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PAVEMENT DEFLECTION MEASUREMENTS AND THEIR APPLICATION TO STRUCTURAL MAINTENANCE AND OVERLAY DESIGN

by

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ABSTRACT

The transient deflection of road pavements under the passage of a heavy wheel-load has been related, by studies on experimental and normal in-service roads, to the long-term performance of the pavements. This provides the engineer with a relatively simple method of forecasting the performance and future structural maintenance requirements for existing roads. This report, which does not discuss the research background to the work, is intended to present to the engineer the information he requires to make and interpret deflection measurements.

The use of the Deflection Beam is described in detail, together with the procedure for correcting measured deflections to a standard temperature of 20°C. As an alternative and more rapid means of measuring deflection, the Deflectograph and its method of operation are described. Curves to correlate deflection derived from the two methods are provided.

Deflection criterion curves, which take into account the changes in deflection which occur with age, are presented and used to estimate the life expectancy of pavements being considered for structural maintenance. Finally curves are provided from which the reduction in deflection and extension of life likely to accrue from the use of different thicknesses of rolled asphalt overlay can be deduced.

Examples illustrate the use of the deflection method in forecasting life and in the preparation of maintenance schedules.

1. INTRODUCTION

As a loaded wheel passes over a flexible pavement a downward deflection occurs which is approximately proportional to the wheel-load. Its magnitude also depends on the type and thickness of the pavement and on the nature of the soil foundation. In a well-designed pavement the deflection is almost entirely elastic in the sense that the pavement returns to its original level and thickness after the wheel-load has passed. The heavier wheel-loads will, however, cause a very small amount of permanent deformation, the cumulative effect of which results in the rutting and cracking in the wheel-paths which are the principal indications of deterioration in flexible pavements.

For a given form of pavement the magnitude of the permanent deformation component increases with the transient deflection. It follows, therefore, that it should be possible to relate the amount which a pavement deflects under a known heavy wheel-load to the future performance of the road under known traffic.

In the middle 1950's when the decision was first taken at the Laboratory to attempt pavement performance forecasting on the basis of measured deflection, little was known about the deformation of soils and pavement materials under repeated loading and any fundamental approach was out of the question. It was decided therefore, to develop empirical relations using the comprehensive range of full-scale pavement design experiments then being constructed on public roads. Measurements of the elastic deflection under a 3175 kg (7000lb) wheel-load using the Deflection Beam were included in the standard test programme for each such experiment. The change of deflection, both with time and traffic carried, has been related to the pavement deterioration in terms of permanent deformation and cracking.

In this way it has been possible to develop a reliable method of estimating future life expectancy from deflection measurements. To use the method, the Engineer must have a broad knowledge of (1) the form of construction and particularly the materials used for the base and surfacing, (2) the nature of the subgrade, (3) the amount of traffic the road has carried since its construction or since the last major strengthening, and (4) the future traffic.

As certain of the experimental road sections have approached the end of their life they have been overlaid with various thicknesses of bituminous material. The effects of the overlays both on deflection and subsequent life have been studied. Although the data available on this aspect are necessarily more limited than is the case with the original construction, sufficient has been done to enable a tentative design procedure for overlays to be formulated. From this work the Engineer can decide whether overlaying or complete reconstruction is likely to be the more economical.

Recently the Lacroix Deflectograph, originally developed by the Laboratoire Central des Ponts et Chaussees, France and now manufactured by MAP SA, Basle, Switzerland, has become available as an alternative to the Deflection Beam for measuring pavement deflection. This provides a more rapid method, particularly suited to long lengths of road. Since the geometry of the Deflectograph is different from that of the Deflection Beam the two methods give different deflections even when the same wheel-load is used. However, correlation curves have been established, so that the methods are interchangeable.

This document has been prepared for the use of engineers wishing to use deflection measurements as an aid in preparing their maintenance programmes. Details of supporting research have not been included, but references are given to relevant research papers.

The document is divided into the following main sections which can be read largely independently:-

A – Procedure for making deflection measurements using the Deflection Beam.

B – The Deflectograph and its use in deflection surveys.

C – Correlation of deflection measurements made by Deflection Beam and Deflectograph.

D – Deflection criteria curves and the estimation of future life from deflection and traffic data.

E – Design of overlays from deflection data and preparation of maintenance requirements.

F – The strategic use of the Deflectograph.

2. A – PROCEDURE FOR MAKING DEFLECTION MEASUREMENTS USING THE DEFLECTION BEAM

2.1 Equipment

2.1.1 The Beam

The Deflection Beam was developed by A.C. Benkelman in the United States and is often referred to as the Benkelman Beam. Deflection of the road surface as a wheel passes over it is measured by the rotation of a long pivoted beam in contact with the road at the point where deflection is to be observed. A long beam is essential to ensure that the pivot supports are remote from the influence of the loaded wheel at the time of measurement.

The design of Beam which has been evolved at the Laboratory is illustrated in Plate 1. This is currently manufactured by suppliers listed in Appendix 1. Detailed drawings are available from the Transport and Road Research Laboratory.

The aluminium alloy beam is sufficiently slender to pass between the dual rear wheels of a loading truck. It is 3.66 m in length and is pivoted at a point 2.44m from the tip giving a 1:2 length ratio. The pivot is carried on a frame made of aluminium angle supported by three adjustable feet. The frame also carries a dial gauge arranged to measure the movement of the free end of the beam. Fig.1, shows the principal dimensions.

The dial gauge used has a 75mm diameter face, a travel of 25mm and is calibrated in 0.01mm graduations. It is reverse printed to enable it to be read from above using a 45^{o} mirror as shown in Plates 2 and 3. For travelling purposes the beam is locked by the rotating handle grip shown in Plate 2. To minimise sticking at the pivot during recording, vibration of the beam is desirable; this is provided by an electric 'buzzer' mounted on the frame close to the pivot, Plate 1. The battery providing the current is clamped to the rear end of the frame and the system is controlled by a hand switch.

The pivot cap can be removed to release the beam for ease of packing.

2.1.2 Calibration of Deflection Beam

To ensure that the dial gauge is operating correctly and the beam is moving freely it is desirable to calibrate the beam before use. Plate 4 shows a simple calibration rig, also supplied by the firms manufacturing the Deflection Beam. (See Appendix 1).

A hand wheel operating through an eccentric bush and hinged bar raises and lowers a horizontal platform, which in use, supports the beam tip under a reference dial gauge, as illustrated in Plate 5. Two operators are required to observe the two dial gauges for maximum deflection as the hand wheel is slowly rotated. Various eccentric bushes give a range of beam movement. The vibrator is used during the calibration process. Because of the 1:2 length ratio the dial gauge reading on the Deflection Beam needs to be doubled to give the deflection at the beam tip. The mean of not less than 10 consecutive readings on the two dial gauges is used as the basis for comparison. If satisfactory agreement is not obtained during calibration, the pivot should be cleaned and oiled and if necessary the dial gauge serviced.

2.1.3 The loaded truck

The 2-axle truck used for deflection measurements should have a rear axle load of 6350 kg (14000 lb) equally divided between the twin wheel assemblies at each end of the axle. An open-bodied truck, loaded with concrete blocks, is satisfactory; it is essential that the load should not shift during testing and from this point of view gravel loading is undesirable. The tyre size should be 7.50 x 20 or 8.25 x 20 with a zig-zag pattern. The inflation pressure should be 590 kN/m^2 and the spacing between the tyre walls approximately 45 mm.

The truck should be fitted with adjustable pointers carried by the chassis on the nearside and offside in line with the rear wheel tracks and directed towards a point on the road approximately 1.2 m in front of the rear axle. The upper photograph in Plate 6 shows one pointer in position. (The design and fixing of these pointers will depend on the type of truck used. They must be adjustable both vertically and horizontally).

2.1.4 Temperature measurement

Since deflection is affected by pavement temperature, the latter must be measured at frequent intervals (approximately 30 minutes) during a survey. The measurement is made at a depth of 40 mm using a suitable short-stem stirring thermometer (see Appendix 1). A percussion-type masonry drill 6 mm in diameter is used to make a hole to the appropriate depth (about 45 mm to allow for the length of the thermometer bulb), which is filled with glycerol before the thermometer is inserted.

2.1.5 Ancillary equipment

To assess the permanent deformation at the time deflection measurements are made, a 2 m straight-edge is used in conjunction with a scale or a graduated wedge.

Other equipment required includes traffic signs, cones and flashing beacons. This equipment is normally carried in the truck.

2.2 Deflection measurements

The points at which deflection measurements are required are each marked by a cross on the road surface. Normally the points will be in the nearside wheel-tracks of the road, 0.9–1.2 m from the nearside verge. A transverse line is drawn on the pavement 1.3 m behind the point of measurement. The truck is positioned parallel with the verge with its front wheels pointing straight ahead, and its rear wheel directly over the line. The transverse positioning is such that when the vehicle is driven forward the gap between the nearside dual rear wheel assembly will pass over the point of measurement.

With the truck in this initial position, the Deflection Beam in the locked condition is placed with the beam tip over the point of measurement and the beam centrally located between the twin tyres. The alignment is finally adjusted by careful sighting through the tyre gap to ensure that the tyres will not foul the beam when the truck is driven forward at creep speed. When this alignment is completed the movable pointer is adjusted to be a few millimetres directly above the shoe. Subsequent alignment can then be achieved using the pointer. When the beam is in position the lock is released, and with the vibrator running, the dial gauge reading is set to zero by rotating the scale. At a signal from the operator the vehicle is driven forward at creep speed to a position where the rear wheels are at least 3 m beyond the test point. The speed should be such that the total time for the movement of approximately 4.5 m is 10 secs ± 1 sec. This speed should be checked against a stop watch once or twice each day. The maximum reading of the dial gauge is noted together with the final reading after the rear wheels of the truck have reached a point 3 m from the beam tip. The magnitude of the pavement deflection is obtained by adding the maximum reading to the difference between the maximum and final readings. (This sum of deflection is not meaned because of the 2:1 length ratio of the beam arms). Plate 6 illustrates a complete measurement cycle.

Two measurements should normally be made at each point tested and the results meaned. When the deflection is greater than 25 x 10^{-2} mm, the readings should not differ by more than 5 percent. For deflections smaller than 25 x 10^{-2} mm the difference should not exceed 10 percent. If larger differences are recorded on the same test point, fouling of the beam by the test wheels should be suspected, or alternatively friction in the beam pivot or the dial gauge. Repeat readings should be taken after attention to these matters, until reliable agreement is obtained. If such agreement cannot be obtained the mean of five measurements should be taken and the variability noted.

Differential thermal expansion within the beam can cause significant errors particularly on stiff pavements. In sunny weather the beam may pass from shade into sunshine as the vehicle moves, as is shown on Plate 6. The thin metal shield carried by the frame of the beam and covering much of its length helps to reduce this effect.

If measurements are also required in the offside wheel track the procedure is repeated with the beam transferred to the offside rear wheel assembly of the truck.

Before or after the deflection measurements are made the structural condition of the pavement close to the point of measurement is assessed by visual inspection and by the use of a 2 m straight-edge. The latter is placed transversely across each of the wheel-tracks in turn over the points of measurement, and the rut depth is measured by a calibrated wedge or by scale. The extent of any cracking is noted and the condition classified in accordance with Table 1.

TABLE 1

Classification of Pavement Condition

Classification	Visible evidence
Sound	No cracking. Rutting under 2 m straight-edge less than 10 mm.
Critical	(a) No cracking. Rutting between 10 and 20 mm. (b) Cracking confined to a single crack in the wheel-tracks, with rutting less than 20 mm.
Failed	Cracking extending over the area of the wheel-track and/or rutting greater than 20mm.

2.3 Deflection Survey Procedure

Deflection measurements should preferably be made when the road temperature is close to 20°C; measurements outside the range 10°C – 30°C should be avoided because of the large temperature correction likely to be necessary. In Britain the spring months, mid-March–June, are preferable for deflection surveys, but as an alternative, measurements can be made in the autumn (September–November).

When particular urgency dictates that measurements must be made during the summer months they should be confined to the very early morning or to cool overcast weather conditions. Similarly, in the winter, any measurements made should be confined to the warmest part of the day and particular care must be taken to avoid freezing conditions. Measurements made during the summer or the winter can only given an approximate indication of the pavement stiffness.

The spacing of points of measurement depends mainly on the purpose of the survey. To check the uniformity and potential life of an apparently sound length of road a spacing of between 20 and 50 m is recommended. Reflecting road studs provide convenient reference points. Where the survey is being made in connection with the maintenance programme for a road already showing signs of distress a similar spacing of test points is recommended but a more detailed survey round areas of failure will be necessary.

The following information should be noted relating to the construction:-

(1) The type of material below the bituminous upper layers, i.e. whether unbound stone, gravel, etc., or whether cemented layers are included.

(2) The thickness, and if possible, the types of bituminous materials present. If this information is not available from reliable records, it may be necessary to take cores or excavate trial pits.

(3) A broad classification of the subgrade.

A suitable form for recording deflection measurements is shown in Table 2. The column for deflection corrected for load is intended for use where the actual test load on the truck wheel is slightly different from the standard 3175 kg. Deflection is adjusted in proportion to the wheel load for loads within the range ± 10 percent of the standard load. Correction of deflection for temperature is dealt with in detail below.

2.4 Correction of deflection measurements to a standard temperature of 20°C

The deflection measured as a loaded wheel passes over the road surface is the summation of the individual deflections in each layer of the pavement and in the foundation. The stiffness of any bituminous layer will change with the temperature of the binder. Consequently the magnitude of the deflection measured on the surface of the pavement will vary with the temperatures of the constituent bituminous layers.

For routine measurements it is not feasible to measure temperature gradients through the pavement structure. The simple procedure of classifying temperature in terms of a measurement made at a fixed depth of 40 mm has been adopted as described in section 2.1.4. Using this method of defining temperature the change of deflection with temperature has been studied for pavements with a wide range of types and thickness of bituminous base and surfacing. The results are summarised in Figs. 2, 3 and 4 which enable measured deflections at any temperature within the recommended range to be corrected to 20°C, for most types of pavement construction. Fig.2 is for pavements in which the upper layers consist of between 100 and 200 mm of bituminous bound material, of which at least the top 100 mm is hot rolled asphalt. Fig.3 also applies to pavements in which there is between 100 and 200 mm of bituminous material, but where the top 100 mm is not all of hot rolled asphalt. Fig. 3 is for pavements having a thickness of more than 200 mm of bituminous material of any type. In all three cases the remaining construction must be of material whose stiffness is not affected by temperature variations (e.g. lean concrete, cement bound granular material, soil cement, wet-mix, dry stone or crusher run material). The relations were established for subgrades predominently in the medium and low-strength categories.

TABLE 2

Suggested form for recording deflection measurements made with the Deflection Beam

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 m m	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.

The procedure for using the temperature correction graphs is evident from the example illustrated in Fig.3. A deflection of 40 x 10^{-2} mm, measured when the temperature was 12°C, is adjusted to the standard temperature of 20°C and then has a value of 45 x 10^{-2} mm.

Where pavements exhibit servere cracking or crazing at the surface, the correspondingly large deflections measured are less affected by temperature changes than is the case with uncracked pavements. Figs. 2, 3 and 4 show alternative dotted relationships to be used for severely cracked pavements.

2.5 Rebound deflection measurements

In some countries 'rebound' deflections are measured by placing the tip of the beam initially centrally between the twin tyres at the point of contact of the rear wheel assembly with the road surface. The rebound deflection is then measured as the truck is driven forward to a point at least 2 m beyond the beam tip. Because of the visco-elastic properties of road materials the rebound deflection depends on the exact procedure used as it is likely to be different from the deflection measured by the method described above. Although simpler, the rebound procedure is not recommended and the criterion curves produced in this report should not be used in conjunction with rebound deflection measurements.

3. B – THE DEFLECTOGRAPH AND ITS USE IN DEFLECTION SURVEYS

3.1 Principle of the Deflectograph

The Deflectograph, Plate 7, was developed by Laboratoire Central des Ponts et Chaussees, France, and is currently manufactured by MAP SA of Basle, Switzerland (see Appendix 1). It consists of a truck with a deflection beam assembly located beneath and an associated recording system. The beam assembly rests on the road, suitably aligned between the front and rear axles of the vehicle and deflections are measured as the rear wheel assemblies each loaded to 3175 kg, approach the tips of the beams, which during this period are at rest in contact with the road surface. As soon as the maximum deflection has been recorded by electrical transducers located near the beam pivots, the beam assembly is pulled forward at approximately twice the speed of the vehicle by an electromagnetic clutch and winch system, to the initial position ready for the next cycle. An arrangement of guides ensures that the beams are 'aimed' at the centre of the space between the rear twin tyres, even when the vehicle is negotiating bends.

The working speed of the Deflectograph is about 2 km/hour and the points of measurement are about 3.8 m apart on the road.

3.2 The Truck

The truck used for the Deflectograph is of French Berliet manufacture (currently type GLM 12) and is normally supplied with a small laboratory behind the driver's cab, which is used for the examination of records, or as an alternative to the driver's cab for housing recording equipment. The vehicle is left-hand drive and access to the laboratory is normally on the right hand side, but access on the left-hand side can be provided if required, as shown in Plate 7. The standard rear axle loading is normally provided by a water tank mounted on the chassis, but as an alternative, an open bodied truck can be supplied, the load being derived from concrete blocks as for the Deflection Beam truck. This is regarded in Britain as the preferable alternative. The open truck can also be used to carry road signs and cones for use with the Deflectograph.

3.3 Beam Assembly

The beam assembly is located by a tubular steel steering frame and guides to ensure that the deflection beams pass safely between the rear twin tyres without fouling the wheels. Whilst in motion, the beam assembly is guided by a vertical roller on the centreline at the front of the T-frame, Plate 8, into the neck of the steering frame, whilst the rear of the T-frame is located by a pair of guides, which are retractable upwards about the vehicle centreline. The steering frame is pivoted near the rear axle and is positioned transversely by a chain system connected to the drop arm of the vehicle steering system. This enables the vehicle to negotiate bends and roundabouts with automatic alignment of the beams.

When the vehicle is travelling at normal road speed and is not recording, the steering connection is isolated by the removal of a pin and locking screw and the beam assembly is raised from the road. In its most forward position relative to the truck, the beam assembly and steering frame are raised using a special tool so that three suspension hooks, fixed rigidly to the chassis, engage with the towing lugs fixed in front of the measuring heads and with one of the cross members at the rear of the T-frame. During this process the front pin on the steering frame disengages from the steering chain to allow lateral movement of the beam assembly to prevent fouling with the vehicle transmission. To permit this lateral movement, the rear guides must be retracted upwards. To prevent strain in the beams, when the assembly is in the raised position, cables fixed to the chassis are engaged by hooks to the beam tips.

Various alternatives of the beam assembly have been used by the Laboratoire Central des Ponts et Chaussees and by MAP SA. The chief variation has been to transfer the third support point from the rearward position shown in Plate 8 to a forward position by inverting the vertical arm of the T to the forward-facing side of the transverse bridge supporting the beams. It is important to realise that this affects the extent to which the front axle of the truck influences the deflection measurement. This in turn influences the relation between the deflections measured by the Deflectograph and the Deflection Beam. It is recommended that a rearward facing T-beam assembly should be used and the correlation given in this paper refers to such an arrangement. The principal dimensions of the Deflectograph are shown in Fig. 5.

3.4 Operating cycle

The initial position for a recording cycle is when the beam first comes to rest in the forward location. There is a short delay corresponding to a few centimetres of vehicle movement before clamping solenoids are energised to connect the transducer armatures to the beams, Plate 9. This delay allows any vibration of the beams to be damped out. The main function of the clamping solenoid is to isolate the transducers whilst the beam assembly is in motion.

The inductance transducers, supplied with alternating current from an oscillator/amplifier unit, are each approximately balanced electrically when in the rest position at the start of a recording cycle. As the rear wheels of the truck approach the beam tips and rotation of the beams occurs, the increasing output from the transducers is, after rectification, fed to the recording galvanometers. The output is linearly related to beam deflection.

At the end of the recording cycle, after maximum deflection has been recorded, the clamping solenoids are de-energised allowing the transducer armatures to fall back to the rest position. The electromagnetic clutch then engages to draw the beam forward to the starting position for the next cycle.

