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PAVEMENT DEFLECTION: OPERATING PROCEDURES FOR USE IN THE UNITED KINGDOM

by

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ABSTRACT

The relationships established between the deflection of road pavements and their long term performance under traffic provide the engineer with a relatively simple means of forecasting the future performance of existing roads and designing measures for their structural strengthening.

This report provides information on the recommended methods of operating the Deflection Beam and Deflectograph, the two types of measuring equipment in use in the United Kingdom. It also draws attention to the possible consequences of using non-standard techniques of operation.

The first part of the report describes preferred operating procedures when the equipment is used to carry out a deflection survey along a length of road and indicates the way in which these procedures are a consequence of the design of the machine and the conditions on the road. The second part describes procedures for ensuring that the Deflectograph is functioning effectively when carrying out a deflection survey.

1. INTRODUCTION

The transient deflection of a road pavement under a heavy wheel load moving at creep speed has been related to the long-term performance of the road pavement under traffic. Studies on experimental and normal roads are described in LR 375[1] and LR 832[2]. They provide the engineer with a relatively simple method of forecasting the future performance of existing roads and designing structural strengthening measures. The method is described in LR 833[3].

Two methods of measuring deflection are used in the United Kingdom. The Deflection Beam, a simple manual device, measures the deflection of the road surface between the dual wheels of a loaded lorry. The Deflectograph, an automatic system for deflection measurement, is capable of making deflection measurements at closely spaced intervals along a road while moving at about 2 km/h. A detailed specification of the vehicles and measuring systems suitable for use with these two pieces of equipment in the United Kingdom is given in LR 834[4]; the present report should be read in conjunction with LR 834.

The present report provides information on the recommended methods of operating the Deflectograph and Deflection Beam and also draws attention to the possible effects and consequences of using non-standard techniques; their use can lead to expensive errors in overlay recommendations.

The report is in two parts; the major part describes preferred operating procedures when the equipment is used to carry out a deflection survey along a length of road and the way in which these procedures are a consequence of the designs of the machines and of conditions on the road. The second part (Section 11) describes procedures for ensuring that the Deflectograph is functioning effectively when carrying out a deflection survey.

2. THE OPERATIONAL UNIT

2.1 Measuring equipment

The essential equipment required to carry out a deflection survey is given in Table 1. Specifications for the individual items are presented in LR 834[4].

TABLE 1

Equipment required to carry out a deflection survey

1.	A Deflectograph with calibration equipment similar in principle to that shown in Plate 1.
OR	A Deflection Beam, calibration device shown in Plate 2 and suitable lorry capable of being fitted with adjustable pointers to assist with the alignment of the beam between the dual rear wheels.
2.	A mercury-in-glass stirring type thermometer or equivalent thermocouple or thermistor device.
3.	A percussion type masonary drill and hammer.
4.	A road marking crayon.
5.	A straightedge 2m in length and calibration wedge.
6.	Suitable road signs, traffic cones and flashing beacons.
7.	Reflective jackets for operators when working on the road.

2.2 Operating team

For Deflection Beam operations the team should consist of four men: a lorry driver, two labourers and the Beam operator who also records the results obtained.

The Deflectograph normally requires a team of two men, a lorry driver and an operator. However, in urban conditions or where unusual traffic hazards or complex road layouts occur, it is often desirable to supply a third man to deal with the extra operating problems which arise.

3. METHOD OF MEASUREMENT

3.1 The Deflection Beam

3.1.1 Initial preparations for testing. The length of road on which measurements are to be made is coned off after suitable warning signs have been erected on the verge ahead of the area. Traffic control requirements depend on the road layout and on the traffic and weather conditions. The advice of the police should be taken in all cases where doubt arises. A temperature hole is then drilled to a depth of approximately 45mm in the road near the kerb (but in material representative in texture and colour of the material at the test points), using the hammer and masonry drill. A small amount of glycerol is poured into the hole and the thermometer is inserted so that the centre of the thermometer bulb is 40mm below the road surface. Where a thermistor or thermocouple is used the hole should be only marginally deeper than 40mm. Traffic cones should be placed on either side of the hole in order to give protection; the shadow from a cone should not however be allowed to fall on the temperature measuring device when the sun is shining.

3.1.2 Test procedure. The Deflection Beam is assembled and calibrated. It should then be locked to the frame using the D-shaped handle. The two pointers, which should be adjustable in vertical and sideways directions, are secured to the chassis of the lorry at points approximately 1m in front of the rear wheels, and in line with the gap between each pair of dual wheels.

Test points are marked in the nearside and offside wheel paths of the nearside lane of the road using road-marking crayon; in a lane of normal width, these would be approximately 1m and 2.9m from the kerb. The distance between test points depends mainly on the purpose of the survey, and the visual condition of the road surface. On an apparently sound length of road, measurements should be made at about 25m intervals, but where the road shows visual signs of deterioration or the deflection measurements are sufficiently high or variable to suggest that structural deterioration is likely, the test points should be placed more closely together; a spacing of about 12 metres is suitable in such circumstances.

The starting point for the lorry in each test is marked by a line drawn at right angles to the kerb at a distance of 1.3m behind each test point. The lorry is reversed parallel with the kerb so that the gap between the nearside pair of dual wheels passes over the appropriate test point, and the rear wheels come to rest on the starting line. The beam is passed through the gap in the dual rear wheels and the tip is placed on the test point. The frame of the Deflection Beam is then lowered on to the road and the locking device released.

By looking through the gap between the dual rear wheels the operator can ensure that the beam is lying in the centre of the gap, parallel with the direction of the lorry's forward movement, and that the tip is approximately in line with the centre of the front tyre when the front wheels of the lorry are pointing straight ahead. The adjustable pointer is then aligned to the position of the beam. The pointer in this position can then be used by the operating team to locate the beam in subsequent testing without reference to the front tyres. The same procedure is used for testing in the offside wheel path.

When the Deflection Beam is being moved, and positioned for a test, the beam should be locked to the frame. Before each measurement the lock is released and the dial-gauge set to zero while the Deflection Beam is being vibrated. When the operator gives the signal the lorry is driven forward at creep speed to a position at least 3m beyond the test point. The speed, which should be checked by stop watch once or twice a day, is that required to cover a distance of 5m in 10 secs $\pm$ 1 sec. Vibration of the beam is continued until the lorry has reached its stopping position, and during this time the maximum and final readings of the dial-gauge are taken. The value of deflection is calculated by adding the maximum reading to the difference between the maximum and final readings. Because of the 2:1 ratio of the beam length about the pivot, the sum, rather than the mean, is defined as the deflection of the road.

Two measurements are normally made at each test point and the mean result obtained. For deflections greater than 25 x 10^{-2}mm the readings should not differ by more than 5 per cent of the mean value; for smaller deflections the difference should not exceed 10 per cent.

Inaccurate measurements are normally associated with under-registration. Therefore, if a low reading is followed by two high values which agree within the limits stated, the low reading can be ignored. Similarly, if a high reading is followed by two low readings which agree, a fourth reading must be taken to verify the two low readings, but if the fourth reading agrees with the high value, the two low readings are ignored. If large differences are recorded on the same test point, these can be caused by the lorry wheels touching the beam or by friction in the beam pivot or dial-gauge. When these points have been investigated and if necessary corrected, further readings are taken. If satisfactory agreement cannot be obtained, the mean of five measurements should be taken and the variability noted.

During sunny weather the beam may pass from shade into sunshine as the vehicle moves away from the test point; this can cause sufficient differential thermal expansion within the beam to give significant errors in the measured deflection, particularly on stiff pavements. Under these conditions, use of the sunshade provided with the Deflection Beam and taking the final deflection reading immediately the lorry is 3m beyond the test point reduce the error.

TABLE 2

Classification of the condition of the road surface

Classification	Code	Visible evidence
Sound	1	No cracking. Rutting under a 2m straightedge less than 5mm.
	2	No cracking. Rutting from 5mm to 9mm.
Critical	3	No cracking. Rutting from 10mm to 19mm.
	4	Cracking confined to a single crack or extending over less than half of the width of the wheel path. Rutting 19mm or less.
Failed	5	Interconnected multiple cracking extending over the greater part of the width of the wheel path. Rutting 19mm or less.
	6	No cracking. Rutting 20mm or greater.
	7	Cracking confined to a single crack or extending over less than half of the width of the wheel path. Rutting 20mm or greater.
	8	Interconnected multiple cracking extending over the greater part of the width of the wheel path. Rutting 20mm or greater.

The condition of the road surface around the test point should also be assessed by visual inspection and by use of the straightedge and calibrated wedge. The straightedge is placed transversely across each of the wheel paths over the test points, and the wedge used to measure the rut depth. The extent of any cracking is noted and the condition classified in accordance with Table 2.

3.1.3 Recording of measurements. A suitable form for recording deflection measurements is shown in Table 3 for data which are to be analysed manually. Where computer-based analysis is to be used a form of the type shown in Table 4 will be more satisfactory. Deflection is adjusted in proportion to wheel load for loads within the range ± 10 per cent of the standard load. Correction of deflections for the effects of temperature is dealt with in LR 833[3].

The assessment of road condition to be associated with deflection measurements is considered further in Section 10 of this report.

3.2 The Deflectograph

3.2.1 Initial preparations for testing. As in the case of testing with the Deflection Beam, traffic control requirements for the operation of the Deflectograph depend on the weather conditions. The advice of the police should be taken in all cases where doubt arises. As a general guide it has been found essential to operate behind cones on motorways and heavily trafficked roads and to use a protecting follow-up vehicle on winding roads with poor visibility.

3.2.2 Test procedure. The Deflectograph should be calibrated daily using the procedure detailed in Appendix 1. During a survey the nearside wheels of the Deflectograph should be maintained at a distance of about 1m from the nearside edge of the traffic lane, or in the wheel-path taken by commercial traffic if this differs appreciably from the 1m position. Temperatures should be measured in accordance with the recommendations given in Section 7 of this report. Detailed instructions for operating the electronics and recording equipment of the Deflectograph are given in the manufacturers' handbooks: these will vary according to the particular model.

3.2.3 Recording of measurements. Data are recorded on a pen chart. On many machines digital output is also available on paper tape and/or on a drum printer. Pen-chart output should always be recorded, even when a digital output is provided, in order to keep a continuous check on the functioning of the equipment. This is considered in more detail in Section 11 of this report.

Features or events on the road such as junctions, marker posts or bridge decks should be recorded on the chart and digital output in order to locate the deflection survey. The spacing of these events should not exceed 0.5km. A separate record of the description of these location points should be made for transfer to the chart output and/or processed digital output.

The assessment of road condition to be associated with deflection measurements is considered in Section 10 of this report.

4. CALIBRATION

For the Deflection Beam and Deflectograph to measure deflection with acceptable accuracy, it is essential that the equipment is working satisfactorily; this can be verified only by daily calibration. The Deflection Beam is a relatively simple mechanical device and if the calibration procedure described in Appendix 1 indicates errors of greater than ± 2 per cent the condition of the dial-gauge, the beam pivot and, in the case of a split beam, the locking bolts, should be investigated and if necessary improved, until satisfactory compliance is obtained.

TABLE 3

Form for recording deflection measurements made with the Deflection Beam suitable for manual analysis

Site & Date	Exact location of test point *	Road temperature °C	Nearside wheel path						Offside wheel path					
			Wheel load kg	Deflection x 10^{-2}mm			Rut depth mm	Condition & remarks	Wheel load kg	Deflection x 10^{-2}mm			Rut depth mm	Condition & remarks
				Measured	Corr[d] to 3175 kg load	Corr[d] to 20°C				Measured	Corr[d] to 3175 kg load	Corr[d] to 20°C		

* Refer to site plan where applicable.

