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A GAUGE FOR THE MEASUREMENT OF TRANSIENT AND LONG TERM DISPLACEMENTS IN ROAD PAVEMENTS

by

N.W. Lister, B.Sc.(Eng), M.I.C.E., M.Inst.H.E. and A.P. Mayo

Pavement Design Section

Road Research Laboratory

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ABSTRACT

This Report describes the development and performance of a gauge designed to measure the transient and the long term movements which occur in the various layers of a road pavement, due to the passage of traffic.

Transient displacement is measured by a small, commercially available, inductive transducer and long term movements by a simple dial-gauge unit. Details of the construction and installation of the equipment are given.

1. INTRODUCTION

The passage of a wheel load over a road surface generates transient stresses and strains within the various layers of the pavement and in the underlying sub-grade. This is reflected in the deflection of the road surface as the sum of the transient deformations of each element of the road pavement and sub-grade.

Measurements of transient stresses, strains and displacements are vital to a complete understanding of the way in which roads behave. They enable the validity of any assumption of idealised transient stress-strain behaviour, such as the widely adopted multi-layer elastic model, to be examined as the first stage in developing methods of pavement design based on concepts of limiting stress or strain.

Gauges for the measurement of the vertical component of stress in the sub-grade and strains in sub-grades, bound bases and surfacings have been developed at the Road Research Laboratory and elsewhere. Such gauges have now been designed to measure the total deflection and the transient movement of pavement interfaces relative to the road surface from which the transient deformation, or deflection, of the road layers can be deduced by difference. They can be used to examine the transient behaviour of roads under rolling wheel loads, either independently or in conjunction with stress and strain gauges. They have the advantage that they can be installed in an existing road giving flexibility in the choice of gauge position.

This report describes the development of the design to its present form, the technique of installation and the performance. In its developed form the gauge can also be used to measure the long term movements after prolonged trafficking as well as the transient ones associated with particular wheel-loads.

2. DESIGN OF THE GAUGE

To measure directly the transient or permanent deformation of any layer of a road directly it is necessary to install a rigid measuring device within that layer anchored at one face so that the relative movement of the opposite face can be detected. In practice it is more convenient to make measurements of this type indirectly, by measuring independently the transient and permanent displacements, with respect to the road surface, of the bottom of each pavement layer. Movements within the layers can then be obtained from differences. The accessibility from the road surface of the measuring system avoids the necessity of burying expensive transducers permanently.

A suitable gauge consists of three principal components.

a) A casing fixed in the road surface acting as a datum from which transient or permanent movements of the interfaces between pavement layers are measured,

b) a rod anchored at its lower end at the interface whose movement is to be measured (or at a great depth in the soil foundation to allow the total movement of the road to be observed),

c) a detachable displacement transducer (or dial guage) which can be installed in the casing when required to measure the movement of the datum rod relative to the casing.

Gauges of an early design installed experimentally in 1957 for the measurement of transient displacements, on seven of the thinner sections of the Alconbury Hill experimental road are shown in Fig. 1.

The gauge consisted of an aluminium casting in the form of a barrel 51 mm in diameter with a wider flange having its upper surfaces machined.

For measurements of transient displacement within the road pavement the anchor rod consisted of a hexagonal steel bar having a self tapping screw at its lower end. This enabled the anchor rod to be screwed into a perforated anchor plate located at the required level during the construction of the road. The 100 mm square anchor plates had flanged edges to provide a key with the underlying material. For gauges intended to measure the total transient or permanent deformation of pavement and sub-grade a modified anchor rod 13 mm in diameter and 3 m long was used, operating in a loose sleeve as shown on Fig. 1. The lowest 300 mm of the rod was knurled to provide a bond with the soil into which it was driven.

To measure transient movements the smallest displacement transducer then available was used, mounted in the manner indicated on Fig. 1. This was a helical wire-wound potentiometer transducer of 13 mm range using varnish-coated platinum-iridium wire to give approximately 0.0254 mm spacings and corresponding sensitivity. When the transducer was in place the shaft was maintained in spring loaded contact with the anchor rod through a brass disc of a diameter slightly less than that of the internal bore of the gauge casing. This permitted operation when there was some eccentricity of the anchor rod relative to the axis of the gauge casing.