3.5 Deflection recording

Various recorders have been used with the Deflectograph. That illustrated in Plate 10 is a Savage and Parsons direct print Type 12-12 driven from the 24-volt vehicle supply. It employs Kodak Linagraph recording paper Type 1895 or 2022. The galvanometers used are Savage and Parsons Type 4-40 or 4-50. In addition a 4-222 recorder operating on the same chart is used as an 'event marker' to relate a deflection survey to fixed points on the road. This galvonometer is operated through a push button from a separate DC supply. The range of the main galvanometers is adjusted by the use of a pre-selected series resistances; this enables the sensitivity to be matched to the stiffness of the pavement. To avoid unnecessary oscillation of the recording galvanometers they are each damped by an electrical shunt during that part of the operating cycle when deflections are not being measured. Alternatively Siemens pen recorders can be used in place of the recording galvanometers, and these are now normally supplied with the equipment, and are quite satisfactory.

The oscillator, amplifier and recorder can be located either in the driving cab of the truck or in the small laboratory behind. The latter gives more operating space but entails the need for a communication link between driver and operator.

3.6 Switching

As the beam assembly moves relative to the steering frame it is arranged to operate a series of switches controlling the following functions:-

(i) engaging and disengaging the electromagnetic clutch which controls the beam movement.

(ii) shunting and de-shunting the recording galvanometers,

(iii) energising and de-energising the clamping solenoids operating the transducers.

The positions of the switches can be varied and are set to ensure correct phasing of the various operations.

3.7 Control Panel

A control panel, Plate 11, is located with the oscillator and recording equipment. In addition to master switches for the amplifier and clamping solenoids, it houses a manual clutch control switch, which over-rides the automatic control switches, and also the reference push-button switch for marking roadside identification features on the records.

3.8 Preparation of the equipment for a deflection survey

On arrival at the site to be surveyed, the following procedure is adopted:-

1. Switch on the amplifier/oscillator and allow a warming-up period of at least 5 minutes.
2. Unhook the deflection beams from their cable supports and, using the tool provided, lower the beam assembly onto the road releasing the three supports in turn.
3. Locate the front pin on the steering frame in the attachment on the steering chain and secure with the locking screw.
4. Lower the rear guides ensuring that the beam frame passes through the two guides.
5. Release the clutch travelling brake and pull the beam assembly manually towards the rear of the vehicle for a distance of about 1 m.
6. Start the engine of the vehicle and set its speed to approximately 1200 r.p.m. on the hand throttle.
7. Turn the power switch to the 'on' position on the control panel and operate the manual clutch switch to draw the beam assembly into its initial recording position, correctly aligned.
8. Switch on the recorder and clamping solenoid switches on the control panel; also the switch on the recorder itself.

The Deflectograph is then ready to record. The temperature of the road pavement should be recorded as described in section 2.1.4.

3.9 Survey procedure

An amplifier sensitivity appropriate to the stiffness of the pavement being surveyed is first selected. With the engine speed set at approximately 1200 r.p.m. and low axle ratio selected, first gear is engaged and the vehicle is allowed to move forward at a steady speed of about 2 km/h. As far as is possible the near-side wheels are kept at a distance of 1 m from the nearside verge.

The reference button is used to mark on the record the location of road identification features such as junctions, marker posts or bridge decks. At least six such reference points should be recorded on each km of carriageway. A separate record of the description of the location points should be made for transfer to the recorder paper as soon as is practicable.

A very slow-moving vehicle is likely to be a traffic hazard on certain types of road and the necessary safety precautions must be taken. The vehicle itself should be fitted with flashing beacons. On motorways it is essential to operate behind cones. On winding roads with poor visibility a protecting follow-up vehicle would normally be used. This carries appropriate signs and must 'dwell' at bends to cover the movement of the Deflectograph. The guidance of the appropriate Local Authority and of the Police on safety problems should be sought.

3.10 Calibration

Calibration entails relating the movement of the beam tip to the associated galvanometer deflection. The simple calibration device shown in Plate 12 is used. The beam assembly is positioned so that the beam tips are sufficiently forward of the rear wheels of the truck to allow the calibration device to be placed under the beam as shown in the Plate. (To avoid complications of illustration Plate 12 shows the beam assembly removed from the truck).

With the electrical equipment switched on and the various switches on the steering frame set manually to the operating condition, the micrometer screw of the calibrator is wound upwards for several turns and then turned back for a fraction of a turn to take up backlash. With the recorder running the beam tip is lowered in steps of 0.1 mm, indicated by the dial gauge, to give a total movement of not less than 0.5 mm., to give a calibration trace of the type shown in Fig. 6. The calibration used should be the mean of at least five such tests. Separate calibrations are necessary for the nearside and offside beams.

Provided the transducers are not changed the calibration should remain constant with time, but checks at about monthly intervals are advisable. Separate calibrations for the various sensitivities are necessary.

3.11 Trace reading

The type of trace obtained from the Savage and Parsons recorder is shown in Fig. 7. Various methods of record analysis are available. The simplest involves the direct measurement of the vertical displacement of the galvanometer spot as indicated by the trace from each recording cycle. To facilitate this a transparent graticule is prepared from the calibration measurements with scribed horizontal lines corresponding to a range of pavement deflections.

Too much weight should not be given to isolated very high or very low deflections. It is recommended that the mean of three consecutive measurements should be taken as representing the condition of the pavement. Since the individual measurements are spaced approximately 3.8 m apart the mean of three readings represents the average condition of 11.4 m of pavement. These average values are first expressed as equivalent Deflection Beam deflections, using the procedure given in Section 4 of this Report and these values are corrected to a temperature of $20^{o}C$ as described in Section 2.4. The results are presented in the form of deflection ordinates accurately located in relation to the geographical features noted on the recorder charts. An example of the method of presentation is given in Fig. 8.

The time taken to read, mean and correct individual batches of three deflections is short but the process become tedious when long lengths of road are involved. To facilitate analysis, the Transport and Road Research Laboratory has designed a digital reading sytem, which is used in parallel with the normal visual recorder. The system arithmetically compares the deflection signals from each transducer and indicates the size in mm x 10^{-2} of the maximum deflection and the wheel-path in which it occurs. These data can be printed out directly or alternatively put on paper tape for computer analysis. A site identification number, the road temperature and the geographical location marks can be injected manually into the paper tape punch operation.

For small surveys the direct print-out is used to replace the trace reading operation, the deflection and temperature corrections being made as described above. For larger jobs a computer programme is used to perform the meaning and correction processes.

The present TRRL digital system is compatible only with the Savage and Parsons recorder. Some re-design is necessary to allow it to operate with other recorders, and work on this is in hand.

3.12 Development of the Deflectograph in Britain

A fuller description of the development work carried out on the Deflectograph to increase its suitability for use on British roads is given in another Report (1).

4. C – CORRELATION OF DEFLECTION MEASUREMENTS MADE WITH THE DEFLECTION BEAM AND THE DEFLECTOGRAPH

4.1 The need for correlation between the two methods of measuring pavement deflection

The deflection criteria discussed in Section 5 of this Report are based on deflection measurements made with the Deflection Beam. Deflection measurements made by any other means, such as the Deflectograph, must be correlated with the Deflection Beam measurements if these criteria are to be adopted.

As used in Britain the Deflection Beam and the Deflectograph use the same wheel load of 3175 kg (7000 lb). If, (i) the tyre spacing and the area of contact of the tyres were identical for the two types of wheel assembly used, and (ii) during the measuring cycle the beam support points in the two methods were influenced in the same manner by the movement of the wheels of the truck, the two methods would indicate the same deflection. Dealing with the first of these points, Fig. 9 shows significant differences in tyre spacing and contact area. With regard to the second point it will be appreciated that neither method gives an absolute measure of deflection since the beam, or beam assembly supports are themselves influenced by the deflection of the pavement under the action of both the front and rear wheels of the truck. With the Deflection Beam, Fig. 1, the front wheels are sufficiently remote to have only a small influence and the rear wheels have a decreasing effect on the beam supports as the truck moves forward. In the Deflectograph, Fig. 5, the beam assembly supports tend to pass out of the influence of the front wheels but into the influence of the rear wheels, during the measuring cycle.

4.2 Correlation measurements

Although theoretical considerations are useful in examining the probable effects of support movements of this type on measured deflection, the accuracy likely to be achieved will be low because the size of the deflection dish associated with each wheel is influenced by the stiffnesses of the pavement materials and the strength of the soil foundation.

It has been necessary therefore, to establish the correlation experimentally on a wide range of pavements over the temperature range $10^{\circ} - 30^{\circ}C$. The method adopted was as follows. A length of pavement of known construction (generally a section of one of the Laboratory's full-scale pavement design experiments) was selected sufficient to give at least 10 points of measurement when surveyed with the Deflectograph. As the machine passed over the selected length at normal running speed the points of measurement were accurately located on the pavement surface. Measurements at the same points were then made in the standard manner with the Deflection Beam, as far as possible without change of temperature in the road structure.

Experiments with a wide range of pavements with unbound, cemented and bituminous bases show that the correlation is slightly dependent upon the pavement temperature but can be sufficiently closely represented by two relations, one relating to pavements with unbound and lean concrete bases and the other to pavements with bituminous bases. These relations are shown in Figs. 10 and 11. Most of the evidence was obtained from roads with surfacings of rolled asphalt 100 mm thick, but less extensive tests on pavements with other surfacings indicate that the same correlation curves can be applied.

The appropriate correlation is used to adjust deflection values measured by the Deflectograph before the temperature correction (Section 2.4) is applied. Simplification of the trace reading/correction procedure can be effected by adjusting the graduations of the transparent graticule referred to in Section 3 to take into account the appropriate correlation between Deflectograph and Deflection Beam measurements.

5. D – DEFLECTION CRITERION CURVES AND THE ESTIMATION OF PAVEMENT LIFE FROM DEFLECTION AND TRAFFIC DATA

5.1 Development of deflection criterion curves

The wide range of full-scale road experiments designed and observed by the Transport and Road Research Laboratory over the past 20 years has provided an unique opportunity for the deflection histories of the individual sections to be observed and associated with the structural performance. The deflection studies have been made with the Deflection Beam and they have been continued up to, and often beyond, the stage where the pavement condition has been defined as 'critical' in accordance with Table 1. In some instances this has involved continuous studies for more than 17 years. Much of this work is described in recent papers (2)(3) and others are in the course of preparation. The intention here is to present only that information necessary to the practical application of deflection measurements to the problems of estimating the life expectancy of pavements and designing suitable overlays to extend pavement life.

To establish useful deflection criteria it is necessary to study the relation between deflection and performance for pavements of the same type (i.e. base material) laid to different thicknesses and on different subgrades. The criteria developed in this paper are derived from sites having weak and medium strength subgrades. They will not necessarily apply to very strong subgrades such as are provided by natural or crushed rock, nor to subgrades of CBR less than 2 percent.

5.2 Deflection criterion curves

Deflection measurements made immediately after a pavement is completed and before it is opened to traffic may be subject to change as the materials compact under traffic and as equilibration of the subgrade moisture takes place. The deflection measured after these initial changes have taken place (generally about 6 months after the opening of the road) is a more reliable guide to future performance.

The deflection of a pavement does not remain constant with time. For all forms of construction the deflection increases slowly as the pavement deteriorates. Studies made at the experimental sites already referred to have enabled deflection histories to be built up, from construction to failure, for each section. This information has been used to prepare the deflection trends and performance relations shown in Figs. 12, 13 and 14 relating to pavements with unbound, bitumen bound and cemented bases respectively.

In using these curves it is necessary to know the present deflection of the road whose life expectancy is required and information on the number of standard axles which the pavement has carried since construction or since the last major strengthening. The deflection is determined by the Deflection Beam or the Deflectograph using the procedures discussed in Section 2 and 3, the deflection being corrected to 20°C. Examples of the use of these criterion curves are given later.

For pavements with lean concrete bases, that part of the criterion curve, Fig.14, corresponding to cumulative traffic in excess of 10 million standard axles, applies to pavements constructed to the recommendations of Road Note No.29 (4), (i.e. pavements in which a bituminous upper base is used to reduce the effects of reflected cracking). If a maximum thickness of 100 mm of bituminous material is used over the lean concrete, deterioration may arise from cracking and break-up of the surfacing, and the dotted branch of the criterion curve will apply. This indicates that once such failure has started its progress will be rapid.

5.3 Estimation of traffic and pavement life on terms of cumulative standard axles

The method of estimating cumulative traffic in terms of standard axles is fully discussed in Road Note No.29 (4), but is summarised here. From the AASHO Road Test (5) equivalence factors for the damage caused by different axle loads were established. It has been usual practice to express the damage caused by a known axle load as a ratio of the damage caused by a 'standard' 8160 kg (18000 lb) axle, as indicated in Table 3.

TABLE 3

Equivalence factors for the damage caused by different axle loads

Axle load kg	(lb)	Equivalence factor
910	(2000)	.0002
1810	(4000)	.0025
2720	(6000)	.01
3630	(8000)	.03
4540	(10000)	.09
5440	(12000)	.19
6350	(14000)	.35
7260	(16000)	.61
8160	(18000)	1.0
9070	(20000)	1.5
9980	(22000)	2.3
10890	(24000)	3.2
11790	(26000)	4.4
12700	(28000)	5.8
13610	(30000)	7.6
14520	(32000)	9.7
15420	(34000)	12.1
16320	(36000)	15.0
17230	(38000)	18.6
18140	(40000)	22.8

From Table 3, it can be deduced that 5000 passes of a 910 kg (2000 lb) axle would do as much damage as the passage of one standard axle and that 23 passes of a standard axle would do as much damage as one passage of a 18140 kg (40000 lb) axle.

At the experimental road sites used to establish the deflection criterion curves, weighbridges set in the road surface have been used to classify continuously the axle weights of the commercial traffic. From this information, Table 3 has been used to compute the cumulative number of standard axles in which the critical life is expressed in Figs. 12, 13 and 14.

On normal public roads no details of axle loads will be available; the only traffic information readily accessible to the engineer will be the number of commercial vehicles per day and an estimated growth rate of commercial traffic. In connection with the preparation of Road Note No.29 studies were made on different types of road to deduce axle load spectra for the commercial traffic typical of those roads. Three types of road were considered and for each the average number of standard axle equivalent to the passage of one commercial vehicle was deduced as shown in Table 4.

TABLE 4

Average number of standard axles equivalent to one commercial vehicle, for three classes of road

Type of road	Average number of standard axles per commercial vehicle
Motorways and Trunk Roads designed to carry over 1000 c.v.d. in each direction at the time of construction	1.08
Roads designed to carry between 250 and 1000 c.v.d. in each direction at the time of construction	0.72
All other public roads	0.45

These values can be used to convert a cumulative number of commercial vehicles to an equivalent number of standard axles and also to obtain a relationship between the age of a road in years and the cumulative number of standard axles carried during that period. To facilitate the latter calculation Figs. 15–20 show for growth rates between 2 and 6 percent the cumulative number of commercial vehicles carried by each slow lane for various initial intensities of commercial traffic and various lives expressed in years. Used in conjunction with Table 4 these graphs give the relation between age in years and cumulative standard axles carried.

For roads constructed in the last 40 years the traffic carried since construction or since the last major strengthening can be estimated with sufficient accuracy using the procedure described above in conjunction with the traffic census figures. The problem of estimating traffic for older country roads which have been updated by little more than periodic surface dressing may appear to be difficult. In fact the contribution of traffic prior to 1930, expressed in standard axles is likely to be negligible for such roads and need not be taken into account. Again, therefore a realistic estimate of traffic can be made from observations of present traffic and the assumption of an appropriate growth rate. In an industrial area the use of an average growth rate of 4 percent per annum over the past 40 years is recommended, but for a predominantly agricultural area the growth rate would probably not have exceeded 2 percent.

5.4 Examples of the use of deflection criterion curves to estimate the future life expectancy of existing roads

Example 1. An industrial trunk road constructed 12 years ago with a wet-mix crushed stone base under a 100 mm asphalt surfacing, and now carrying 1500 commercial vehicles per day in each direction has a deflection of 45×10^{-2}mm measured by the Deflection Beam at 20°C. The subgrade is a sandy clay. It is required to know the future life of the pavement before structural maintenance will be necessary.

The commercial traffic growth rate over 12 years for an industrial trunk road is likely to have been close to the average value of 4 percent for such roads.

If A = present traffic in commercial vehicles per day in each direction
B = corresponding traffic when the road was first opened
r = growth rate
x = life to date in years, then

$$A = B(1 + r)^x$$
$$\text{or } 1500 = B(1.04)^{12}$$
$$\text{and } B = 940.$$

Fig. 17 shows that for an initial traffic of 940 c.v.d. the cumulative number of commercial vehicles carried during 12 years would be 5 millions. For a road initially carrying 940 c.v.d. the number of equivalent standard axles per commercial vehicle can be taken as 0.72 (Table 4). Hence the cumulative number of standard axles carried in 12 years will be 3.6 millions.

Reference to Fig.12 shows that a pavement having a deflection of 45×10^{-2}mm after carrying 3.6 million standard axles will reach the critical condition after carrying 9 million standard axles. A total life of 9 million standard axles corresponds to 12.5 million commercial vehicles, which, from Fig.17, will represent a structural life to the critical condition of about 24 years. It follows therefore that the road should remain structurally sound for a further 12 years under the anticipated traffic.

Example 2. A rural secondary road with a gravel base under a bituminous surfacing is currently used by 50 commercial vehicles per day in each direction. In connection with a nearby motorway contract it is anticipated that 40,000 cu m of bituminous material and stone sub-base will pass over the road. The average deflection measured by the Deflectograph at a temperature of 25°C is 58×10^{-2} mm. It is required to know if the existing pavement, which was last overlaid 15 years ago will carry the additional traffic without structural failure.

A deflection of 58×10^{-2}mm measured by the Deflectograph will from Fig.10 correspond to a deflection of 70×10^{-2}mm measured by the Deflection Beam. From Fig.3 the deflection corrected to 20°C will be 64×10^{-2}mm. Since the road is in a rural area and is lightly trafficked a growth rate of 2 percent can be assumed.

Using the same procedure as in the previous example it follows that the current traffic of 50 c.v.d. would have been 37 c.v.d. 15 years ago, at the time of the last strengthening. Fig.20 shows that in 15 years a road initially carrying 37 c.v.d. in each direction would have carried a total of 0.25 million commercial vehicles in each direction. This is equal to 0.25 x 0.45 million or 0.11 million standard axles using the factor of 0.45 from Table 4. From Fig.12, a deflection of 64 x 10^{-2}mm at 0.11 million standard axles indicates a total life of 1.8 million standard axles. The pavement has therefore a potential average life of 1.8–0.11 or nearly 1.7 million standard axles.

The 40,000 cu m of material would probably be carried in 10 cu m trucks loaded to about 22 tonnes, with approximately 8 tonnes on each rear axle and 6 tonnes on the steering axle. From Table 3 each vehicle passage would be equivalent to 2.3 standard axles and the total movement of material would involve 9200 standard axles. This is clearly insignificant in relation to the potential average life and no strengthening would be required.

NOTE: It must not be assumed from the above example that minor roads are unlikely to be damaged by heavy construction traffic. Many country lanes are, in the interest of economy, maintained close to the critical condition by the regular application of surface dressings. Such roads can fail rapidly if subjected to construction traffic, particularly where the latter includes large numbers of heavy vehicles engaged in earthmoving. A deflection study will show if the existing road has a low potential life.

6. E – DESIGN OF OVERLAYS FROM DEFLECTION DATA AND PREPARATION OF STRUCTURAL MAINTENANCE REQUIREMENTS

6.1 Function of an overlay

The deflection of a flexible pavement can be reduced, and the structural strength increased, by the addition of a bituminous overlay. The reduction of deflection will depend on the thickness of the overlay and on its elastic properties.

The Engineer requires to know the thickness of overlay necessary to extend the life of a pavement by a given amount. He will then decide if the use of this thickness is practicable or whether it will be preferable to reconstruct the pavement. This decision will depend partly on economics and partly on such factors as levels and bridge clearances. On a multi-lane highway it may be cheaper to reconstruct a short length of the slow lane than to apply a thick overlay to the whole carriageway width.

6.2 Overlay studies

As they have reached the critical condition, a number of the Laboratory's experimental road sections have been overlaid with asphalt. The reduction of deflection for various thicknesses of asphalt has been observed on different types of pavement structure and the influence on the subsequent life of the sections is being studied.