DEFLECTION BEAM

Punch columns 1 – 20 on each data record

SECTION IDENTIFIER			Sheet No.	
Road – link/street code	SectNo	D E F B		of
1		13	17	19

	DATE OF SURVEY	TWIN REAR WHEEL LOADS		Number of Type 3 entries below	COMMENTS
		Nearside (kg)	Offside (kg)		
1					
21		28	32 35	36	

	FROM NODE	TO NODE	Lane No.	Length of Section (m)	DIRECTION OF TRAVEL FROM	DIRECTION OF TRAVEL TO
2						
21		27	32	36		

	DEFLECTION								CONSTRUCTION			TRAFFIC				
	Chainage from start	Wheel track NS/OS	Mean deflection (mm x 10^{-2})	WORKING AREA	Rut depth (mm)	Condition	Wheel used NS/OS	Temperature (°C)	Base type	Thickness of sound bituminous material (mm)	Thickness of dense bituminous material (mm)	Commercial vehicles/24hr average day in lane	Standard axles/ commercial vehicle	Age of road (years)	% Future CV growth rate	% Past CV growth rate
3													•			
3													•			
3													•			
3													•			
3													•			
3													•			
3													•			
3													•			
3													•			
3													•			
3													•			
3													•			
21			30		31				38			48	53	57		62

Table 4 SUGGESTED FORM FOR RECORDING DEFLECTION MEASUREMENTS MADE WITH THE DEFLECTION BEAM SUITABLE FOR AUTOMATIC ANALYSIS

The Deflectograph is a complex electro-mechanical system requiring regular calibration. The simple mechanical procedure, designed for convenient use on the road, is of limited accuracy because of the small size of the calibration movements involved. In consequence an individual calibration reading may be in error by as much as $\pm$ 8 per cent of a mean value established in a continuous series of calibrations. Individual calibrations are therefore not trustworthy and a statistical approach is necessary. This is detailed in Appendix 1.

5. EFFECT OF TEST-VEHICLE SPEED

The elastic modulus of some road materials and subgrades depends on the rate at which they are loaded, the modulus increasing with increased rates of loading. This is reflected in a decrease in deflection measured with increasing vehicle speed[5]. Results for the particular case of the loaded dual wheel moving at creep speed, a loading regime employed by both Deflectograph and Deflection Beam, indicate a five per cent change in deflection for a 1 km/h change in speed; this is typical of many pavements. The speed checks for the Deflection Beam lorry given in Section 3.1.2 of this report should therefore be strictly enforced. The road speed of the Deflectograph can be kept within acceptable limits by controlling the speed of the engine of the lorry.

A second and more important speed-related effect specific to the Deflectograph is that the possibility of the measuring period being terminated before the peak deflection is detected increases as the speed increases. To ensure that the peak deflection is recorded, it has been found necessary on some pavements to allow the beam tip to reach a position approximately 230mm behind the centre-line of the rear wheels before the rear switch controlling the end of the measurement cycle is operated. Operation of this switch de-energises the clamping solenoids and activates the clutch system to pull the T-frame forward. A delay occurs between the two operations, and an additional time interval is associated with clutch take-up. Because of these delays a speed of approximately 2 km/h is the maximum that will permit the beam tip to extend beyond the rear-wheel centre-line by the required 230mm and that will also ensure that the frame does not hit the overshoot protector before the frame is moved forward. The exact speed is related to delay caused by the clutch take-up and this delay is a function of the roughness and the gradient of the road surface.

For these reasons a precisely defined maximum permissible speed cannot be given for the Deflectograph for all conditions; the recommended procedure for selecting a satisfactory speed is to adjust the position of the rear switch, under static conditions, so that it is operated when the beam tip is 230mm behind the centre-line of the rear wheels. Then, with the vehicle operating normally, the speed is adjusted to the maximum that is consistent with the frame being pulled forward before it hits the overshoot protector.

The range of operating conditions examined by TRRL indicates that the road speeds for satisfactory working are between 1.5 and 2.0 km/h ; these are obtained by engine speeds between 1,000 and 1,200 rpm. The corresponding change in deflection is about 2½ per cent.

6. EFFECT OF VEHICLE LOADING AND OF SUPERELEVATION

The loads on the front and the rear wheels of the Deflection Beam lorry and the Deflectograph affect the magnitude of both the pavement deflection and the recorded deflection. The recommended rear-axle loading is 6,350 kg and should be equally divided between the dual wheels at each end of the axle. If the wheel loading during testing is different from the recommended value, the measured deflections must be corrected. The correction factor, by which the measured deflections should be multiplied, is

$$\frac{3175}{\text{wheel loading during testing in kg}}$$

This correction factor is strictly applicable only when the load is within 320 kg of the recommended value; when outside this range the position of the load blocks on the vehicle must be adjusted.

The measurement of wheel loading will normally be carried out using a mechanical weighbridge with the vehicle standing on level ground. When the vehicle is operated on in-service roads, some crossfall is in general present and this will result in some redistribution of the load between the two pairs of dual rear wheels. The crossfall normally used in modern road construction of 1 in 40 (25 mm/m) does not produce a significant change in loading. However, when measuring deflection on superelevated curves the redistribution of load can become substantial. A guide to the changes in wheel loading which takes place is given in Table 5.

TABLE 5

Change in wheel loading as the result of superelevation

Superelevation	Percentage change in wheel loading
Flat to 40 mm/m (1 in 25)	.05 per mm/m
Greater than 40 mm/m	2 per cent plus 0.1 for each mm/m above 40 mm/m

Deflection measured under wheel loads adjusted for the effect of superelevation should then be corrected to the standard wheel loading using the appropriate correction factor.

The front skids of the T-frame of the beam assembly can be within the bowl of deflection generated by the front wheels of the Deflectograph. Because the load on these wheels can influence the magnitude of the measured deflections, it is therefore important to standardise the load on this axle in addition to that on the rear axle. Careful positioning of the road blocks to give a front axle load of 4,500 ± 250 kg is recommended; it is not possible to use a simple scaling factor. Front-wheel loading on the Deflection Beam lorry is less important because of the remoteness of the Beam from the front axle. Nevertheless it is recommended that the front-wheel loading is within this range.

7. THE EFFECT OF TEMPERATURE

The temperature of the bituminous layers of a road influence greatly its stiffness and therefore the magnitude of the measured pavement deflection. Figure 1 shows the change of deflection with temperature measured 40mm below the road surface for different types of flexible pavement. The pavement with an uncracked cement-bound base is least affected whereas the crushed-stone base has the greatest rate of change of deflection with temperature, or temperature susceptibility; the two bases of bituminous material, whose temperature susceptibilities are intermediate, have the greatest proportional change of deflection with temperature, as would be expected of pavements whose stiffness is almost entirely derived from temperature-susceptible materials.

Figure 1 demonstrates the need for a procedure for comparing measurements of deflection made on pavements at different temperatures so that the results can then be used on a common basis for the purpose of predicting pavement life or designing overlay thickness. Extension studies, described in LR 832, on the Laboratory's full-scale road experiments have led to the formulation of charts suitable for correcting deflections to a standard temperature of 20°C; the design system, described in LR 833[3], requires different charts according to the thickness and type of bituminous materials in the pavement.

The procedure for temperature correction is simple and convenient in requiring measurement of pavement temperature at one shallow depth only and the correction charts are easy to use. The requirements and operational limitations of deflection testing as they are influenced by temperature are considered below. Appendix 2 describes the consequences of errors in deflection and temperature measurements for deflections corrected to the standard temperature and emphasises the need to observe the prescribed operating limits.

7.1 Measurement of temperature

The measurement of temperature is made at a single depth of 40mm below the road surface; normally a short-stem stirring thermometer is used but thermistor or thermocouple devices are also suitable. A percussion-type masonry drill, 7mm in diameter, is used to make a hole for the thermometer; the hole should be 45mm deep in order that the centre of the thermometer bulb is 40mm below the surface. For a thermistor or thermocouple the hole requires only to be marginally deeper than 40mm. The hole should be filled with glycerol before the thermometer is inserted. Care should be taken to allow any heat generated in making the hole to dissipate before a measurement is taken. A true temperature is obtained when the same value has been read on three consecutive observations at intervals not less than one minute.

7.2 Effect of temperature gradients

When a road warms-up or cools rapidly considerable temperature gradients are generated in the bituminous pavement layers. Where these layers are of considerable thickness the effect of the gradients on the stiffness of the bituminous materials is sufficiently large to invalidate the normal relations between deflection and road temperature given in LR 833. In these circumstances the use of these relations to correct deflections measured on a rapidly warming pavement for the effects of temperature, results in unrealistically low corrected values; on pavements cooling rapidly the reverse is true. Deflection testing should therefore cease on roads containing more than 175mm of bituminous material when the rise or fall in pavement temperature is greater than 2.5°C per hour. In view of the relative simplicity and rapidity of the site procedure adopted for measuring temperature at one depth only, this operational restriction is considered acceptable.

On days which are for the most part sunny, temperature measurement at a single depth is valid for measurements taken during normal working hours, ie between about 0900 hours and 1800 hours. During predominantly cloudy weather this can be extended to the period 0700 hours to 2100 hours. If measurements are taken outside these times, short lengths of road should be resurveyed within the preferred time period so that the temperature corrections applied to the original data can be checked.

7.3 High temperatures

At temperatures greater than about 30°C the pushing up of the softened surfacing material between the dual wheels in the deflection test masks the normal linear increase in deflection with temperature; the result is shown in Figure 1. The temperature correction charts in LR 833[3] cannot therefore be extrapolated beyond 30°C and it is recommended that this temperature should be the maximum temperature at which testing is permitted on pavements surfaced with rolled asphalt containing 50-penetration-grade binders.

For surfacings having softer binders this limit may need to be reduced and a figure of 25°C has been suggested[6].

7.4 Low temperatures

The relations between deflection and temperature on the correction charts of LR 833 converge at low temperatures in such a way as to reduce greatly the accuracy with which deflections measured at low temperatures can be corrected to their values at the standard temperature of 20°C; the loss of accuracy is acceptable on stiffer pavements containing less than about 200mm of bituminous material, but unacceptable on all but the very stiffest pavements containing more than 200mm of bituminous material. On the less stiff pavements, normally those which have deteriorated to the greatest extent, a lower operating temperature limit of about 10°C should in general be applied. In cases of pressing need, operation at lower temperatures should be permitted only if the following criteria relating to the thickness of bituminous material present and corrected deflections are met.

Thickness of bituminous material	Measured deflections corrected to 20°C are less than
$<$195 mm	90×10^{-2} mm
195–274 mm	60×10^{-2} mm
$>$274 mm	20×10^{-2} mm

A lower minimum temperature of 7°C should always be adopted except for pavements with less than 195mm of bituminous material, of which less than 75mm is rolled asphalt; the lower limit may then be reduced to 5°C. In these circumstances however, it is advisable to re-test short lengths when temperatures are closer to the standard of 20°C as soon as practically possible so that the temperature corrections applied to the original data can be checked.

7.5 Frequency of temperature measurement

The frequency of temperature measurement required cannot be defined precisely; it will be influenced by weather conditions, by the degree of exposure of the road, and also by type and colour of the road surface. These influences are considered below:

(a) *Weather conditions* – the most frequent measurements are required on days with sunny intervals and a cooling wind. The maximum interval between readings should not exceed 20 minutes. More frequent measurements will be required on a continuously sunny day than on a continuously cloudy day, typical intervals being 30 minutes and 40–60 minutes respectively.