At failure, roads may be subject to permanent deformation of up to 25 mm. To maintain the displacement transducer in its working range, under such conditions, provision was made to take up this movement by adjustable caps carried on sprung micrometer threads at the top of the anchor rod. Double units of this type giving a travel of 32 mm were used on the total transient deformation gauges anchored at sub-grade level and single units on the gauges measuring displacements in the pavement in which the permanent movement would be less, Fig. 1. The screw threads were protected from rust and dirt by rubber sleeves packed with grease.

3. RECORDING

In operation the potentiometer transducer constituted the two active arms of a commercially available Wheatstone Bridge unit having a supply, variable up to 24 volts. The output signal was displayed on a double beam oscilloscope and recorded by a multi-speed camera on 35 mm photographic paper.

A typical output record is given in Fig. 2. This shows the total transient deformation of a road structure (datum rod anchored below sub-grade level) as the front and rear wheels of a loaded commercial vehicle passed over the point of measurement. At the maximum supply voltage the sensitivity achieved was approximately 0.015 mm deflection per mm of trace. The steps caused by the movement of the transducer wiper from one winding to the next can be seen.

On this record a second oscilloscope channel was used to provide a distance scale. This was done by causing one wheel of the vehicle to complete battery operated circuits via contacts placed on the road surface, in front of, and behind the gauge.

4. INSTALLATION OF THE EARLY-TYPE GAUGES AT THE ALCONBURY HILL SITE

During construction of the pavements at Alconbury Hill anchor plates were placed on the formation and on the top of the sand sub-base and their exact position located from the edge-beam used on this road. After the wearing course was laid a rock drill was used to drive a 51 mm diameter hole through the surfacing and base above the centre of the buried plate. For a gauge anchored at the top of the sub-base the hole was lined with brass tubing and the anchor pin screwed down tightly into the most conveniently placed perforation in the plate. Installation at formation level involved removing the single-size sand sub-base and to avoid possible collapse of the sand a liner tube was first driven down and the enclosed sand removed by jetting with compressed air.

For gauges designed to measure total movements a liner tube was installed in the same way and the bore then extended with a 25 mm screw auger to a depth of 3 m. A further brass liner of 19 mm internal diameter was lowered down the hole and the anchor rod, greased to reduce possible friction in the liner, inserted and driven for about 300 mm below the end of the liner into the sub-grade.

To accommodate the flange of the gauge casing a dish was cut in the wearing course using a chisel attachment to the rock drill. The gauge casing was then fixed level with the road surface using a hot poured mastic asphalt filling.

5. PERFORMANCE OF THE GAUGES AND DEVELOPMENT OF THE FINAL DESIGN

In the absence of previous experience with gauges of this type their use at Alconbury Hill was largely in the nature of an experiment. They were installed in the weakest sections included in the Alconbury Hill trials. The sections failed within the first two years so that the experience gained was relatively short-term.

The modified design, shown in Fig. 3 has been evolved in the light of this experience and subsequent trials in the Laboratory grounds. This is considered below.

5.1 Gauge resolution

The limitation on the resolution of transient movement imposed by the wire-wound potentiometer type of transducer was not serious in recording the total deflection or the component displacements in relatively weak pavements. It was clear however that this type of transducer would be too insensitive to record component displacements of modern forms of construction incorporating bound bases laid in thicknesses dictated by current design standards.

The development during the past 10 years of very compact transducers based on the measurement of reluctance change brought about by the movement of a magnetic core in the two halves of a centre-tapped solenoid has enabled a much more sensitive gauge to be designed round the original principles.

The transducer used is 13 mm in diameter with a coil length of 64 mm and giving a linear response over a range of ± 6 mm. The transducer unit is sheathed in a nylon sleeve serving as a frictionless bearing to guide the shaft carrying the magnetic core. The spring loading system to maintain positive contact with the anchor pin is retained in the modified design. The transducer unit is shown in Plate 1.

The centre tapped solenoid configuration of the windings constitutes two arms of an A.C. bridge excited at a frequency of 3 kilocycles per second. The output is passed through a demodulator and, if greater sensitivity is required, through a further carrier amplifier. The output signal from this equipment is normally displayed on a multi-channel recorder using paper sensitive to Ultra-violet light. However the output is also suitable for magnetic tape recording if required. Fig. 4 shows a typical record reproduced from the recording paper. In this case transient displacements at various levels in a road structure are recorded for the passage of a single heavy wheel-load.