The amount of information concerning the deflection histories of overlaid sections is small in comparison with the studies on new pavements. However, time/deformation trends indicate that provided the original pavement is overlaid before, or as it reaches the critical condition the overlaid structure will behave similarly to a new pavement with the same early life deflection. This assumption which is made in the following overlay recommendations may need some revision in the light of further long-term studies. If the pavement condition has passed the critical stage at the time of the overlay the extension of life will be reduced.

The experimental work on which the recommendations are based used exclusively rolled asphalt overlays. It seems probable, however, from pavement performance studies that the reduction of deflection and extension of life achieved from overlays employing dense coated macadam basecourses under a rolled asphalt wearing course would not be much less than when the basecourse was rolled asphalt.

Fig. 21 summarises the results from the overlay studies. The same curves apply to all forms of original pavement construction. The use of the curves will be apparent from the example given below. Briefly, the potential life of the existing pavement is assessed in standard axles from deflection studies as previously described. The life required from the overlaid pavement in standard axles is then calculated. The difference between the potential and the required lives is used in conjunction with the appropriate Fig. 12–14 to derive the required initial deflection for the overlaid pavement. Fig. 21 then gives the thickness of overlay required.

6.3 Example of the preparation of structural maintenance requirements from a deflection survey

A road opened to traffic for nine years has the following construction:– 100mm of two-course rolled asphalt surfacing, 125mm of rolled asphalt roadbase and 300mm of Type 2 sub-base material on a subgrade of CBR 4 percent. Initially the road carried 800 commercial vehicles per day in each direction with an annual growth rate of 2 percent. However, owing to adjacent road improvements the commercial traffic is expected to increase immediately to 1200 c.v.d. in each direction with a new growth rate of 5 percent. It is required to know what strengthening measures should be carried out to achieve a life of at least 15 years under the new traffic before further strengthening is required. The results of a deflection survey of the road are shown in Fig.8. Each ordinate represents the mean of three deflectograph measurements corrected to an equivalent deflection beam reading at 20°C.

The initial traffic of 800 c.v.d. in each direction with a growth rate of 2 percent gives a cumulative total of 3 million commercial vehicles after 9 years, Fig.15, equivalent to 2.2 million standard axles (Table 4). The required future life is not less than 15 years commencing with 1200 c.v.d. in each direction at a growth rate of 5 percent. This produces a future cumulative total of commercial vehicles of 9 million, Fig.18, equivalent to 9.7 million standard axles (Table 4). It follows that at the end of the 15 years the pavement will have carried throughout its life 11.9 million standard axles. Fig.13 shows that if the deflection measured now (after 2.2 million standard axles) is less than 36 x 10^{-2}mm the pavement will be structurally capable of carrying the proposed future traffic without overlay. Only over a limited length does this apply (Fig.8). After the pavement has been strengthened it is assumed to behave similarly to a new pavement. The future life required before further strengthening is 9.7 million standard axles, which from Fig.13 will be achieved if the initial deflection is 38 x 10^{-2}mm or below. From Fig.21 it follows that 50mm of asphalt would reduce a present level of deflection of 43 x 10^{-2}mm to 38 x 10^{-2}mm and that 100mm of asphalt would similarly reduce a present level of 57 x 10^{-2}mm to 38 x 10^{-2}mm. Horizontal lines drawn on Fig.22 at 57 x 10^{-2}mm, 43 x 10^{-2}mm and 36 x 10^{-2}mm isolate areas to be treated with 50mm and 100mm overlays as indicated on the diagram. A small length of road shows higher deflections requiring either a 150mm overlay or reconstruction of the base.

7. F – THE STRATEGIC USE OF THE DEFLECTOGRAPH

7.1 The need for a maintenance programme

A road authority responsible for the design and maintenance of roads may need some guidance on the strategic use of the Deflectograph in framing a rolling maintenance programme. The following recommendations are based on only a limited use of the machine over a period of four years and they must be regarded as tentative.

7.2 New roads

The Deflectograph is not intended to be used as an acceptance tool for new road pavements. If such pavements have been constructed to the requirements of the DOE Specification for Roads and Bridgeworks and of Road Note No.29, the design life will be achieved. The Engineer may, however, wish to use the machine to examine the uniformity of the finished pavement, and particularly the influence of local variations of the subgrade encountered during the construction.

For the reasons given in Section 5.2, a deflection survey made before a road is opened to traffic can be misleading. Nevertheless, this is a particularly convenient period for a detailed survey of all the traffic lanes and it is recommended that such a survey should be made if the temperature conditions are acceptable (see Section 2.4).

If high deflections, indicating a life very much shorter than the design life are encountered on roads with cemented bases, the quality of the cemented material must be suspect, and an investigation by coring or other means is advisable to locate the cause of the weakness. If the deflection level is consistent with the design life no further action will be required. The initial deflections of pavements with unbound or bituminous bases and unbound sub-bases may decrease if compaction takes place under traffic. If a deflection survey made before such a road is opened to traffic indicates a future life less than one quarter of the design life the quality of the construction must be suspected and an investigation of the cause is recommended. Where the deflection is lower, but is nevertheless consistent with a life less than the design life, the measurements should be repeated in the slow traffic lanes about six months later. If the deflection is still high an investigation of the cause will be desirable. If construction has taken place during an exceptionally dry summer the deflection of pavements with unbound and bituminous bases may for this reason be low and a repeat survey of the slow lanes after 6–12 months is recommended.

7.3 In-service roads

The main value of a Deflectograph survey will relate to the maintenance of in-service roads. The first objective of a road authority should be to cover the whole of its major road network as quickly as possible, but the time required to achieve this will naturally depend on the extent to which the authority has access to a Deflectograph.

The average length of Trunk and Principal roads per County in Britain is about 1100 km or 2200 km of slow traffic lane. Assuming an output of 10 km of traffic lane per day this would mean that a County with continuous use of a Deflectograph should be able to survey the whole of its major road network in one year. With a staff of two people using computer analysis procedures it should be possible to analyse the data obtained in another year and to produce a priority programme for structural maintenance. However, before detailed proposals for a particular length of road are drawn up it is essential that measurements are repeated so that the delay between the structural evaluation and the completion of the maintenance work does not exceed one year. Cases have occurred where the delay has been several years with the result that additional structural deterioration occurring between the survey and the maintenance work has not been taken into account.

The frequency with which the major road network is re-examined with the Deflectograph must depend on the results of the initial survey, but it is envisaged that the second survey could be spread over a period of five years.

In most counties the length of the Trunk and Principal roads accounts for only about one quarter of the total road network. The systematic testing of the remaining roads could well be confined to the Class 1 category, which could probably be included in the operations for the second or third years. Deflection studies on Class II and Class III roads could be confined to establishing the maintenance requirements for isolated lengths where observation indicates the need for structural repair.

8. ACKNOWLEDGEMENT

The work described in this report was carried out in the Pavement Design Division of the Structures Department. Mr. N.W. Lister was responsible for the organisation and conduct of most of the research work on which the report is based.

9. REFERENCES

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2. LISTER, N.W. Deflection criteria for flexible pavements and the design of overlays. Proc. 3rd International Conference on the Structural Design of Asphalt Pavements, Vol.1, 1972 (University of Michigan, Ann Arbor), pp 1206 – 26.

3. LISTER, N.W. Deflection criteria for flexible pavements. Department of the Environment, Transport and Road Research Laboratory Report No. LR 375, 1972 (TRRL Crowthorne).

4. ROAD RESEARCH LABORATORY. A guide to the structural design of pavements for new roads. Department of the Environment, Road Note 29, 3rd edition, London, 1970 (H.M. Stationery Office).

5. LIDDLE, W.J. Application of the AASHO Road Test results to the design of flexible pavements. Proc. 1st International Conference on the Structural Design of Asphalt Pavements, 1962 (University of Michigan, Ann Arbor), pp 42–51.

10. APPENDIX 1

Suppliers of Deflection Equipment

Deflection Beam and Calibrator:

Leonard Farnell and Co.Ltd.,
North Mymms,
HATFIELD,
Herts.

Thermometers (150 mm BEE-KA 0–50°C Cat. No. P 10683):

H.J. Elliot Ltd.,
E-MIL Works,
Treforest,
Glamorgan.

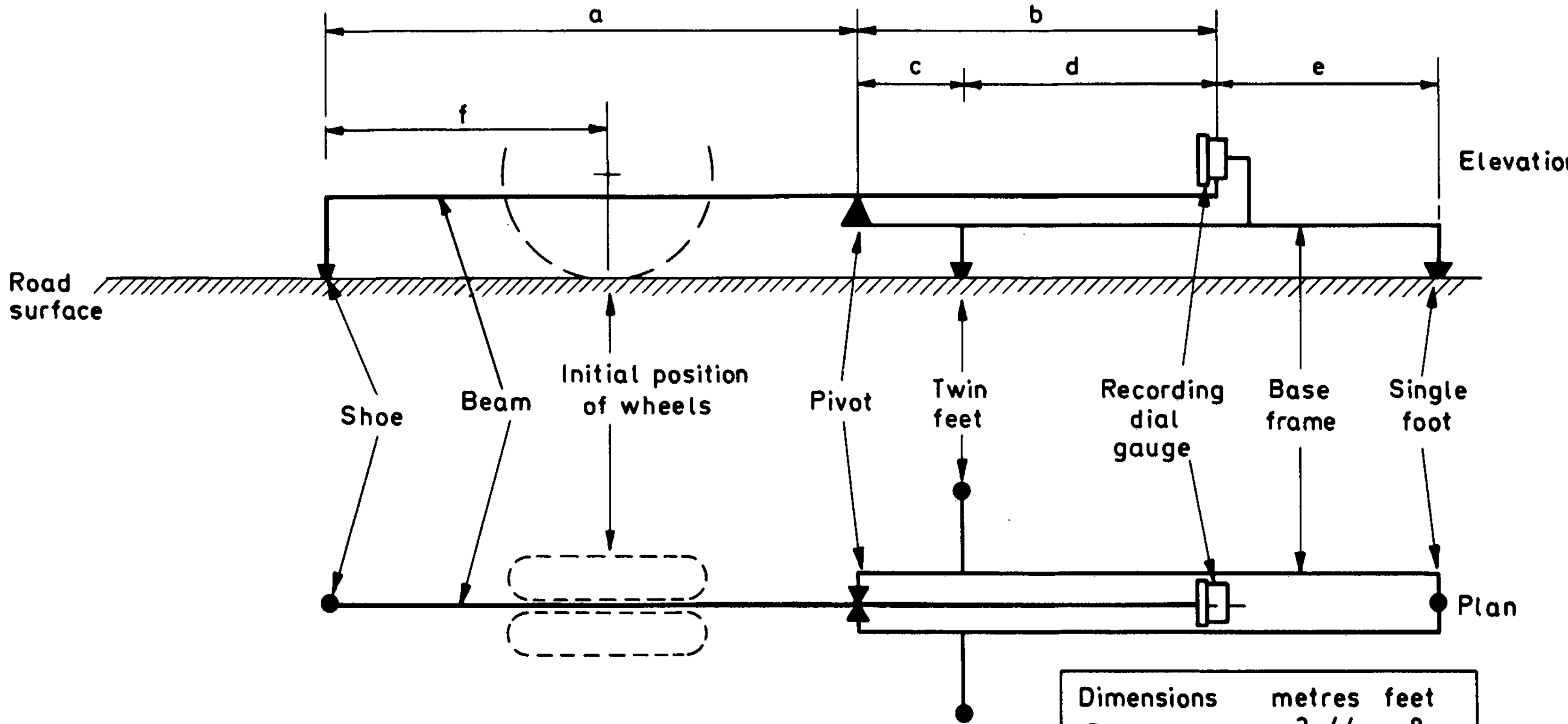
Stafford & Sunderland 57251
Stafford (0785) 83 2121

Deflectograph and Calibrator:

MAP SA
Solothurnerstrasse 45,
BASLE,
Switzerland.

letters to:

P.O. Box 4008,
BASEL,
Switzerland.



Dimensions	metres	feet
a	2·44	8
b	1·22	4
c	0·30	1
d	0·92	3
e	0·61	2
f	1·30	4·25

Fig. 1. DIAGRAMMATIC REPRESENTATION OF THE DEFLECTION BEAM

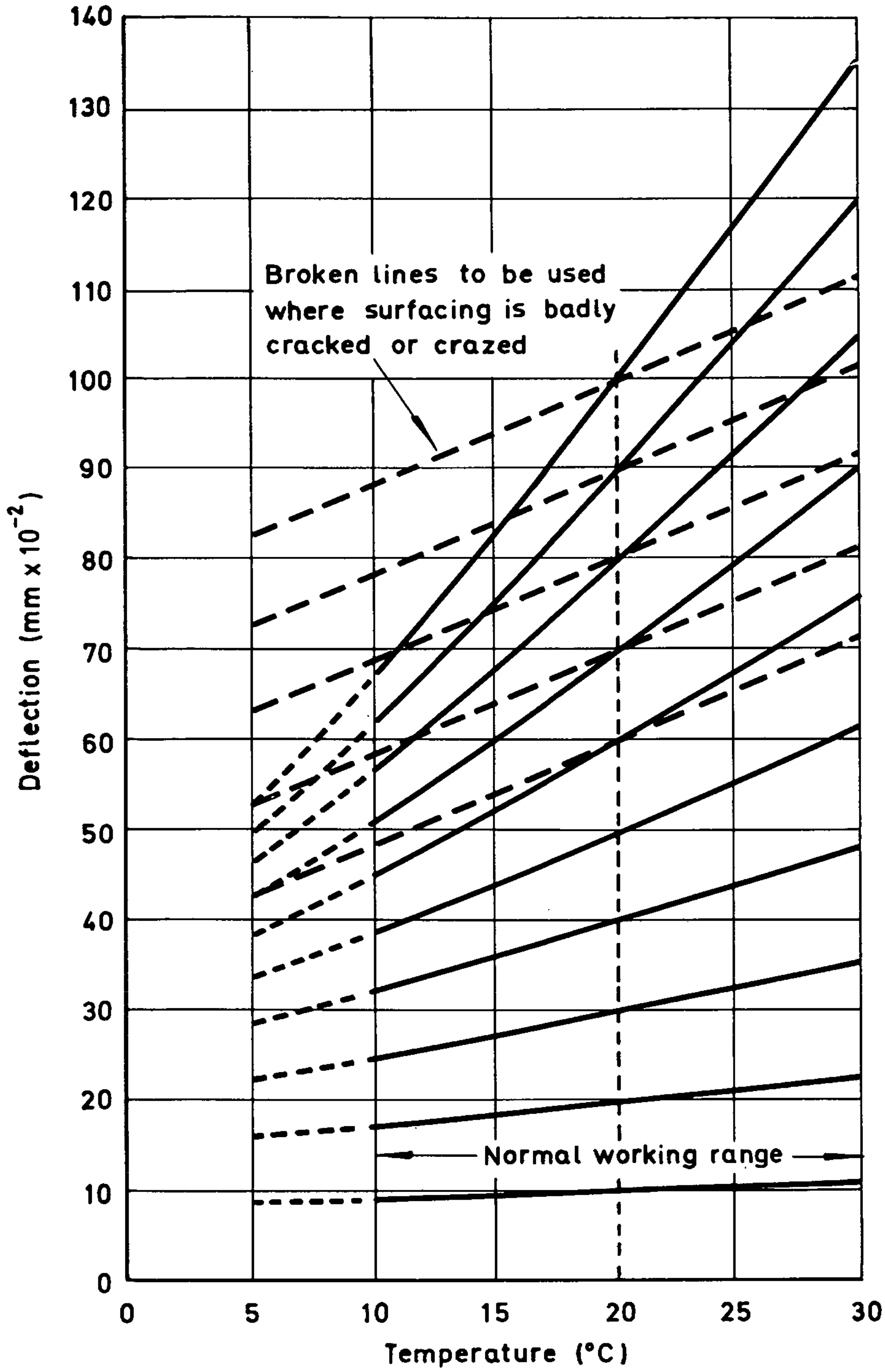


Fig. 2. RELATION BETWEEN DEFLECTION AND TEMPERATURE FOR PAVEMENTS WITH NOT MORE THAN 200mm OF BITUMINOUS MATERIAL OF WHICH AT LEAST 100mm IS ROLLED ASPHALT

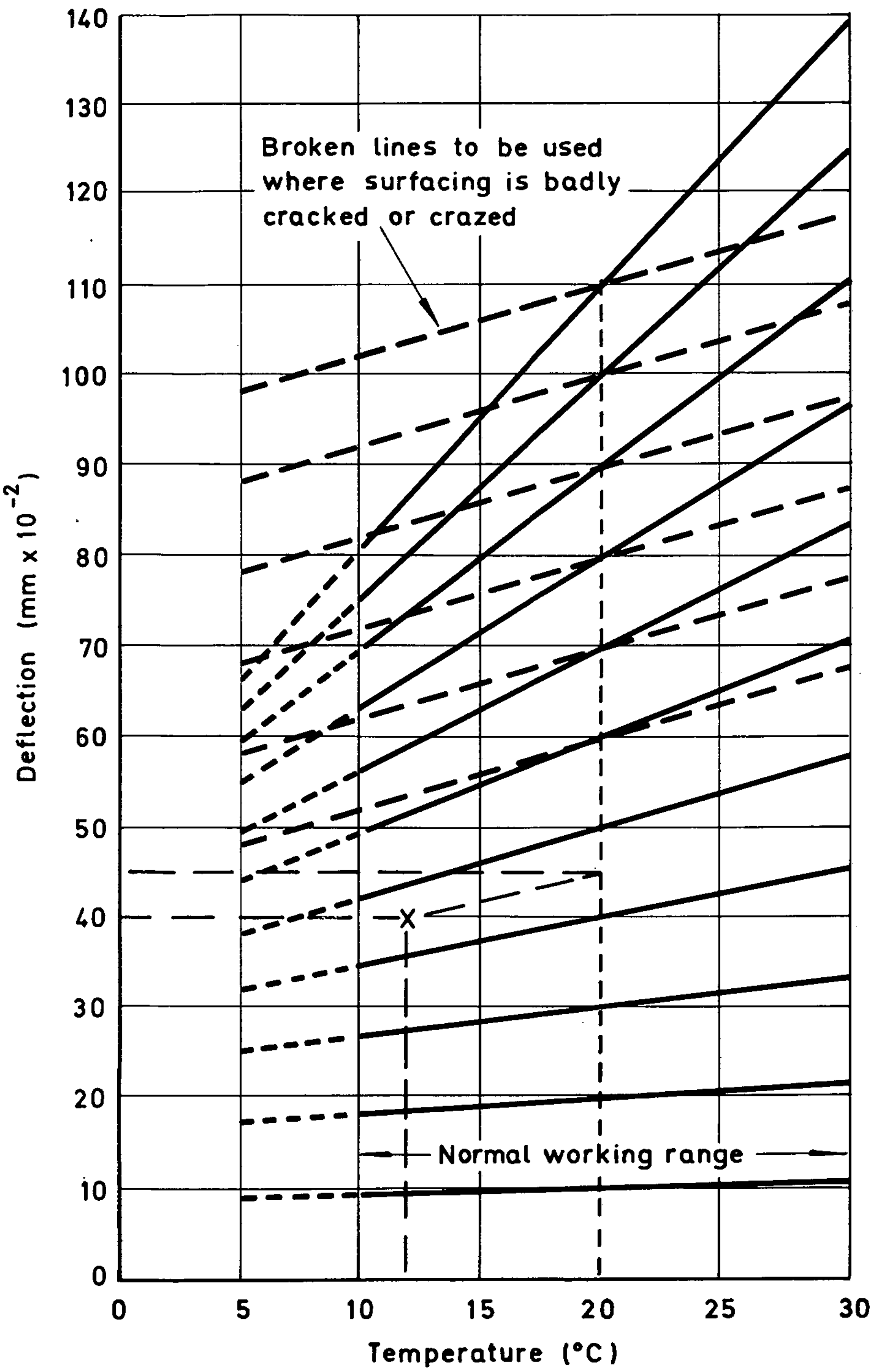


Fig. 3. RELATIONSHIP BETWEEN DEFLECTION AND TEMPERATURE FOR PAVEMENTS WITH BETWEEN 100mm AND 200mm OF BITUMINOUS MATERIAL OF WHICH LESS THAN 100mm IS ROLLED ASPHALT

