Measurements of Loads and Strains in Earth Supporting Structures

Mesure des charges et des déformations dans les constructions soumises à une poussée de terres argileuses

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Summary

The paper gives a brief survey of methods used by the Building Research Station over the past ten years for the field measurement of loads and strains in structures supporting clay. These include both timbered and steel sheet piled excavations and tunnels. Typical results obtained in various field investigations are included.

Sommaire

Les auteurs donnent un aperçu des méthodes employées depuis dix ans par le «Building Research Station», Angleterre, pour la mesure des charges et des déformations dans les constructions qui supportent des terres argileuses. Ces mesures concernent les soutènements en bois et en palplanches métalliques et les tunnels. Les résultats typiques de quelques investigations sur place sont également exposés.

Introduction

In the present stage of development of soil mechanics it is generally recognised that one important sphere of activity to which attention needs to be devoted is that of improving the techniques of field observations so as to permit the collection of reliable factual data on the behaviour of soils and structures in practice. Among the problems which present most difficulty, and therefore give scope for substantial improvements in technique, are those concerned with the pressure of clay on supporting structures. The present paper gives a brief survey of the methods used for this purpose by the Building Research Station over the past ten years and gives an outline of the changes in technique adopted as the result of experience gained on practical jobs.

Requirements in a Field Method

Most of the techniques used in engineering for the measurement of strain and load have been developed to function under laboratory conditions or at least under conditions where there is little risk of damage. Often they are used for short term loading tests which permit frequent zero checks. Elaboration of method is no great drawback for it is fairly easy to take the necessary precautions for protection.

In contrast, a field method must be fairly simple to instal and to use since it must not interfere unduly with construction procedure. Any instrument once installed must be capable of giving reliable measurements over long periods under the most severe exposure to weather. Zero shift should be a minimum because it is usually only possible to check this after the instrument has been finally removed. It must also be robust and not susceptible to damage even under such hazardous conditions as those which commonly obtain on heavy construction jobs. Although great accuracy may not be required for many field jobs, there are a number of problems where a fair degree of accuracy is necessary and in such cases it is not easy to combine the accuracy requirement with those of simplicity and robust construction.

From this brief discussion it is obvious that there is quite a substantial step between having a method of measuring loads and strains and the successful application of that method in a practical field job. Much of the field work at the Building Research Station has been in the nature of gaining experience in the practice of such field observations. In reviewing the methods a description will be given of apparatus together with details of practical points in their field use and with a brief summary of the results obtained in the various investigations.

Load Measurements in Strutted Excavations

In the earlier work on timbered excavations, which began in 1941, non-interference with construction progress was an over-riding requirement and so the measurement of the load in the struts was carried out by a simple direct method. The strut itself was used as a measuring device to assess the load in it. Typical results of measurements have been given in a paper by *Golder* (1948) who describes the procedure in detail and outlines the means taken to allow for temperature variations. The accuracy of measurement was found to be of the order of ±2 tons.

Other studies have been made with the same technique of using the strut as the strain unit but with minor modifications. In one case which involved long timber struts, the gauge length was increased to 8 ft. and the measuring device used was a 1/10,000 in. dial gauge fitted at the end of a brass tube. Large temperature fluctuations interfered with the accuracy of these observations. In another case, at the suggestion of the Building Research Station, the resident engineer employed a technique similar to that used by Golder but with steel struts. The results are described in a paper by *T.M.Megaw* (1951) and the accuracy was of about the same order as in the other cases.

The general experience with this method may be summarized briefly as follows:—

a) the accuracy is not high because temperature strains are large compared with load strains;

b) although simple in principle the method is rather inconvenient in practice because each measurement involves clambering among the timbering of an excavation and taking readings under difficult conditions;

c) the reference points were found to be somewhat vulnerable to damage.

For these and other reasons a load measuring unit placed at the end of the strut was next used. This was a type of mechanical beam gauge similar to that developed by Prof. Converse (1943). A sketch showing the main features of the unit is given in Fig. 1.

This type of gauge has several advantages. Although rather heavy, it is very robust and much less vulnerable to damage. A few tests carried with it have shown it to be reliable and accurate to about ±1 ton. However it has not been used sufficiently in the field to give a definite opinion as to its overall suitability. While more accessible than the strut reference points, it is still necessary to get down to the place where it is fixed before a reading can be taken.

