Professor C. P. Wroth

The measurement of the expansion of the membrane of the self-boring pressuremeter is made by three separate feelers which are symmetrically placed around the circular section of the pressuremeter and act on the central plane of the membrane. Each feeler gives an electrical signal, so that the movement of each of the three points on the membrane is recorded. In ground which has the same in situ horizontal stress in all directions, it is expected that the membrane will expand uniformly and remain circular in section, with the lift-off pressure given by each feeler being the same.

At Dunton Green, where the process of excavation will disrupt the axial symmetry of the horizontal stress, the membrane can be expected to expand non-uniformly (presumably so that it takes up an elliptical shape in section). The lift-off of the three feelers will not occur simultaneously, and they will not indicate the same in situ horizontal stress.

By arranging for one feeler arm to act in a plane that is perpendicular to the retaining wall, the lift-off pressure from that arm can be used alone to estimate the total horizontal stress acting in the ground perpendicular to the wall. This technique was adopted at Dunton Green.

Mr Dalton of Cambridge Insitu has reported results of tests in the Gault Clay in which consistent and marked anisotropy of horizontal stresses has been observed by using this method.

J. C. P. Dalton, *Cambridge Insitu*

Some tests have been carried out in the Gault Clay at Eversden, near Cambridge, where substantial degrees of anisotropy were revealed by large differences, up to 2:1 ratio, in the lift-off pressures between the three strain arms of an expansion pressuremeter (Dalton & Hawkins, 1982). This observation of considerable anisotropy in stiff clay has also been made subsequently by Professor Jamiolkowski and Dr Ghionna at La Spezia in Italy (Ghionna, Jamiolkowski & Lancellota, 1982). Using a machine identical with that used at Dunton Green they went, in 3–4 m of water, first through a soft clay layer showing complete isotropy and then immediately into a stiff clay layer showing a considerable degree of anisotropy.

There has been some discussion subsequently both about whether the instruments were being pushed on a straight path and about whether there was not an artefact on the surface of the instrument giving rise to the effect observed. However, in the tests at Little Eversden two completely different self-boring instruments were used. The second was a load cell pressuremeter in which the outside curved surface of the cylindrical instrument is designed purely to measure the in situ stress continuously. A rotation of this instrument in the ground confirmed a horizontal anisotropy of the in situ stress that was very similar to that shown by the expansion pressuremeter tests at the same site.

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C. A. Raison, *Ove Arup & Partners*

The new British Library is currently under construction on the north side of Euston Road adjacent to St Pancras station (Fig. 5). Unfortunately progress on site was not sufficiently advanced for us to present a paper in the Symposium in Print. However, we now have some preliminary results of ground movements which we wish to present. These results have been processed and stored by computer which has enabled us to develop a number of different ways of plotting and displaying data. Examples of these are included here.

Preliminary substructure works were carried out during 1982 and 1983 and have been described in detail elsewhere (1984). These included the installation of secant piles to form the basement retaining walls, excavation up to 5 m below street level to remove old foundations and the construction of large diameter underreamed bored piles. Of particular interest is that the pile cut-off level is at a level 24 m below street level which necessitated leaving an empty bore above each pile lined with flexible Armco casing.

Ground movements were anticipated as a result of the limited excavation and the horizontal stress relief caused by the bored piling. At this stage of construction the retaining walls were not propped and were acting as cantilevered walls. To measure these movements a considerable quantity of ground instrumentation has been installed within and around the site. In addition 20 secant piles were installed with inclinometer access tubes which