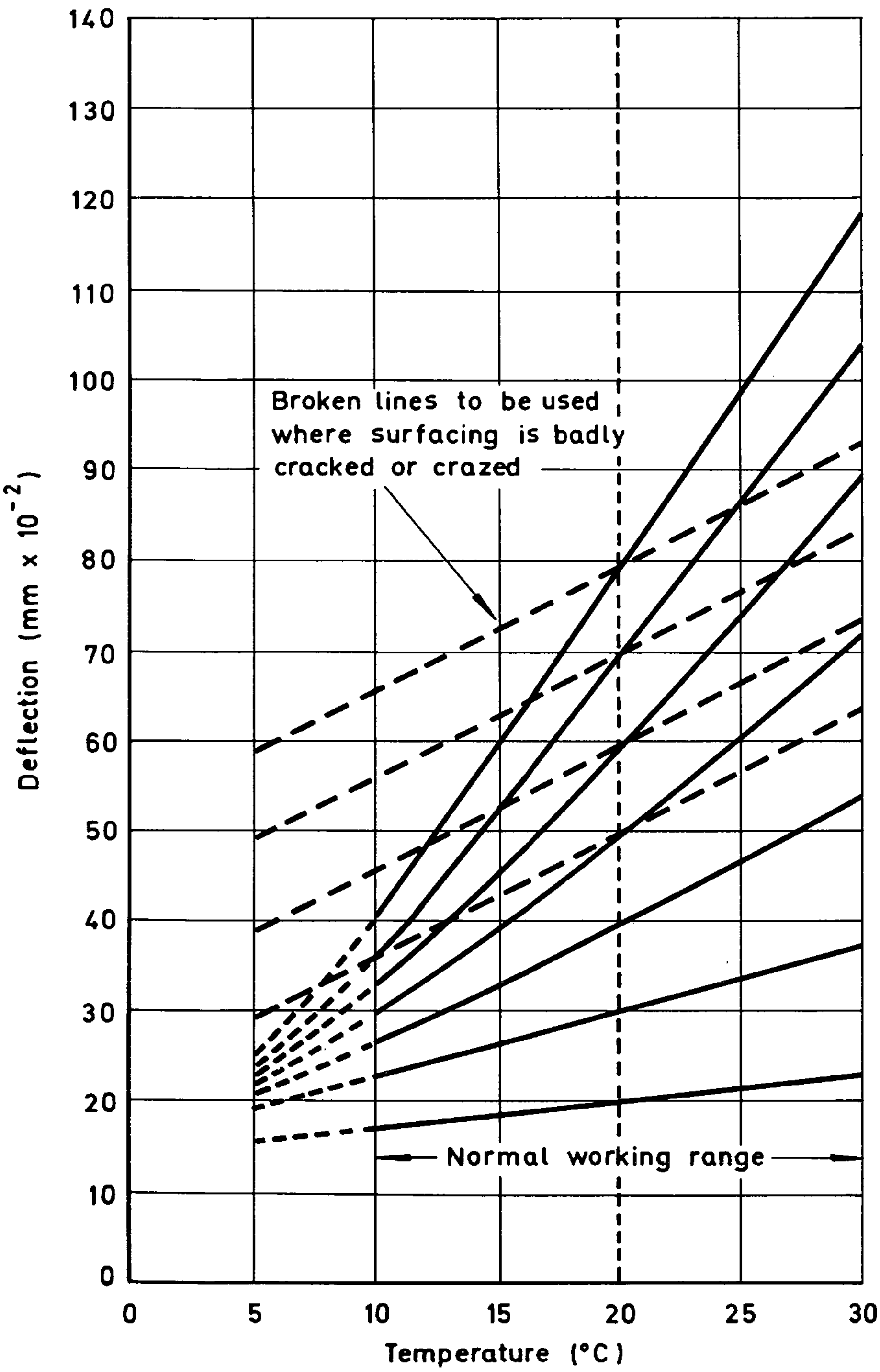


Fig. 4. RELATION BETWEEN DEFLECTION AND TEMPERATURE FOR PAVEMENTS WITH MORE THAN 200 mm OF BITUMINOUS MATERIAL

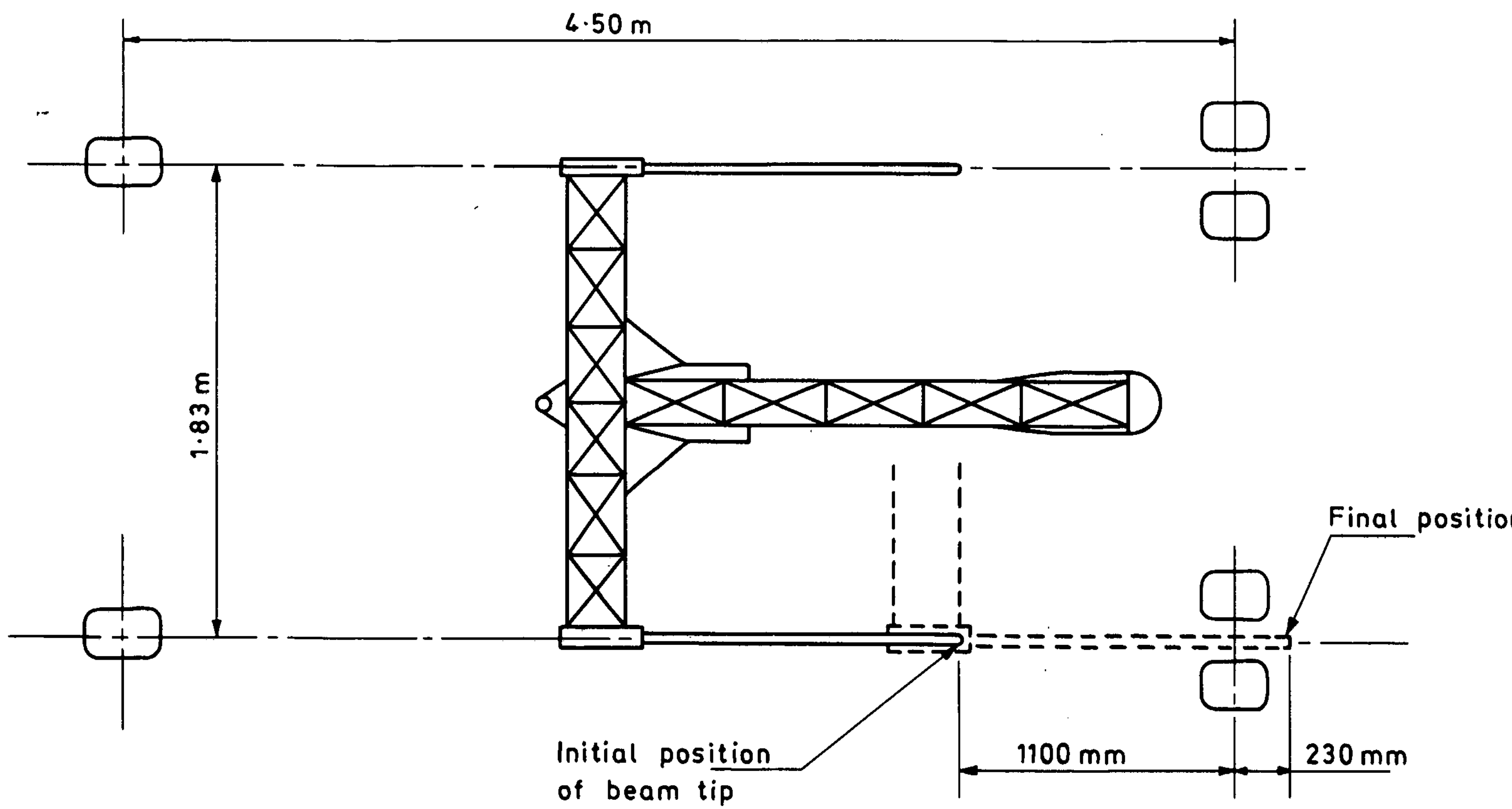


Fig. 5. DIAGRAMMATIC REPRESENTATION OF DEFLECTOGRAPH

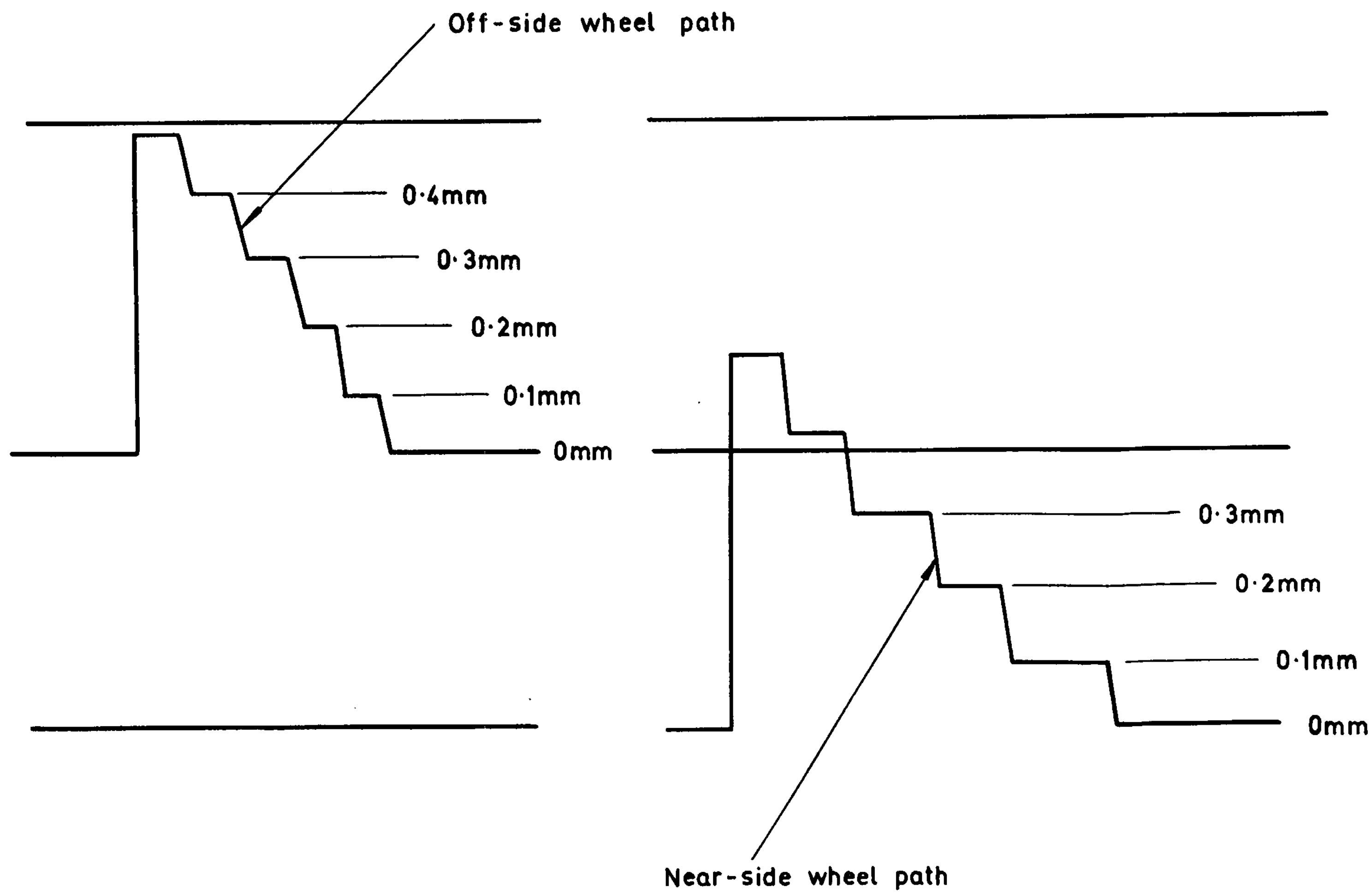


Fig.6. DEFLECTOGRAPH - CALIBRATION TRACE

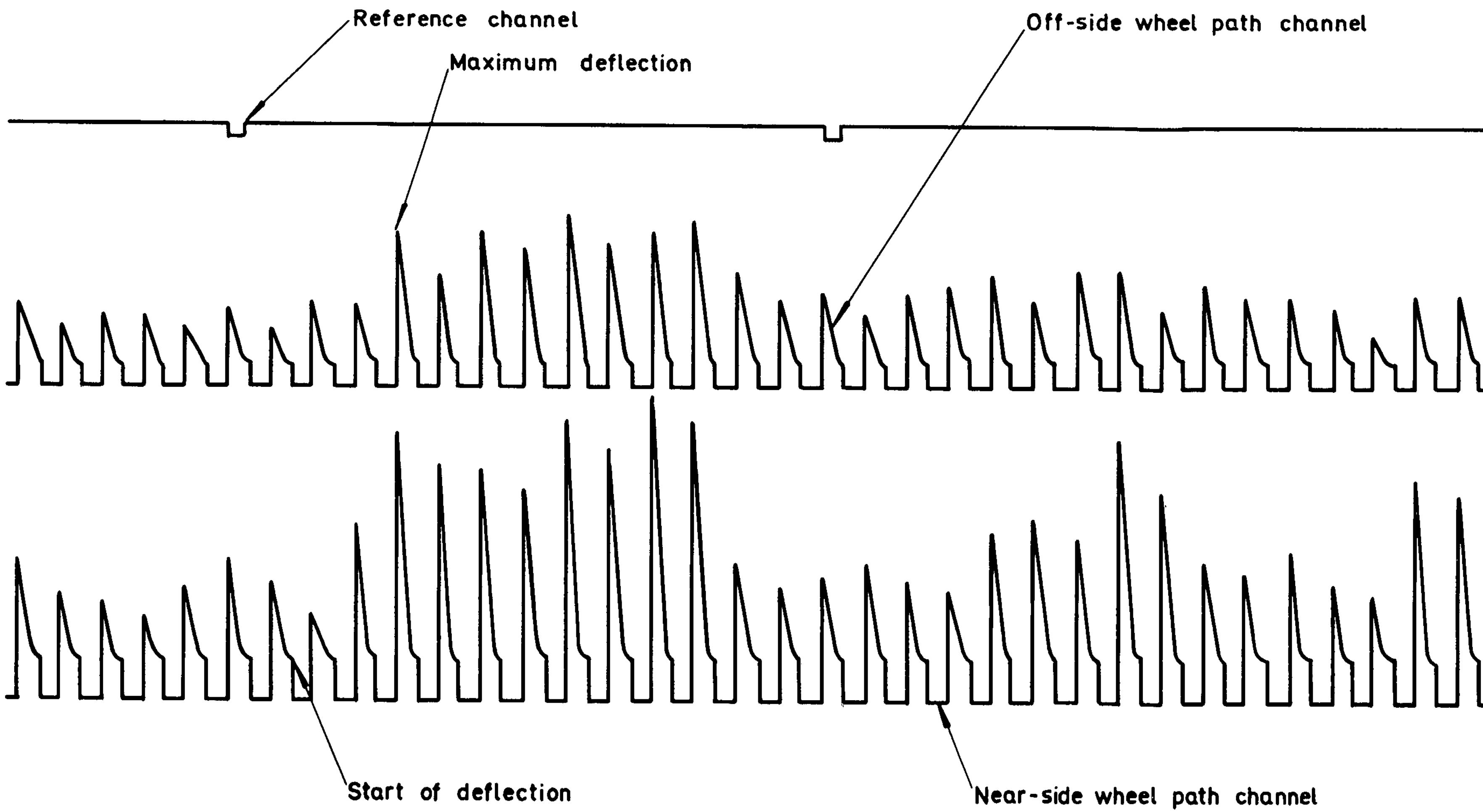


Fig. 7. DEFLECTOGRAPH - TYPICAL TRACE FROM SAVAGE AND PARSONS RECORDER

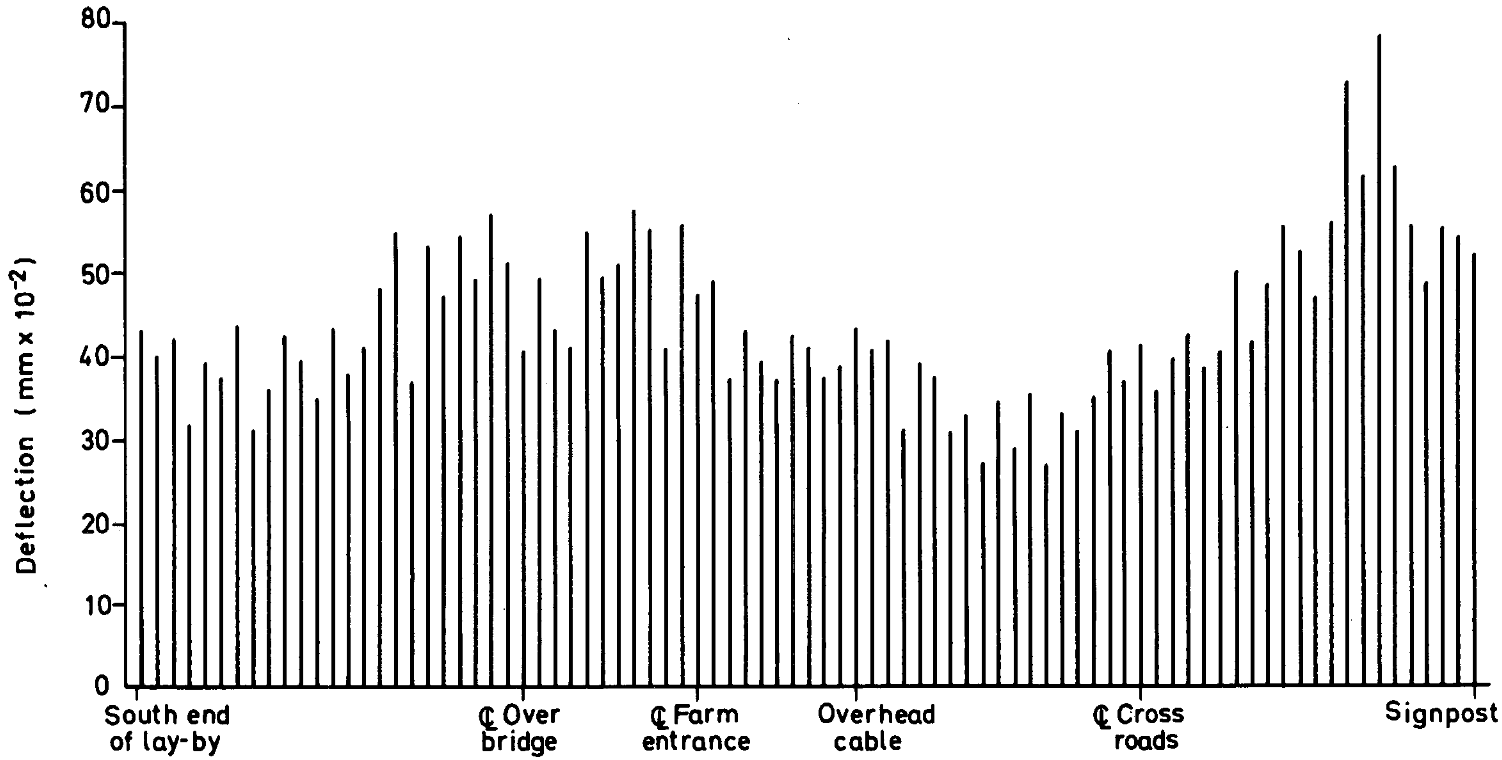
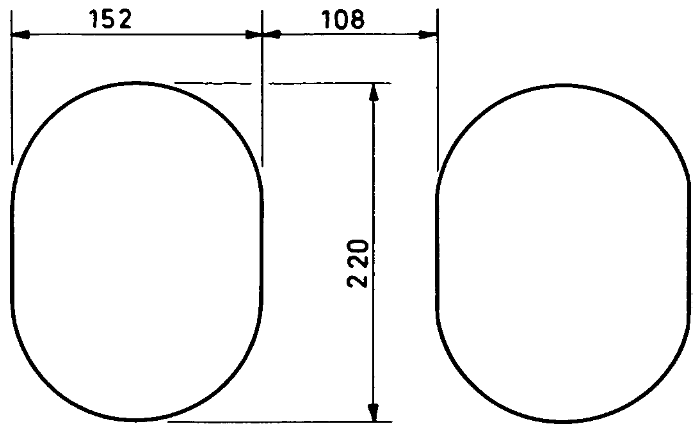
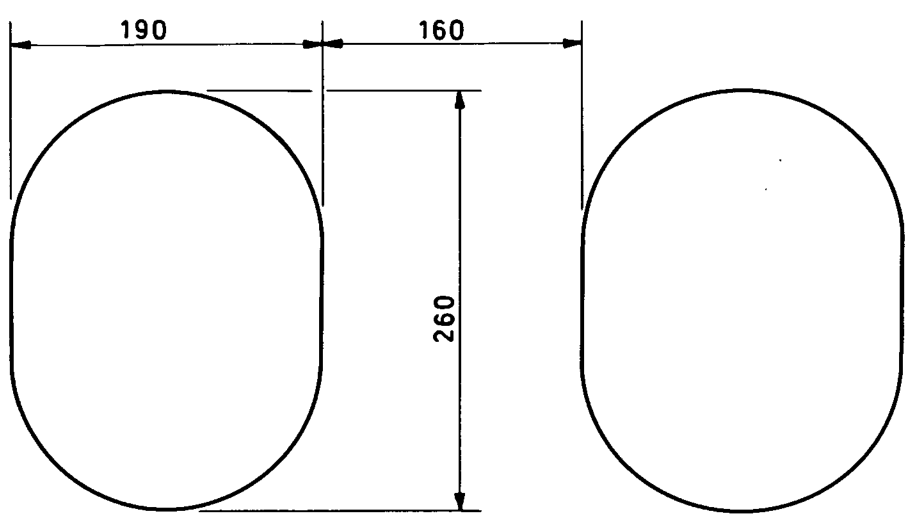


