Papers

In recent issues of *Ground Engineering* Dr Clarke and others have described a new pressuremeter able to bore into weak rock and make an expansion test. They assert that this has major advantages over a pre-bored pressuremeter test in weak rock. The authors of this discussion paper consider one claim; that this new pressuremeter can make direct measurement of the insitu lateral stress.

Discussing 'experience with the self boring rock pressuremeter'

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Introduction

The RSBP is a development of the Cambridge Self Boring Pressuremeter (SBP) invented by Hughes and Wroth in 1973. It has been demonstrated that the expansion test which the SBP produces, provided that it has been installed correctly, is of such quality that the insitu lateral stress can be determined from the pressure at which the membrane lifts off the body of the probe. It is an important and fundamental instrument.

Soon after its inception it became apparent that to be a success as a site investigation tool in the UK, the SBP would have to be able to test stiff materials. The current model of the SBP has a pressure capability of 4MPa, as against 1.4MPa of the original, and the membrane with its stainless steel sheath protection permits boring in quite hostile ground conditions. Changes have been made to the cutting geometry to allow the SBP to penetrate stiff materials more easily. The use of a rock roller bit within the cutting shoe has proved very successful.

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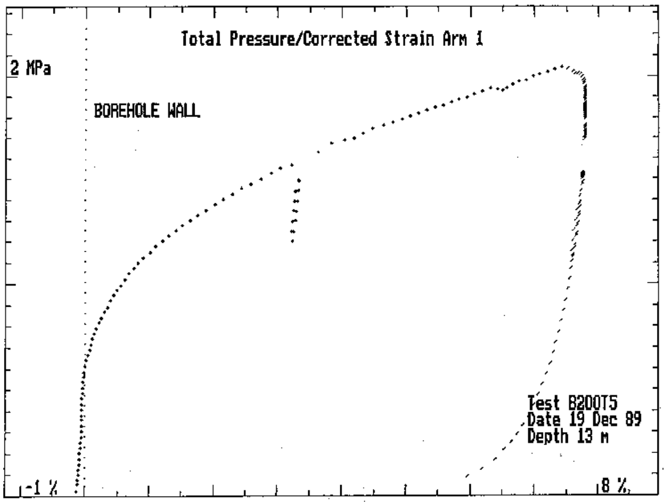


Fig 1. Self boring pressuremeter test at 13m in Keuper Marl.

However the SBP test in stiff material is and will continue to be expensive, using the standards of cost normally applied to site investigation. Despite the modifications to the instrument, it remains difficult to push the pressuremeter with sufficient force to allow it to self bore to its test depth. It always has the insitu lateral stress pressing against it, and hence there are problems finding the required reaction against which to jack the instrument once the force due to skin friction exceeds 2 tonnes.

The instrument is in effect a steel cylinder of diameter 83mm with a length of 1000mm. It has a surface area of about 0.26 square metres. An insitu lateral stress in excess of 1.4MPa has been measured on several occasions. If a coefficient of friction of 0.1 for steel is assumed then this is equivalent to a resistance due to friction alone of nearly 4 tonnes.

It is not easy to find reaction in excess of 4 tonnes. The authors describe adapting a rotary drilling rig to place the RSBP. This is already common practice but it is not necessarily the most cost effective option. Self boring is not like rotary drilling and it takes a substantial rotary rig with a corresponding cost to provide the jacking reaction required. It is an alarming sight to see a large truck mounted rotary rig being lifted off the ground by the SBP.

There are no sensible ways of increasing the effective reaction of a rotary rig. For this reason a dedicated drilling rig continues to be a viable option. It is customary now in stiff materials to couple the hydraulic rams which place the pressuremeter on to a column of casing previously hammered into the ground. Using this approach we have pushed the SBP with more than 6 tonnes.

This is the operational limit of the SBP. It is not, as stated by the authors, primarily a function of shear strength, but of skin friction. There is no reason why a few minor modifications to the cutting arrangement would not allow it to penetrate materials with a shear strength greater than 5MPa. However if the insitu lateral stress is to be determined from lift-off then the limitation of skin friction means that the instrument can only be placed in materials with an insitu lateral stress below 1.6MPa.

Determining the insitu lateral stress from lift off

As stated above, if the SBP is inserted with care then the pressure at which the membrane lifts off the body of the instrument can give a good indication of the insitu lateral stress.

