles which span the joint should not be used in expansion or contraction joints; a continuous tie across a joint will inhibit movement and might result in cracking elsewhere in the slab. Only fastenings, such as staples or thin wire, of low strength should be used to hold the two halves of a joint assembly together.

A typical detail of a standard cradle-type assembly for an expansion joint is shown in Fig 1 and that for a contraction joint in Figs 15 and 16.

6.1.2 Methods of fixing to the base Two basic methods can be used to fix cradle assemblies to the base, by nailing or by mortar bed. Nailed fixings are shown in Fig 1 and mortared fixings in Fig 15.

Nailed base fixings in granular bases should be made using 230 mm long wire nails, and in lean-concrete bases large-diameter masonry nails of about 60 mm length are most suitable. The nails should be used in pairs at 600 mm centres, one on either side of the assembly. The assemblies should then be tied to the nails with wire or alternatively held down by roofing washers or thin metal strips.

Nailing the cradle assemblies to the base, particularly to a lean-concrete base, can be difficult, and the mortar-bed method would appear to be preferable. If a mortar bed is used, the joint assemblies should be set in position at least 12 hours and not more than 48 hours before concreting, to allow the mortar to gain sufficient, but not too much, strength.

The fastening procedure is best carried out using a simple jig erected and levelled on the base. The joint assembly should be placed in the jig and each dowel bar checked for vertical alignment, because errors at this stage will be permanently incorporated. Any gaps at the sides and bottom of the joint filler should be plugged with compressible material. The mortar, with a sand/cement ratio of 3 : 1 by weight, should then be poured around the assembly to form a level bed which just includes the bottom wires of the cradle. When the mortar has hardened the jig can be removed.

The main problem is to avoid making a fixing so rigid that it will inhibit the free movement of the slab. In order to prevent excessive bond strength between the mortar and a lean-concrete base, it is recommended that the mortar should extend only over the outer portions of each cradle (see Fig 15).

An excessive thickness of mortar would reduce the thickness of the pavement concrete and might structurally weaken the ends of the slabs.

6.2 Welded assemblies

The problem of incorporating dowelled joint assemblies into concrete pavements which are to be constructed using slip-form techniques has been referred to in 4.2.

In addition to the overall requirements for joint assemblies, the joints are required to be sufficiently rigid to withstand the forces imposed by the paver, and to be capable of rapid erection to permit front-feeding, with base fixings which would withstand overrunning by site traffic. All these conditions were fulfilled by the welded assembly joint developed during the slip-form paver trials at Cromwell.

6.2.1 Form of construction This joint, shown in Fig 2, is used both as an expansion joint and as a contraction joint, the only difference between the two types of joint being in the number of fixing feet used for each half-width assembly. An extra pair of feet are provided on expansion-joint assemblies because the loads imposed on expansion joints during construction are greater than those on contraction joints. The dowel bars are welded on to a 3.8 m long by 76 mm deep by 6 mm thick mild-steel plate, the assembly is then braced with a 13 mm diameter tie-bar welded along the ends of the dowel bars and with several 6 mm diameter diagonal braces to form a rigid structure. In the expansion joint a number of 76 mm square mild-steel buttress plates are welded to the top of the vertical plate to support the joint filler. As the dowel bars are welded to the main rib, it is important that the required degree of alignment be built into the assembly. This may be readily achieved by the use of a robust, accurate, jig.

6.2.2 Method of fixing to the base The joint is fastened to the base by six feet per 3.6 m lane-width in the case of expansion joints, and by four feet per lane-width in the case of contraction joints. Each foot consists of a length of 19 mm diameter round bar welded to the assembly and bent into the horizontal plane at ground level. The base-fixing consists of a horizontal tube welded to a vertical lug which is grouted into a hole drilled in the road base.

After drilling the holes in the base, the assembly must be supported on a jig and adjusted for alignment of the dowel bars before the vertical lugs are grouted in. Once the mortar has hardened and the jig has been removed, the joint can be removed or replaced easily by sliding the feet in the horizontal tubes. Freedom of movement of the joint during the life of the road depends upon the sliding action of the feet in the tube sockets, and wooden plugs and rubber collars are used to prevent cement grout entering the tubes.

The fixing feet of the welded assembly are not adjustable in the vertical direction and this requires them to be supported on mounds of mortar when the base is low. Such mounds should be surrounded by fine cold asphalt to prevent the slab from locking on to them, or an alternative method of fixing used. In this method, shown in Fig 2, the tube socket is screwed into a wooden block which is then set into a hole drilled in the base, and grouted in. The advantages of this arrangement are that the wooden block can project above the base to support the assembly at the correct height and that, even if the socket becomes locked with the slab, the compressibility of the wood allows movement to take place. The method has the disadvantage, however, of poorer fixing rigidity.

7. WARPING JOINTS

7.1 Introduction

In concrete road slabs, warping stresses developed as a consequence of temperature gradients in the slab cause cracking in both reinforced and unreinforced pavements. In reinforced concrete pavements, crack opening is controlled by the reinforcement and load transfer is maintained by aggregate interlock. Between the cracks, the reinforcement serves little purpose. In unreinforced pavements, contraction joints are usually provided at 5 m intervals to give stress relief. However, theory suggests that the stresses caused by warping moments are greater than those due to contraction in the longitudinal direction for normal slab lengths. Thus warping joints designed to relieve warping stresses may be used instead of contraction joints only in situations where the longitudinal movements are likely to be very small ie in short slabs. Recommendations were made permitting up to three consecutive contraction joints in unreinforced pavements to be replaced by warping joints. The use of warping joints in reinforced concrete pavements is not permitted.

The requirements for a warping joint, in accordance with general requirements for joints, are:

(a) a discontinuity in the slab to provide release of warping moments

(b) a load-transfer device

(c) a seal against water and grit.

The discontinuity in the slab is obtained by inducing a crack by a combination of top sealing groove and middle or bottom fillet. The load-transfer is obtained by aggregate interlock, and tie-bars are necessary to prevent the crack from opening to such an extent as to render this ineffective, ie to perform a function similar to that of the steel in reinforced concrete slabs. The seal is obtained by a conventional sealing groove filled with a sealing material.

7.2 Design

Early designs of these joints were based on the use of steel in the same form as for normal mesh reinforcement having 8 mm diameter wires at 75 mm centres. This design was used for a 300 mm thick slab and gave a steel/concrete ratio by area of 0.2 per cent, thus providing an area of steel similar to that which would normally be used in a reinforced slab of the same thickness. There was an effective length of 600 mm of steel on either side of the joint.

The use of ordinary mesh reinforcement was found to be unsatisfactory because the assemblies tended to distort easily during handling on site. Also, some concern was expressed at the possibility of corrosion of the steel which, in time, could lead to a loss of load-transfer efficiency and provide a source of structural weakness.

Experience of dowel bars and reinforcing mesh suggests that the problem of corrosion would be particularly serious in the case of the thinner bars, and it was considered desirable to use a larger diameter tie-bar, maintaining the steel/concrete ratio by area constant at 0.2 per cent. This is achieved by using a 12 mm diameter tie-bar throughout, and varying the spacing of the bars according to the slab thickness.

7.3 Specification

Reinforcement for warping joints should consist of a fabricated welded mesh with 12 mm diameter longitudinal bars at least 1.4 m long at the spacing given in Table 3 and a minimum of three transverse wires of 6 mm diameter at 700 mm centres. The number of transverse wires may be increased to stiffen the mesh for handling purposes, if required. At least every third longitudinal bar shall be longer than 1.4 m and shall be bent in order that a 1.4 m effective length of longitudinal reinforcement shall lie at half depth of the slab with the assembly resting on feet supported on the base. The feet are formed from the extension of the longitudinal bars in the manner shown in Fig 17. The effective lengths of the bars shall be approximately parallel to the finished surface of the slab and to the centre line of the carriageway. The centre 200 mm of each 1.4 m effective length of bar should be painted with bond-breaking compound (described in paragraph 4.2.2).

TABLE 3

Recommended spacing of longitudinal bars in warping joints

Slab thickness (mm)	Spacing (mm)
300	180
280	200
260	220
240	240
220	270
200	300
180	360

Where several assemblies are used in one joint they may be independent of each other to facilitate handling, but all the assemblies in one joint should be truly aligned to an accuracy of ± 5 mm.

The reinforcement assemblies should be fixed to the base, one method being to use mortar pads round the horizontal portion of the feet. The mortar should consist of one part by weight of Portland cement to three parts by weight of sand and should be placed within one hour of mixing.

A crack inducer should be provided at the base and a sealing groove at the top of the slab so that the combined depth of discontinuity is a least one-third of the depth of the slab, and so that the difference in the depth of the discontinuity at the top and bottom is not greater than 12 mm. The crack inducer should be fastened to the base along the centre line of the joint to within ± 5 mm by nailing or other approved method. The sealing groove, located with its centre line vertically above the crack inducer within a horizontal tolerance of ± 12 mm, should conform with the dimensions given in Table 4. A typical detail of a warping joint assembly is shown in Fig 17.

8. LONGITUDINAL JOINTS

Longitudinal joints are required in concrete pavements more than 4.5 m in width in order to allow for transverse warping.

When carriageways are constructed as two or three lane widths in one operation, longitudinal joints should be provided between adjacent lanes. At these joints, a crack-inducing fillet of timber, steel, or synthetic material should be fixed to the base along the line of the joint groove. Reinforcement, in the form of either mild-steel tie-bars or special reinforcement mats, should be provided across the joint.

TABLE 4

Recommended dimension for sealing materials and grooves for joints in concrete roads

Type of joint	Spacing (m)	Width of groove (mm)	Depth of seal† (mm)
Contraction joint	Under 8) 8 – 15)* 15 – 20) Over 20)	10 15 20 see note ‡	20 – 25 20 – 25 25 – 30 25 – 30
Warping joint	All spacings	5	15 – 20
Expansion joint	All spacings	5 mm greater than thickness of filler	25 – 30
Longitudinal joint	–	5	20 – 25§

* When warping joints are used the spacing applicable is the distance between adjacent sliding joints.

† If the grooves are made deeper than is required for the sealing material, they should be caulked to an appropriate depth with a compressible filling material considered suitable by the joint-sealing-compound supplier.

‡ For contraction-joint spacings in excess of 20 m, the width of groove should be increased by 5 mm for each 5 m in excess of 20 m.

§ If the joint is formed and sealed simultaneously by the insertion of an 8-mm-wide bituminous preformed filler strip, the depth of strip should comply with the requirement that the combined depth of the filler and the crack-inducing fillet should be one-quarter to one-third of the thickness of the slab.

The tie-bars should be 12 mm diameter, 1.1 m in length and spaced at 600 mm centres at mid-depth in the slabs. They may be provided either as individual bars or as a fabricated self-supporting assembly but, in the case of the latter, adjoining assemblies should be tied together with wire ties and also tied to transverse joint assemblies to prevent displacement during construction.

The Ministry of Transport specification, Clause 1010, permits the omission of a crack-inducing fillet if the sealing grooves are sawn in concrete made with crushed-stone coarse aggregate, but in that case the depth of the groove sawn should not be less than one-third of the depth of the slab, and the alternative use of special reinforcement mats would not be permitted.

9. SEALING GROOVES

9.1 Introduction

In concrete roads, the presence of irregularities at joints has, probably more than any other factor, created an unsatisfactory impression on the road user.

During the 1950's, joint sealing grooves in concrete roads in Britain were generally sawn, and the surface irregularities which had resulted from earlier methods of forming the grooves were avoided.

However, increased output from fully mechanised concreting equipment, together with difficulties experienced in sawing concrete made with flint or quartzite gravel coarse aggregate, made the operation expensive and one which required critical timing in order to achieve satisfactory results. Therefore in the early 1960's, contractors examined new techniques for forming the grooves in the plastic concrete.

In addition, there has been considerable research and development carried out on methods of sawing which has resulted in high-speed multi-saw machines, and improvements in cutting blades and blade life, all leading to a reduction in the cost of sawing.