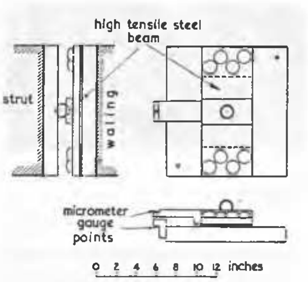

Fig. 1 Steel Beam Gauge
Dynamomètre à poutre

A cylindrical load gauge, on the vibrating wire principle which permits remote observations, has since been developed by the Station (see later) and is likely to be preferred to the beam gauge.

Observations in Steel Sheet Piled Cofferdams

Towards the end of 1949 two investigations were undertaken which concerned large deep excavations supported by cofferdams composed of steel sheet piling braced with a bolted steel framework.

In the first of these investigations an attempt was made to measure strains in the framework by means of electrical wire-resistance strain gauges of the stick-on type. Anticipating unfavourable conditions as much care as possible was taken in fixing the gauges. The steelwork was first ground locally to remove mill scale; the gauges were stuck on with cellulose acetate cement which was then dried with infra-red lamps; finally each gauge was waterproofed with a wax coating. At each measuring point gauges were placed on the upper flange, the web and the lower flange of the member. Dummy gauges for temperature correction were also included. Connections from each group of gauges were run back in multicore cables to the site engineer's office where individual measurements were made on a slide-wire bridge used in conjunction with a fifty point selector switch. Details of this work will not be given here because the readings suggested that there were a number of complicating factors, bending and twisting of the framework combined with temperature effects. In consequence the results were found to be too complex for easy interpretation in terms of earth pressure. While experience in the laboratory had indicated that this method can be eminently suitable for strain measurements, the impression gained from this trial was that under field conditions of exposure to adverse weather and the hazards of construction work, the gauges were vulnerable to damage unless rather elaborate precautions were taken.

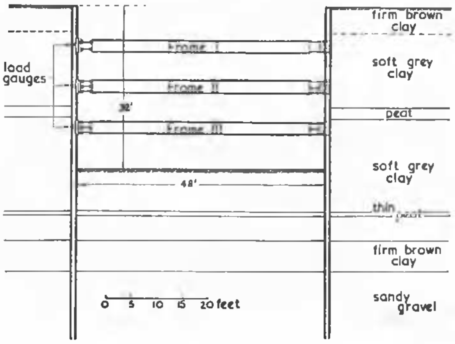

Fig. 2 Cross-Section of Shellhaven Cofferdam
Coupe transversale du coffrage à Shellhaven

The second investigation concerned a deep cofferdam in soft alluvial clay at Shellhaven in the Thames Estuary. A detailed account of the work at this site has already been published in a paper by *A. W. Skempton* and *W. H. Ward* (1942) which gives the results of both soil tests and observations and also outlines an interpretation of the results in the light of the calculated earth pressures. For the present purpose it is sufficient to indicate that two types of measurement were taken, one to find the loads in the struts and the other to measure the loads transmitted from the sheet piling to the walings. An indication of the strut-waling system for the excavation and the position of the measuring points is given in Fig. 2.

Stick-on electrical resistance gauges were again used to measure the strains in the struts. Five struts in each of the three frames were fitted with stick-on strain gauges (ninety in all), and readings were taken at a central recording hut. Unfortunately the exposure conditions at this site were worse than those at the first site both as regards weather and construction hazards and the casualty list was very high. Damage occurred by gauges being ripped off and by breakdown of the insulation and it was not found possible to get final zero readings to check the drift. Consequently this further experience of the use of this method in the field was not encouraging.

In contrast the other method used gave very satisfactory results. In this method a section of the sheeting, comprising eleven contiguous sheet piles on one side of the cofferdam, was supported against the walings at the level of each of the three frames solely by cylindrical load gauges.

The positions of the load gauges are indicated in Figs. 2 and 4 and it will be seen that each gauge measured the load imposed by adjacent pairs of sheet piles. The method of installing the load gauges was briefly as follows. After the frame had been wedged against the sheet piles, short vertical steel joists were inserted in the sheet pile recesses to bear across the full face of the waling. The load gauges were then packed in with steel plates and soft aluminium bedding washers placed between the centres of the short joists and the sheet piles. The wooden wedges were then removed and the load was thereby transferred to the gauges. Outside the test section the spaces between the walings and the sheet piles were filled with concrete.