In the case of the SBP this is made possible by the patented self boring head. The SBP cuts with an internally tapered and sharp edged shoe. The material entering the shoe is sliced into particles by a cutting device inside the shoe and the particles are flushed to the surface (by water or air) through the annulus within the instrument.

The relationship between the static cutting edge and the rotating cutting device is important. By adjusting the distance between them the end loading acting on the instrument can be maintained at about 0.5 tonnes for every 1MPa of insitu stress. The majority of the resistance to the boring results therefore from the skin friction resulting from the presence of the insitu lateral stress.

If the full skin friction is not present then the pressure at which the membrane 'lifts off' the body of the instrument will not be the insitu lateral stress. From the description of the RSBP it seems that the membrane is rubber with nylon filaments, and hence the coefficient of friction would be high by comparison with the steel sheath of the SBP. If the RSBP was seeing the full skin friction then the membrane would not survive the boring process. The fact that it does survive indicates that there has been some stress relief of the test cavity.

The authors present plots of 'lift-off' as if this was itself proof that the instrument is measuring the insitu lateral stress. This is not so. There are many examples of SBP tests with good lift-off characteristics which bear little relation to the insitu lateral stress that existed before the instrument was bored into the test position. It is partly because of this that in recent years there has been much interest in applying the Marsland and Randolph (ref.3) argument to SBP data, in the hope of reducing the scatter that examining lift-off alone generates. This scatter is primarily a function of the stiffness of the ground. Tiny errors in the seating of the strain arms can give rise to a large degree of uncertainty about lift-off pressures in stiff materials, and it is disappointing that the authors do not acknowledge the potential problems involved in making this demanding measurement.

Consider how critical manufacturing tolerance must be. The authors state that the RSBP is the same diameter over the full face cutter and the membrane. We are familiar with the process by which the RSBP membrane is made, and we know that the tolerance on the thickness of the section of rubber alone is at least 0.4mm. Translated into strain this represents a substantial unloading of the cavity wall.

The size of this potential stress relief can be estimated from the figures obtained for stiffness. An error of 0.4mm for an instrument with a diameter of 73.6mm is a strain of about 0.5%. If we take as an example one of the West Burton tests described by the authors we see that at about 27.5 metres they quote a modulus of approximately 1.5GPa and a lateral stress of 0.4MPa. In material this stiff a roughness of only 10 microns would be sufficient to reduce the lateral stress, assuming for the moment that it were real, to zero. The degree of uncertainty is absurdly high and indeed makes it clear that a suitable instrument is not even a practical proposition to manufacture.

We have tested our observations about skin friction with the following experiment in chalk. It is a straightforward matter to change the diameter of the cutting shoe edge. Increasing the diameter so that it was 0.75mm greater than the diameter over the measuring section allowed the standard SBP to self bore into material with an insitu lateral stress of about 4MPa and a stiffness of about 4GPa. The choice of 0.75mm oversize was arbitrary; an increase of only 0.25mm would have been sufficient to give complete relief from skin friction in this material. When operating with an oversize shoe it is not possible to use 'lift-off' to determine the insitu lateral stress; instead a modified form of the Marsland & Randolph argument (ref. 4) is used to give the figure quoted above.

The authors do not present a theoretical basis to support their assertion that the RSBP with its full face cutter can measure the insitu stress directly. Neither do they