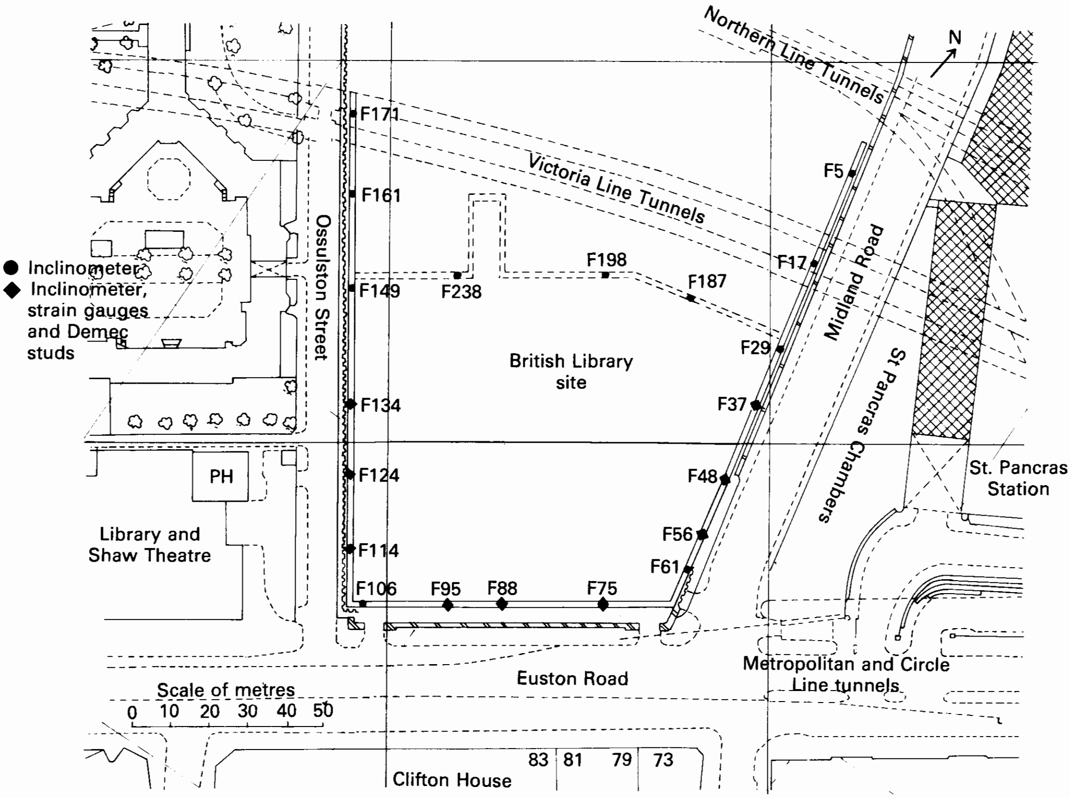

Fig. 5. Secant pile instrumentation

have been monitored on a regular basis since installation (Fig. 5).

An attempt was made to measure ground movements in inclinometers close to the line of the retaining walls during installation of the secant piling. However, negligible movement was recorded in contrast with the large movements recorded during piling for the Bell Common tunnel (Tedd, Chard, Charles & Symons, 1984). This difference may be attributable to the different piling technique adopted. At the British Library the secant pile bores were cased throughout their depth, casing only being withdrawn during concreting.

The movements measured in the secant pile inclinometers are shown in Fig. 6. This plot shows an inward movement of the top of each wall between 10 mm and 20 mm at the mid-point. Although monitoring of these instruments began as soon as possible after installation, some major excavation works were carried out towards the north of the site before commissioning. Ground movements shown may therefore not include some early movement.

Figure 7 shows a comparison between measured wall movements and those predicted by finite element computer analyses using the OAP London Clay model described by Simpson, O'Riordan & Croft (1979). This plot shows the movements predicted at the top of the secant piles (+17 to +18 m OD in July 1984) between 10 mm and 20 mm and shows a slight but conservative overestimation.

A north–south section is shown in Fig. 8 and includes inclinometer and extensometer movements combined. Up to 30 mm of heave has been recorded in the central area overlying the London Transport Victoria Line tunnels. Surveys in the tunnels confirm that these have heaved about 4 mm. In the south area stress relief due to the piling has resulted in up to 10 mm of settlement.