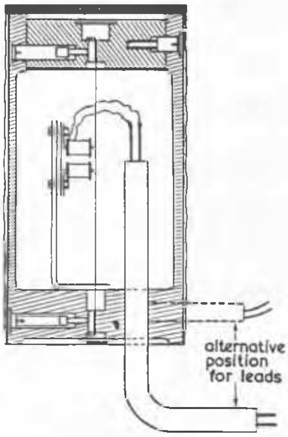

Fig. 3 Vibrating Wire Load Gauge
Dynamomètre à fil vibrant

The cylindrical load gauge is of the vibrating wire type and was developed at the Building Research Station from a similar type of instrument manufactured by Messrs. Maihak of Hamburg. The principle features are given in Fig. 3 and may be briefly described as follows. The gauge consists of a cylindrical steel tube about 5 in. long and 3 in. diameter with a wall thickness which is varied according to the sensitivity required and the load to be carried. Circular steel plates are anchored into recesses at each end of the tube and between the centres of these plates is stretched an axial pretensioned, silver-plated piano wire. A small electro magnet plucks the wire and also picks up its vibrations. The load is carried axially on the tube and compression of the tube alters the frequency of the wire. The gauge is calibrated for load in a testing machine by matching the wire frequency against that of a standard reference gauge. The reference gauge has a tension head fitted with a screw micrometer which can be adjusted to stretch the reference wire until it gives exactly the same frequency as the load gauge wire. The frequencies of the two vibrating wires are balanced either by the absence of beats on headphones or visually on a cathode ray oscilloscope. The calibration curve, which is a plot of load against micrometer reading, is linear and shows very little hysteresis. Considerable eccentricity of load on the tube has little effect on its calibration and temperature effects are relatively small. The deformation of the gauge with wall thickness of $\frac{3}{8}$ in. is about 1×10^{-4} in. per ton and its accuracy is about $\pm\frac{1}{2}$ ton up to loads of about 30 tons.

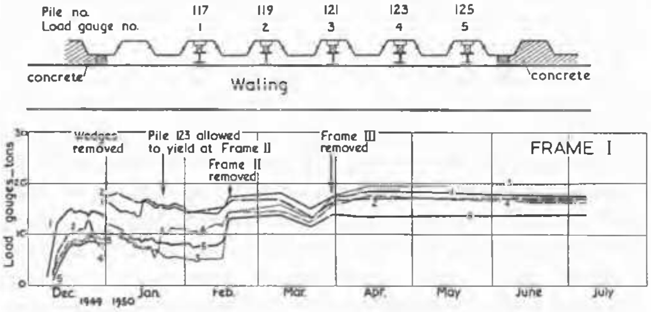

Fig. 4 Typical Load Gauge Readings — Shellhaven
Observations typiques de dynamomètre — Shellhaven

Experience of its use in the field has shown that this load gauge has many advantages. It is compact and robust and can be readily weatherproofed. Once fitted, observations can be taken remotely. It has proved very stable when kept under load for many months and zero readings checked well after months in use. It appears to be eminently suitable for use on construction jobs.

Typical results obtained at Shellhaven are given in Fig. 4.

The influence of the deflection of the sheeting on the actual loads measured was brought out clearly in this investigation but this question, though of prime importance in relation to earth pressures, is outside the scope of the present paper.

Fig. 5 Gauge Fitted to Segment
Réglage du dynamomètre au segment

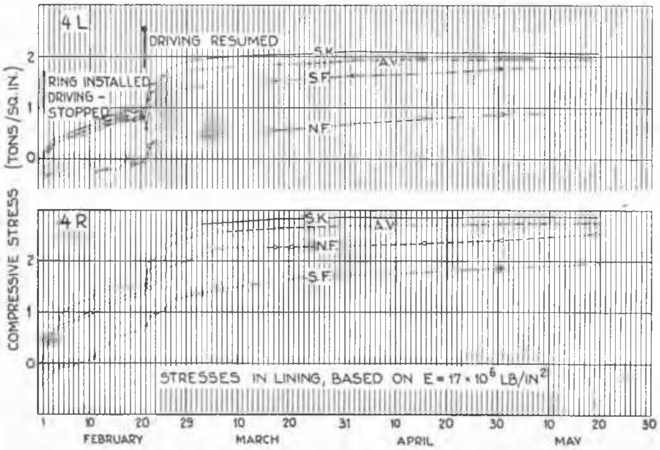

Fig. 6 Typical Results of Tunnel Measurements
Résultats typiques de mesures en tunnel