The Ministry of Transport specification permits the use of both methods, subject to certain requirements.

9.2 Sawn grooves

When the joint sealing grooves are sawn in the hardened concrete, the surface profile of the slab, and hence the riding quality, remains unaltered. Also, the grooves will have truly vertical and parallel sides. It is, however, essential to carry out the sawing operation as soon as possible, within 8 hours after the final compaction of concrete laid before noon, and within 18 hours after the final compaction of concrete laid after noon. Failure to observe this condition in the specification will mean that there can be no relief for stresses induced by shrinkage, and the risk of premature random cracking will be high.

Attempting to meet this requirement creates the main problem in sawing the grooves, If sawing is carried out before the concrete has developed sufficient strength, damage will occur to the edges of the groove. This is particularly true of concrete made with flint and quartzite gravel aggregate. If such damage occurs, and cannot be eliminated by the use of other types of blade or sawing equipment, initial stress relief can be provided by sawing a provisional slot 3 mm wide centrally over contraction joints, and a slot 6 mm wide over expansion joints, each to the specified depth of the groove. The grooves should be sawn to full width at a later date, prior to the joint-sealing operations.

9.3 Wet-formed grooves

The main advantages of this method over sawing are that the risks of premature cracking are eliminated and that, in the case of expansion joints, the sealing groove can be made to coincide precisely with the joint filler. There have been many instances in the past of damage in the form of cracking and spalling at joints as a result of warped or displaced joint fillers. Cracks develop above the line of the filler, and if they are not contained within the limits of the sawn groove, they quickly deteriorate under the action of traffic.

Virtually all longitudinal joint grooves are now successfully formed in the plastic concrete by means of a device mounted on the rear of one of the finishing machines. This inserts a preformed rubber-bitumen or neoprene sealing strip into the concrete and recompacts the concrete back into the slab.

For transverse joints, grooves have been successfully formed using a vibrating blade or by a rotating eccentric wheel. Neoprene, fibreboard or extruded plastic strips are then inserted into the slots as temporary formers before the final finishing operation.

There are, however, a number of difficulties to wet-forming techniques. Any method of forming a groove in the plastic concrete must disturb the compaction of the concrete at that point, and also interfere with the surface profile. It is particularly important that any disturbance caused to the surrounding concrete should be restored by compaction, and that the substantial quantity of concrete displaced in forming grooves wider than 12 mm should be removed completely. Failure to recompact the concrete leads to spalling of the joint faces with subsequent costly repair work. Table 5 shows the results of a survey of wet-formed joint-sealing grooves for contraction joints on four major concrete road contracts; the length of spalling has been expressed as a percentage of the total length of joint face, the approach and departure sides of the joint being considered separately.

TABLE 5

The incidence of spalling at wet-formed joint sealing grooves
showing the effect of recompaction after formation

Site	Formation of groove	Spalling of joint face (%)					
		Near-side lane		Centre lane		Off-side lane	
		Approach	Depart	Approach	Depart	Approach	Depart
1	Rotating eccentric wheel followed by recompaction of the concrete	0.1	0.1	2 lanes only		0	0
2	Rotating eccentric wheel followed by recompaction of the concrete	0.2	0.1	2 lanes only		0	0
3	Transverse vibrating blade followed by recompaction of the concrete	0.5	0.4	0.3	0.1	0	0.1
4	Transverse vibrating blade No recompaction before finishing	16.1	21.6	6.5	9.2	not recorded	

Finally, the surface finish across the joint must be restored to within the permitted tolerances given in the specification. The successful application of wet-forming techniques must be coupled with the use of the diagonal finishing machine. The reciprocating action of the beam operating on both sides of the joint simultaneously without applying its full weight onto the entire length of the joint has contributed much towards the achievement of satisfactory surface profiles across wet-formed joints.

This technique has not been possible with slip-form construction and considerable effort has been put into the development of suitable methods of wet-forming joints in this type of construction. One successful method has been to use a 3 m wide aluminium float with a small vibrator unit attached to recompact the concrete around the temporary former and to ensure that the surface profile is restored across the joint.

The level of the temporary filler inserted into the groove is critical for the success of this operation, because if it is positioned too high, it will be displaced by the finishing machine. This may result in non-vertical sides to the narrower grooves, particularly when neoprene temporary fillers are used. Alternatively, if the temporary filler is set too low, it will be bridged over by a layer of cement mortar, which if not removed, may lead to spalling of the joint edges when thermal expansion or contraction occurs.

10. PROCEDURE FOR TESTING THE RIGIDITY AND ALIGNMENT OF TRANSVERSE JOINT ASSEMBLIES

10.1 Introduction

The purpose of this section of the Report is to describe the procedure for testing the rigidity and alignment of transverse joint assemblies for compliance with the standards given in the specification.

10.2 Personnel and apparatus

At least two persons should be available to conduct the tests, one to apply the loads and hold the measuring tapes, and the second to read deflections and measurements and to record them on a check list (shown in Appendix 1). The apparatus required for the tests is listed in Appendix 2.

10.3 Order of testing

Where rigidity tests are being carried out, these should be completed before the alignment tests are made.

10.4 Rates of testing

10.4.1 Rigidity During the construction of trial slabs, all joint assemblies should be tested for rigidity.

During normal pavement construction, rigidity tests should be carried out on contraction joints at the rate of one per 100 m length of pavement. Whenever expansion joint assemblies are used, at least one joint should be tested on each day that concreting takes place.

10.4.2 Alignment During the construction of the trial length, all joint assemblies should be tested for alignment of both dowel bars and the joint filler. These tests should be carried out before concreting and again immediately after concreting by digging out the plastic concrete. During normal pavement construction, alignment tests should be carried out before concreting at the rate of one joint of each type per 100 m length of pavement.

10.4.3 Base fixings The contractor should demonstrate, during or before the construction of the trial length, that the base fixings will fail at the required loading.

10.5 Method of testing

10.5.1 Rigidity of the joint filler This test, for expansion joints only, is carried out using the large spring balance and the leverage system consisting of a wire strop attached to a steel spike driven into the road base (a length of steel tubing will increase the leverage effect). The apparatus is shown in Plate 1.

The balance is attached to the vertical face of the joint filler, at mid-depth, by means of the G-clamp. The softwood packing, drilled and split to fit over adjacent dowel bars, should be fitted between the clamp and the filler.

A load of 135 kg (equivalent to a force of 1.33 kN) should be applied smoothly in the direction of concreting, and held for a few seconds. The deflection at the top of the joint filler is measured by means of the dial gauge mounted on the retort stand. When the load is released the residual displacement is recorded.

Two such tests should be carried out on each length of joint filler, at 300 mm from either end of each length if a continuous fixing to the roadbase is used, or midway between individual base fixings.

10.5.2 Rigidity of dowel bars This test is carried out using the small spring balance, with two dial gauges for testing in the horizontal direction, and with the adjustable spirit level for testing in the vertical direction.

The balance is hooked on the end of each dowel bar and a load of 10 kg (equivalent to a force of 100 N) applied smoothly by hand and held for a few seconds.

For measurements in the horizontal direction, a dial gauge should be set at each end of the dowel bar, 600 mm apart on opposite sides of the bar. The result to be recorded is the maximum deflection of the four readings obtained. To express this value in terms of the deflection over 300 mm length of bar, the sum of the two dial gauge readings should be halved. For rigidity measurements in the vertical direction, the spirit level can be set in any position on the dowel bar and the deflection over 300 mm read directly because the graduations on the spirit level represent a vertical difference of 1.5 mm over a length of 300 mm, ie 0.5 per cent (see Plate 2).

Three bars on each length of joint filler should be tested.

10.5.3 Rigidity of the base fixings In order to demonstrate that failure of the base fixings will occur when a force of 2.67 kN is applied to the expansion joint assembly, a mechanical method of applying the load is required.

Using the two large spring balances, coupled in parallel, and with one end attached to the joint filler a vehicle can be used as a convenient means of applying a steady load. Failure of the base fixings should occur when the total load on the two spring balances is in the region of 270 kg, say between 250 and 300 kg.

10.5.4 Alignment of dowel bars The horizontal alignment is measured using two steel tapes stretched across the ends of the dowel bars and fixed to the side form or other datum point at one end (see Plate 3). Misalignment over 300 mm is half the difference between the readings on the two tapes. It is desirable to adopt a sign convention for recording these values and it is suggested that for dowel bars rotating, in plan, in a clockwise direction, they be expressed as positive misalignment.

The alignment in the vertical direction, ie parallel to the finished road surface, is checked with the adjustable spirit level. The level must first be set to zero by standing it on the basic datum which determines the plane of the road surface at the joint being tested, ie the side forms or banquette, the guide wire, or other datum line. The level is then transferred to each dowel bar in turn and a direct reading obtained. The direction of misalignment should be recorded, and it is suggested that an upward misalignment of the end of the dowel bar nearest the approaching concreting plant is shown as positive.

10.5.5. Inspection of joint assemblies In addition to the tests outlined, all joint assemblies should be inspected in accordance with the routine set out in Appendix 3. Any defects found during inspection or testing should be made good and the assembly retested. If serious defects persist in either the fabrication or the fastening of assemblies to the base, then the site procedures used should be re-examined before concreting is allowed to continue.

10.5.6 Alignment of dowel bars after concreting Checks similar to those for alignment described above should be carried out on joints in the trial length after concreting. The procedure for digging out the plastic concrete around the joint is described in Appendix 4.

11. ACKNOWLEDGEMENTS

The Transport and Road Research Laboratory wishes to acknowledge the very valuable co-operation given by the Cement and Concrete Association in this programme of research. In particular, the contribution made by the Construction Research Department of the Association and by the engineers who served on the Working Group is gratefully acknowledged.

The Laboratory also wishes to thank all the Highway Authorities, Consulting Engineers and Contractors involved in these studies, too numerous to mention individually, for their assistance and co-operation.

The members of the Transport and Road Research Laboratory research team who took part in the investigations were E E Lock, P A Looker, B S Parmenter, J P Stott and P J F Wingate.

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13. APPENDIX 1

CHECK SHEET AND RECORD OF JOINT TESTING AND INSPECTION

Project	Type of paver
Carriageway	Type of joint
Reference Number	Type of filler
Slab Number	Formation of groove
Chainage	Date of laying

Inspection

√ if satisfactory, X if unsatisfactory.

Location	Materials	Assembly	Fixing	Rigidity	Alignment

Rigidity

Joint filler – deflection at top, quoted in mm, due to 1.33 kN (135 kg).

Between dowel bar nos.										
Maximum										
Residual										

Dowel bars – deflection, quoted in mm, due to 100 N (10 kg) over 300 mm

Dowel bar numbers										
Horizontal *										
Vertical										

* Recorded figure is half the sum of the two dial-gauge readings

Alignment

Dowel bars – misalignment quoted in mm over 300 mm

Bar number																		
Horizontal																		
Vertical																		

Bar number																		
Horizontal																		
Vertical																		

Horizontal alignment – clockwise +
Vertical alignment – + up applied to
end of bar nearest approaching train

Origin of bar numbering:

Acceptability YES/NO

Signed:

14. APPENDIX 2

JOINT TESTING EQUIPMENT

200 kg Spring balance	2 no.
25 kg Spring balance	1 no.
Dial gauge, reading mm	2 no
Retort stand and rod	2 no.
Spirit level, 300 mm long with adjustable legs, reading 1.5 mm in 300 mm	1 no.
Steel tape, 15 m long	2 no.
Steel rule, 300 mm long	1 no.
Leverage complete	1 no.
G-clamp	1 no.
Softwood packing piece, 600 mm x 150 mm x 25 mm, drilled and split to fit dowel bars	1 no.