(b) *Degree of exposure* – large temperature variations can occur between shaded and unshaded areas and between lengths of road exposed and protected from cooling winds. Temperature measurements should therefore be taken at all changes of the conditions of exposure and in particular where there are comparatively short lengths of a shaded road that remain shaded for a large part of the day.

(c) *Surface type and colour* – two surfacing materials on adjacent lengths of road can be at different temperatures because of their differing reflectivities and thermal properties. Temperature measurements should therefore be taken at all changes of surface type, the determination being made in material representative in colour and texture of the material in the wheel paths.

It is recommended that the maximum period between successive temperature determinations should never exceed one hour.

7.6 Consequence of cracking and stripping of bituminous layers

A pavement having the pattern of interconnecting and well developed cracks shown in Plate 3 is, in general, substantially less temperature susceptible than one which is uncracked. It is important therefore that cracked areas are accurately located and that the appropriate temperature correction curves are used to obtain the equivalent 20°C deflection value. If a bituminous layer is substantially stripped it should be treated as a granular layer for the purpose of temperature correction.

8. PREFERRED PERIODS FOR DEFLECTION SURVEYS

8.1 Season of the year

The spring and autumn periods are recommended as being the only satisfactory periods of the year for carrying out deflection surveys. Experience from TRRL full-scale road experiments shows that, during these two periods, the yearly variation in subgrade moisture conditions and hence subgrade stiffness, is generally small; relatively steady equilibrium deflection values are obtained under these conditions. The two preferred periods are from March to mid-June and from September to November. Within these periods measurements should be made when pavement temperatures lie within the range 10 to 30° C and, in the case of thick bituminous pavements, when the rate of change of pavement temperature does not exceed 2.5°C per hour. Acceptable temperature conditions for testing normally occur within the preferred periods on between 100 and 110 days per annum.

Deflection testing in the summer months is not recommended because of the frequency with which the maximum test temperature of 30°C is exceeded, because of the difficulty of obtaining reproducible results and because there is some evidence of temporary weakening of the pavement in hot weather. This weakening, which cannot be accounted for by making an appropriate temperature correction, disappears at the end of the hot weather. A typical example of this behaviour is shown in Figure 2. Corrected measurements taken during the third and fifth summers of the life of the Laboratory's full-scale road experiment at Nately Scures (A30) indicate a weakened pavement in relation to spring and autumn deflections which follow the general trend.

After the exceptionally prolonged period of dry weather in 1975 and 1976, the measured deflections on some road experiments dropped considerably, presumably as the result of drying-out of the subgrade. Where it is absolutely necessary to test during the summer months or after any period of drought which lasts for more than about three months, it is advisable to resurvey short lengths of road under more normal conditions in order to provide a check on the accuracy of the deflection measurements previously obtained.

During periods of mild weather in the winter it is also possible to make deflection measurements; the temperature conditions are however unlikely to make this attractive except for pavements whose stiffness owes little to the presence of bituminous materials.

8.2 Timing within the life of the road

In the first few months after the opening of a road to traffic its deflection may change considerably before settling down to an equilibrium value. The change is the consequence of one or more of the following factors:

a) further compaction of granular materials under traffic,

b) changes in the moisture condition of these materials,

c) development of cementing action in some types of granular material,

d) changes in the moisture conditions of the subgrade after the disturbance of the construction phase.

Deflection will therefore increase or decrease according to circumstances.

Figure 2 gives two examples where considerable changes took place during the first year of the life of the road. At the road experiment at Nately Scures (A30) the rapid reduction in deflection reflects a drying-out of the clay subgrade after construction, accompanied by traffic compaction (and possible cementing action) in the limestone roadbase and gravel sub-base.

At Wetherby By-pass (A1) the stiffening of the granular layers of the pavement by traffic compaction (and possibly by cementing action) was over-ridden by the effects of the wetting-up of the subgrade subsequent to building the road in a recently excavated marl cutting during the course of an abnormally hot summer.

The changes at these two sites are larger than those which would normally be expected. However, the differences generally experienced are such that a deflection survey made in the first few months of the life of a road should not be used for predicting its long term structural performance.

An early survey can, however, indicate areas of relative weakness; this is also true of deflection measurements made on the surface of road layers during construction. Areas that are relatively weak during construction and early in the life of the road are those more likely to perform poorly.

These deflection results can therefore be used by an engineer to identify potential problem areas. The trend established by further deflection measurements made on these areas will indicate whether the weakness is likely to be only temporary; alternatively the engineer may wish to investigate the areas in more detail immediately in order to establish the cause or causes of weakness.

8.3 Time of day

The normal limitations regarding the time during the day when deflection testing can be carried out and the reasons for these limitations are given in Section 7.2 of this report. If it is found necessary to work outside the specified period, short lengths should be resurveyed during preferred periods in order to provide a check.

9. LOCATION OF DEFLECTION MEASUREMENTS ON A DEFLECTION SURVEY

Deflection values obtained with the Deflection Beam or Deflectograph must be related to their position on the road so that recommendations based on the survey can be implemented. Accurate location is particularly important in the case of areas requiring reconstruction; these may be as short as 10m in length and therefore may require to be located within one or two metres. To provide a level of accuracy sufficient to guarantee this, use is made of objects or events on or beside the road, which can serve as reference positions. For the Deflectograph these are recorded, both on a record sheet and on the chart and digital output; deflection readings between events are then located by spacing the readings equally between successive events. Because the spacing of deflection measurements on the road does not vary appreciably over short distances, events may be as much as 0.5 km apart. Chainages should be recorded at the time of survey where the Deflectograph equipment provides a display of this measure (usually a drive from the cam shaft to a digital display), but these values should be used only for locating deflection values in the absence of chainages measured directly by, for example, a rolling-wheel distance-measuring device.

When operating the Deflection Beam the location of each measurement point should be recorded by a chainage either from the start of the survey length or from the closest event.

10. CONDITION SURVEYS

10.1 Visual assessment

A visual assessment of the road condition should be made in conjunction with deflection surveys.

With Deflection Beam surveys the condition of the surface of the road can be assessed at each test point and a classification made on the basis of Table 2. Where a Deflectograph is to be used a pre-condition survey should be carried out and lengths of road classified on the basis of Table 2. Holes for the measurement of temperature can be made at the same time as the pre-condition survey, (see Section 7) and events on the road, together with their chainage, can also be marked (see Section 9).

Additional information that should be recorded includes location of lines defining the boundaries between lengths of road in cut and on fill, evidence of drainage problems (eg standing water in ditches), and location of changes in soil type: changes in soil type may also influence the drainage characteristics of the pavement.

10.2 Details of the pavement structure

The following information about the pavement structure is required:

1. The type of material below the bituminous surfacing layers, ie whether it is unbound or bound with cement or bituminous material.

2. The thickness of bituminous materials present and any evidence as to stripping.

3. The thickness of dense bituminous materials.

4. A broad classification of the subgrade strength.

For recently constructed roads this information will usually be available from construction drawings but, for older roads and undesigned roads, cores will normally have to be taken or trial holes opened.

10.2.1 Spacing of cores and trial holes. Where construction records are available, cores or trial holes will be required only to provide a general check on the design thicknesses and types of material specified in the design. In general only one or two cores will be required within any one continuous length of a given construction.

On lengths of road where details of construction are known with less certainty, the location of cores or trial pits should be selected in conjunction with the deflection profile obtained. Thus, a sudden change in deflection level, as opposed to a gradual increase along the length of the road, often indicates a change in construction, particularly if not associated with any change in visual condition. Coring on either side of the change point in deflection will identify the change in construction.

Details of the information required from the cores or trial pits are given in LR 833[3] together with information on the use of the data to select the appropriate design charts.

11. CHECKING THE DEFLECTOGRAPH OUTPUT

The Deflectograph is a complex electro-mechanical device for the routine measurement of very small displacements. Although every effort has been made to make the machine reliable, long experience indicates that, in order to obtain reliable results, it is necessary to monitor its deflection output continuously. Failure to detect a malfunction quickly will result in a waste of survey time, with possibly substantial lengths requiring repeat runs. If the unchecked data collected are analysed on the assumption that they represent a true and correct deflection record, this will result in incorrect design of strengthening measures.

The calibration procedure described in Appendix 1 provides a check on the electro-mechanical sensitivity of the equipment in artificial conditions, ie with the Deflectograph stationary. In order to check on the functioning of the complete Deflectograph system, measurements are also required while the machine is in operation, preferably on a length of road whose basic deflection characteristics are known.

The remainder of this section discusses the selection of a suitable calibration length and the use of chart output to identify faults in the operation of the electro-mechanical equipment.

11.1 Deflectograph calibration length

The repeatability of results given by a Deflectograph can be determined by comparing the Deflectograph readings with Deflection Beam readings obtained on the same length of road; these Deflectograph readings are corrected to equivalent Deflection Beam readings using the appropriate correction figure in LR 833[3].

For the direct comparison of deflection measurements made with the Deflection Beam and Deflectograph, the measurements need to be taken at the same location, time and temperature. This requires the use of at least one Deflection Beam and associated lorry, the Deflectograph and their two operating teams: it is therefore not recommended.

The preferred approach is the use of a control length whose deflection profile can be established by measurements with a Deflection Beam under temperature conditions close to 20°C. The effect of temperature and subgrade strength should be established by a number of Deflectograph runs throughout a year.

The subsequent check on the Deflectograph would be to run over this length to compare the pattern and general level of deflection along it with that already established. Given that these are generally satisfactory, the form of the trace output is then used to look for errors as described below in Section 11.2.

The choice of a control length should take into account:

(a) *Unexpired life.* A section should be chosen with a relatively large unexpired life so that the length can be expected to remain in use for a reasonable period; deflection levels over this period should therefore also remain reasonably stable.

(b) *Length of site.* A length of at least half a kilometre should be selected having a relatively uniform deflection profile. It should include a large number of events to enable accurate location of deflections. Gradual changes of deflection, even if over a large range, are acceptable, indeed desirable, but a rapidly varying deflection profile will make the checking procedure more difficult and less precise.

(c) *Accessibility.* The length should be situated within the normal operating area of the Deflectograph so that as little time as possible is spent in travelling to and from the control length.

11.2 Forms of output trace

The recorders fitted to the majority of Deflectographs in operation in the United Kingdom provide the two basic forms of trace output shown in Figure 3. These two output forms differ in the proportion of the period of the measuring cycle for which chart movement occurs; chart movement takes place either only during the measurement cycle as in Case (a), or between successive measurement cycles, ie when the beam is moving forward as in Case (b).

The selection of a slow chart speed, with chart movement between measurement cycles, provides a high spatial density of data and consequent economy in the use of paper. However chart movement during the measurement cycle with the chart moving at a higher speed is the only form of output which can be used to detect errors in the electrical and mechanical systems and faults that can occur in the pen recorder. It also has the advantage that nearside and offside deflections at the same locations can be easily identified.

Regardless of other output facilities available, chart output with the paper moving during the measurement cycle should always be used to provide the essential continuous check on the machine's performance.

11.3 Common faults

Common faults, their probable causes, and the form of their associated output trace, are presented in Figure 4 and Table 6. This list is not exhaustive and whenever unusual output traces are obtained the possibility of a fault developing should be investigated.

Faults A to G in Table 4, will produce incorrect values on digital tapes; H, J, K and L may be identified by the digitising logic as faults, but a large number of faulty readings will lead to uncertainty as to the correct deflection profile.

12. CONCLUSIONS

Operating procedures for use with the Deflection Beam and the Deflectograph during a road survey have been presented; they are designed to ensure the maximum precision of the recorded data. The operating costs associated with these procedures are small, particularly when they are compared with the costs associated with initiating incorrect strengthening measures on the basis of unreliable results.