In examining the results presented here it should be borne in mind that at the early stage of construction both the predicted and the measured movements are small and therefore subject to a high proportion of error. This has been particularly so for measured movements

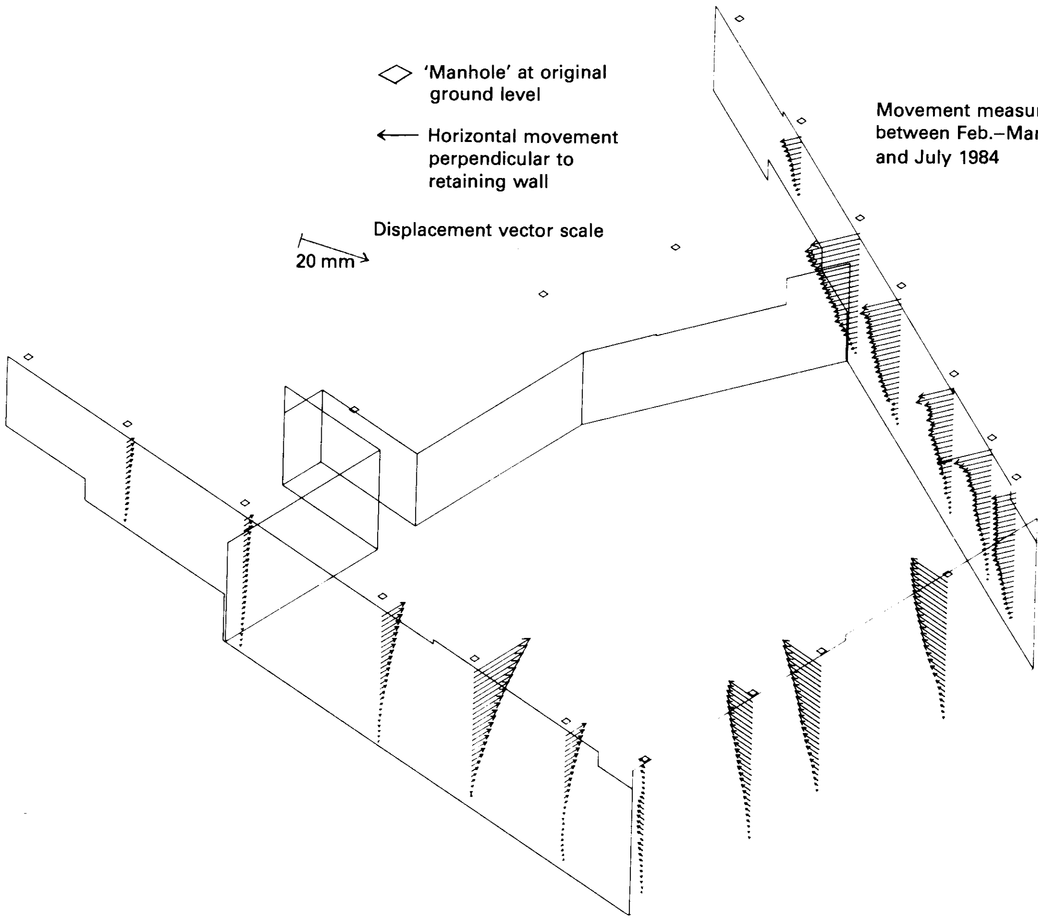

Fig. 6. Secant pile wall movements

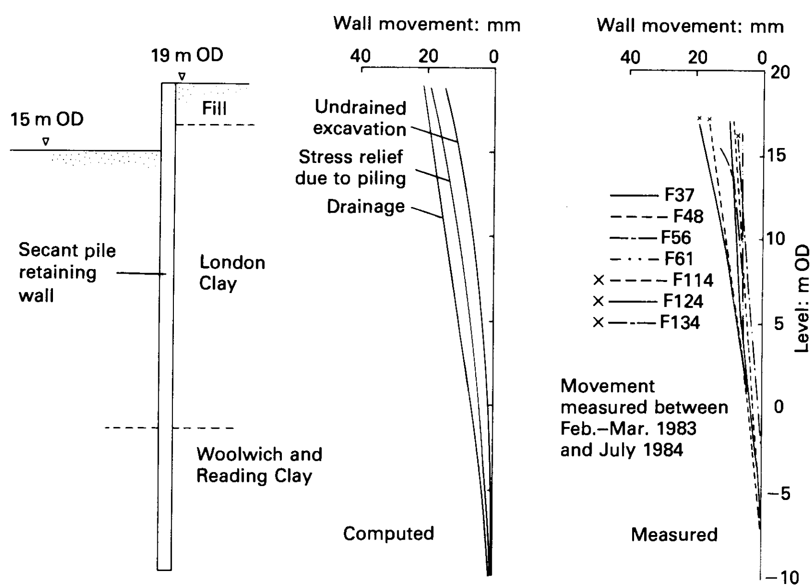

Fig. 7. Comparison between measured wall movements and computed movements

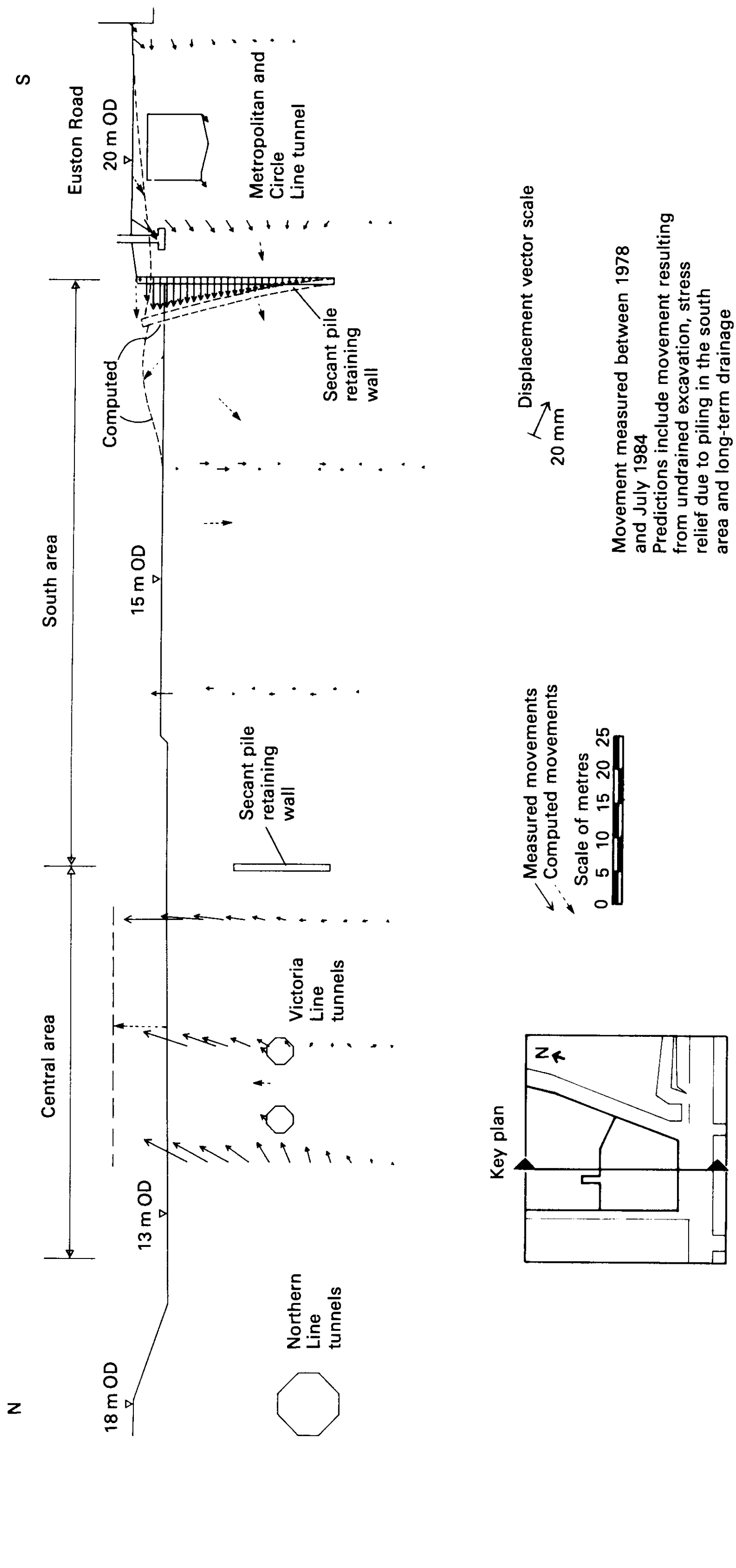

Fig. 8. Comparison between measured movements and computed movements: north–south cross-section

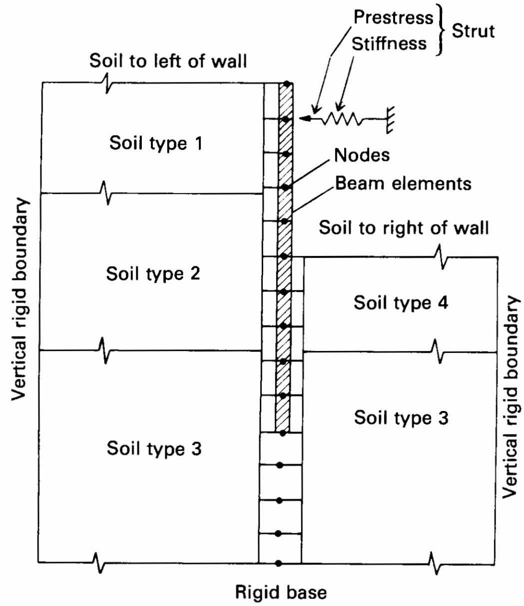

Fig. 9. Numerical representation of the soil–wall problem

where the accuracy and repeatability of the ground instrumentation is large in comparison with the movements.

This note has of necessity been brief and it has not been possible to comment further on the subject of accuracy of the measurements. However, it is hoped that this can be included in a fuller presentation of ground movements associated with the British Library basement excavations to be made at some future date.

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J. W. Pappin, *Ove Arup & Partners*