15. APPENDIX 3

INSPECTION OF JOINT ASSEMBLIES

All joint assemblies should be inspected on the basis shown below, and in that order to ensure that they are correctly located and assembled. Joint assemblies should be available for inspection in adequate time before concreting so that any adjustments required as a result of the inspection or testing can be made. Mortar-bedded joints should be available at least 12 hours before concreting, so that, if any adjustments have to be made, there is sufficient time for the fresh mortar to harden.

Welded joint assemblies with spigot-and-socket base fixings can be removed after inspection, but should be given a final check after being replaced for concreting. Points to be checked are grouped under general headings as below:

1. Location

(a) spacing from previous joint

(b) transverse location relative to centre-line of carriageway

(c) provision for locating accurately the joint filler or crack-inducing fillet after concreting, so that the sealing groove is formed exactly over the filler or fillet.

(d) joint filler is perpendicular to the finished surface and at the correct depth

(e) dowel bars are at the correct depth.

2. Materials

(a) joint filler or fillet are of acceptable materials, free from warping and of the correct dimensions

(b) the joint filler has been prepared in accordance with the specification

(c) dowel bars are of the correct diameter and length, clean and free from burrs

(d) bond-breaking material complies with Clause 2605 of Specification.

3. Assembly

(a) dowel bars are correctly spaced

(b) dowel bars are wired to the cradles at all intersections, or satisfactorily welded, as applicable

(c) cradles are stapled or wired to the joint filler

(d) breaks in the joint filler and the cradles are off-set by at least 300 mm

(e) dowel bars are a push-fit in the joint filler

(f) cradles are wired together under the joint filler.

4. Fixing to base

(a) base level without high spots or hollows, and not trenched

(b) gaps between joint filler and base or side forms are filled with compressible material

(c) where a mortar-bed fixing is used, the thickness of the mortar should just encompass the bottom wires of the cradles

(d) where spigot-and-socket fixings are used, any gap between the socket and the base is mounded with compressible material, the open ends of the sockets are plugged, and the exposed necks of the spigots are surrounded with compressible collars

(e) crack-inducing fillet is firmly fixed to the base.

5. Rigidity

(a) all packing pieces, where used to adjust alignment, are fitting tightly.

6. Alignment

(a) whole assembly (by visual inspection)

(b) individual dowel bars by testing.

16. APPENDIX 4

INSPECTION OF JOINTS IN TRIAL LENGTHS OF CONCRETE CARRIAGEWAYS BY REMOVAL OF THE PLASTIC CONCRETE

1. Purpose

To measure any distortion or displacement of dowel bars and/or filler which may have occurred during the placing and compaction of the concrete.

2. General

After compaction the plastic concrete should be carefully removed by hand digging, over the whole width of the slab on both sides of the joint to expose the dowel bars and the joint filler. The dowel bars should be exposed sufficiently to enable the tests for horizontal and vertical alignment described in paragraph 10.5.4 to be carried out. The top of the joint filler should be exposed sufficiently to permit measurement of lateral and vertical displacements due to distortion of the joint filler or complete shifting of the whole assembly. Particular care should be taken not to disturb the dowel bars or joint filler.

2.1 Two-course construction when the bottom layer is compacted separately The plastic concrete should be removed after compaction of the lower layer. If the slab reinforcement has been placed before compaction of the lower layer, it should be cut back after compaction to a distance of at least 750 mm on either side of the joint to allow access to the dowel bars.

After completion of the tests, the excavation should be made good with fresh concrete spread to the correct surcharge, new reinforcement placed in position with the appropriate specified overlap on the undisturbed reinforcement and the whole recompacted to Specification before the top layer of concrete is laid.

2.2 Single-course construction and two-course construction when the bottom layer is not compacted separately The plastic concrete should be removed after compaction but before insertion of any longitudinal joint filler and final finishing. The width taken out should be sufficient for the removal of any slab reinforcement, and for the overlap of the replacement reinforcement, approximately 1.4 m total.

After completion of the tests, the excavation should be made good with fresh concrete and new reinforcement to the requirements of the specification. Normally the spreader and compactor should be brought back and re-run to place and compact the concrete but, where a slip-form paver is used, the making good should be by hand methods.