Observations in Deep Tunnels in Clay

The first preliminary experiments in Great Britain to measure the stresses set up by earth pressures in the cast-iron linings of a deep tunnel in clay were carried out in 1942. The results were published in a discussion by Mr. *A. W. Skempton* of a paper on "Tunnel Linings" by Mr. *G. L. Groves* (1943). The tunnel was 12 ft. in diameter and its axis level lay 109 ft. below the street. For the measurements a 10 in. Whittemore strain-gauge was used, readings being taken on a dial graduated in ins. × 10^{-4}. The method proved convenient and is free from risk of damage because the gauge is removed between readings. However the accuracy obtained depends a good deal on the skill and experience of the operator and the accuracy obtained in this case of 0.3 tons/sq.in. compared with the maximum average value of 2.6 tons/sq.in. compression in the ring, can be considered as good.

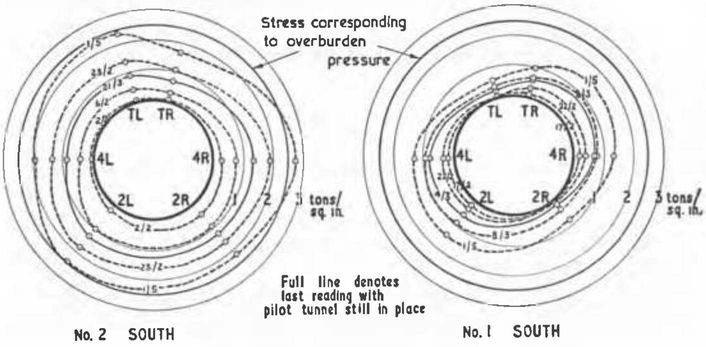

Fig. 7 Distribution of Compressive Stress in Tunnel Rings
Répartition des contraintes dans deux bagues de tunnel

Early in 1952 another investigation was commenced to measure the stresses in the cast iron linings of a group of 25 ft. diameter tunnels whose axis level lay about 100 ft. below ground level in London clay. It was decided to take detailed observations on one ring in each of two adjacent tunnels. A tunnel ring comprised fourteen segments and of these six, spaced at selected points around the ring, were fitted with gauges. Each of these segments was fitted with three vibrating wire gauges, one on the skin and two on the flanges. Steel posts, which served to anchor the vibrating wires, were screwed into the segments and spaced to give a wire length of 6 in. The wire was tensioned up to about 10 lb. and was then secured to the posts by tapered pins. Cast iron cover boxes which served as protection also carried the exciting magnets (see Fig. 5).

Typical results of the measurements are given in Fig. 6 which shows for two segments the increase with time of the compressive stress in the skin (SK), the south flange (SF) and the north flange (NF). The "average" stress also given in the figure is based on the assumption that only plane bending took place parallel to the skin. Fig. 7 shows the distribution of this "average" stress round the two tunnel rings and its variation with time. The stress corresponding to the full overburden pressure was estimated to be about 2.5 tons/sq.in.

The vibrating wire gauges proved very satisfactory for this investigation and gave an accuracy of the order of about 0.03 tons/sq.in. compression. Whittemore gauge readings were also taken but these had not the same degree of accuracy nor was the reading of them convenient in such a large tunnel (25 ft. diameter).

Another investigation which commenced in 1952, concerned a small 9 ft. diameter water tunnel with its axis 90 ft. below ground in London clay. The tunnel is lined with pre-cast concrete segments and was built by a patented system in which ten wedge-shaped plain concrete segments forming a ring are jacked into place by the shield jacks and in so doing are thrust tight against the clay surface cut by the shield. A description of the method has been included in a recent paper describing an earlier tunnel (*Scott*, 1952).