Fig. 8. METHOD OF PRESENTATION OF DEFLECTOGRAPH SURVEY



Deflection Beam tyre print



Deflectograph tyre print

(Dimensions in mm)

Fig. 9. COMPARISON OF WHEEL SPACINGS AND ENVELOPES OF CONTACT AREAS - DEFLECTION BEAM AND DEFLECTOGRAPH

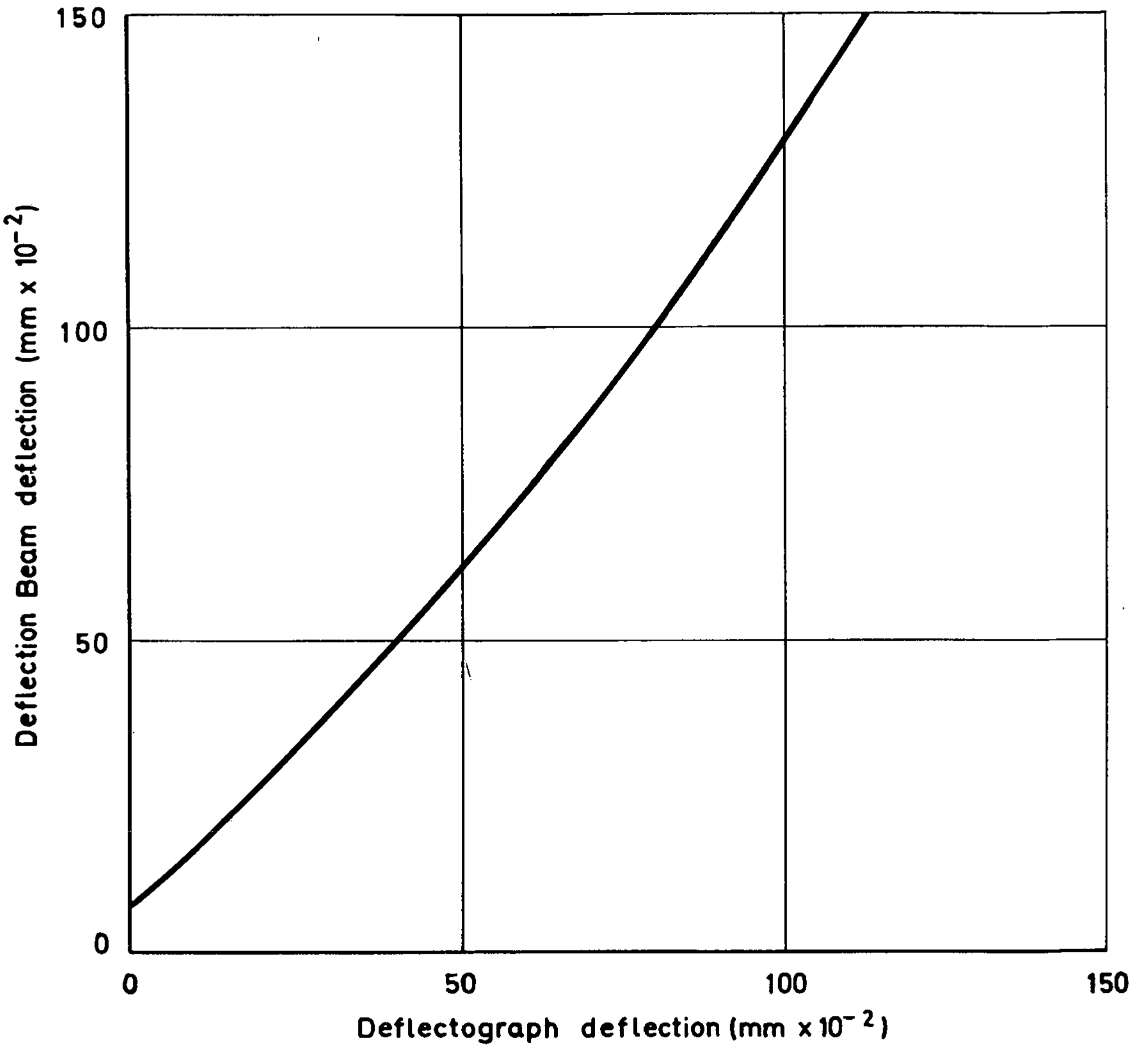


Fig. 10. CORRELATION BETWEEN DEFLECTION BEAM AND DEFLECTOGRAPH FOR PAVEMENTS WITH UNBOUND AND LEAN CONCRETE BASES AND HOT ROLLED ASPHALT SURFACING

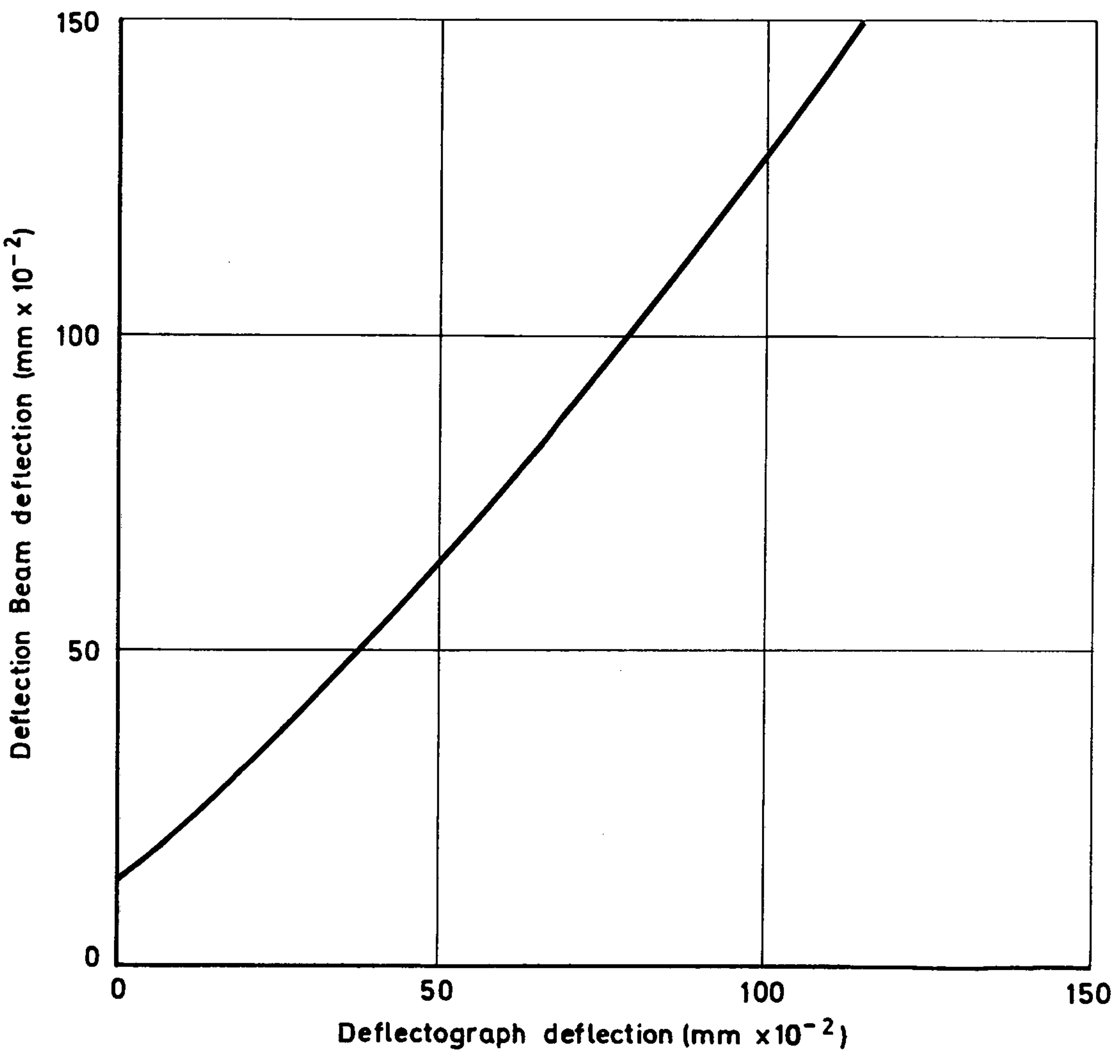


Fig.11. CORRELATION BETWEEN DEFLECTION BEAM AND DEFLECTOGRAPH FOR PAVEMENTS WITH BITUMINOUS BASES AND HOT ROLLED ASPHALT SURFACING