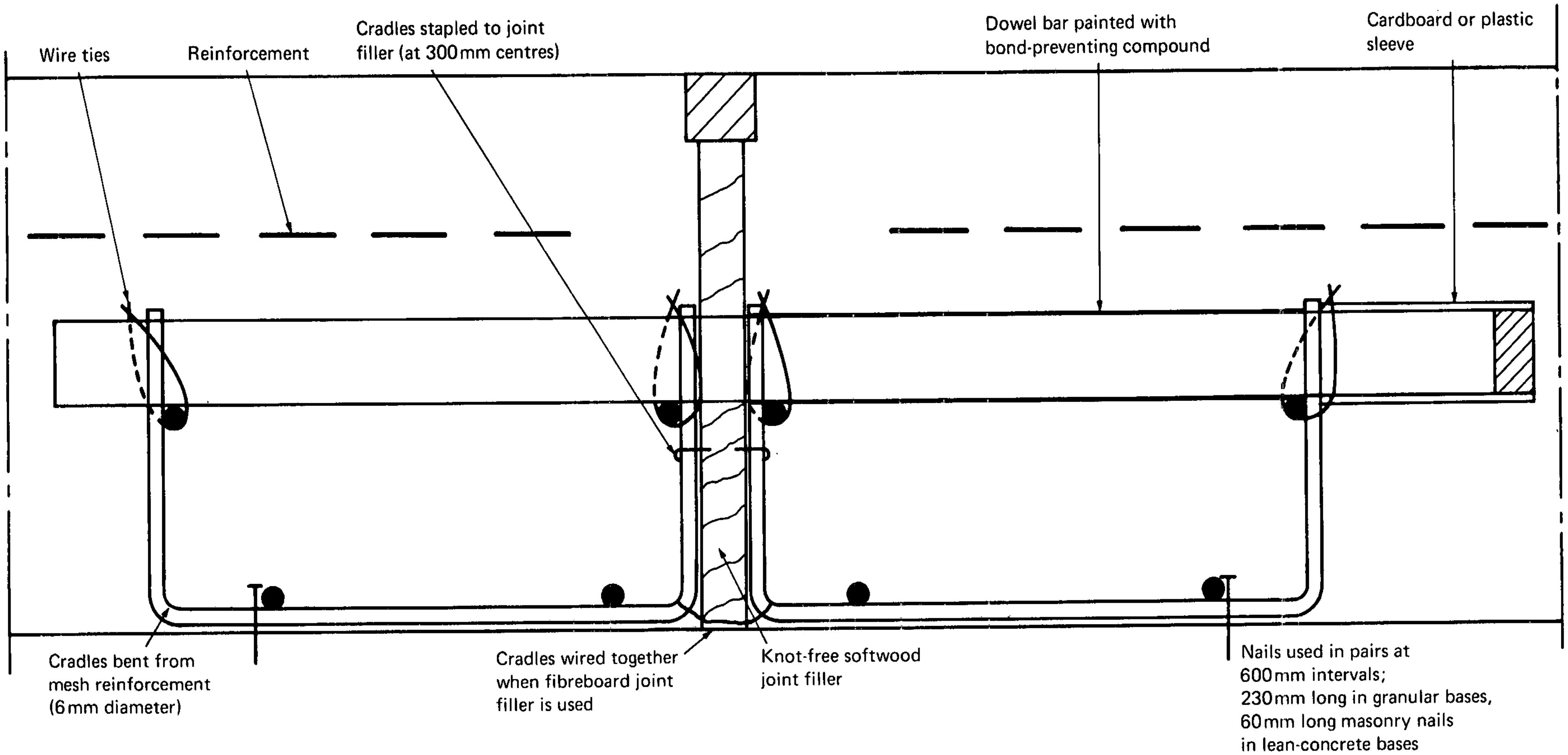


Fig1 TYPICAL DETAIL OF CRADLE-TYPE ASSEMBLY FOR AN EXPANSION JOINT

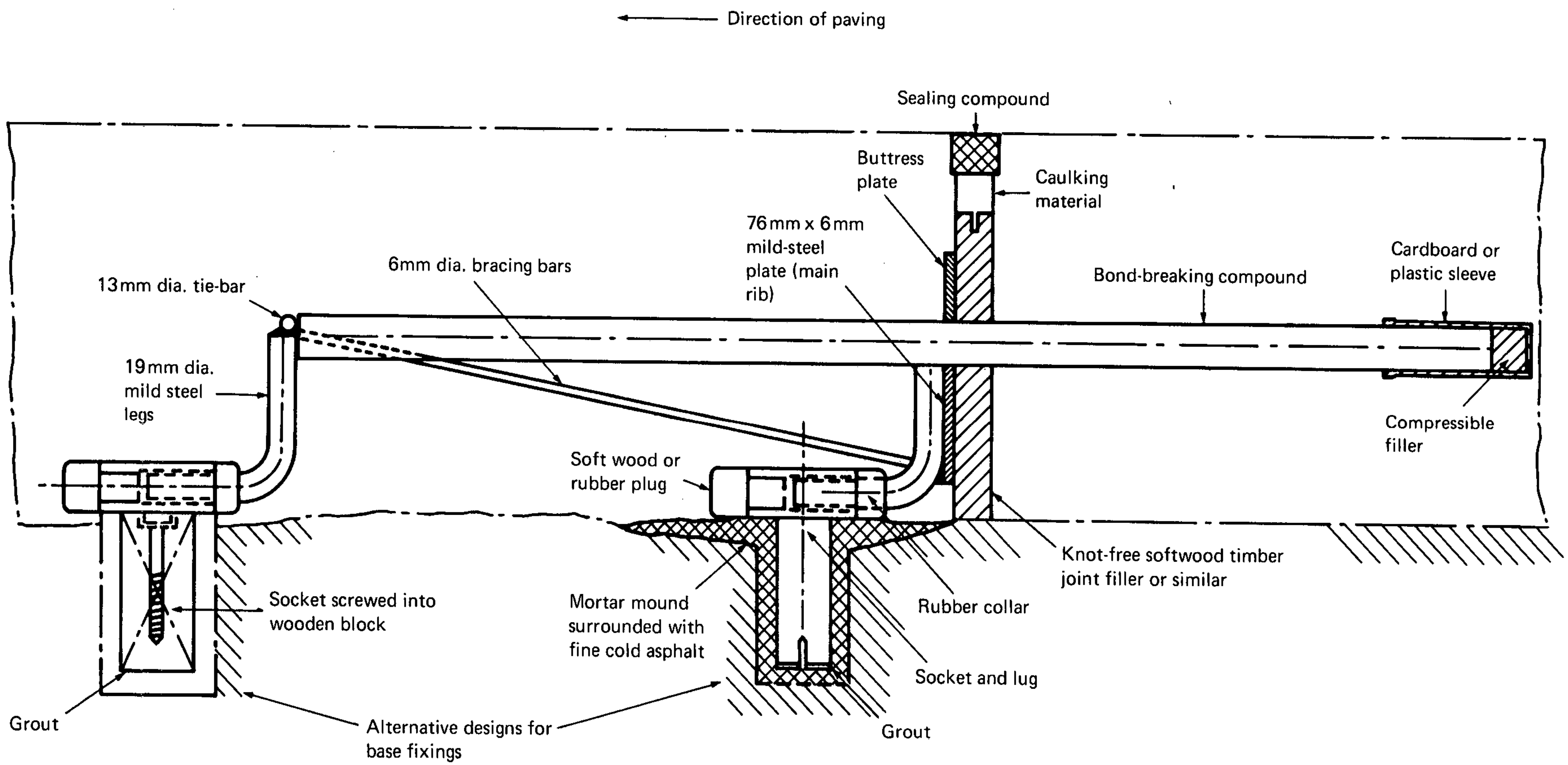


Fig 2 TYPICAL DETAILS OF A WELDED EXPANSION JOINT ASSEMBLY

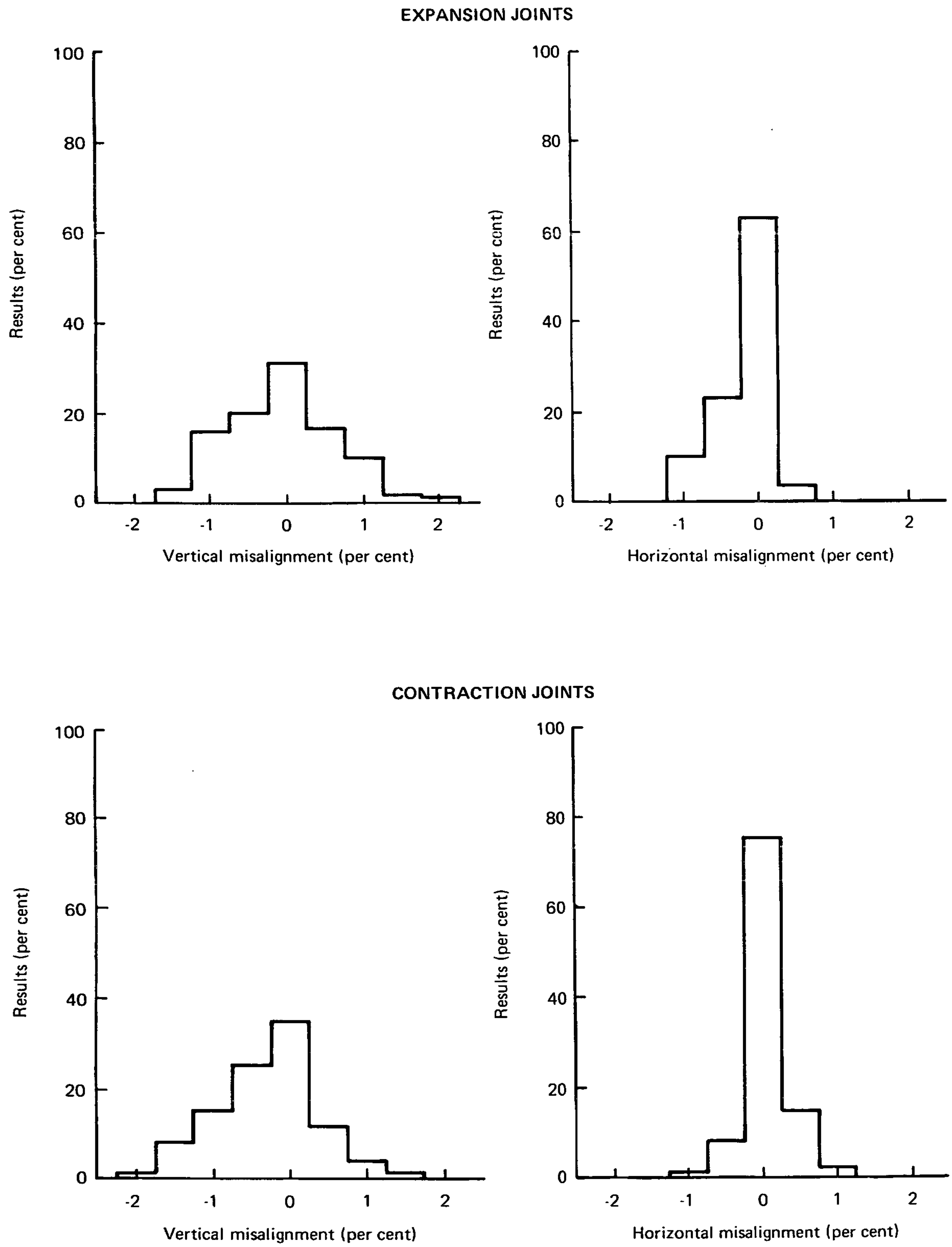


Fig 3 VERTICAL AND HORIZONTAL ALIGNMENT OF DOWEL BARS IN JOINTS ON M74 HAMILTON BY-PASS

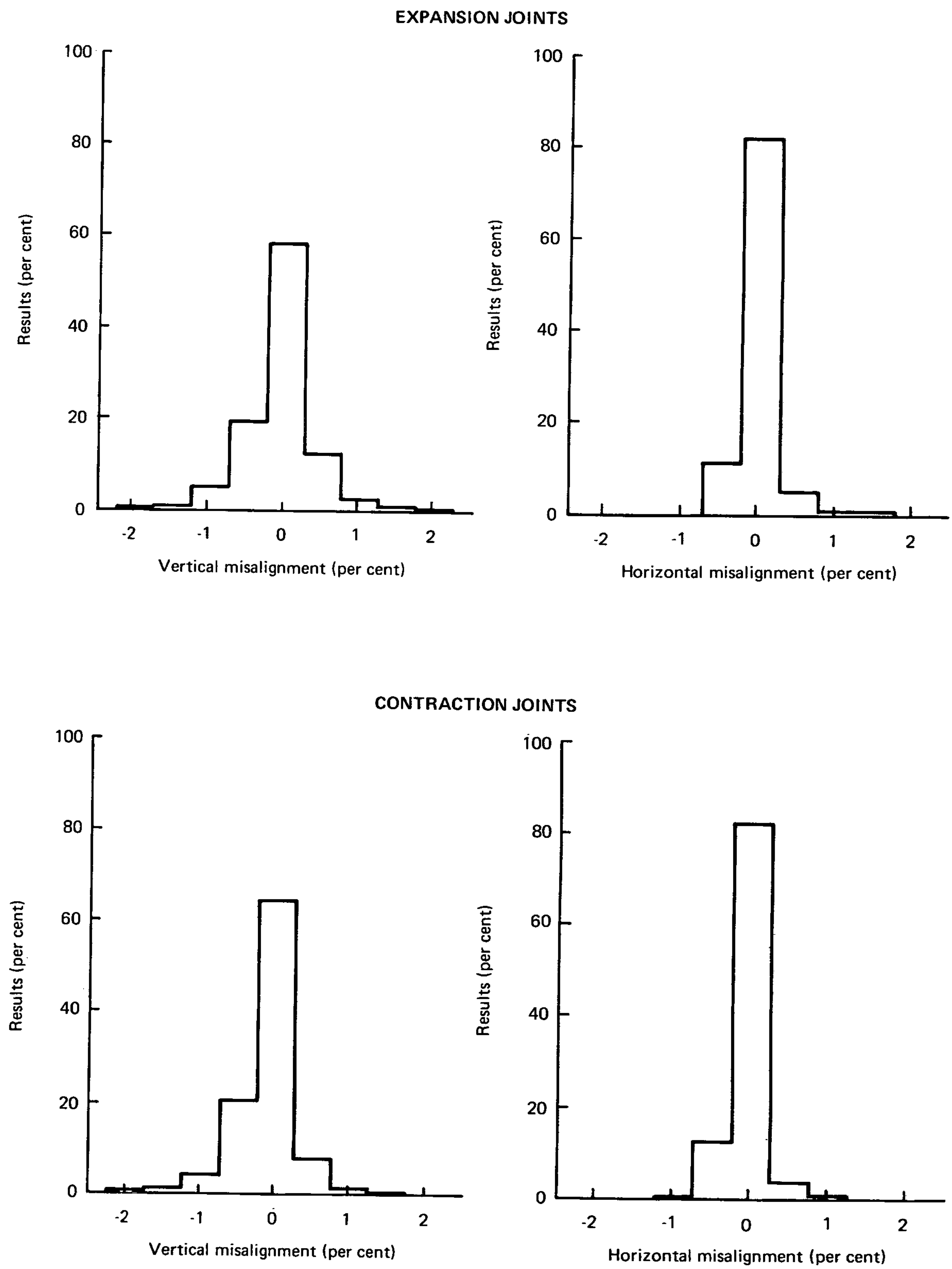


Fig 4 VERTICAL AND HORIZONTAL ALIGNMENT OF DOWEL BARS IN JOINTS ON A1 TUXFORD BY PASS