5.2 Depth of anchorage necessary for the measurement of total transient deformation

It is known that the influence of traffic stresses and strains extends to a considerable depth in the sub-grade. Under thick pavements and under those whose stiffness is great relative to that of the sub-grade, the absolute stress levels in the sub-grade are small but the depth influenced by them is greater than is the case for weaker pavements on strong sub-grades. This has been demonstrated in practice by Hveem who detected significant movement at depths greater than 6 m in the extreme case of rigid pavements situated on a sub-grade of weak normally consolidated clay sediments[1].

On the weak pavements instrumented at the Alconbury Hill experiment, deflections measured by the Deflection Beam and by the gauges recording total transient deformation were not significantly different indicating that the embedment depth of 3 m used at that site was satisfactory.

At a later experiment where stronger pavements were instrumented, while good agreement between gauges and Deflection Beam was obtained on sections constructed with a bituminous bound and crushed stone bases, on very stiff lean concrete bases the deflections measured with the Beam were appreciably the greater. The order of the difference found has been confirmed by multi-layer elastic analysis. While lowering the anchorage level to depths greater than 5 m increases installation difficulties, this appears to be necessary to record total deflection satisfactorily under very stiff pavements.

5.3 Effect of the gauge's presence in the road

The presence of even a small gauge will interrupt the continuity of the pavement and may possibly alter the magnitude of the movement it is designed to measure. The significance of this effect has been investigated. The Deflection Beam was used to examine the variation of road stiffness in the immediate vicinity of the gauges and no significant changes attributable to the gauge's presence could be detected. However softening of the mastic asphalt under the flanges of several of the original gauge casings resulted in settlement and tilting under hot summer weather.

Reduction of the flange diameter to 70 mm has enabled the seating aperture for the redesigned casing to be accurately cut in the wearing course with a 76 mm diameter rock drill. The use of epoxy-resin to fix the casing in this accurately prepared aperture has eleminated all relative movement.

No evidence was obtained that the presence of rigid liner tubes, not grouted into the surrounding material, affected the stiffness or performance of the road in the immediate vicinity of the original gauges during the period of observation at Alconbury Hill. However the opportunity was taken in the redesign to modify the liners within the pavement to give radial stiffness to the holes while providing flexibility in the vertical direction. This was achieved in the surfacing by inserting spaced brass liner rings designed to be a sliding fit in the newly drilled hole. These were held in place by a film of adhesive. Through granular bases and sub-bases a composite liner of alternate lengths of brass and P.V.C. tubing fulfilled the same function. The detailed procedure recommended for installing the gauges in the road is given in Appendix 1.

5.4 Measurement of long term displacements

A slightly modified version of the original gauge described in Section 2 of this Report was used to measure long term movements and separate units were installed for this purpose at Alconbury Hill. The latest gauge has been designed to be suitable for the measurement of permanent as well as transient displacements within the same unit. The permanent deformation of the road is deduced from measurements made between the anchor rod and the gauge casing secured in the road surface, and deformation within various layers is obtained by difference as with the transient deformation measurement. Clearly no change must be made in the length of the datum rod once the first observations have been made. This means that the value of the adjustable rod length in compensating for long term movement in transient displacement measurements (Section 2) is lost, and an alternative method of compensation is required. This can be provided in the mounting of the transducer unit in its brass collar, Plate 1. The nylon sheath of the transducer is a push sliding fit in the collar and can be secured in any desired position by grub-screws engaging with closely-spaced dimples in the sheath. If this arrangement is adopted the adjustment at the datum rod can be dispensed with, as shown in Fig. 3, but provision of adjustment at this point can be a convenience, in obviating the need for close length specification of the rod.

To measure long term movement of the pavement interfaces relative to the road surface or the total permanent deformation of the road the displacement transducer is replaced by the dial gauge unit shown in Plate 2. This is carried on three radially aligned knife edges which rest on the recessed upper surface of the gauge casing. Contact is made between dial gauge and anchor pin by a set of interchangeable feet. Before use the zero of the gauge must be set using a suitable calibrating jig.

Initial readings taken before the road is opened to traffic establish the datum from which subsequent permanent movements are then established by difference.