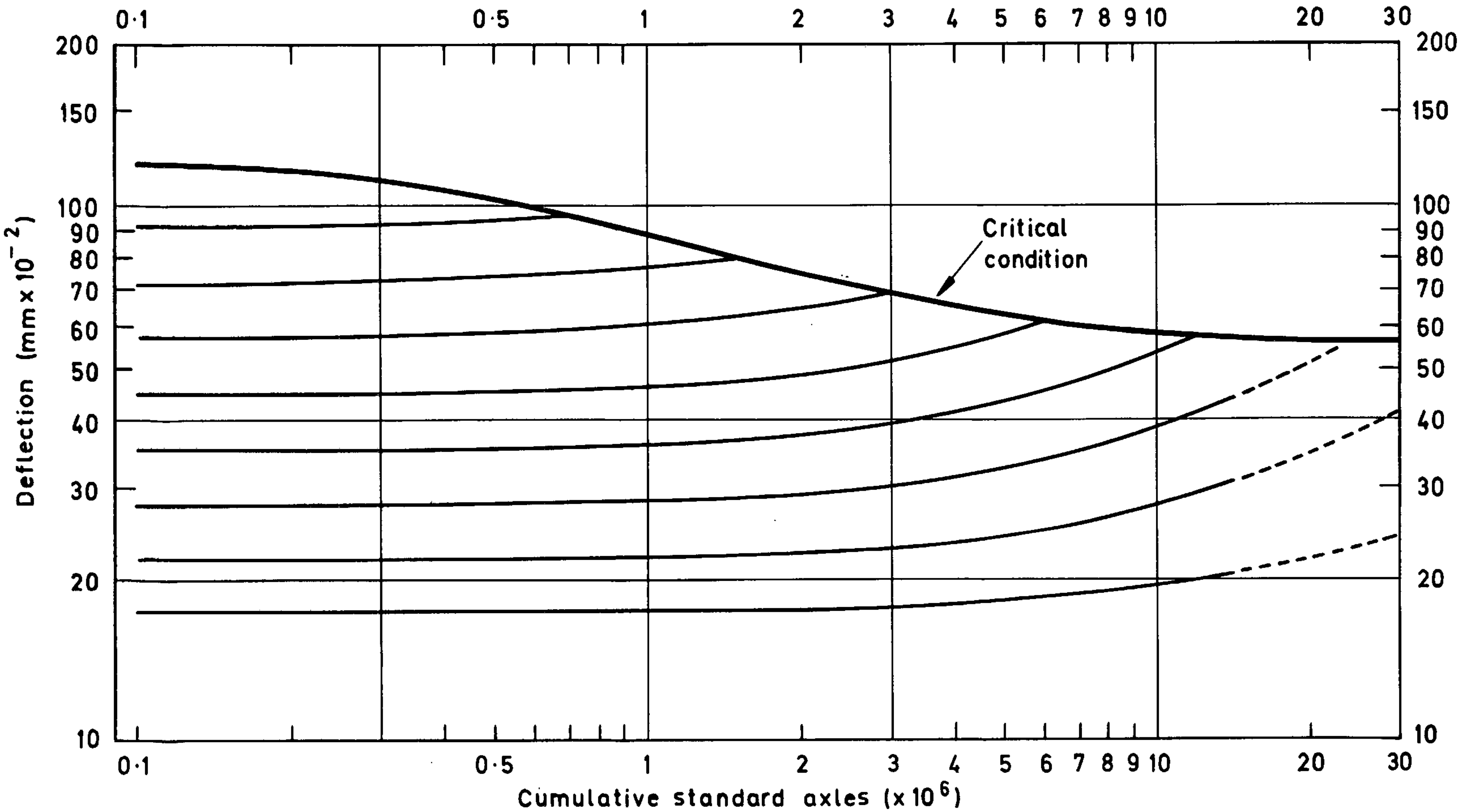


Fig. 12. DEFLECTION-LIFE RELATIONSHIPS FOR PAVEMENTS WITH UNBOUND BASES

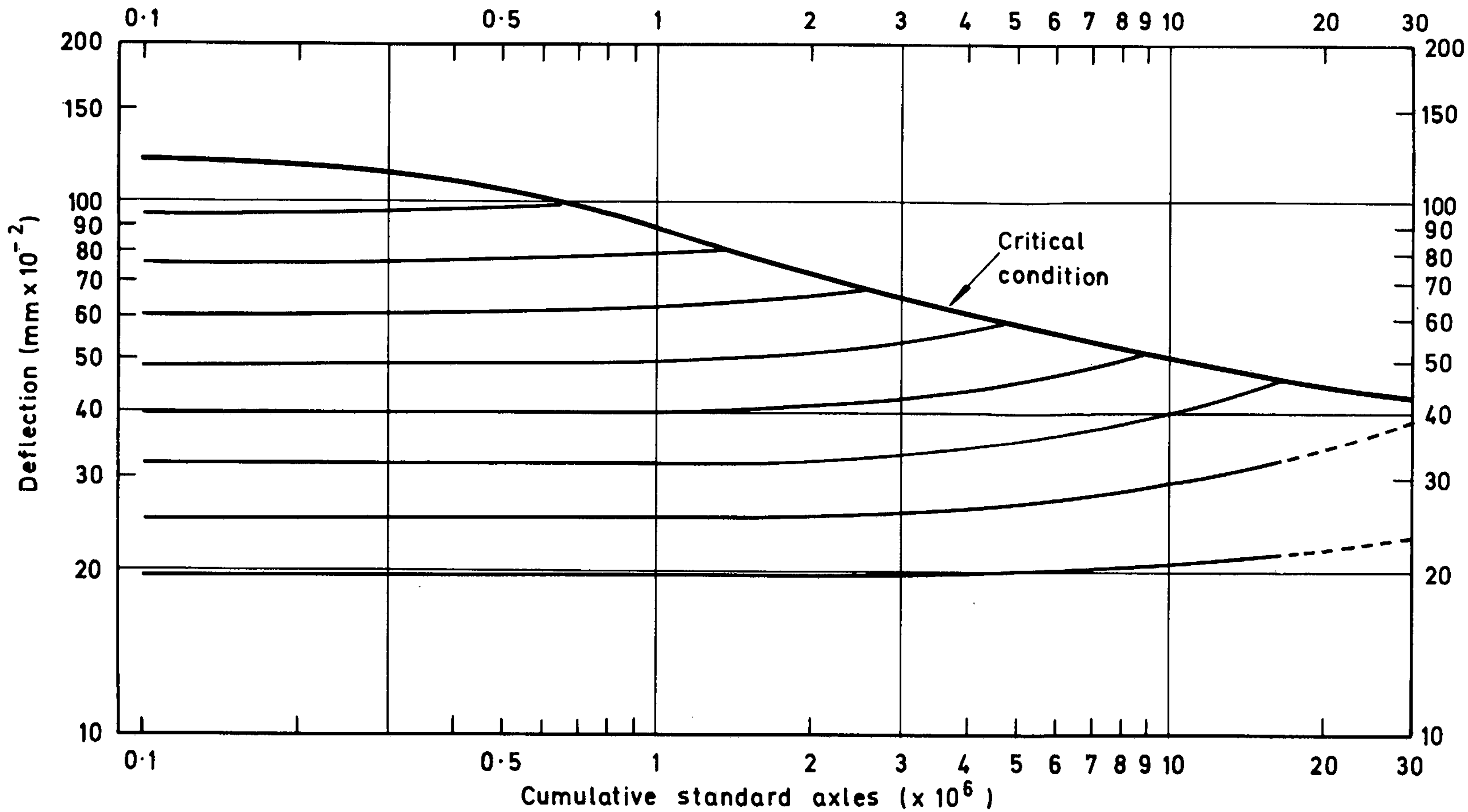


Fig. 13. DEFLECTION-LIFE RELATIONSHIPS FOR PAVEMENTS WITH BITUMINOUS BASES

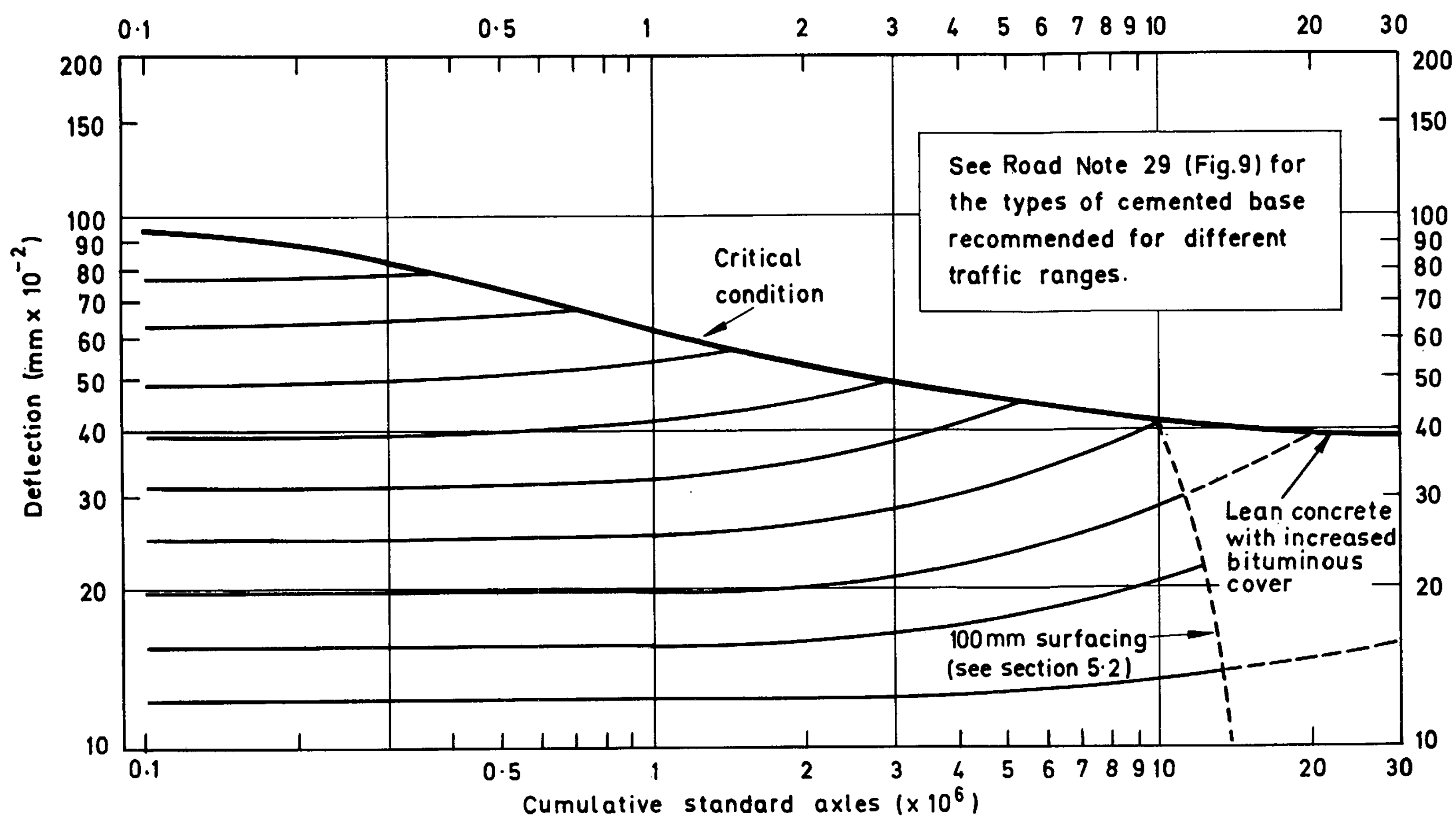


Fig. 14. DEFLECTION - LIFE RELATIONSHIPS FOR PAVEMENTS WITH CEMENTED BASES

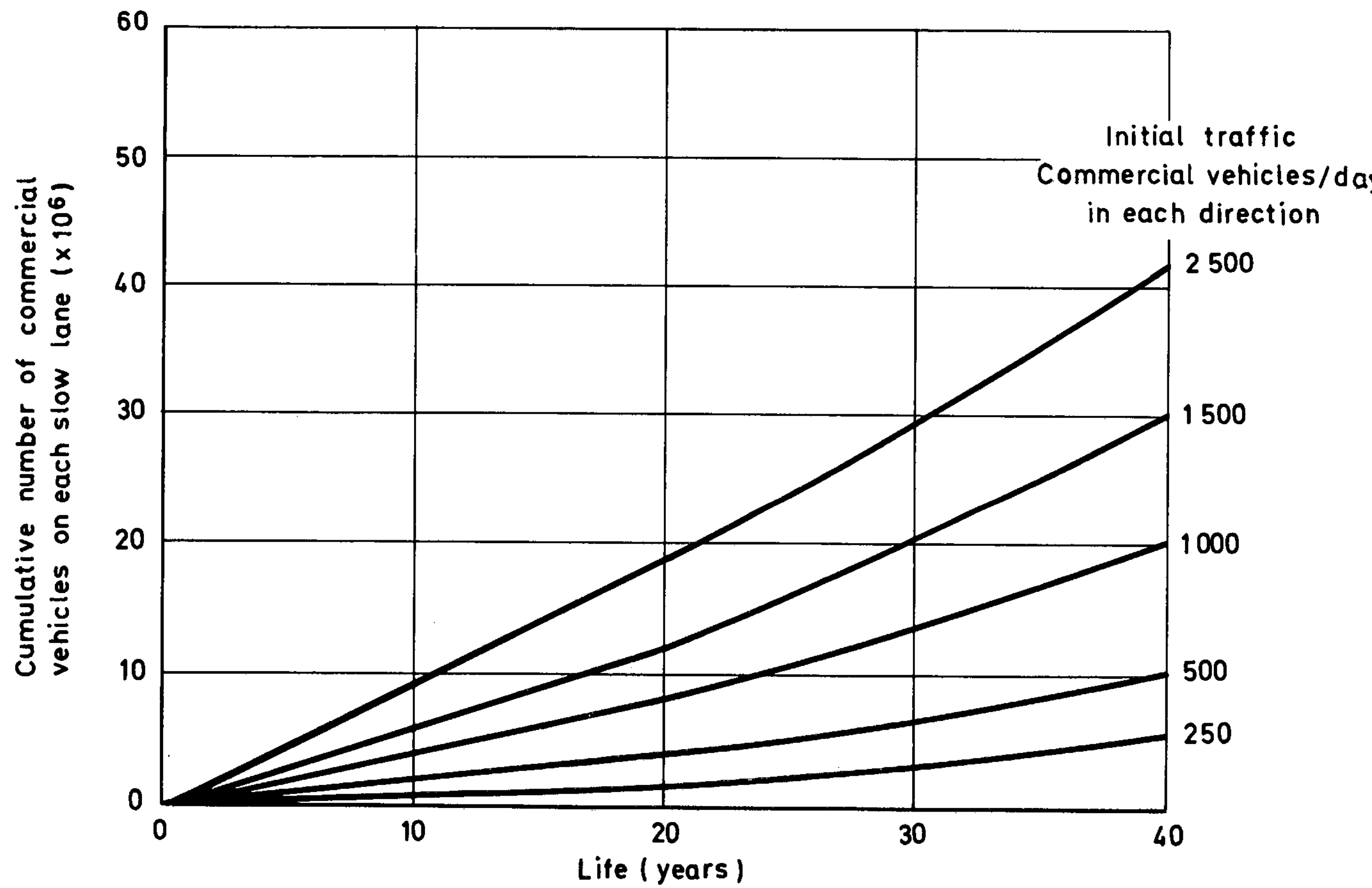


Fig. 15 RELATION BETWEEN CUMULATIVE NUMBER OF COMMERCIAL VEHICLES CARRIED BY EACH SLOW LANE AND LIFE :- GROWTH RATE 2 PER CENT

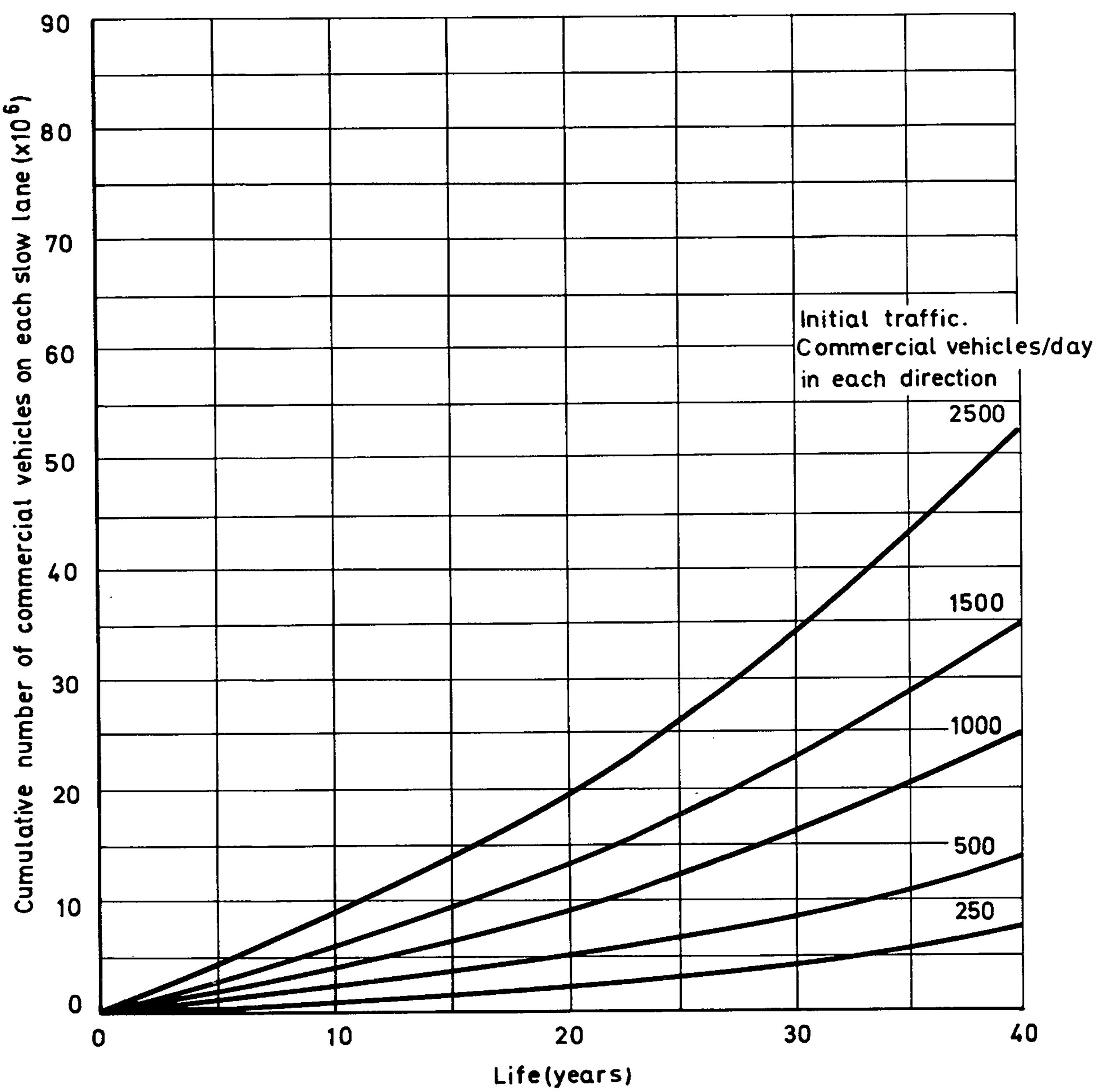


Fig.16. RELATION BETWEEN CUMULATIVE NUMBER OF COMMERCIAL VEHICLES CARRIED BY EACH SLOW LANE AND LIFE :- GROWTH RATE 3 PER CENT

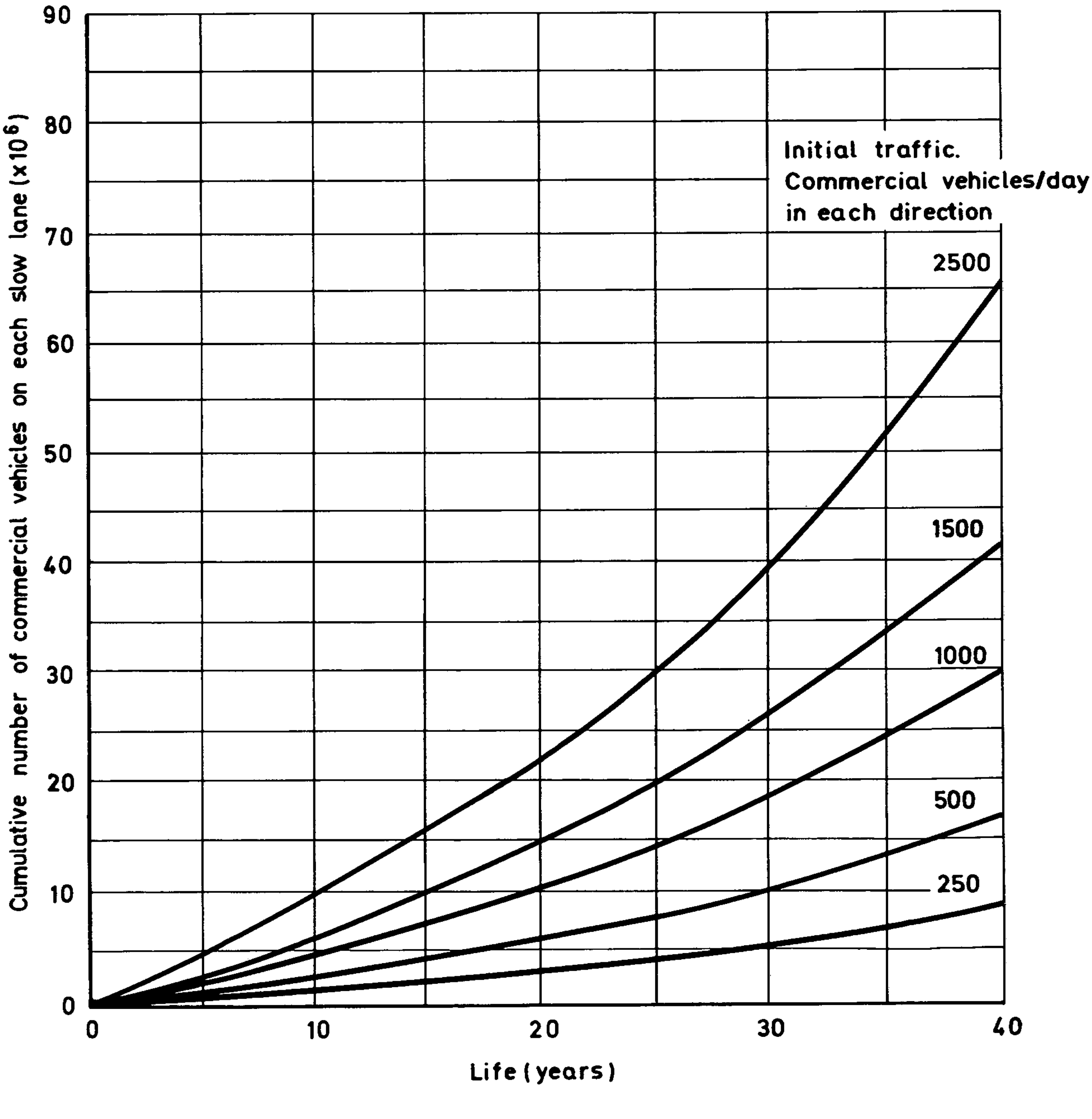


Fig.17. RELATION BETWEEN CUMULATIVE NUMBER OF COMMERCIAL VEHICLES CARRIED BY EACH SLOW LANE AND LIFE:- GROWTH RATE 4 PER CENT

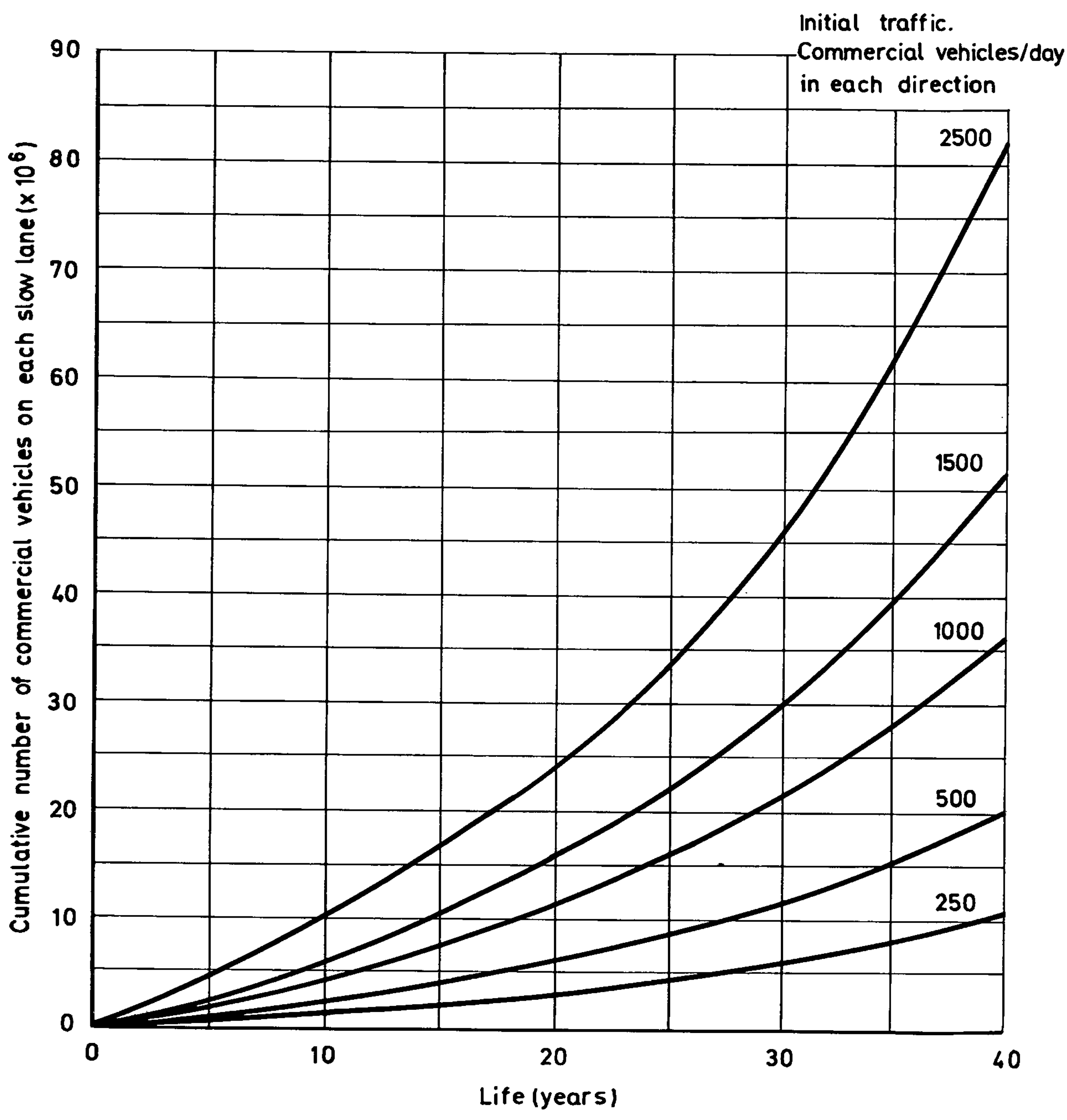


Fig.18. RELATION BETWEEN CUMULATIVE NUMBER OF COMMERCIAL VEHICLES CARRIED BY EACH SLOW LANE AND LIFE:-GROWTH RATE 5 PER CENT

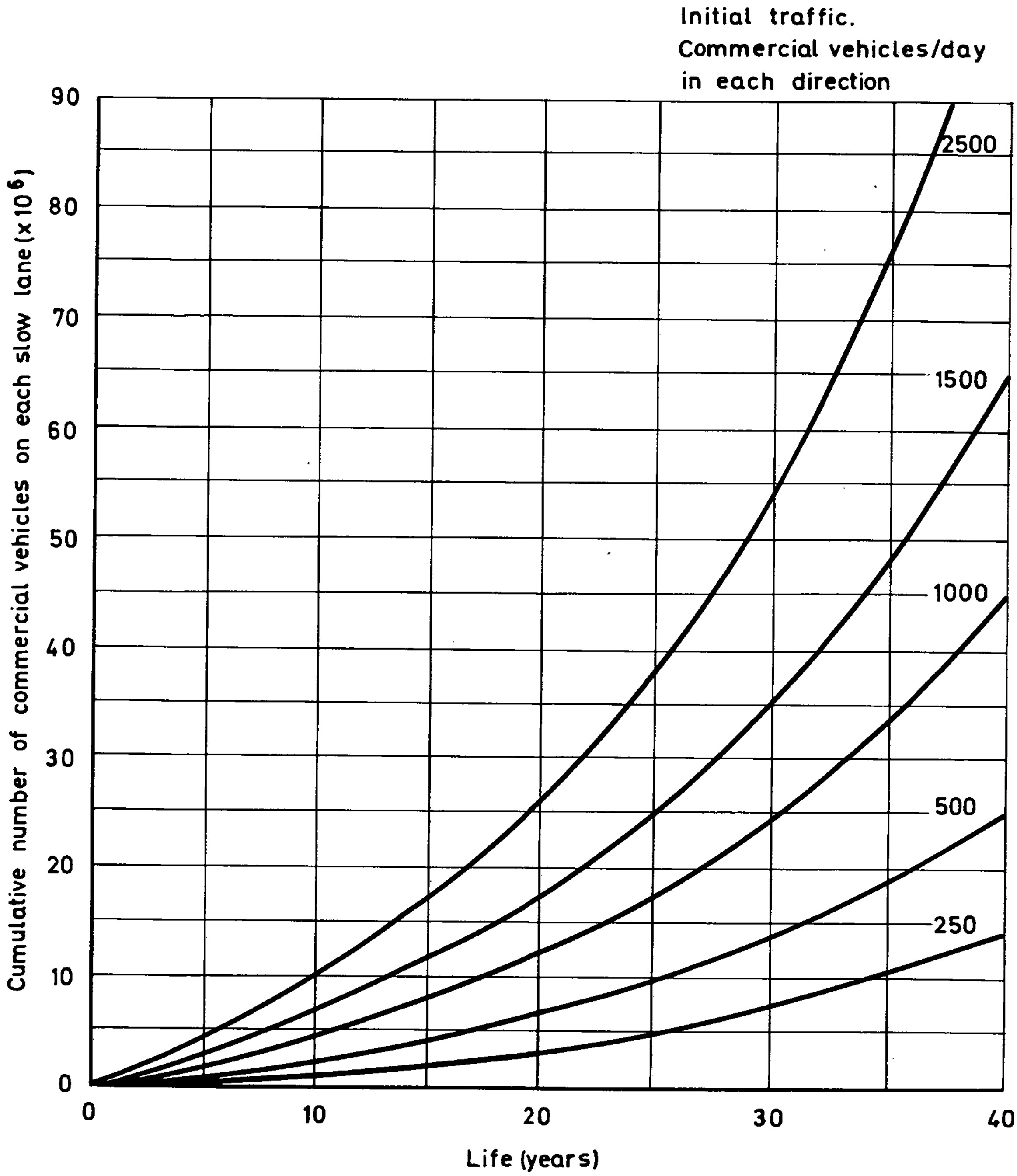


Fig. 19. RELATION BETWEEN CUMULATIVE NUMBER OF COMMERCIAL VEHICLES CARRIED BY EACH SLOW LANE AND LIFE:-GROWTH RATE 6 PER CENT