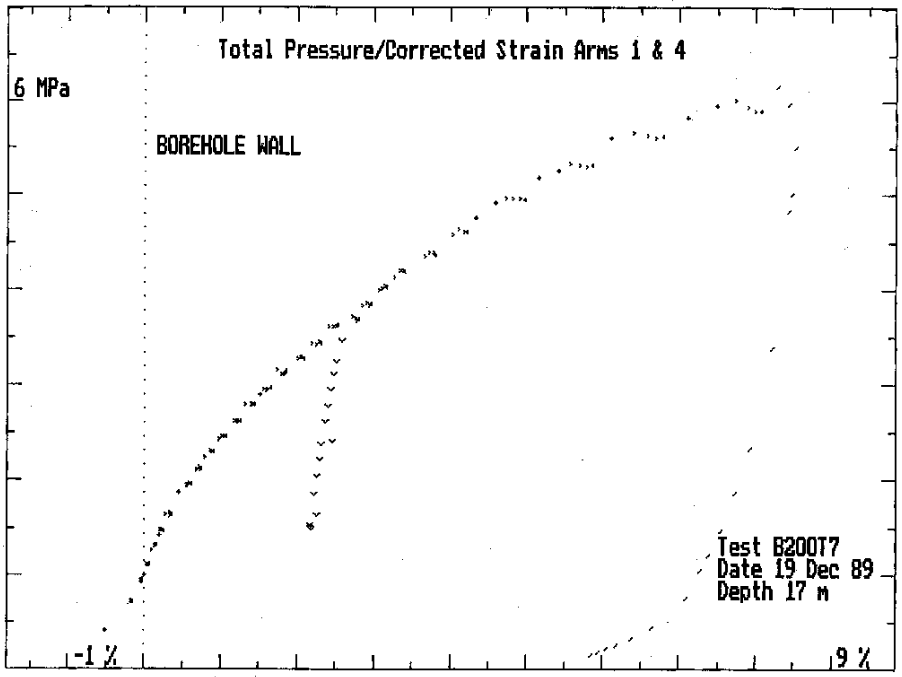


Fig 2. High pressure dilatometer test in same borehole and material as Fig 1.

offer the evidence of controlled experiment in materials with well established properties. Instead the evidence quoted in the paper is the West Burton field tests themselves.

If the results of these were in even rough agreement with other tests or other methods of calculating the insitu lateral stress then their data would be more convincing. In fact, as is shown in their ***Figure 6***, they quote values which indicate the total insitu lateral stress decreasing with depth, resulting in values of K_o below unity. This is attributed to variations in the grade of material. The more likely conclusion is that the lift off pressures of the RSBP were not occurring at the insitu lateral stress.

The authors state that there have been no self boring tests in the Keuper Marl previous to the development of the RSBP. This is not so. There are a number of tests, some of which are quite good. Of particular interest are sites where SBP testing was followed by the High Pressure Dilatometer, a pre-bored hole instrument mentioned by the authors. Hence the two methods of pressuremeter testing can be compared. ***Figures 1 and 2*** show an SBP test at 13 metres and an HPD test at 17 metres in the same borehole.

Figures 3 and 4 show the results of applying a modified Marsland and Randolph type analysis to an enlarged portion of these pressure/strain curves. Note that in ***Figure 3***, the SBP test, the