6. CURRENT INSTALLATIONS

The gauges in their present form have been installed in experimental pavements at Harmondsworth, in Road Machine No. 3 and on the road experiment at Conington Lodge on A.1. Results obtained are to be the subject of separate reports.

7. ACKNOWLEDGEMENTS

This report was prepared in the Pavement Design Section of the Design Division.

8. REFERENCES

1. HVEEM, F. N., Pavement Deflections and Fatigue Failures. Highway Research Board Bulletin No. 114. 1955.

9. APPENDIX I

DETAILS OF THE INSTALLATION OF DEFLECTION GAUGES IN THE ROAD STRUCTURE

The method adopted for the installation of the latest type of deflection gauge, Fig. 3, is as follows:-

1) The pavement is drilled to the steel anchor plate installed during construction of the pavement or, for the total deflection gauge, to the formation level, with a 38 mm diameter rock drill.

2) The road surface is recessed to a depth of 25 mm with a 76 mm diameter rock drill to accommodate the gauge casing.

3) For the total deflection gauge a hole, 32 mm diameter, is bored in the sub-grade to a depth of at least 3 m with a soil screw auger of suitable diameter.

4) The hole in the sub-grade is lined to its full depth with a 25 mm O.D. brass tube to prevent collapse of the soil.

5) The datum rod for the total deflection gauge is machined to length, greased and driven into the sub-grade at least beyond the bottom of the liner tube so that its top is about 150 mm below the road surface.

   For each intermediate gauge the hexagonal bar, with a self tapping thread on one end, is machined to length and screwed into the anchor plate to leave the top 150 mm below the road surface.

6) The base and sub-base layers are lined with 51 mm lengths of brass tube 32 mm O.D. x 1.6 mm wall thickness, linked together with soft P.V.C. tubing of similar dimensions to give a gap of about 25 mm between each brass tube.

7) The top 100 mm of construction is lined with three brass rings 38 mm O.D. x 1.6 mm wall thickness x 13 mm long, fixed in place with Araldite, with the top ring 38 mm below the surface and 13 mm separating the remaining rings.

8) The gauge casing is fixed in the surface with an epoxy resin, with the top of the casing accurately flush with the road surface.

To install intermediate gauges in a road which has not had the anchor plates built in during the construction stage, the hole is drilled and lined in the normal way but the datum rod with a 19 mm disc welded on the lower end is anchored by a cement grout plug at the bottom of the hole.