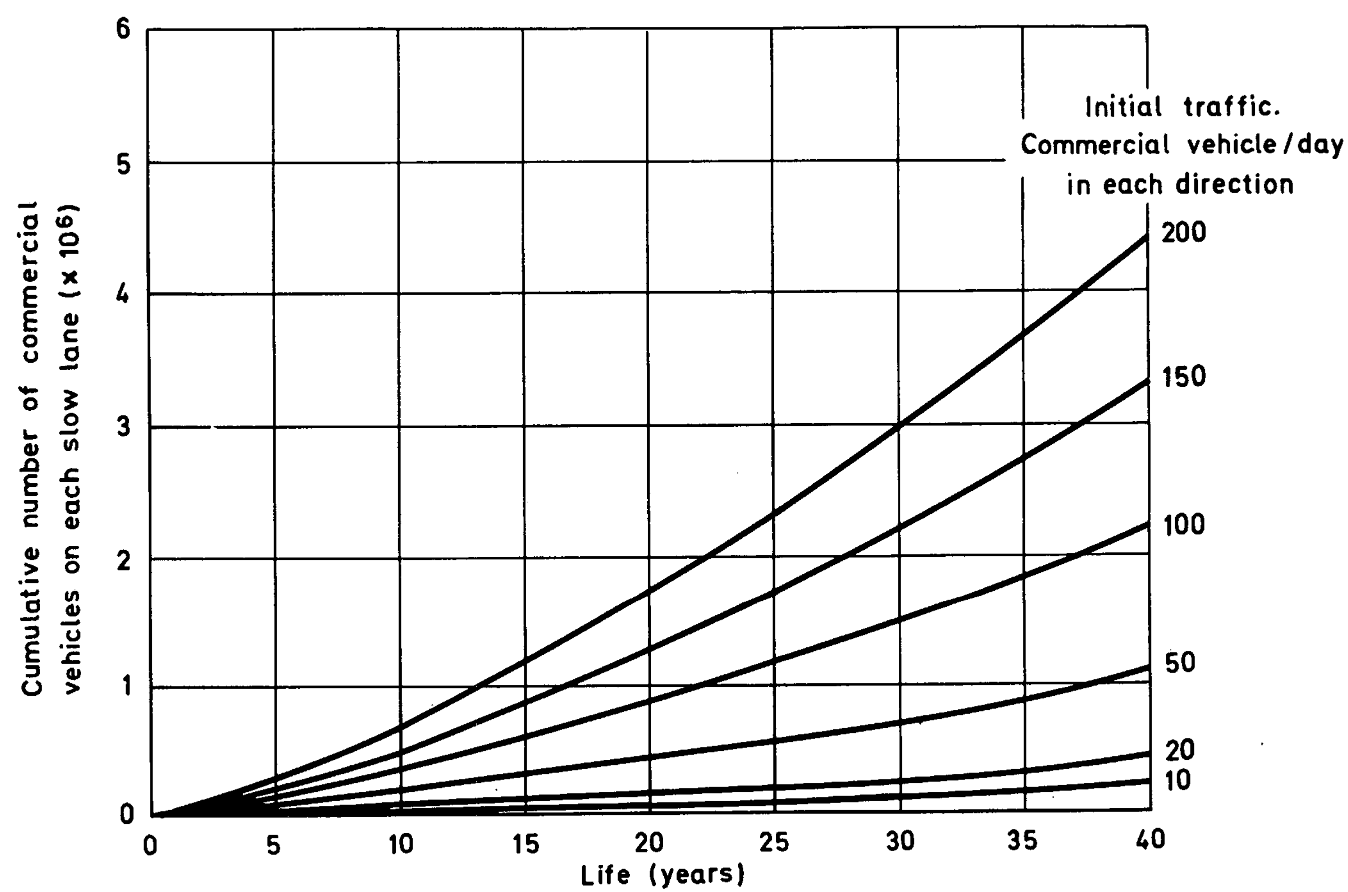


Fig. 20. RELATION BETWEEN CUMULATIVE NUMBER OF COMMERCIAL VEHICLES IN EACH DIRECTION ON LIGHTLY TRAFFICKED ROADS:-GROWTH RATE 2 PER CENT

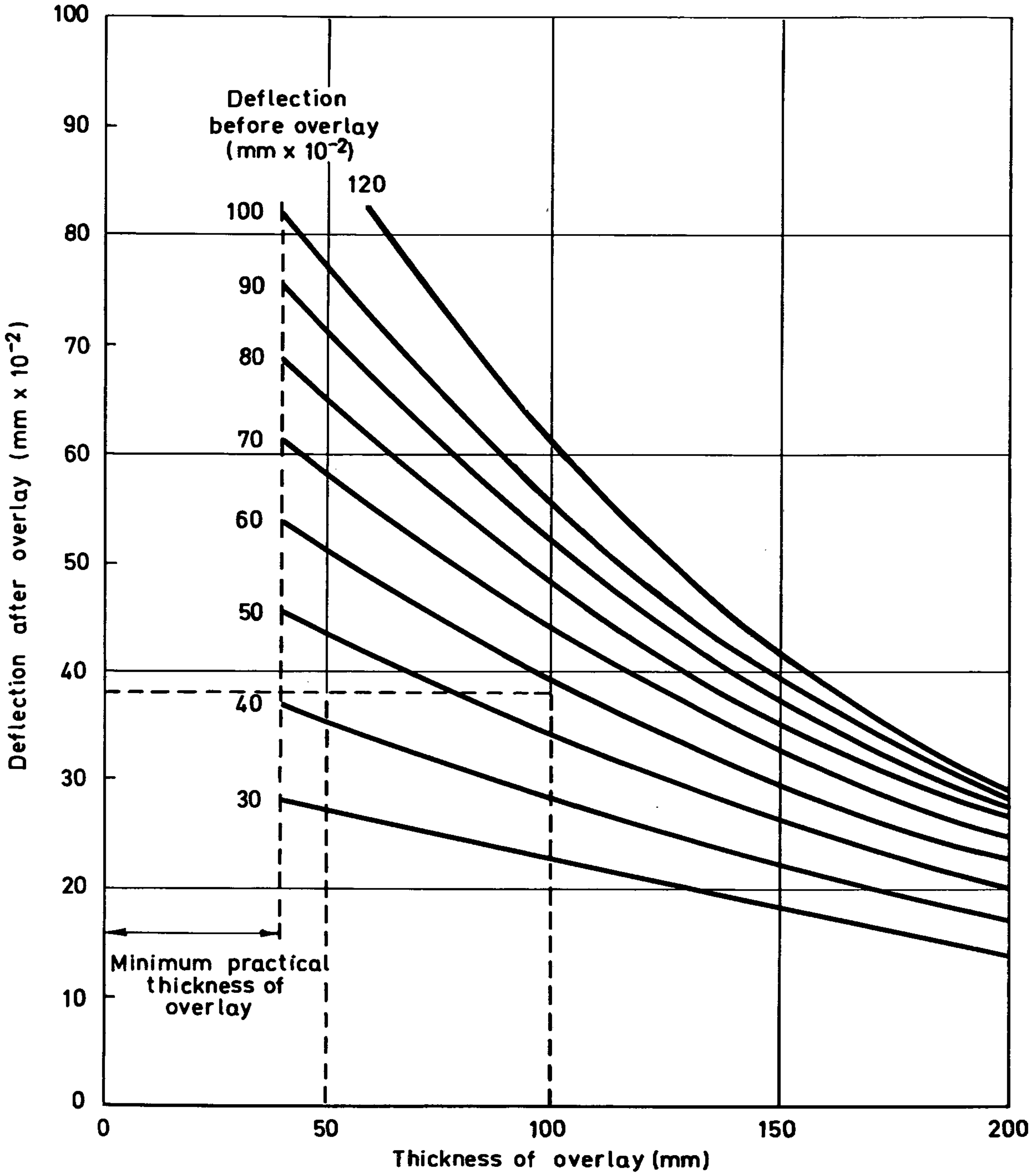


Fig. 21. OVERLAY DESIGN CHART

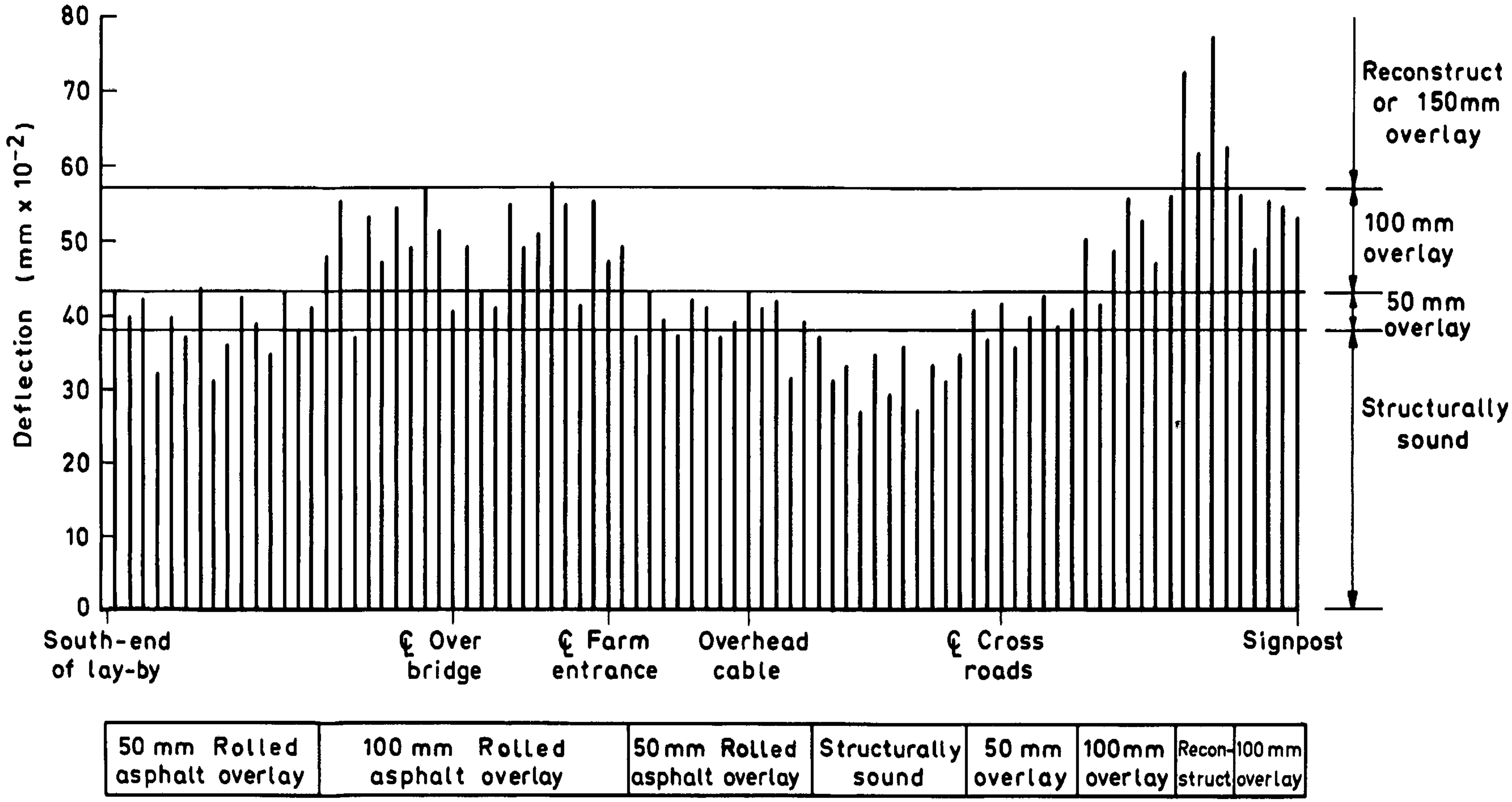
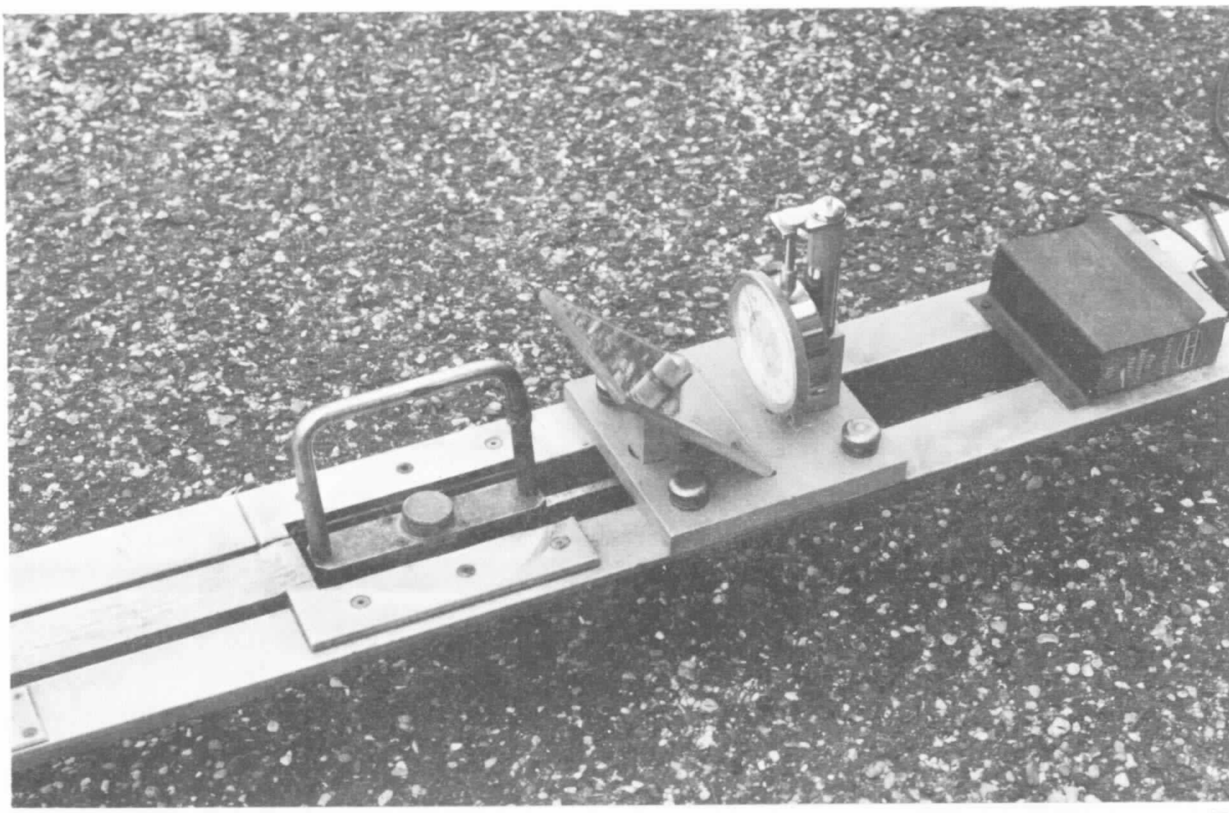