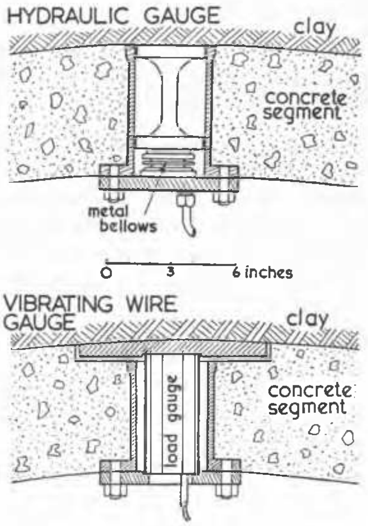

Fig. 8 Earth Pressure Gauges
Indicateur de poussée des terres

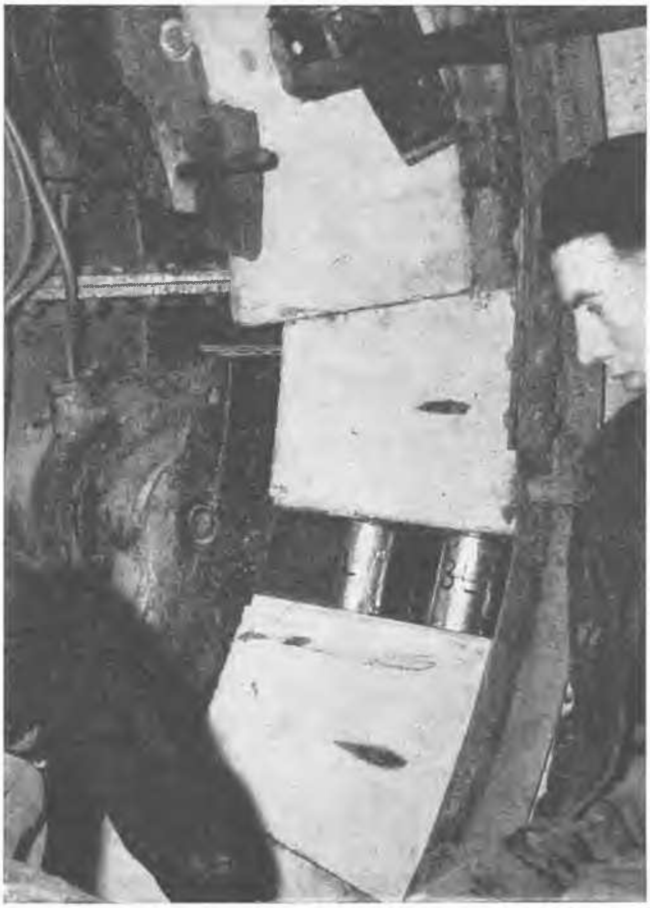

Fig. 9 Load Gauges in Tunnel Ring
Dynamomètres assemblés dans une bague de tunnel

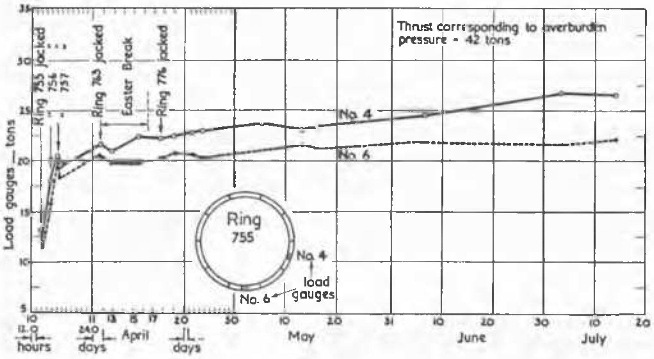

Fig. 10 Typical Results of Thrust in Tunnel Ring
Résultats typiques de butées dans une bague de tunnel

The investigation was undertaken to measure (a) the earth pressure coming on to the outside of the tunnel, (b) the compression load in the tunnel ring, (c) the distortions of the tunnel. For the measurement of the earth pressure special segments were made which housed within the segment a load gauge bearing against a steel face plate which formed part of the earth face of the segment (Fig. 8). Twenty of these segments had installed in them a cylindrical vibrating wire load gauge while ten were fitted with a hydraulic load gauge. These were included in nine experimental rings. In four other rings apparatus was installed to measure the circumferential load in the ring. For this purpose part of a segment was replaced by a pair of vibrating wire load gauges placed as indicated in Fig. 9. All the vibrating wire load gauges have been made watertight since it is intended to use them when the tunnel is filled with water under a head of about 140 ft.

Typical results of these measurements are shown in Fig. 10 which gives values of the circumferential thrust observed at two places in one ring and how it changes with time. It can be seen that the thrust builds up as this ring and adjacent rings are jacked and then assumes a more or less steady value. The thrust corresponding to the full overburden pressure was estimated to be about 42 tons.

Measurements of the distortions of the tunnel, by means of a screw micrometer stick, showed that they were very small and of the order of only a few thousandths of an inch.

A detailed account of this investigation is in course of preparation.

Acknowledgment

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