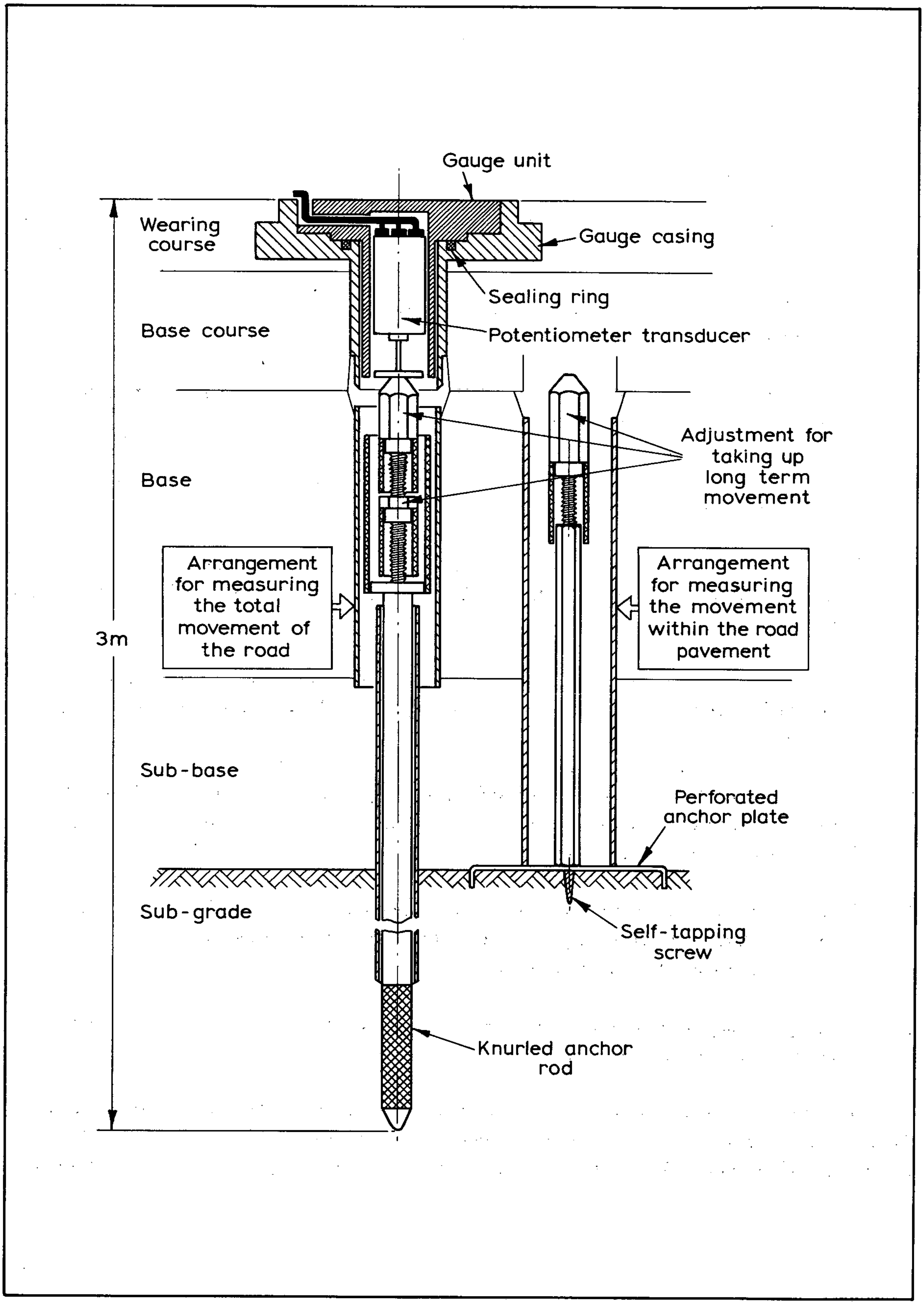

Fig. 1. SECTION VIEW OF THE ORIGINAL GAUGE INSTALLATION FOR MEASUREMENT OF TRANSIENT DISPLACEMENTS

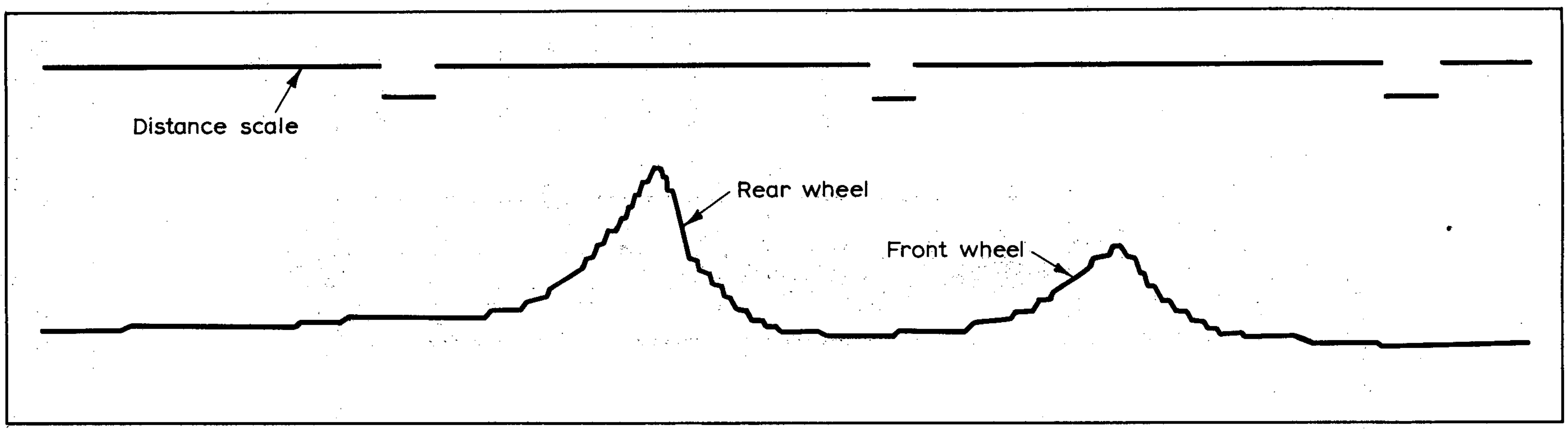

Fig. 2. TYPICAL RECORD OF THE DEFLECTION OF A PAVEMENT STRUCTURE, CAUSED BY THE FRONT AND REAR WHEELS OF A LOADED TRUCK — ORIGINAL EQUIPMENT USING POTENTIOMETER TRANSDUCER