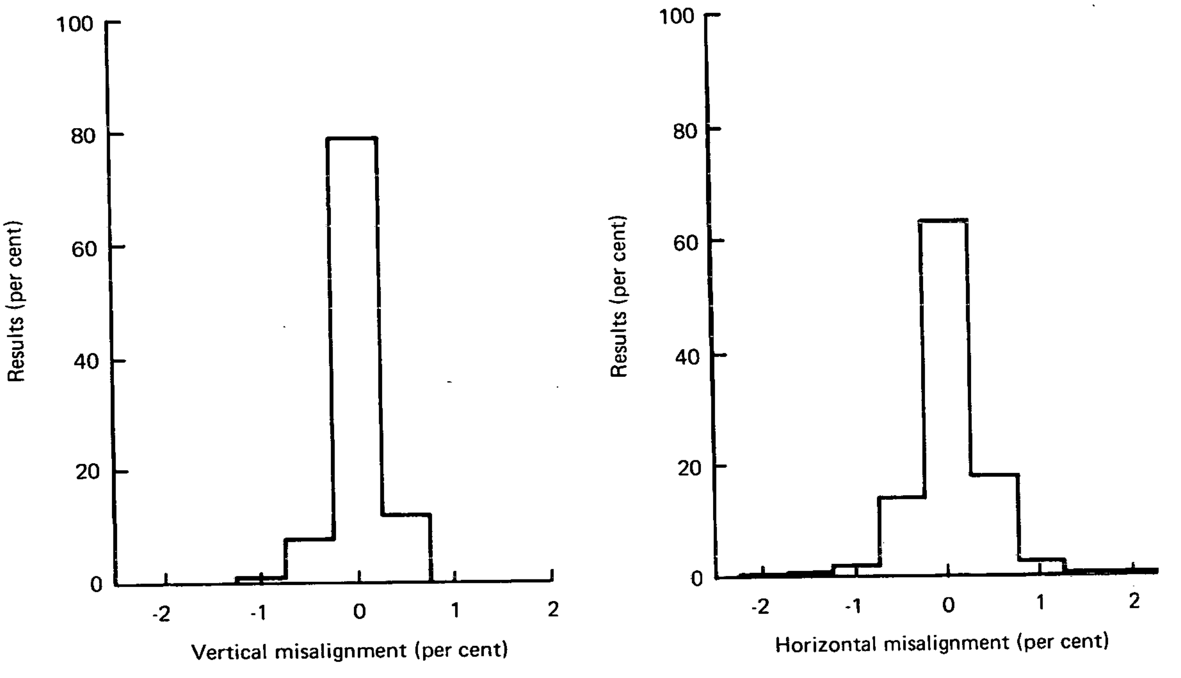


Fig 5 VERTICAL AND HORIZONTAL ALIGNMENT OF DOWEL BARS IN EXPANSION JOINTS ON M1 SOUTHERN EXTENSION

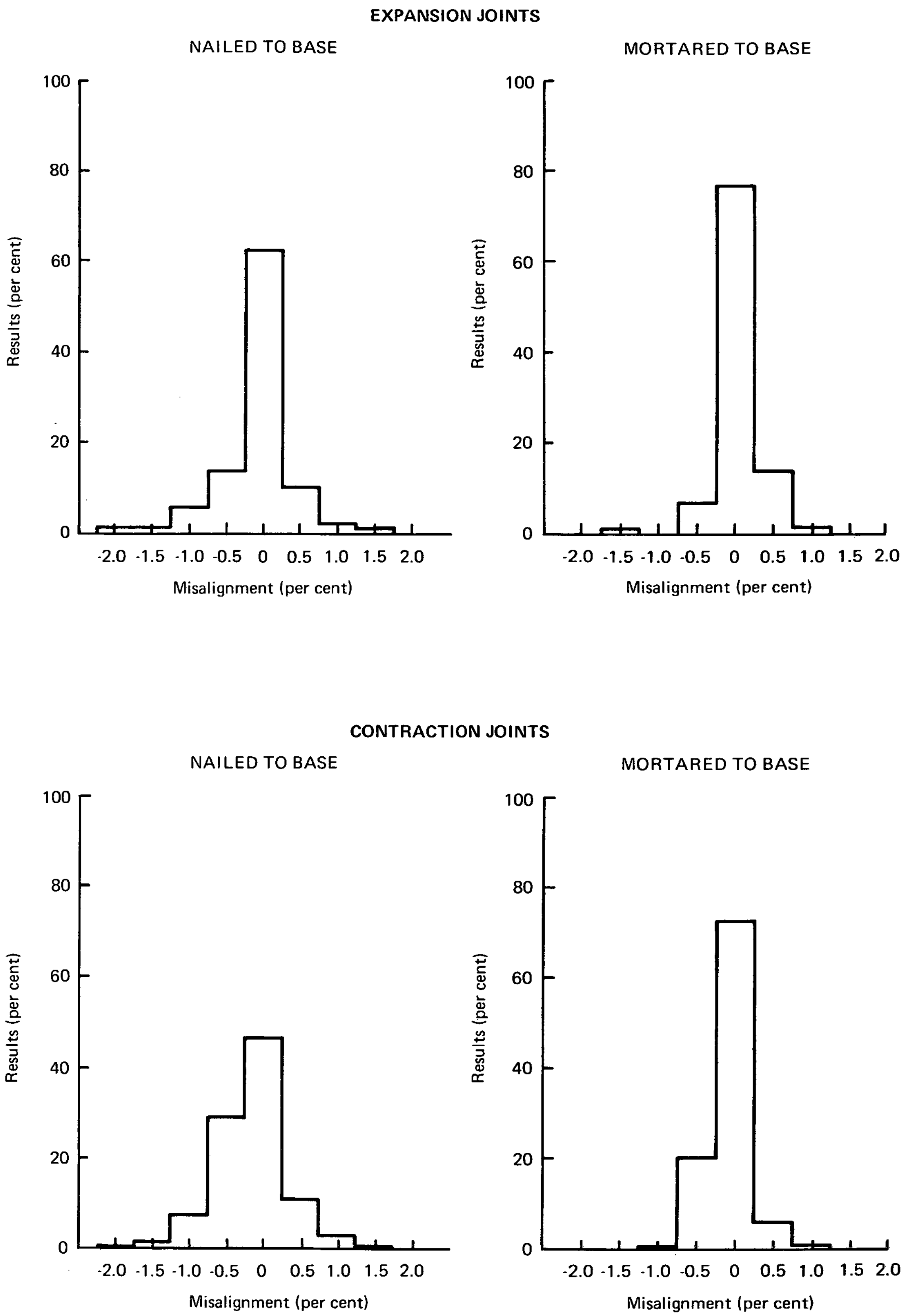


Fig 6 VERTICAL ALIGNMENT OF DOWEL BARS IN JOINTS AT LONG BENNINGTON (BEFORE CORRECTION)

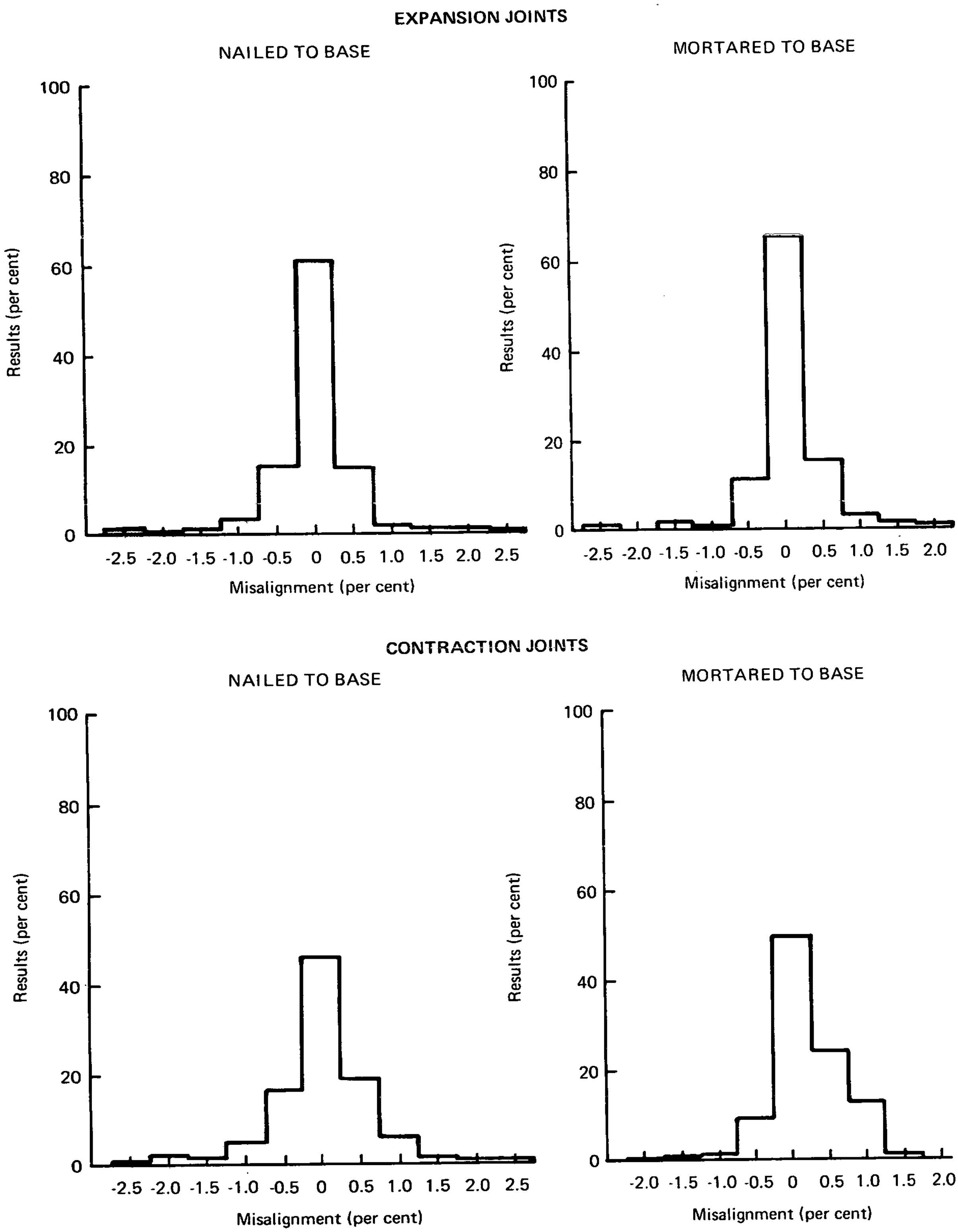


Fig 7 HORIZONTAL ALIGNMENT OF DOWEL BARS IN JOINTS AT LONG BENNINGTON (BEFORE CORRECTION)

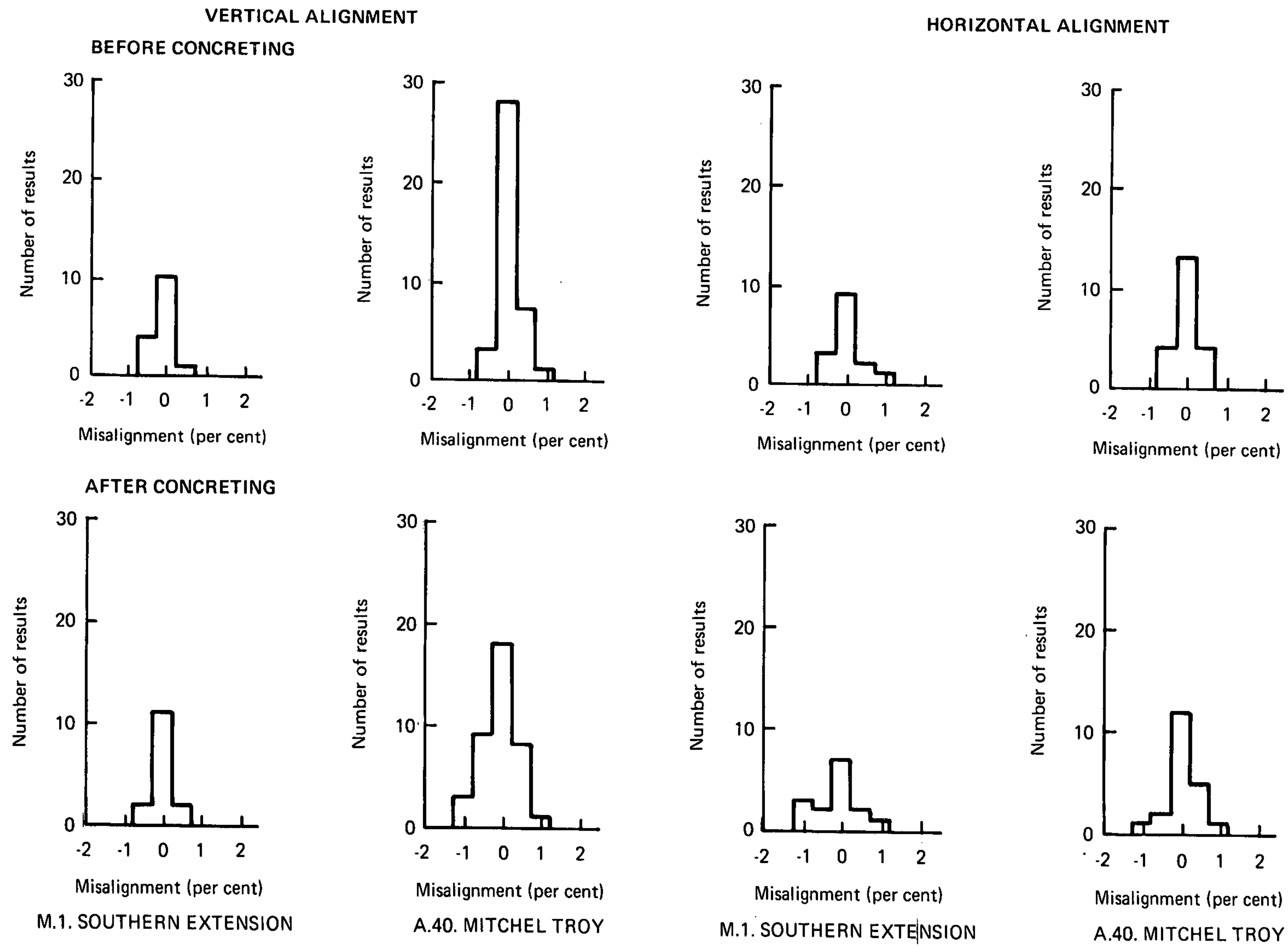
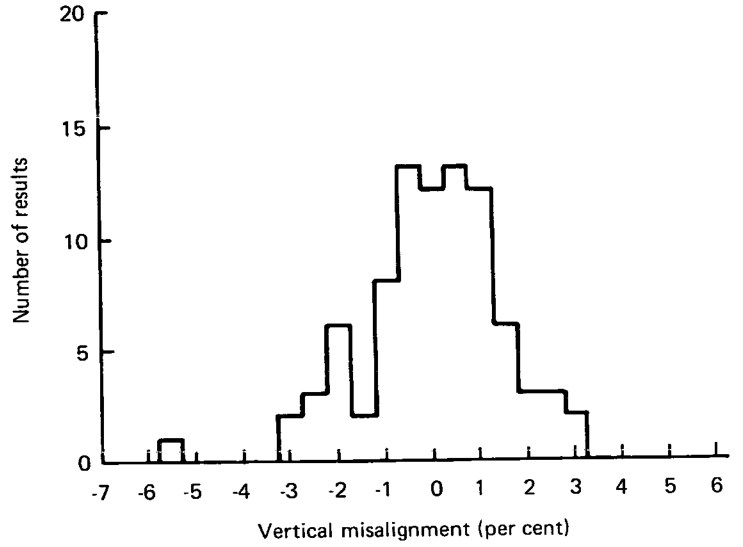