Fig. 22. STRUCTURAL MAINTENANCE REQUIREMENTS BASED ON DEFLECTOGRAPH SURVEY

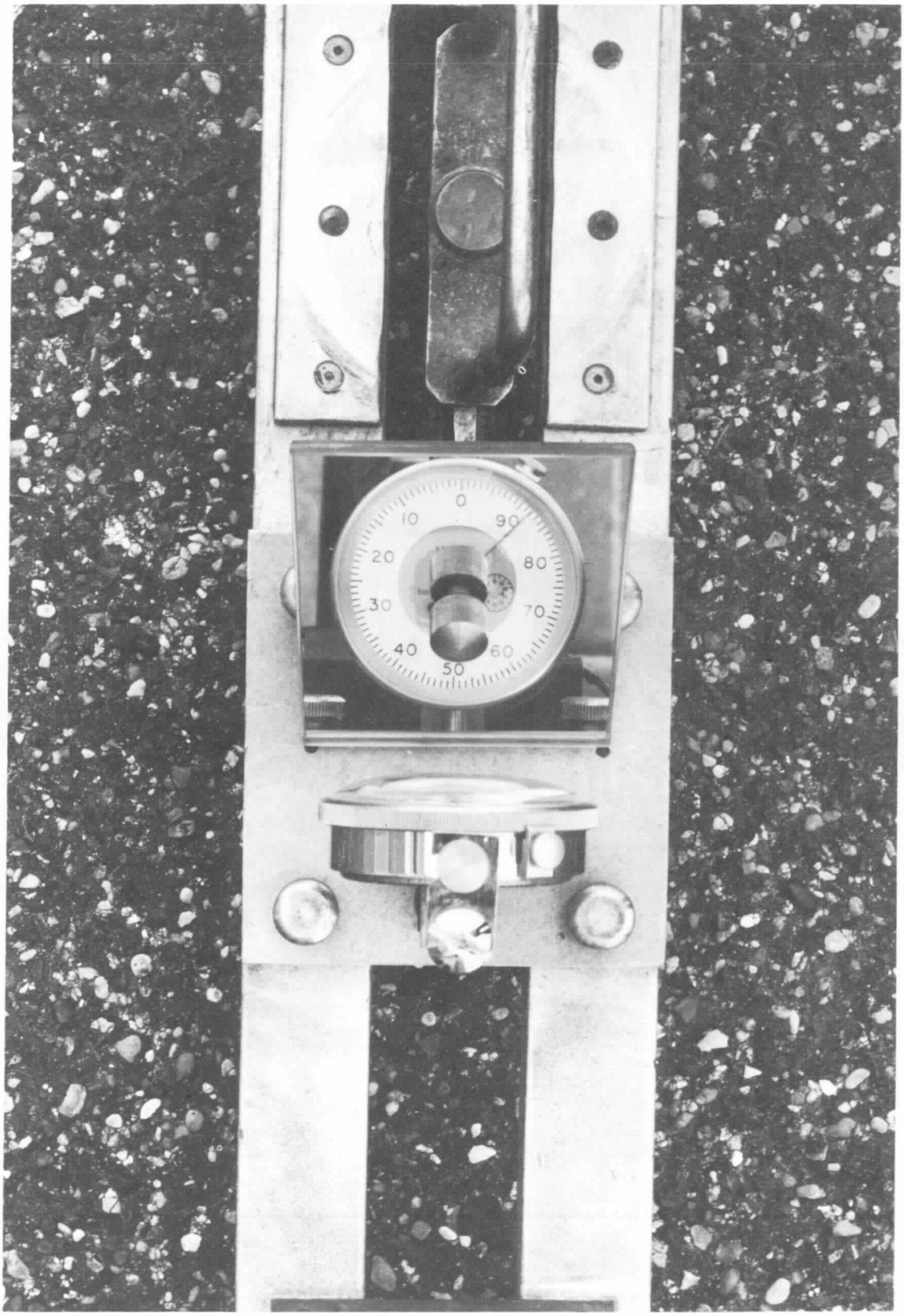
Neg. No. H320/72

Plate 1 THE DEFLECTION BEAM



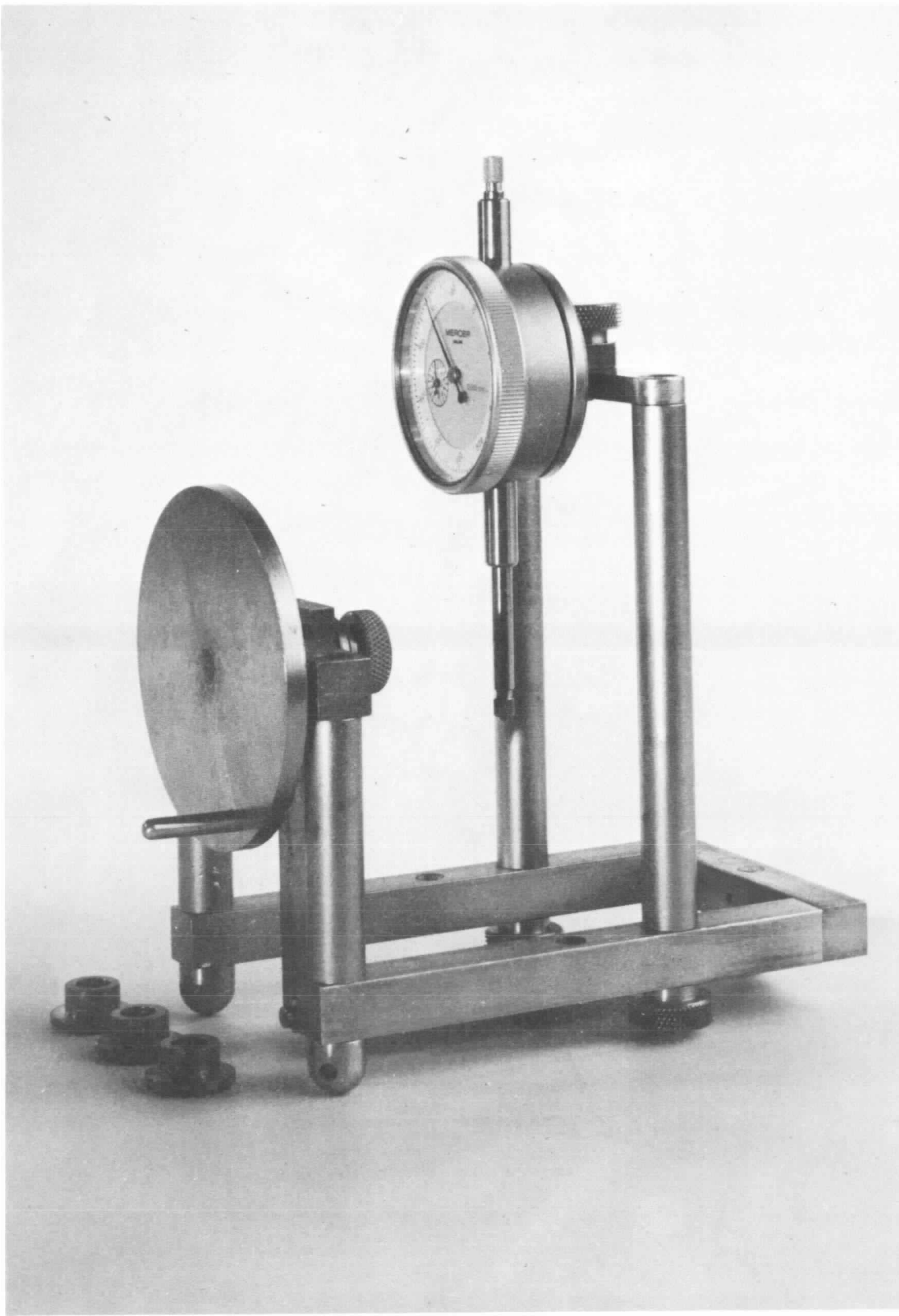
Neg. No. H319/72

Plate 2 CLOSE UP VIEW OF MIRROR AND DIAL GAUGE



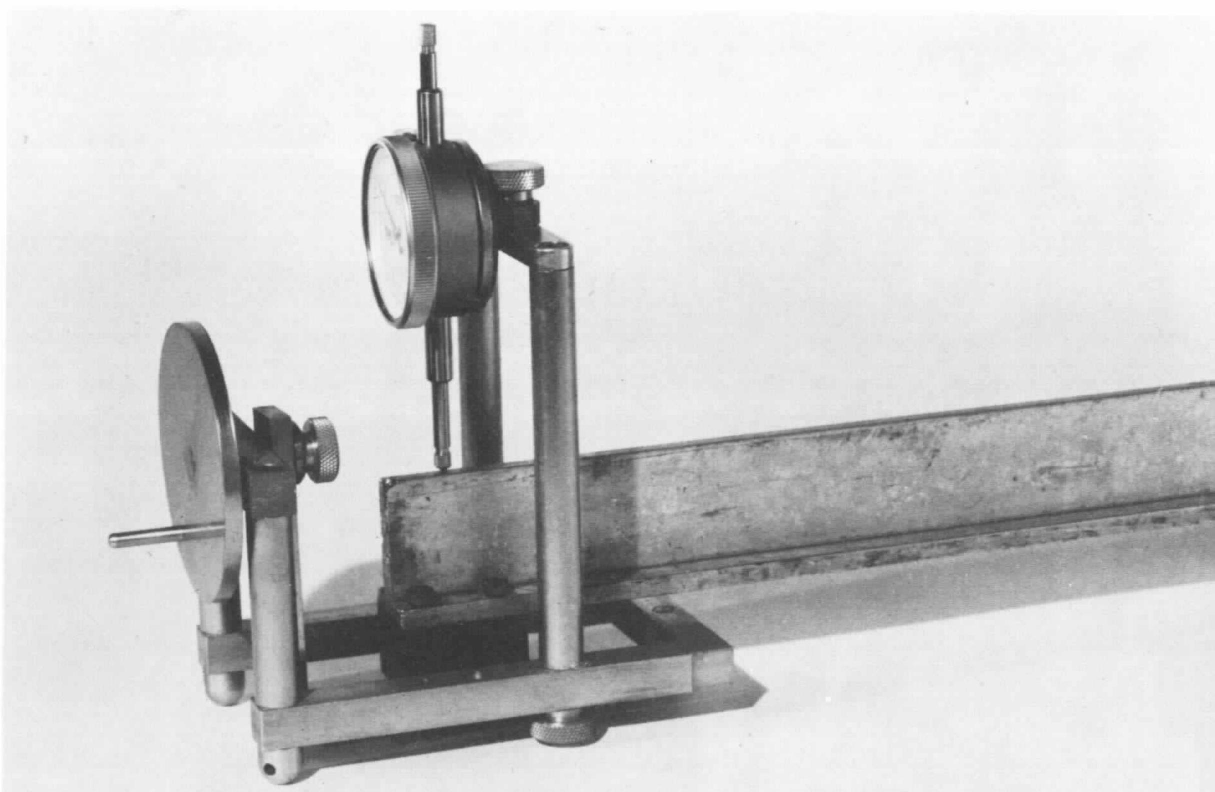
Neg. No. H317/72

Plate 3 VIEW OF DIAL GAUGE AS SEEN BY OPERATOR



Neg. No. H325/72

Plate 4 DEFLECTION BEAM CALIBRATOR

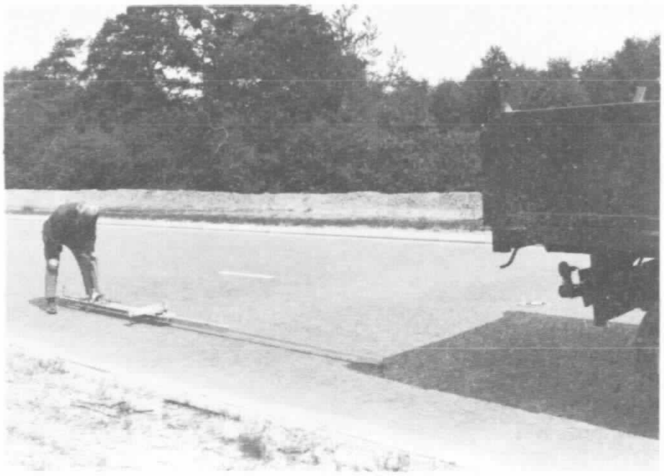


Neg. No. B3270/70

Plate 5 SHOE OF DEFLECTION BEAM IN POSITION ON PLATFORM OF CALIBRATOR

Neg. No. B1953/70

Neg. No. B1962/70

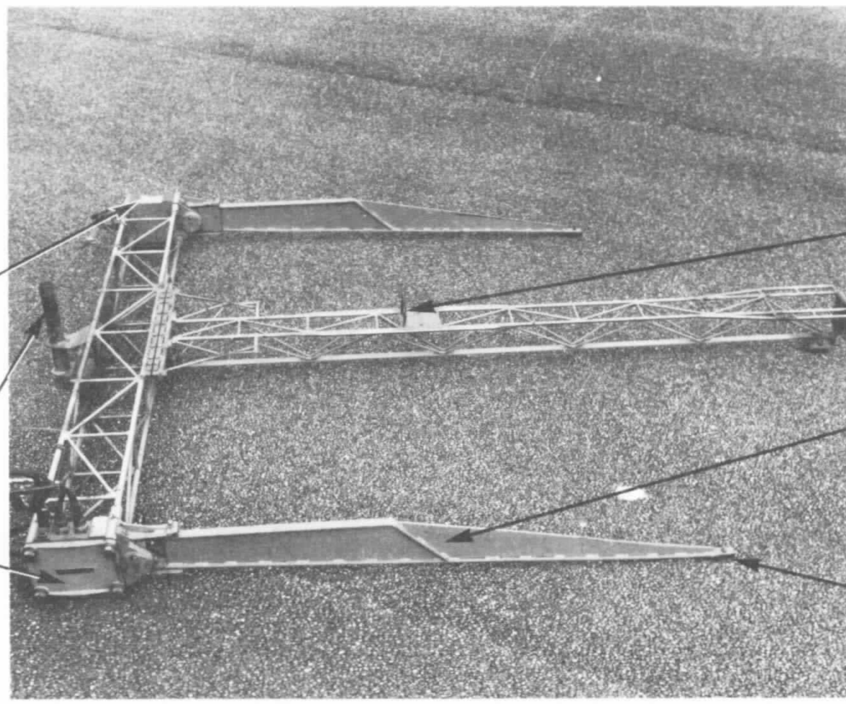


Neg. No. CB 2050/70

Plate 6 DEFLECTION BEAM – TEST SEQUENCE

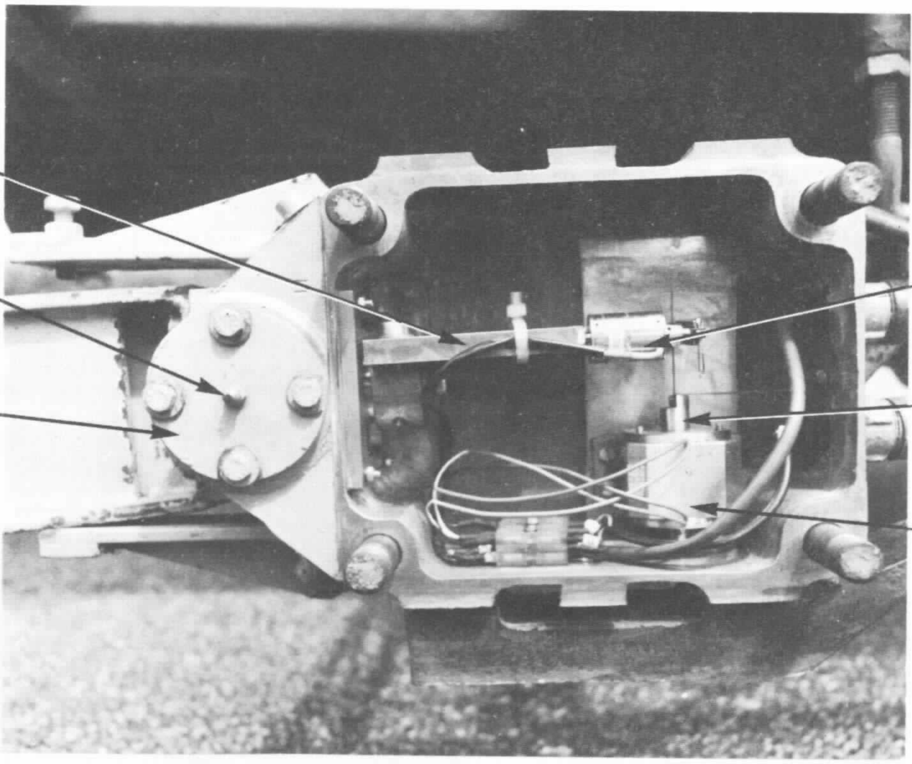
Neg. No. B1085/72

Plate 7 THE DEFLECTOGRAPH



Neg. No. B3150/71

Plate 8 DEFLECTOGRAPH – BEAM ASSEMBLY

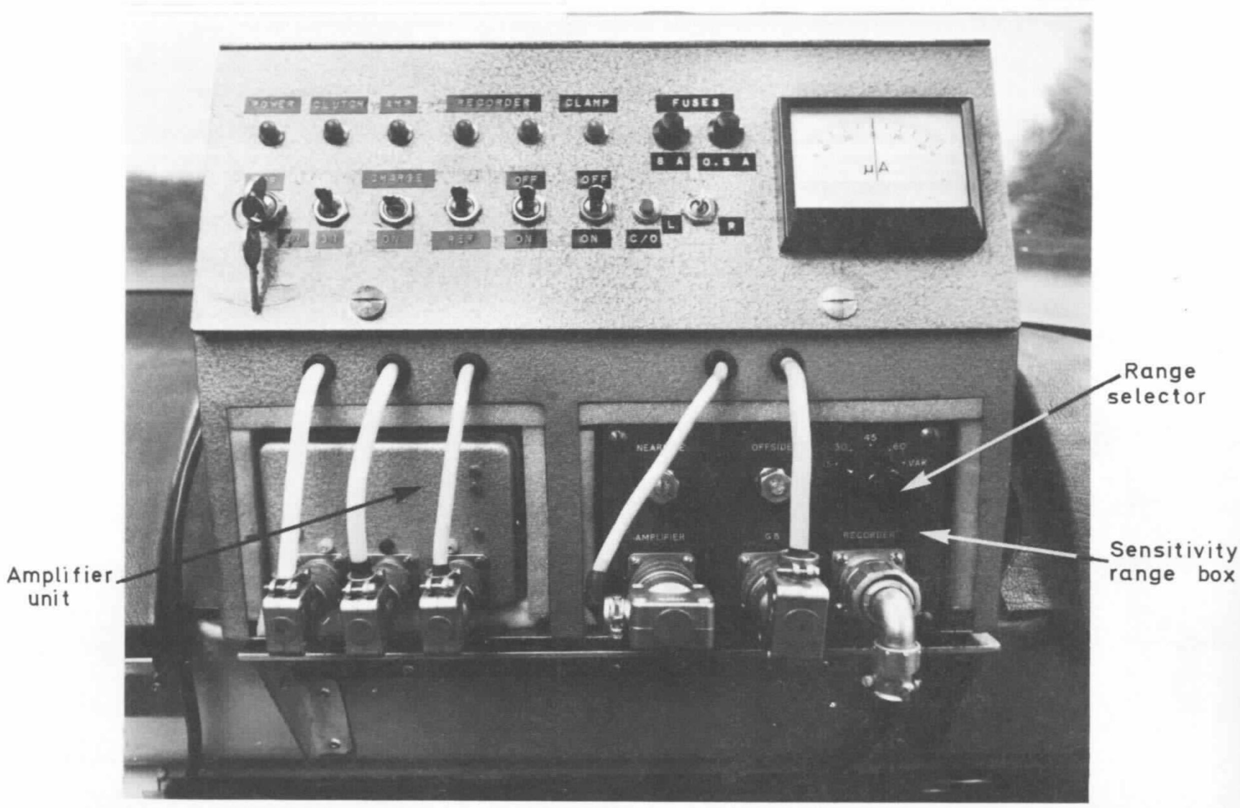


Neg. No. R3153/71/8

Plate 9 DEFLECTOGRAPH – RECORDING HEAD

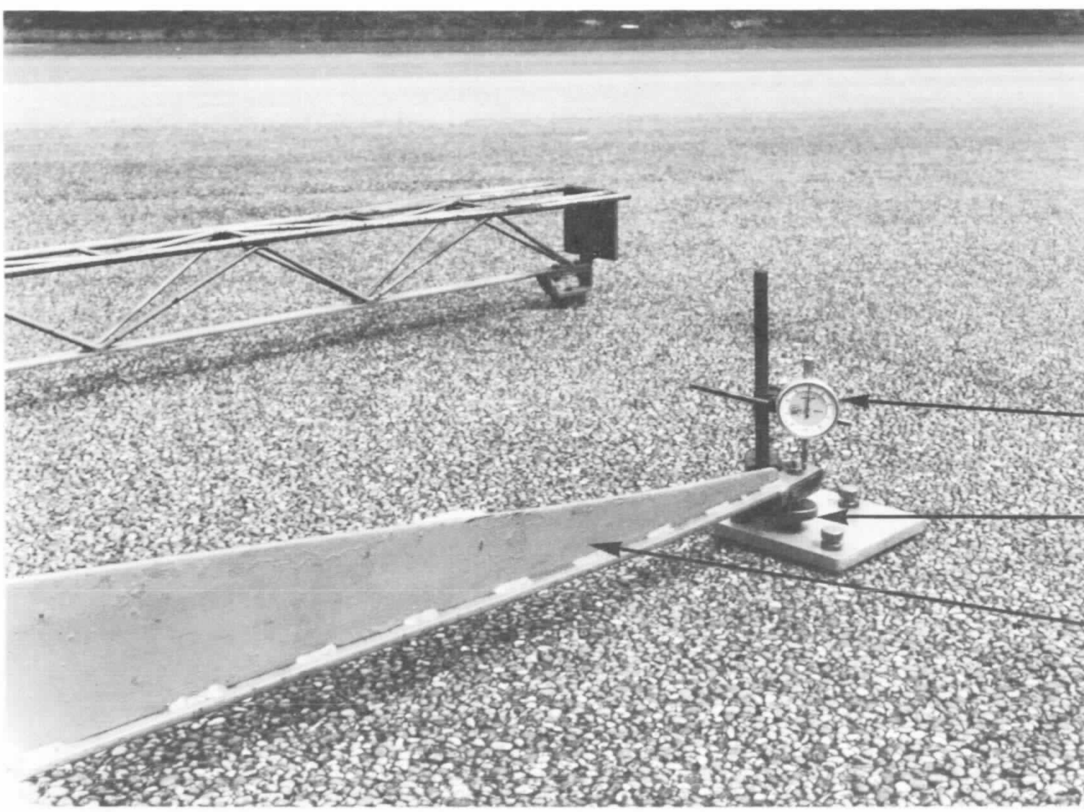
Neg. No. R3152/71/12

Plate 10 DEFLECTOGRAPH — RECORDER



Neg. No. R3152/71/6

Plate 11 DEFLECTOGRAPH – CONTROL PANEL



Neg. No. B3149/71

Plate 12 DEFLECTOGRAPH — CALIBRATION DEVICE

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ABSTRACT

Pavement deflection measurements and their application to structural maintenance and overlay design: Department of the Environment, TRRL Report LR 571: Crowthorne, 1973 (Transport and Road Research Laboratory).
The transient deflection of road pavements under the passage of a heavy wheel-load has been related, by studies on experimental and normal in-service roads, to the long-term performance of the pavements. This provides the engineer with a relatively simple method of forecasting the performance and future structural maintenance requirements for existing roads. This report, which does not discuss the research background to the work, is intended to present to the engineer the information he requires to make and interpret deflection measurements.

The use of the Deflection Beam is described in detail, together with the procedure for correcting measured deflections to a standard temperature of 20°C. As an alternative and more rapid means of measuring deflection, the Deflectograph and its method of operation are described. Curves to correlate deflection derived from the two methods are provided.

Deflection criterion curves, which take into account the changes in deflection which occur with age, are presented and used to estimate the life expectancy of pavements being considered for structural maintenance. Finally curves are provided from which the reduction in deflection and extension of life likely to accrue from the use of different thicknesses of rolled asphalt overlay can be deduced.

Examples illustrate the use of the deflection method in forecasting life and in the preparation of maintenance schedules.

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