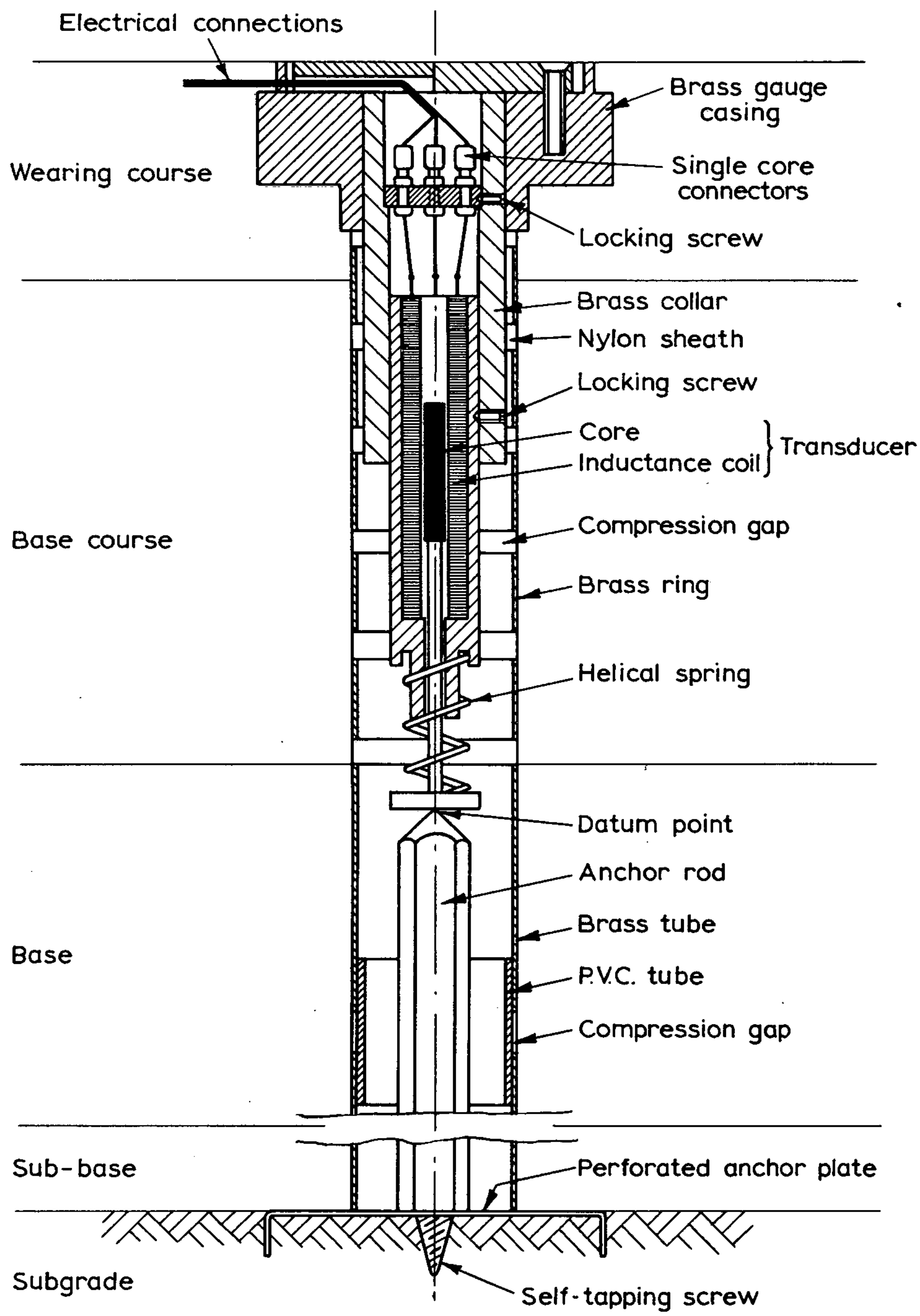

Fig. 3. SECTIONAL VIEW OF THE MODIFIED GAUGE INSTALLATION FOR MEASUREMENT OF TRANSIENT DISPLACEMENTS

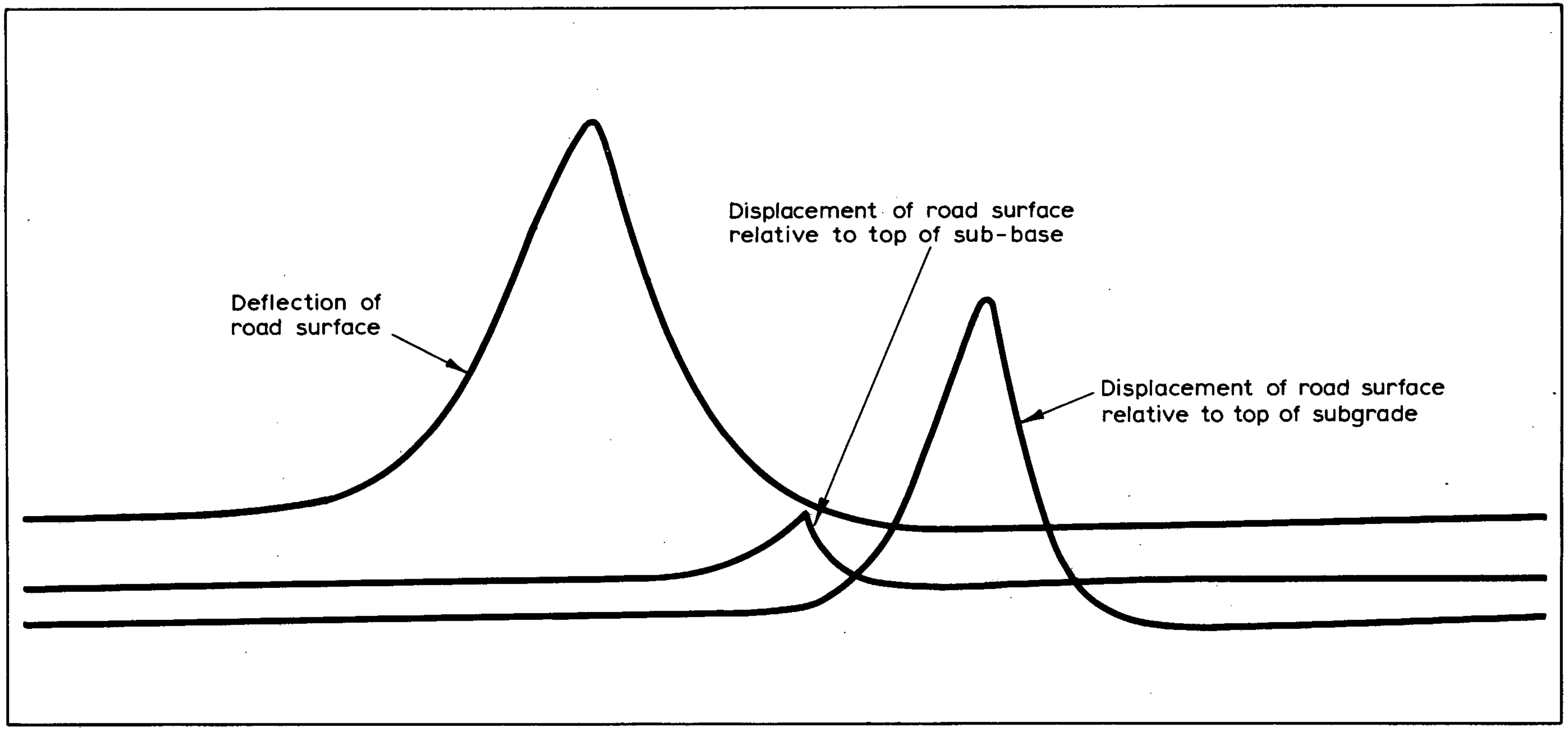

Fig. 4. TYPICAL RECORD OF TRANSIENT DISPLACEMENTS WITHIN A ROAD DUE TO THE PASSAGE OF A HEAVY WHEEL-LOAD — LATEST EQUIPMENT USING INDUCTANCE-CHANGE DISPLACEMENT TRANSDUCERS