Regardless of the operating procedures used, the accuracy of the data recorded during a survey is ultimately dependent on the performance of the Deflectograph's mechanical and electrical equipment. Several simple techniques can be used to check continuously for possible faults. The static calibration procedure should be used to provide a daily check on the response of the recording system with the Deflectograph stationary. The occasional use of a length of road for which the deflection profile is known is also recommended as a further check on the overall operation of the electro-mechanical system under normal operating conditions.

The dynamic response of the system can be checked by adjusting the chart recorder to produce a record of the bowl of deflection. Deflection profiles obtained in this way provide a continuous check on the behaviour of the system and can also be used to identify the most probable origin of faults when they occur. The cost of the additional paper used, is insignificant in comparison to the cost of incorrect recommendations or the cost of resurveying lengths of road.

13. ACKNOWLEDGEMENTS

The work reported was carried out in the Pavement Design Division (Head of Division: Mr N W Lister) of the Highways Department of TRRL.

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TABLE 6

Error (letter refers to output shown on Figure 4)	Probable cause
A – Flattening out of trace	1. Pen sticking due to damaged or dirty pen-carrier cable. 2. Transducer clamps slipping. 3. Mechanical stop on beam travel incorrectly set.
B – Floating electrical zero	1. Too coarse or dirty zero-shift potentiometer. 2. Cracked transducer core.
C – No electrical zero, and/or no output	1. Transducer faulty. 2. Wiring faulty. 3. Where there is no zero but subsequently output is obtained during measurements; there is a poorly adjusted electrical zero and/or mechanical stop is not in range.
D – Sudden change in actual calibration	1. Mechanical stop moved and transducer no longer operating in linear range. 2. Amplifier faulty. 3. Transducer faulty. 4. Power to transducers out of specification range. 5. Cracked transducer core.
E – Initial flattening out of trace	1. Bent vertical spring on transducer. 2. Transducer clamps slipping.
F – No vertical movement after electrical zero	1. Solenoids not operating or a transducer wiring fault.
G – Sudden large changes in electrical zero	1. Solenoids failing to release; this usually causes full-scale movement (also J).
H – Spike on trace	1. Insufficient electrical damping in the recording system. 2. Rear wheels touching beam.
J – Irregular trace	1. Drive to chart recorder faulty. 2. Winch clutch not free-running.
K – Electrical zero poorly defined	1. Insufficient time lag between end of beam's forward movement and start of recording cycle. 2. Insufficient damping of beam. 3. Insufficient damping of pen. 4. Vibration transmitted from the lorry steering.
L – Irregular zero	1. Dirty transducer 2. Cracked transducer core. 3. Coarse zero-shift potentiometer. 4. Cracked zero-shift potentiometer. 5. Dirty zero-shift potentiometer.

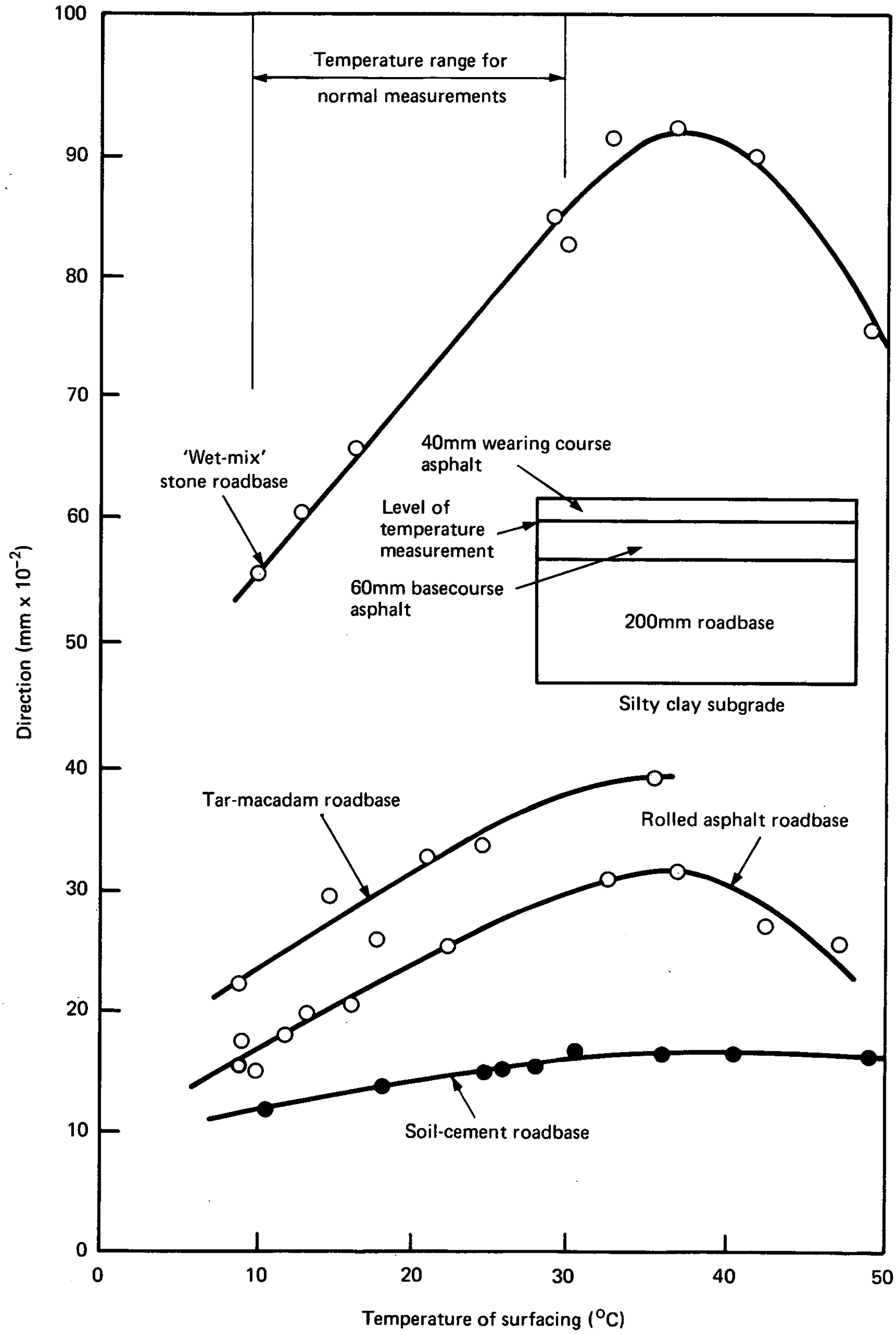


Fig. 1 CHANGE IN DEFLECTION WITH TEMPERATURE ON 4 TYPES OF ROAD PAVEMENT HEATED BY INFRA–RED HEATERS

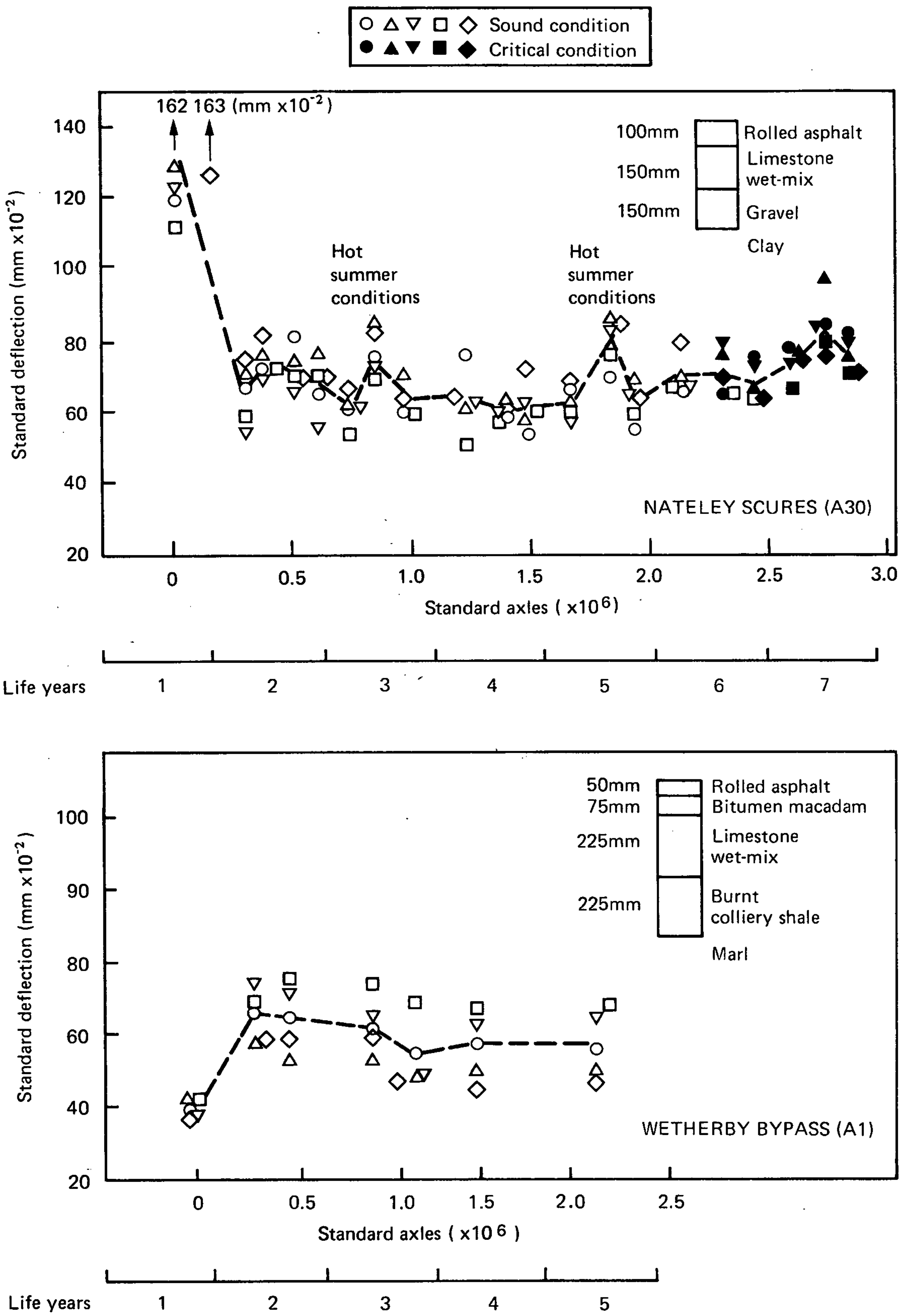


Fig. 2 DEFLECTION HISTORIES OF PAVEMENTS WITH GRANULAR BASES

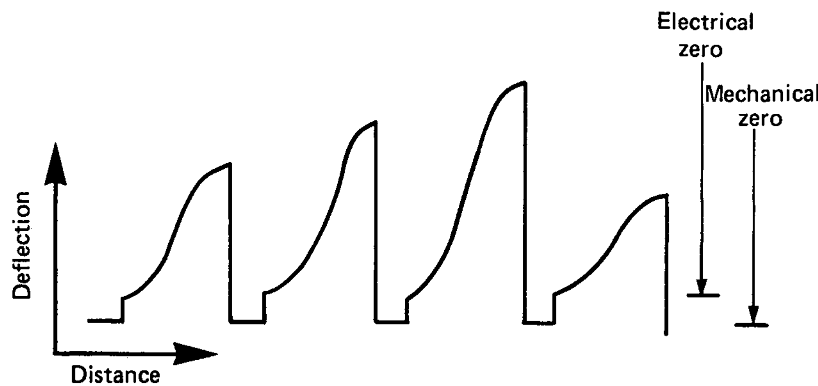
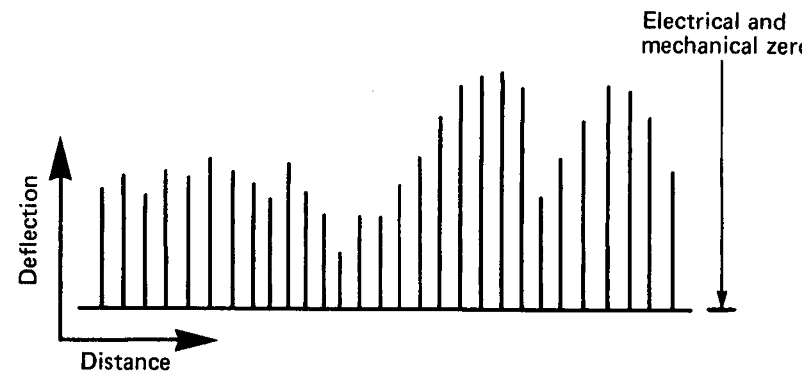