Fig 8 HISTOGRAMS SHOWING DOWEL-BAR ALIGNMENTS BEFORE AND AFTER CONCRETING IN CRADLE JOINT ASSEMBLIES



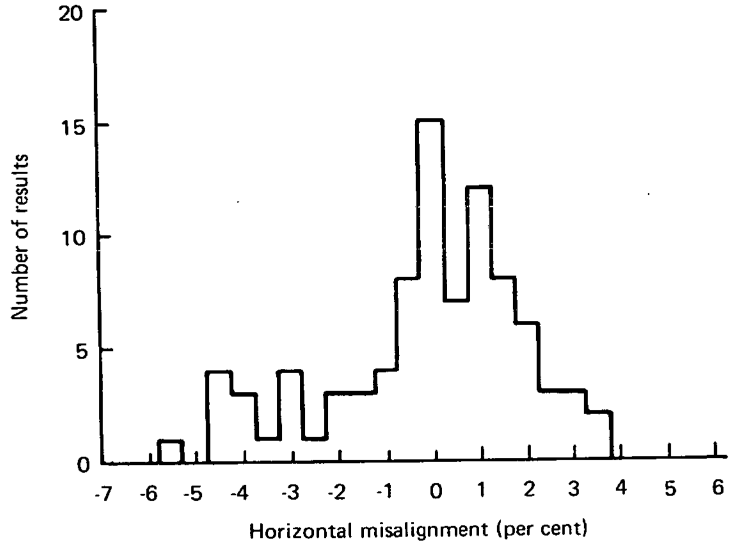
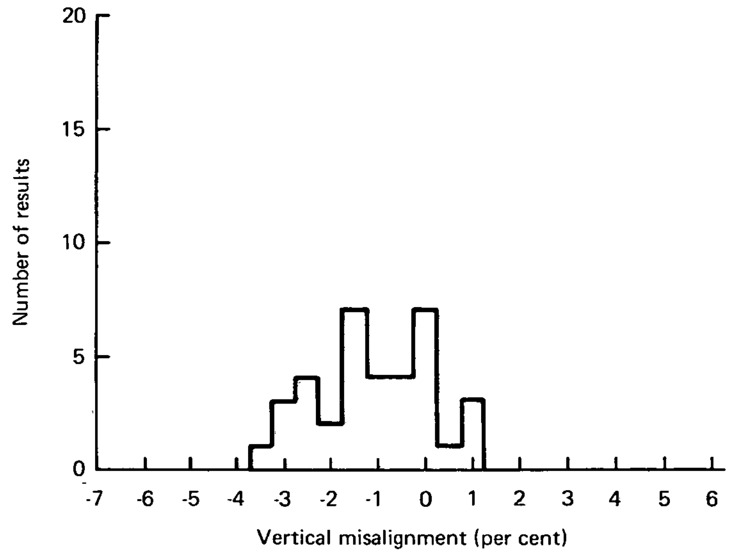


Fig 9 VERTICAL AND HORIZONTAL MISALIGNMENTS OF DOWEL BARS INSERTED INTO COMPACTED BOTTOM LAYER (RAGLAN-USK SECTION A40)



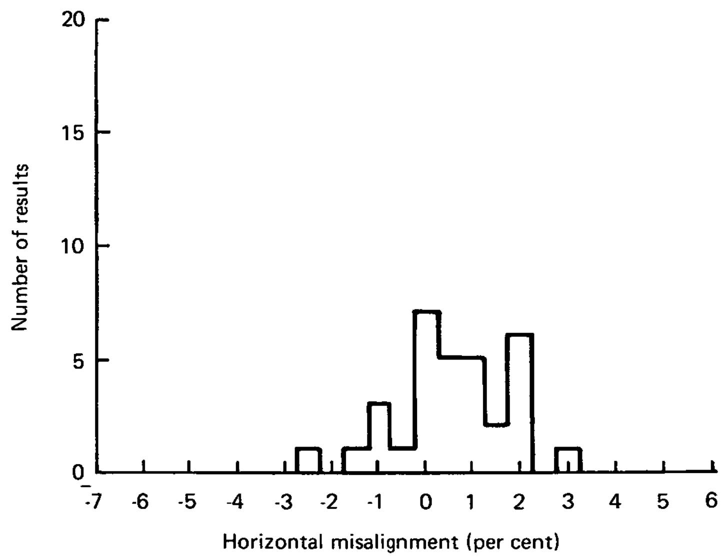
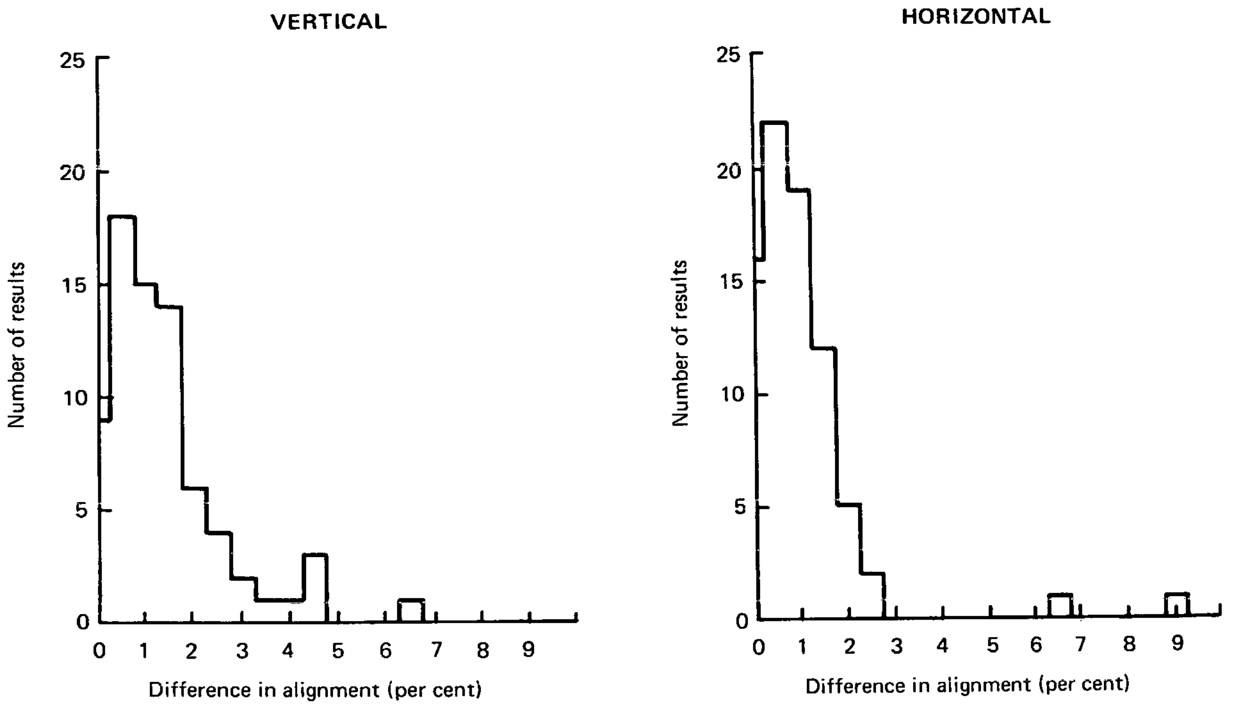


Fig 10 VERTICAL AND HORIZONTAL MISALIGNMENTS OF DOWEL BARS PLACED THROUGH COMPACTED SURFACE LAYER (RAGLAN-USK SECTION A40)

(a) BARS PLACED INTO COMPACTED BOTTOM LAYER



(b) BARS PLACED THROUGH COMPACTED SURFACE LAYER

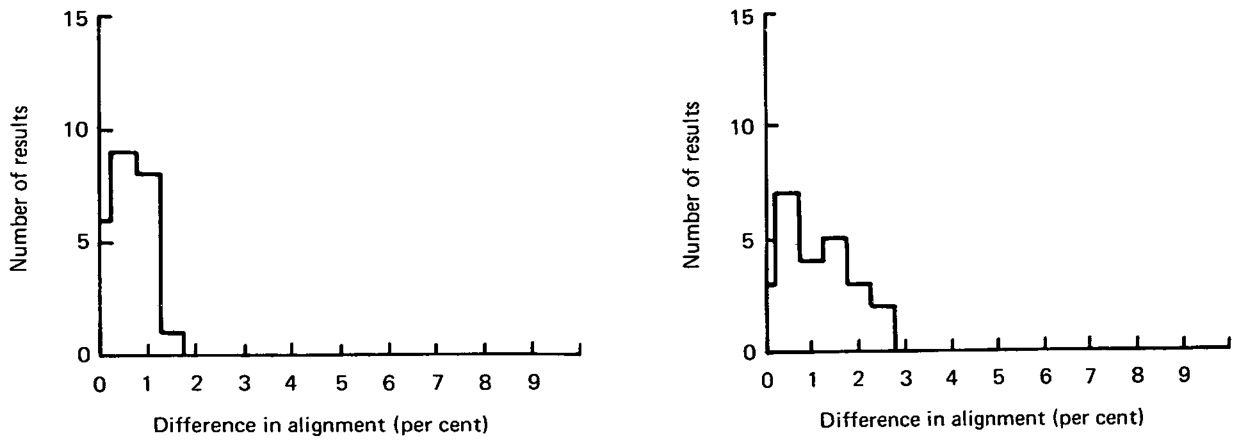
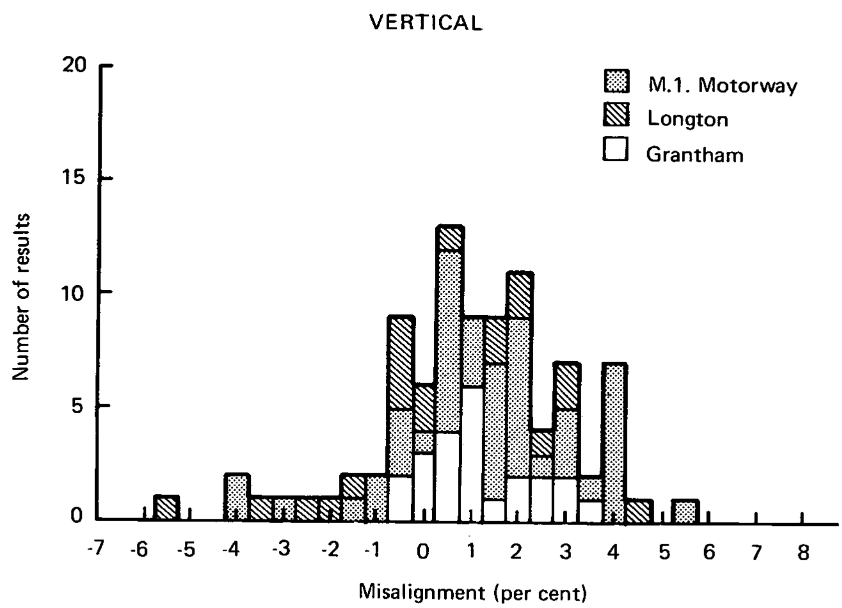