Most of the Papers in the symposium refer to the finite element method of analysis being used to predict the behaviour of the retaining walls. The only exception to this is Wood and Perrin who use the program LAWWALL. Ove Arup & Partners have been using a LAWWALL-type program for several years as an aid to the design of flexible retaining walls. The program, while not being as general as the finite element method, has a significant advantage over the finite element method in that it is much cheaper to use and is sufficiently accurate for most design problems. It is particularly suitable for parametric studies.

The program models the soil–wall interaction problem as shown in Fig. 9. The soil to each side of the wall is represented by an elastic solid, the flexibility of which is generated either by way of the integrals of the Mindlin equations (Vaziri, Simpson, Pappin & Simpson, 1982) or by interpolation and sealing of flexibility matrices calculated for a simplified soil profile using finite element methods. A semiempirical formulation has been developed to allow for variations in the soil stiffness with depth. The wall stiffness is represented by a series of elastic beam elements. In addition the earth pressures are limited to be within active and passive limits. Arching is permitted by considering the soil forces acting on the wall compared with the forces consistent with possible failure surfaces within the soil. Other features that can be accommodated by the program include struts, anchors and the effects of surcharges.

Full details of the program including various validation procedures are given in Pappin, Simpson, Felton & Raison (1985).

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B. Simpson, *Ove Arup & Partners*

I would like to invite Wood and Perrin to comment further on their choice and use of Young's modulus for the London Clay. They state that the undrained Young's modulus was derived by multiplying the measured undrained shear strengths by a factor of 200. On the basis of their Fig. 3 this would give a Young's modulus of about 40 MN/m^2 at a depth of 20 m, for example. Values derived in this way are considerably less than those which have been found by back analysis by previous researchers. For example, Cole & Burland (1972) showed a value of about 120 MN/m^2 at a depth of 20 m. Similar values were reported from back analyses by St John (1975) and Burland, Simpson & St John (1979).

The Authors have used their values of