Chart length per measurement approx. 10–15mm

(a) HIGH SPEED CHART MOVEMENT DURING MEASUREMENTS

Advantages
1. Detection of electrical and mechanical zero errors possible*
2. Detection of electrical and mechanical error during reading possible*
3. Detection of pen recorder errors possible*
4. N/S and O/S readings easily paired
5. Possible to identify individual deflection corresponding to an event

Disadvantage
1. Small quantity of data per unit length of chart output



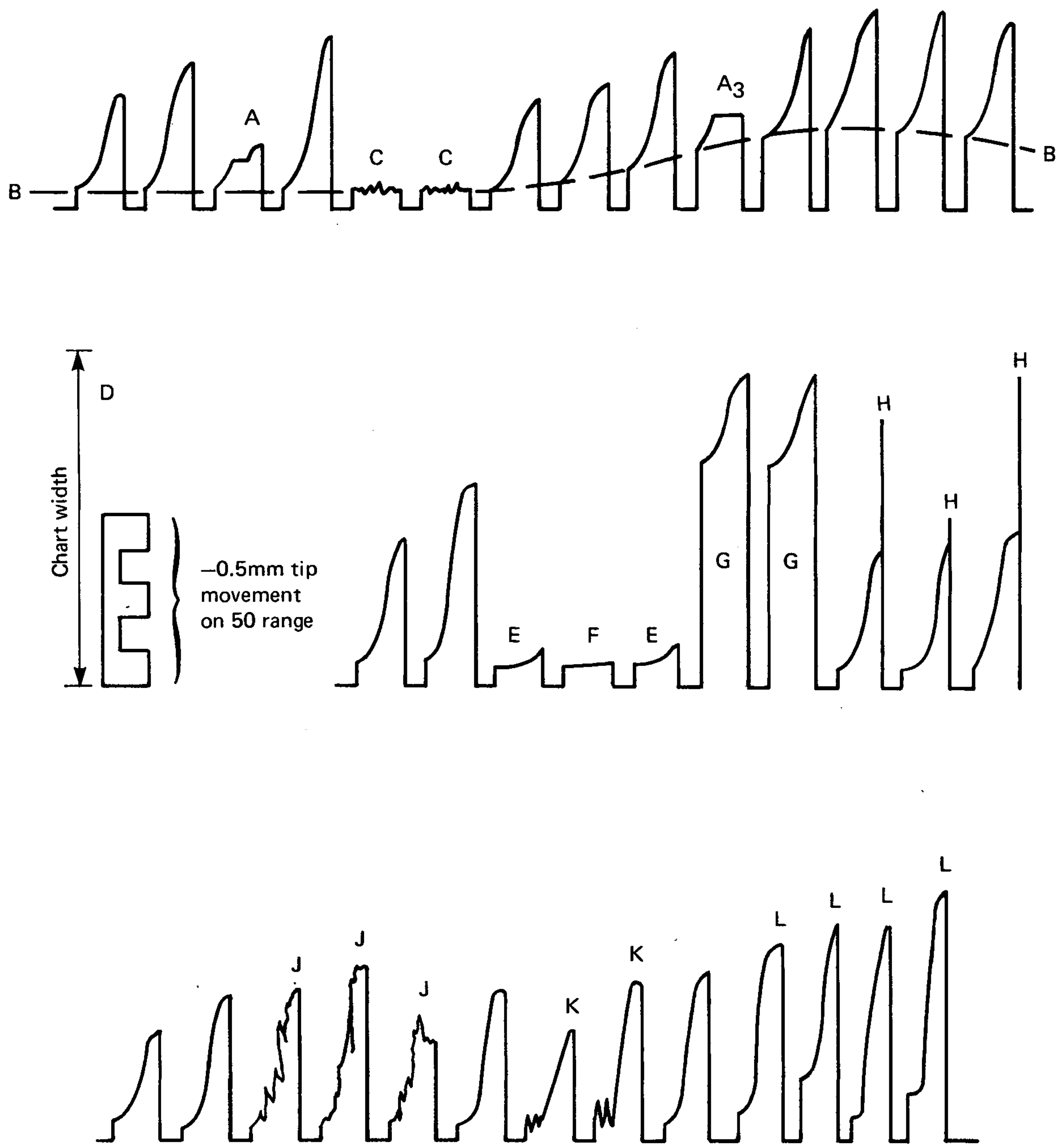
(b) LOW SPEED CHART MOVEMENT BETWEEN MEASUREMENTS

Advantage
1. Large quantity of data per unit length of chart output

Disadvantages
1. Unable to detect electrical and mechanical errors*
2. Unable to detect a number of common pen recorder errors*
3. Extremely difficult to pair N/S and O/S readings

*See Fig.4 for common forms of error

Fig. 3 FORMS OF CHART OUTPUT



Probable causes of the various error forms are given in Table 6

Fig. 4 COMMON FORMS OF ERROR

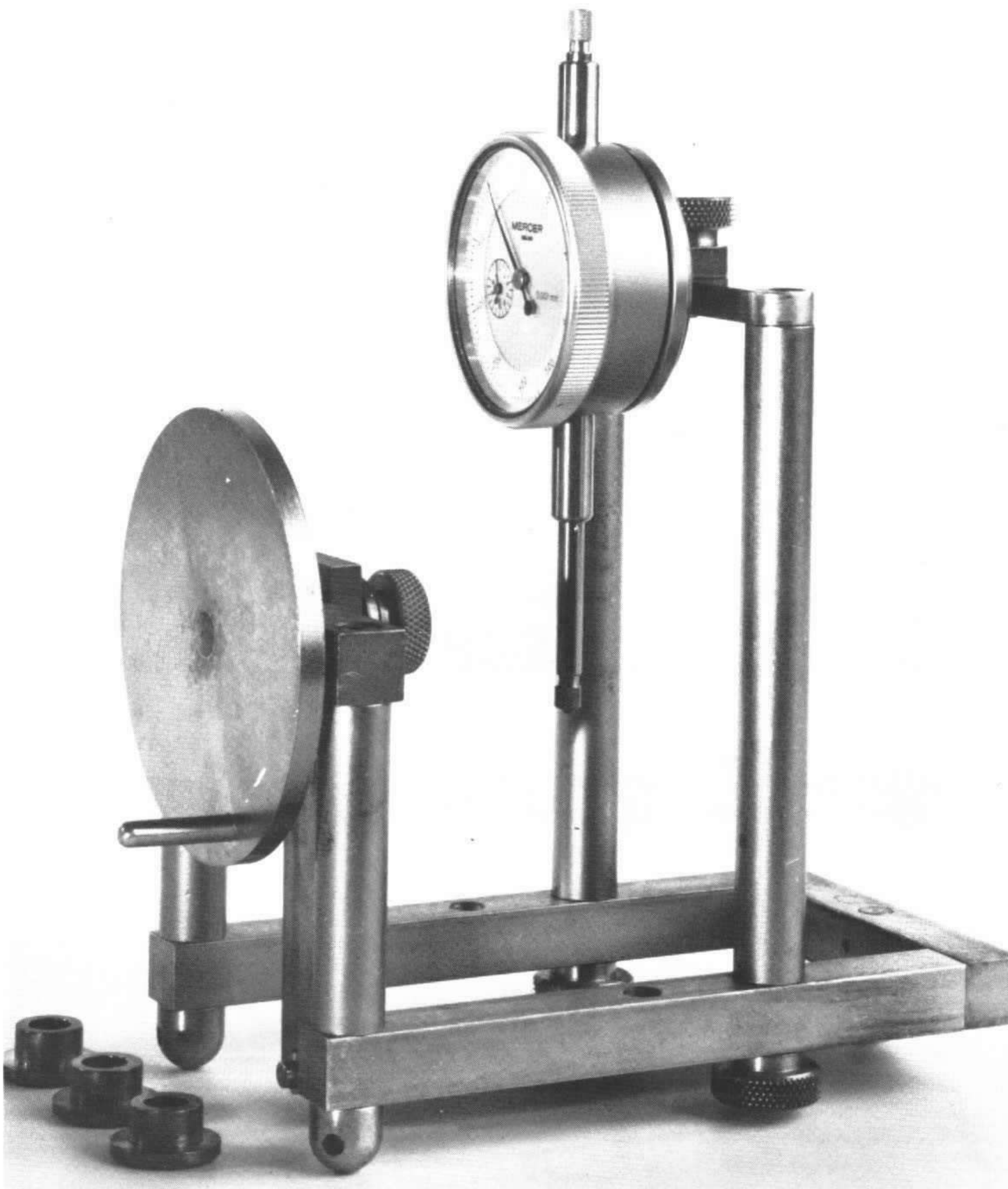


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Plate 1 DEFLECTION BEAM CALIBRATOR