Fig 11 DIFFERENCE IN ALIGNMENT BETWEEN ALTERNATE DOWEL BARS INSERTED MECHANICALLY



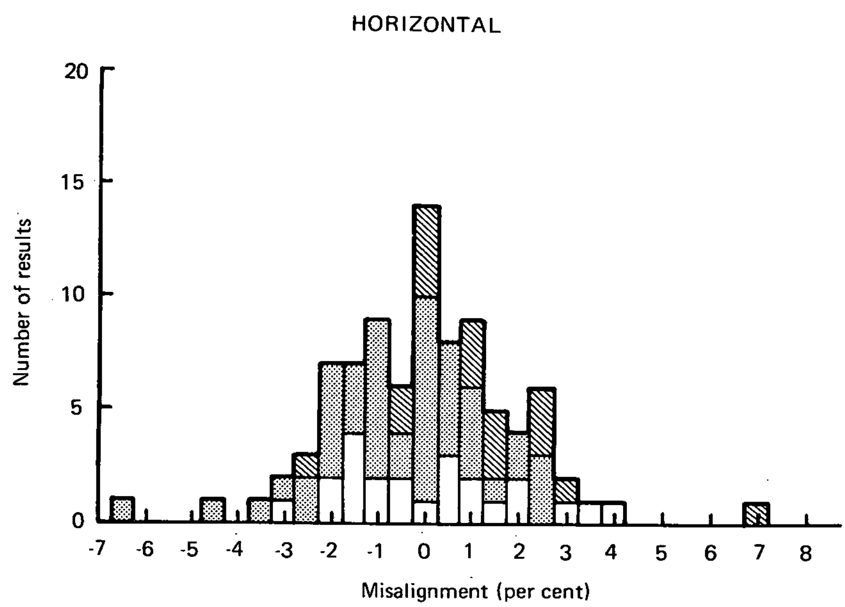
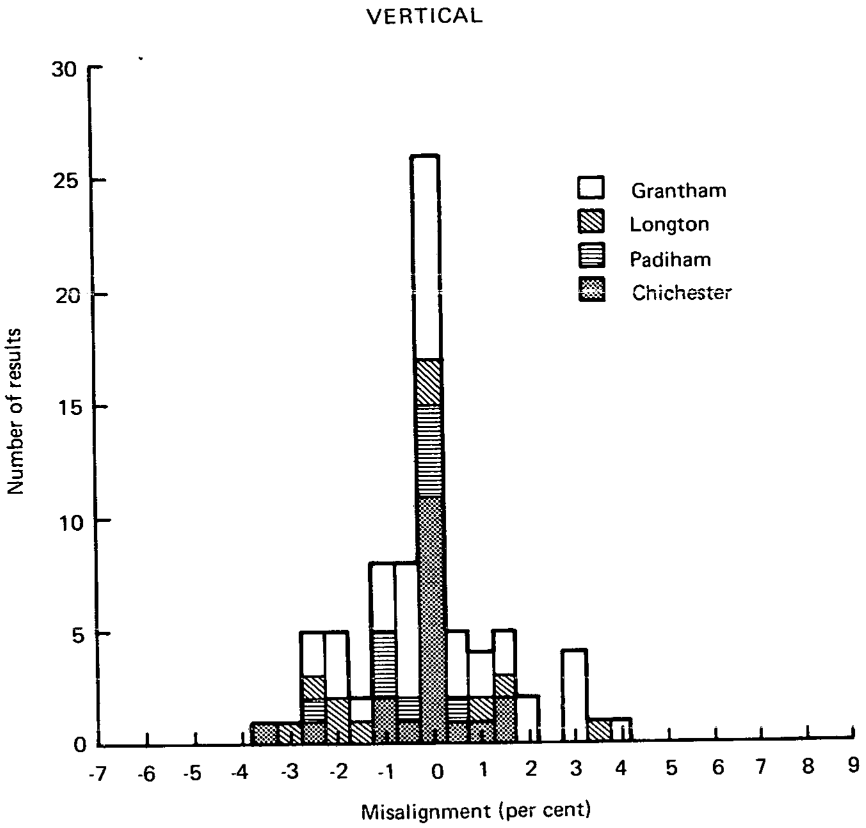


Fig 12 VERTICAL AND HORIZONTAL MISALIGNMENTS OF DOWEL BARS IN THE EXPANSION JOINTS OF THE A1 GRANTHAM BY-PASS, A59 LONGTON BY-PASS AND THE M1 MOTORWAY



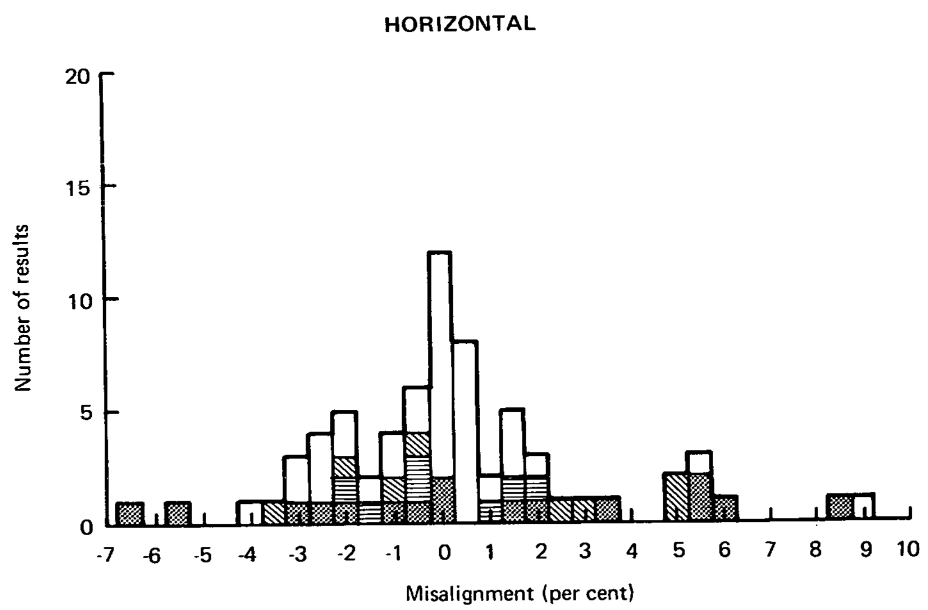


Fig 13 VERTICAL AND HORIZONTAL MISALIGNMENTS OF DOWEL BARS IN THE CONTRACTION JOINTS OF THE GRANTHAM BY PASS, THE LONGTON BY PASS, THE CHICHESTER BY PASS AND THE PADIHAM BY PASS