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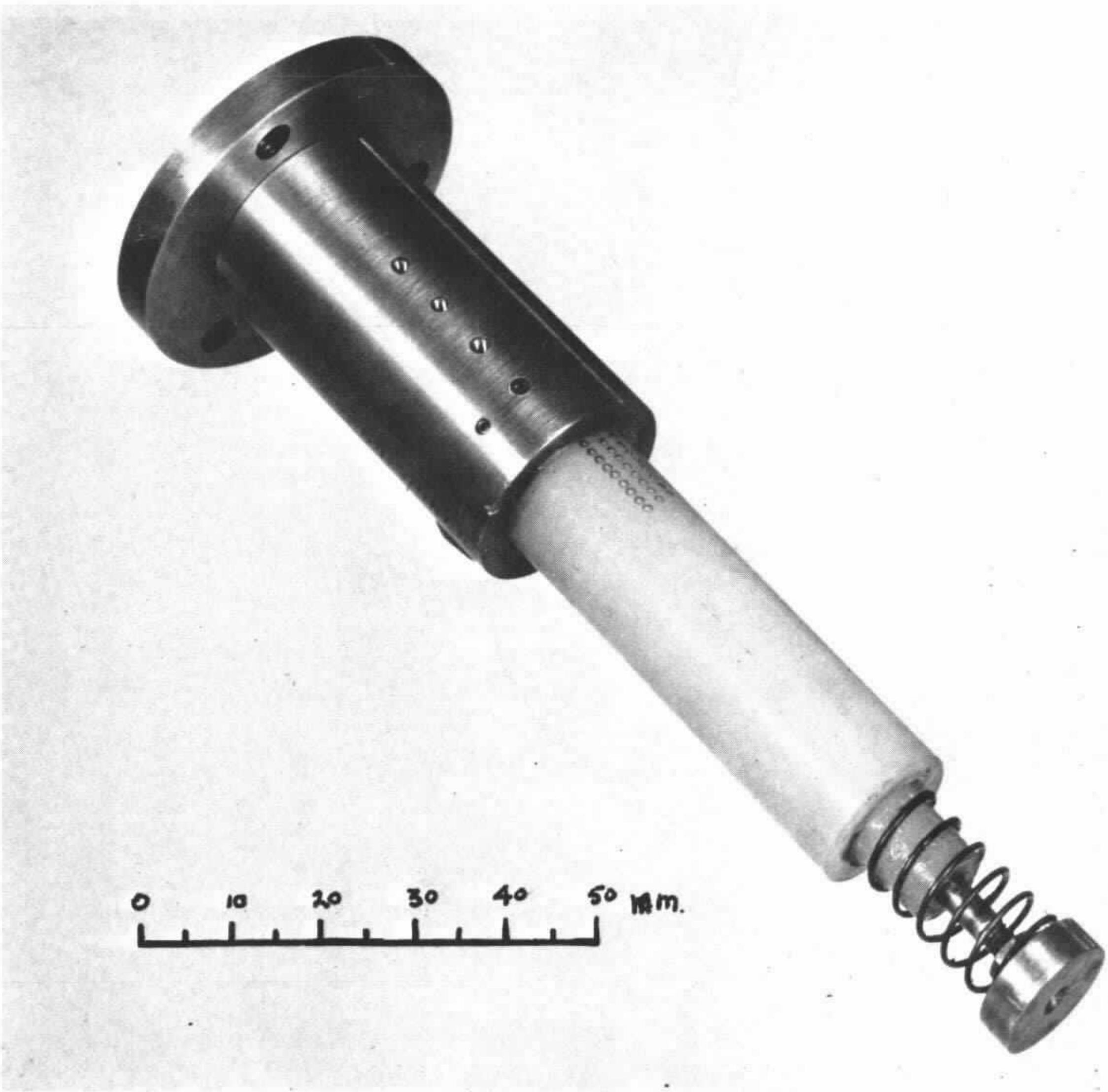

Neg. No. B1926/64

PLATE 1

Modified Transient Displacement Gauge Unit

Neg. No. B3022/63

PLATE 2

Dial Gauge Unit for the measurement of long term displacements

ABSTRACT

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