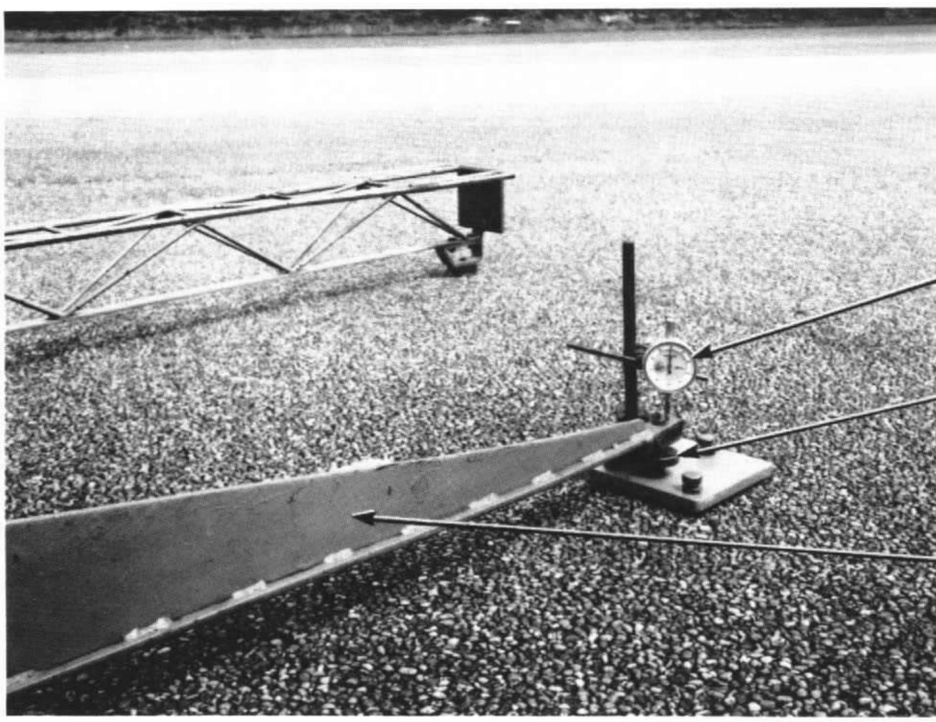

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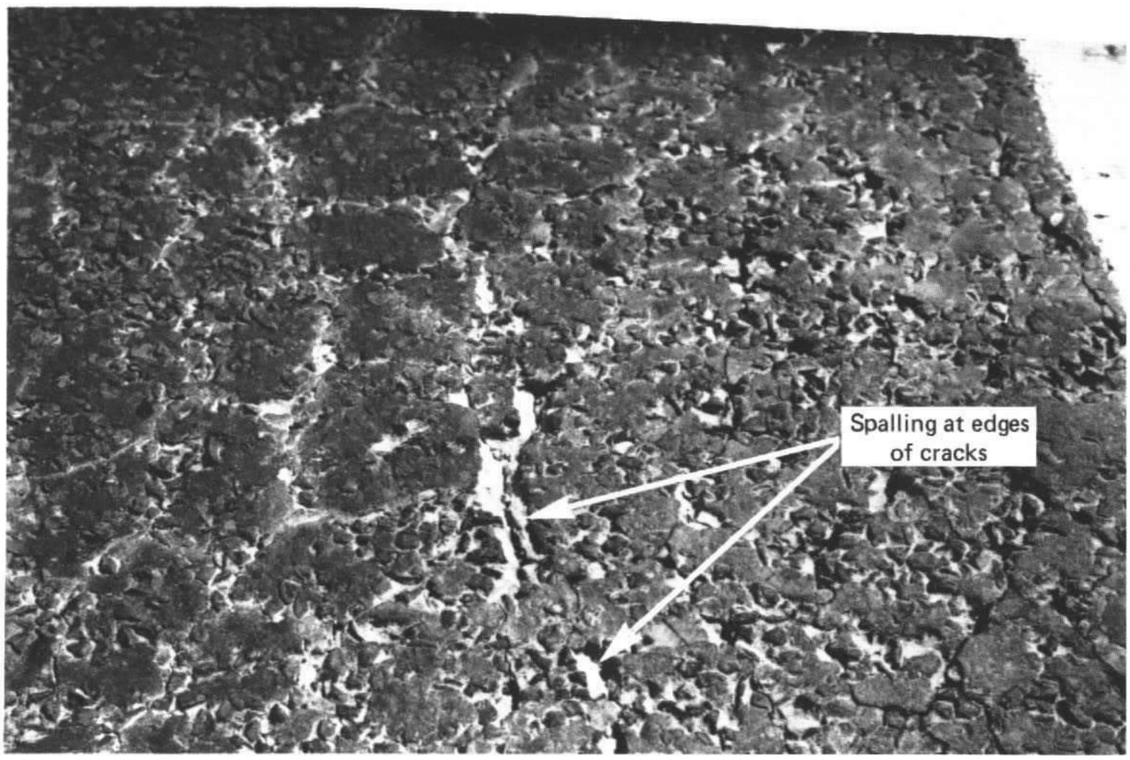
Plate 2 DEFLECTOGRAPH – TYPICAL CALIBRATION DEVICE



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Approximate scale ←— 200mm —→

Plate 3 TYPICAL EXAMPLE OF AREA CRACKING

15. APPENDIX 1

CALIBRATION OF EQUIPMENT

15.1 Calibration of the Deflection Beam

The Beam should be calibrated daily in order to ensure that the dial-gauge is operating correctly and that the beam is moving freely. Plate 1 of the main report shows a simple calibration rig which should be used for this purpose. Turning the hand-wheel of the rig rotates an eccentric bush which raises and lowers a horizontal platform by means of a hinged bar. In use the platform supports the beam tip under a reference dial-gauge. Two operators are required to observe the readings of the two dial gauges as the hand-wheel is turned at the rate of one revolution in 6 seconds, with the beam vibrator operating. A choice of eccentric bushes provides a range of possible beam movement; the bushes selected for calibration should give readings in the range expected during testing.

The dial-gauge on the Beam records half the actual movement of the beam tip on the road surface. The readings obtained should therefore be doubled. The means of at least 10 consecutive readings on the two dial-gauges are used as the basis for comparison. If the means of values differ by more than 2 per cent, the pivot should be cleaned and oiled and, if necessary, the dial-gauge serviced. If the Deflection Beam is of the split-beam design, the tightness of the fixing bolts should be checked.

15.2 Calibration of the Deflectograph

Calibration entails relating the movement of the beam tip to the associated chart movement and digital output. The simple calibration device shown in Plate 2 of the main report is used. The beam assembly is positioned so that the beam tips are sufficiently forward of the rear wheels of the lorry to allow the calibration device to be placed under the beam; for clarity Plate 2 shows the beam assembly removed from the lorry.

With the electrical equipment switched on and the various switches on the control panel set manually to the operating condition, the micrometer screw of the calibrator is wound upwards for several turns. It is then turned back for a fraction of a turn in order to take up backlash in its screw thread. The beam tip is lowered in equal increments, as indicated by the dial gauge, until full-scale deflection is achieved on the chart recorder. The size of the increments should allow at least five steps to be used for each of the three ranges of sensitivity. Recommended maximum increments are given in Table 7.

TABLE 7

Recommended deflection increments for calibrating the deflectograph output

Sensitivity range	Approximate beam movement for chart recorder full-scale movement mm x 10^{-2}	Incremental step size mm x 10^{-2}
200	200	25
100	100	20
50	50	10

For digital equipment the incremental step size used should be 20 x 10^{-2}mm.

Separate calibrations are necessary for the nearside and offside beams. The six individual calibrations thus obtained represent one calibration set. The calibration value, ie the height of the chart recorder trace or digital output value produced by a given beam movement during a series of calibrations can vary by up to $\pm$ 8 per cent of its mean value. This variation is primarily the result of employing a mechanical device for monitoring very small displacements and is not necessarily the result of variation in the response of the electro-mechanical measuring system of the Deflectograph. Individual calibration values used for the interpretation of data should, therefore, be the mean of at least ten calibration sets. These sets of data should not be obtained by moving the beam tip up and down repeatedly; some attempt should be made to represent the variation likely to occur in the survey period. Because the greatest source of variation arises from the actual setting-up procedure, this should be repeated between each successive calibration set. Ideally the calibration should be repeated on several successive days. During the period of the testing programme further calibrations should be made at least daily.

The daily calibration values should be used to monitor both the long-term behaviour of the measurement system and to identify any day-to-day changes in the characteristics of the system.

Three conditions can occur:

1. No change in behaviour from that identified from the pre-survey calibrations.
2. A sudden substantial movement of the mean or variance of the calibration values.
3. A small but statistically significant long-term change in the mean and/or variance of the calibration values.

In defining a satisfactory monitoring plan it is necessary to compromise between

a) the time required to operate the plan adopted,
b) the probability of indicating that a change has occurred when in fact no change has occurred,
c) the probability of not identifying a change when one actually occurs, and
d) the rapidity with which changes are identified.

15.2.1 The recommended scheme. The pre-calibration values for each of the increment steps input should be used to determine mean calibration values and warning limits set at the 90 per cent level, as shown in Appendix 1, Table 8. An example calculation is given in Appendix 1, Table 9. A graphical display of these values in the form of a control chart, should be prepared and placed in the Deflectograph; a typical control chart is shown in Appendix 1 Figure 2.

The Deflectograph should be calibrated daily, and the calibration results should first be compared with the control limits plotted on the control chart (subject to the restrictions on plotting given below).

If the daily calibration values lie within the control limits the equipment can be operated normally for the rest of the day.

If the calibration lies outside the limits a second calibration set should be taken immediately.

If the second calibration set lies within the limits the first set can be considered as a statistical outlier and surveying continued. Both calibration sets should be plotted on the control chart.

If the second calibration set also lies outside the limit a change has almost certainly occurred and the equipment should be checked and adjusted. Neither calibration set should be plotted in this case. After adjustment two further calibration sets should be taken. If either one or both of these sets lie within the control limits they should be plotted on the control chart and testing continued. If both calibrations lie outside the control limits they should not be plotted. It is then necessary to carry out further adjustments to the equipment and to calibrate until agreement is achieved. Alternatively, if there is reason to expect that a complete change in calibration has occurred the equivalent of 10 pre-survey calibration sets should be carried out during the following day-or-two to produce a new control chart.

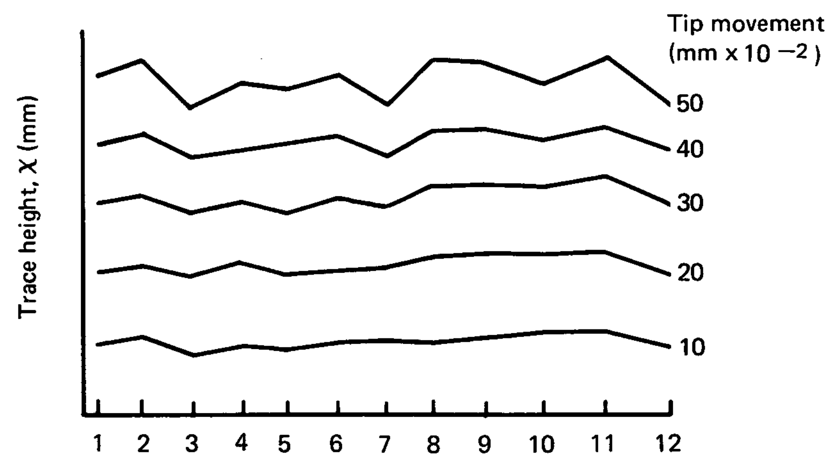
Long-term changes are identified from the daily calibration values plotted on the control chart. If more than three individual daily calibration values in a consecutive set of ten lie outside the limits or, five in a consecutive set of twenty, a change in calibration can be assumed. If this is not accompanied by a bias in the results by consecutive runs of 3 in 10 or, 5 in 20, of values lying on one side of the mean, then the variability of the system has most probably increased; a typical cause would be a fluctuating battery voltage. If it is accompanied by a bias then the mean has most probably changed; a typical cause would be a bent vertical spring. In either event the equipment should be checked and adjusted and a new set of pre-calibration figures produced.

By consulting the control chart the operator should be able to identify on which of his survey lengths there is some doubt as to the calibration. He can then arrange for short check surveys to validate the data already collected.

The recommended checking procedure is detailed in flow chart form in Appendix 1, Figure 1 as given.

TABLE 8

Determination of calibration means and control limits from pre-survey calibration data



TYPICAL SERIES OF CALIBRATION CHECKS

Mean trace height $\overline{x}$ (calibration value) $= \dfrac{\text{Trace height for any one level of toe movement}}{\text{No. of calibrations}}$

Digital output value $\overline{x}$ (calibration value) $= \dfrac{\text{Digital output values for any one level of tip movement}}{\text{No. of calibrations}}$

$$= \frac{xi}{n}$$

Control limits $= \overline{x} \pm 1.64\,\sigma$

where σ

$$= \sqrt{\frac{\Sigma x_i^{\,2} - \dfrac{(\Sigma x_i)^2}{n}}{n-1}}$$

A mean and its associated control limits should be computed for every movement of the beam tip on each sensitivity range tested. Separate values should be computed for nearside and offside wheel-paths.