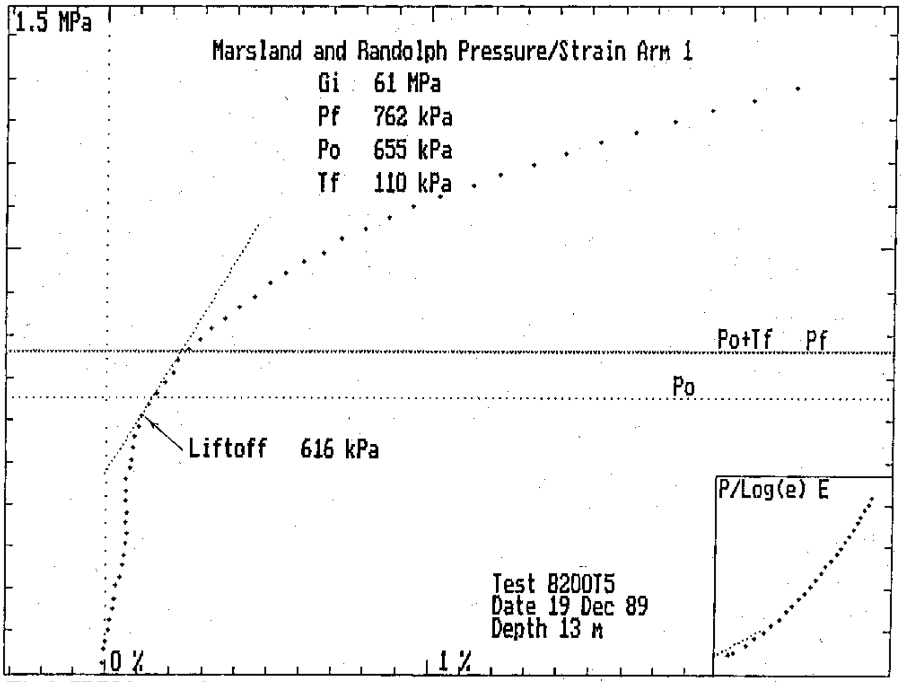


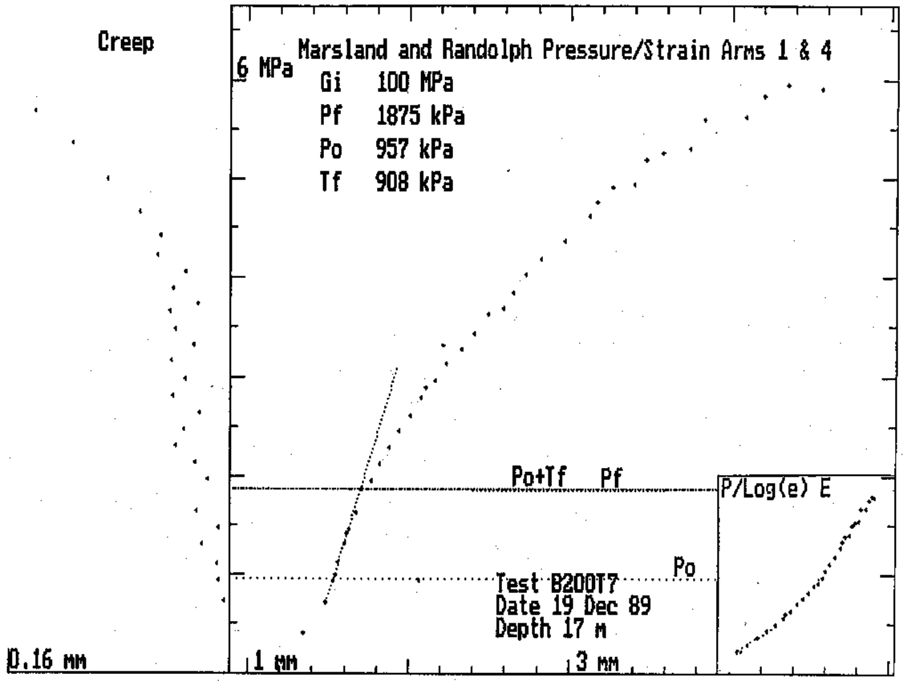
Fig 3. SBPM test of Fig. 1 analysed. 'Po + Tf Pf' labels the coincidence of two lines. Tf is shear stress at failure.

lift-off pressure has been marked for comparison purposes.

The test curves exhibit a pleasing similarity; the derived values of P_o, the insitu lateral stress, suggest a K_o value of about 2.5. A small rotary rig was used to place the SBP. It had a maximum pull down of 1.8 tonnes and was on its limit for this test. A P_o of 655 kPa and an assumed coefficient of friction of 0.1 suggests a skin resistance of 1.6 tonnes. This is encouraging agreement.

It is invidious to use data from one site to criticise data from another, but in our experience this is typical Keuper Marl behaviour. Extrapolating from these two tests indicates that even with a substantial rotary rig the SBP would not have penetrated much further than 13 metres before running out of reaction. It seems to us unlikely that at the West Burton site, with which we are familiar, that the insitu lateral stress at 27.5 metres was less than 400kPa. If this was the case then there would be many more SBP tests in Keuper Marl.

None of this is intended to damn the RSBP. It is potentially an excellent instrument for making measurements of shear modulus in very stiff materials. However the evidence suggests that the RSBP gives rise to unpredictable stress relief in the test cavity and is therefore at best a high quality pre-bored hole pressuremeter. Appropriate methods of analysis should be used to derive values for insitu horizontal stress. Quoting lift-off pressures is not one of them.



HPD test of Fig. 2 analysed by the same technique.

References

1. Clarke, B. G., Newman, R. L. and Allan, P.G. 'Experience with a new high pressure self boring pressuremeter in weak rock.' Ground Engineering July 1989 pp 36-39.

2. Clarke, B. G., Newman, R. L. and Allan, P. G. 'Experience with a new high pressure self boring pressuremeter in weak rock.' Ground Engineering Sept 1989 pp 45-52.

3. Marsland, A. and Randolph, M. F. (1977). 'Comparisons of the results from pressuremeter tests and large insitu-plate tests in London Clay.' Geotechnique June 1977 V.27(2), pp 217-243.

4. Hawkins, P. G., Mair, R. J., Mathieson, W. G. and Muir Wood, D. 'Pressuremeter measurement of Total Horizontal Stress in stiff clay' (1989). Proceedings ISP.3 Oxford April 1990 (in print).