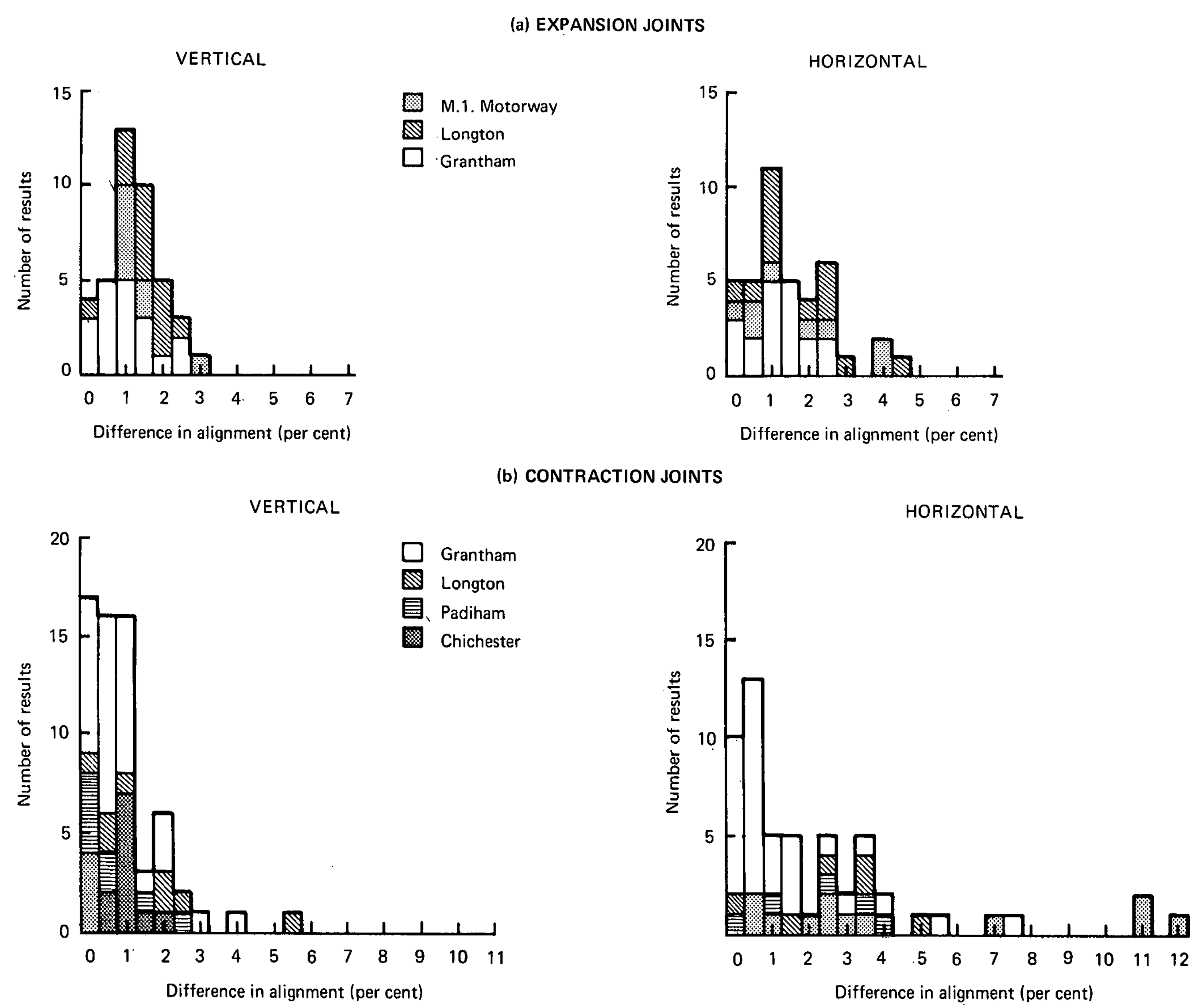


Fig 14 DIFFERENCE IN ALIGNMENT BETWEEN ALTERNATE DOWEL BARS INVESTIGATED ON 5 SITES

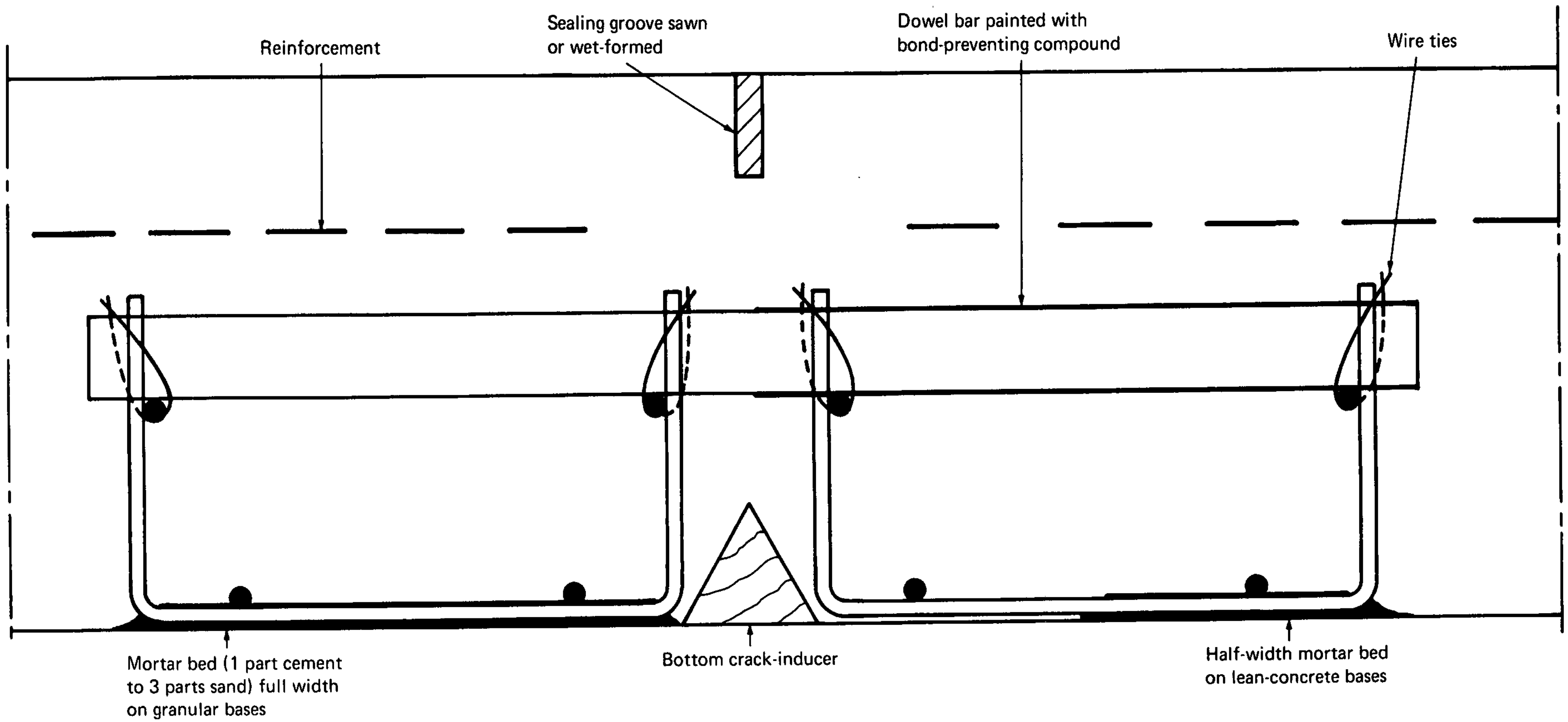


Fig15 TYPICAL DETAIL OF CRADLE CONTRACTION JOINT ASSEMBLY

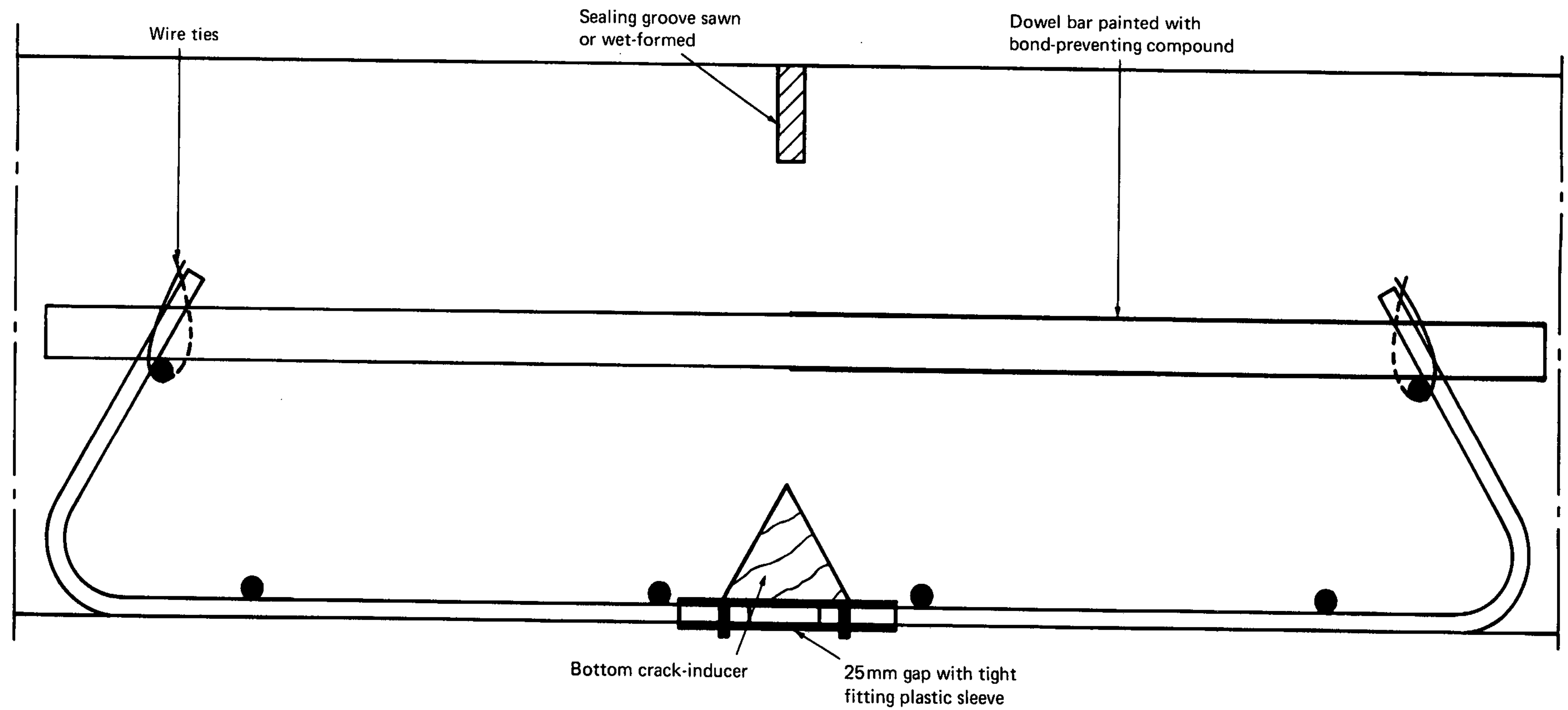


Fig 16 TYPICAL DETAIL OF REINFORCEMENT MANUFACTURERS ASSOCIATION STANDARDISED CONTRACTION JOINT ASSEMBLY

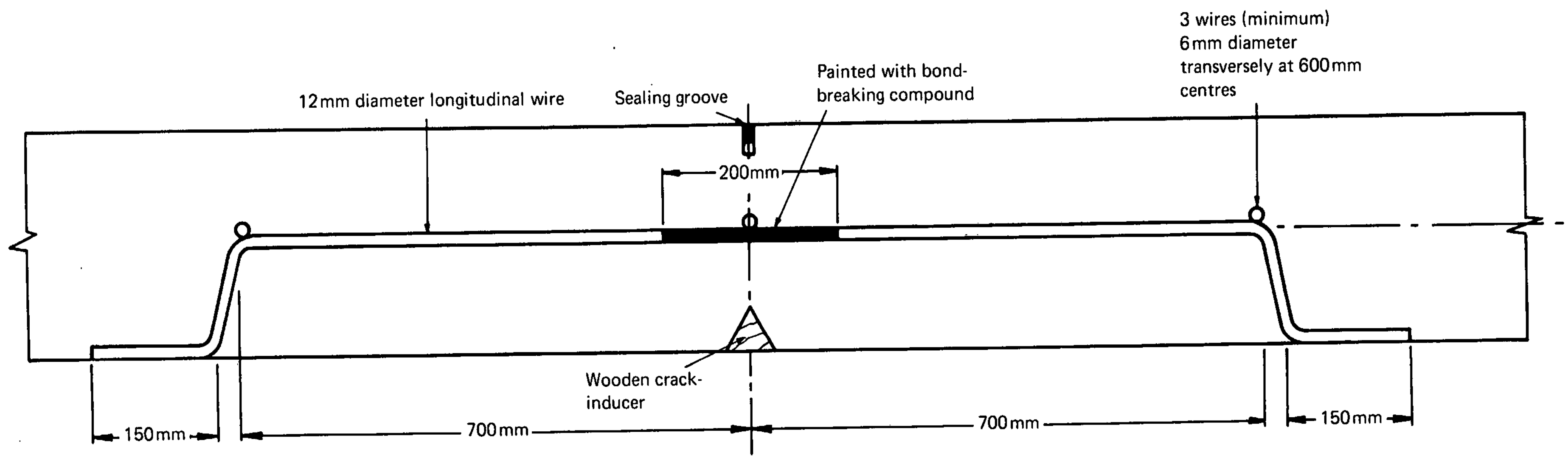


Fig 17 DETAILS OF A WARPING JOINT

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PLATE 1

Apparatus for testing the rigidity of joint fillers

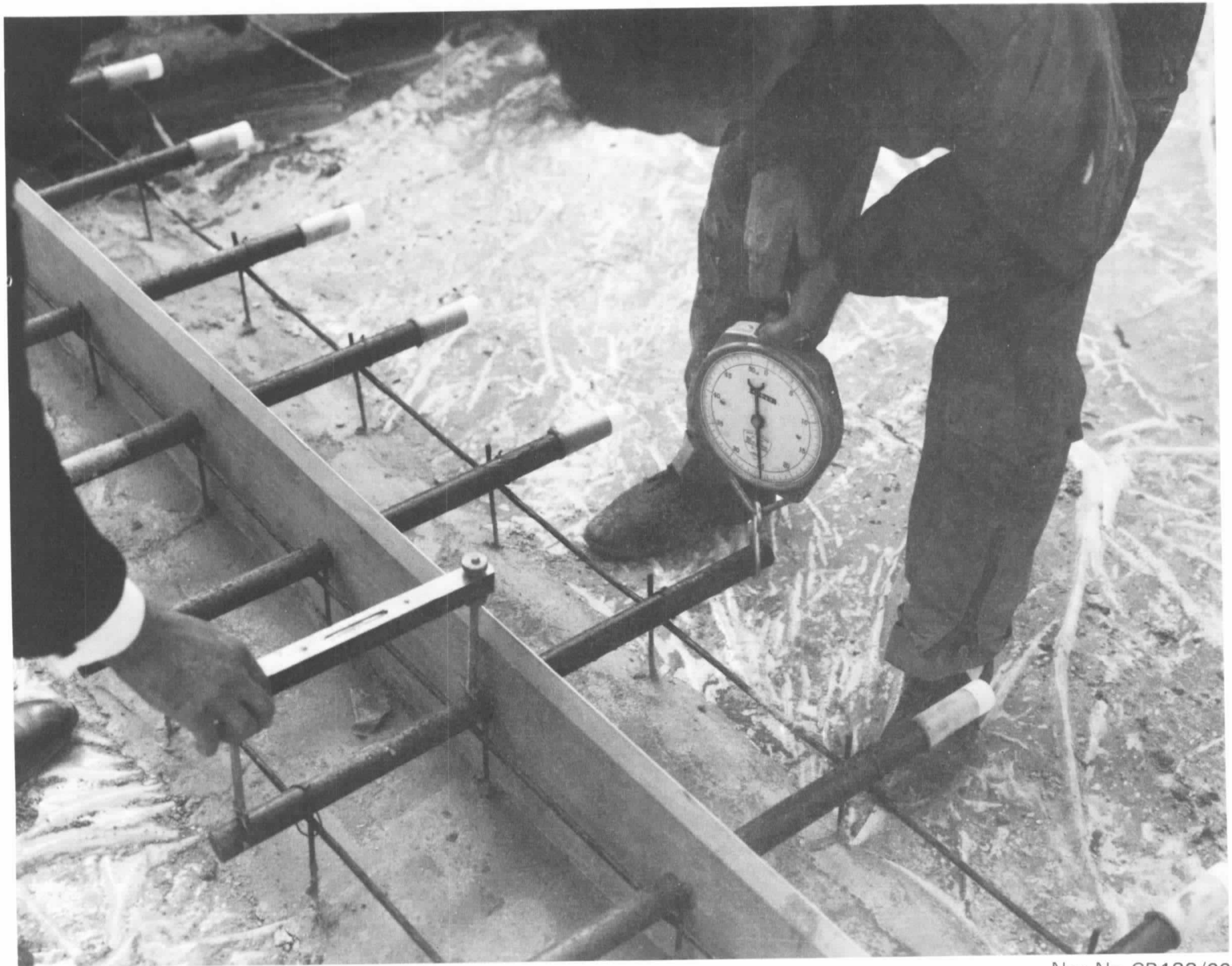

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PLATE 2

Test for vertical rigidity of dowel bars

PLATE 3

Neg No CB190/66

Test for horizontal alignment of dowel-bars

(1973) Dd635221 3,750 11/73 HPLtd, So'ton G1915
PRINTED IN ENGLAND

ABSTRACT

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The recommendations are based on the results obtained from a comprehensive programme of laboratory tests and site studies carried out jointly by the Transport and Road Research Laboratory and the Cement and Concrete Association. Standards for the rigidity of transverse joint assemblies are discussed, and a relaxation in the tolerances for alignment of dowel bars is suggested.

The report also discusses simple procedures for site tests on joint assemblies before concreting to ensure satisfactory performance both during the construction and the subsequent life of the road.

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