TABLE 9

Calculation of calibration mean and standard deviation – Worked example

Consider the digital output value, x, for a toe movement of 60 x 10^{-2}mm obtained from eleven pre-survey calibrations.

x	x^2
60	3600
60	3600
60	3600
57	3249
61	3721
62	3844
60	3600
56	3136
60	3600
56	3136
59	3481
$\Sigma x = 651$	$\Sigma x^2 = 38567$

The mean output value $\bar{x} = \frac{651}{11} = 59.2$

$\bar{x} = 59$

The standard deviation $\sigma = \sqrt{\dfrac{\Sigma x^2 - \dfrac{(\Sigma x)^2}{n}}{n-1}}$

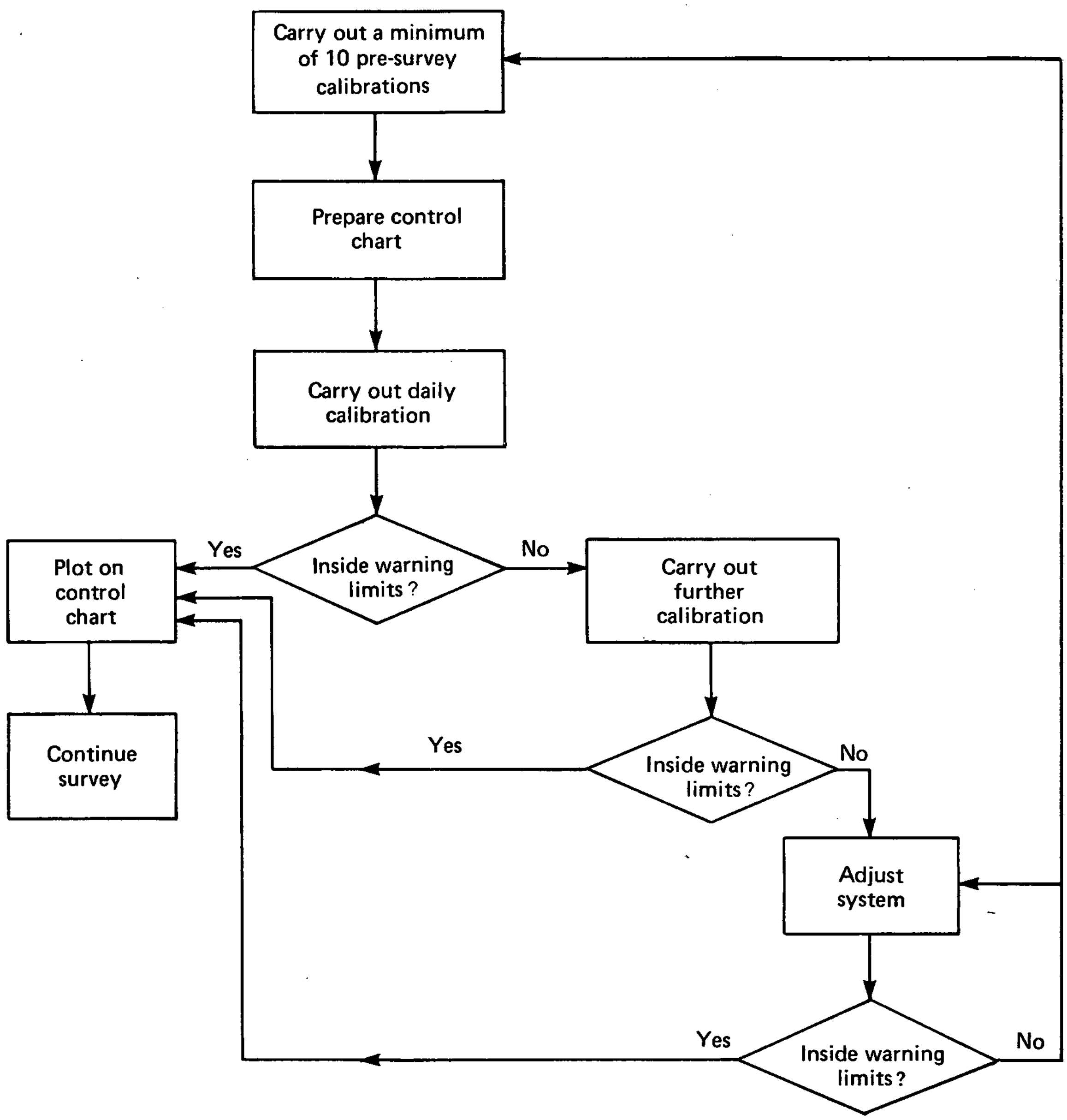
$= \sqrt{\dfrac{38567 - \dfrac{651^2}{11}}{10}}$

$\sigma = 1.99$

The control limits $= \bar{x} \pm 1.64\sigma$

$= 59.2 \pm 1.99$

$= 57$ and 61 mm x 10^{-2}



Appendix 1 Fig. 1 FLOW CHART FOR CHECKING THE CALIBRATION OF THE DEFLECTOGRAPH

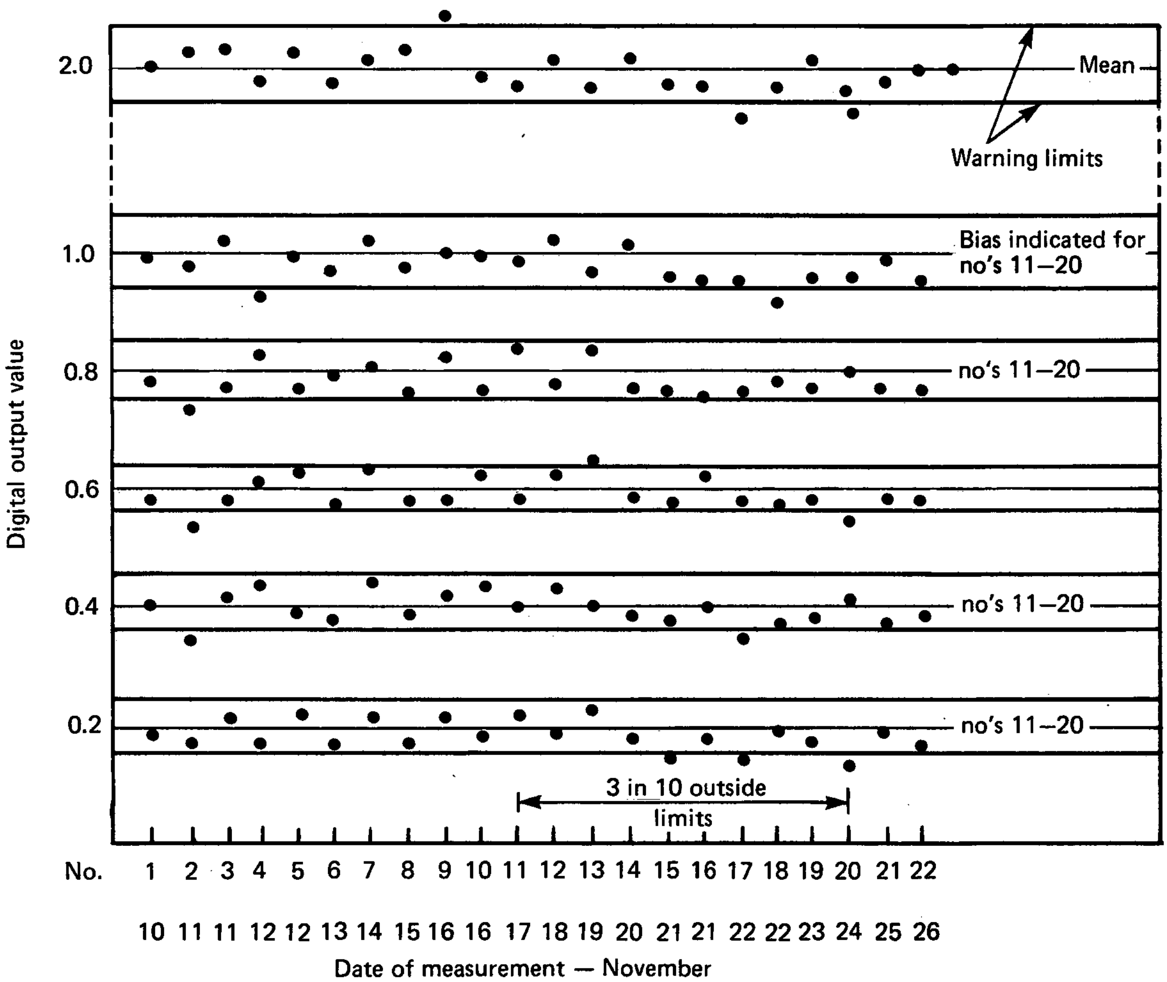


Chart shows that change was indicated on the 24th November when the equipment should have been checked.
A number of the tip movements indicate a bias in the output. It would appear therefore that the mean level has changed. Results are probably satisfactory up until 21st November.

Appendix 1 Fig. 2 TYPICAL CONTROL CHART

16. APPENDIX 2

THE IMPORTANCE OF ASSOCIATING ADEQUATE MEASUREMENTS OF PAVEMENT TEMPERATURE WITH THOSE OF DEFLECTION

16.1 Introduction

The stiffness of the bituminous elements of a road depends on the temperature of the materials. As a result the measured deflection of the surface of a pavement changes as the temperature of the bituminous layers varies. The greatest proportional changes occur with pavements which include substantial thicknesses of bituminous material. In order to compare different lengths of road surveyed at different temperatures on a standard basis it is therefore essential to be able to make allowance for the temperature effect.

A systematic investigation of temperature susceptibility, pavement stiffness and thickness of bituminous material is presented elsewhere[2]. These data have been used to prepare charts which can be used to correct deflections measured at various road temperatures to a standard temperature of 20°C. This 20°C deflection level can then be used in the design method[3].

The accuracy of the corrected deflection level is greatly influenced by the accuracy of the measurement of the temperature of the bituminous elements of the road, the frequency of its measurement, and the absolute level of this temperature during deflection measurement. The selection of the appropriate correction relation, particularly when the surface is extensively cracked, is also important.

The importance of these factors is discussed below.

16.2 The effect of an error in the temperature assigned to the pavement on the temperature-corrected value of deflection

Errors in temperature measurement can arise from three main sources:

1. Mistake in measurement
2. Faulty equipment
3. Insufficiently frequent measurement.

The first two errors can be overcome only by frequent checking.

The importance of the effects of errors and the need for constant vigilance for errors occurring from all three sources can be assessed from Appendix 2, Figure 1. This figure shows two typical temperature-correction curves, one for a pavement containing a relatively thin bituminous layer and one for a pavement with a substantial thickness of bituminous material. On both figures two measured deflections of 40 and 80 x 10^{-2}mm have been corrected to equivalent deflections at 20°C, assuming various pavement temperatures. The typical results given in Table 10 are obtained.

TABLE 10

Errors in corrected deflection arising from errors in pavement temperature

Thickness of bituminous material	Error in corrected deflection information mm x 10^{-2} per ^{o}C error in pavement temperature	Measured deflection mm x 10^{-2}	Pavement temperature^{o}C
75–95mm	2	40	10
	5	80	12.5
	2	80	22
195–274mm	4	40	14
	9	80	17.5
	3	80	25

These values are typical but the error per ^{o}C increases at low pavement temperatures and is considerably less for pavement temperatures near and above 20^{o}C.

By allocating surveys on pavements containing substantial thicknesses of bituminous material to times within the recommended periods during which temperature conditions are most likely to be favourable, it is possible to minimise the influence of errors in temperature measurement.

16.3 The effect of an error in the measurement of deflection on the temperature-corrected value

An error in the measurement of a deflection at a temperature other than the standard value of 20^{o}C will be magnified or reduced by the process of correction to that temperature.

The accuracy of an individual deflection measurement taken with a Deflectograph has been assessed by studying the variability of repeat Deflection surveys taken on a series of pavement types. The results have been analysed on the basis of the mean of three successive deflection readings and indicate that in the great majority of cases, the true value of deflection is within $\pm$ 3 x 10^{-2}mm of the recorded value.

It is difficult to assign a value to the variability of the deflection level which is used in assessing strengthening requirements because the length of road which is characterised by a mean level of deflection will change depending on such factors as: the minimum length over which overlay thickness can change; the variability of the deflection profile; and external factors such as kerb height, drainage requirements etc. Taking these factors into account would reduce the error.

Appendix 2, Figure 2, indicates the range of corrected deflection values that would result from a variation in measured values of $\pm$ 3 x 10^{-2}mm recorded at various temperatures. The variation in corrected values is strongly influenced by the shape of the temperature-correction curves, being greatest when measurements are taken at low pavement temperatures, ie points 3 and 5 on Figure 2. It is least when taken above 20^{o}C, ie points 4 and 6 on Figure 2. The importance of working only within the recommended ranges and the need to make check measurements under more favourable conditions when circumstances demand low temperature surveys are obvious.

The effect of errors in deflection measurement can again be minimised by allocation of surveys for pavements on which this error may be large to the times during the recommended periods when temperatures will be close to 20°C.

16.4 The effect of pavement condition on the temperature-corrected value of deflection

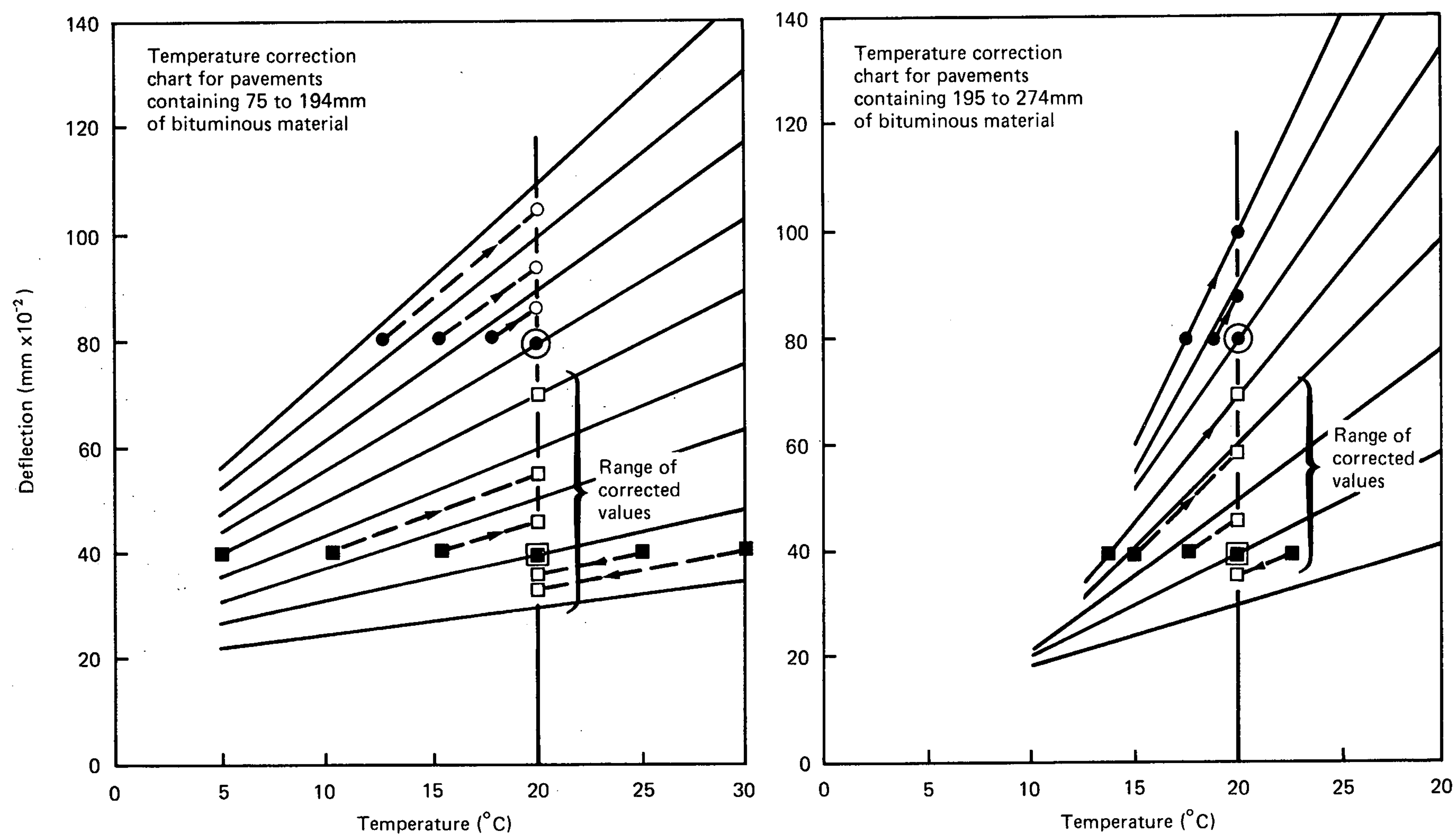
Where a pavement is extensively cracked (see Plate 3 of the main report) it is recommended that the temperature-correction curve for the thickness below that appropriate for the actual pavement thicknesses[2] should be used. The importance of noting areas of cracking can be assessed from Figure 1 of Appendix 2; a measured deflection of 40 x 10^{-2}mm measured at 15°C on a pavement containing 250mm of bituminous material corrects to 59 x 10^{-2}mm if the pavement is uncracked, but to only 45 x 10^{-2}mm if extensively cracked.

16.5 Conclusions

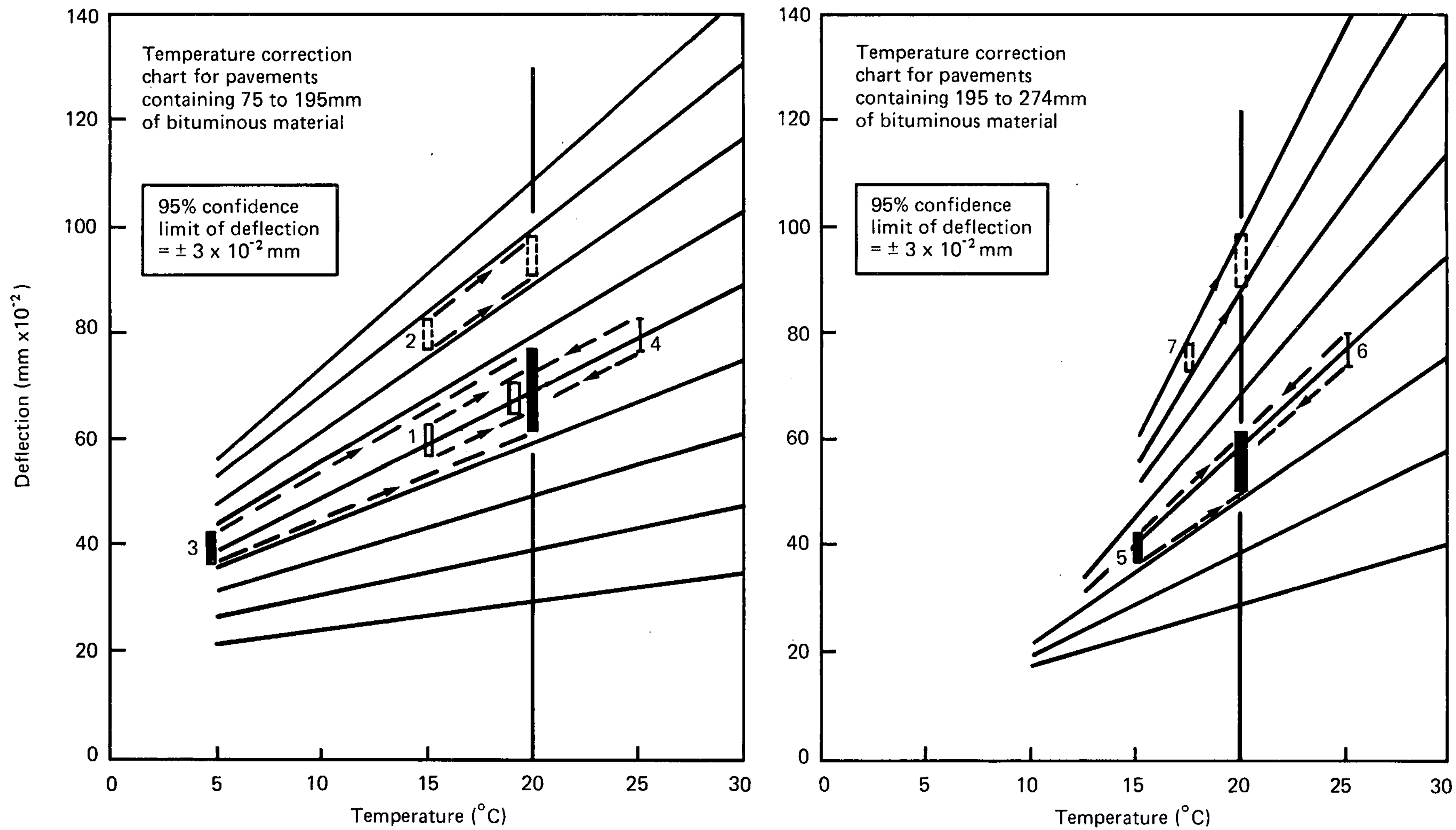
The accurate and frequent measurement of pavement temperature is a prerequisite for obtaining accurate corrected deflection. In addition, except when absolutely necessary, surveys should not be conducted at low temperatures. When low temperature work is performed it is essential that check measurements are made under more favourable conditions in order to validate the corrections applied to the original data before strengthening work is started.

It is not possible to specify a single temperature range for all pavements within which testing is permissible. The appropriate range depends on the stiffness of the pavement, together with the type and thickness of bituminous material present. Typical ranges are given in Section 7 of this report and the published temperature-correction curves[5] give more details about the restrictions on the working range that should be applied.

It is necessary to carry out a detailed condition survey in areas where there is extensive and substantial cracking of the bituminous material. Outside such areas less detailed surveys are required.



Appendix 2 Fig. 1 THE INFLUENCE OF ERRORS IN TEMPERATURE MEASUREMENT ON DEFLECTIONS CORRECTED TO THE STANDARD TEMPERATURE



Appendix 2. Fig. 2 THE INFLUENCE OF AN ERROR IN THE MEASURED DEFLECTION ON THE DEFLECTION CORRECTED TO THE STANDARD TEMPERATURE

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ABSTRACT

Pavement deflection: operating procedures for use in the United Kingdom: C K KENNEDY: Department of the Environment Department of Transport, TRRL Laboratory Report 835: Crowthorne, 1978 (Transport and Road Research Laboratory). The relationships established between the deflection of road pavements and their long term performance under traffic provide the engineer with a relatively simple means of forecasting the future performance of existing roads and designing measures for their structural strengthening.

This report provides information on the recommended methods of operating the Deflection Beam and Deflectograph, the two types of measuring equipment in use in the United Kingdom. It also draws attention to the possible consequences of using non-standard techniques of operation.

The first part of the report describes preferred operating procedures when the equipment is used to carry out a deflection survey along a length of road and indicates the way in which these procedures are a consequence of the design of the machine and the conditions on the road. The second part describes procedures for ensuring that the Deflectograph is functioning effectively when carrying out a deflection survey.

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