of the complication of incremental loading. It is probable that pure peat never comes to final equilibrium (Hanrahan, 1964). Therefore many of the expressions used by Barden, e.g. degree of compression, stable equilibrium, e versus p plot, are meaningless when applied to the peat of my experience. The effect of pressure increment ratio, e.g. Fig. 8, is not unique and almost any desired behaviour can be achieved for the load increment simply by varying the duration of the previous load. The 100% efficiency of consolidation–acceleration devices (Hanrahan, 1965) in peat is valuable confirmation of the dependence of the scaling law on H^2.

A major criticism of laboratory studies of consolidation is the dependence on the one dimensional test, which because of undefined boundary stress conditions is little better than an empirical test. There is mounting evidence (Hanrahan and Walsh, 1965; Hanrahan, 1967) of the complexity of this test, e.g. internal tension, non-uniform distribution of internal strains and pore-pressure. With a view to increasing the reliability of this test I have proposed a method of evaluating the lateral stresses (Hanrahan, 1968). Recently a simple modification of the triaxial test has been devised which permits a plane strain, one dimensional consolidation test to be carried out with continuous observation of vertical and lateral pressures. In one such test the σ_1/σ_3 ratio (total stresses) was observed to fall from 1:1 initially to 5:1 after a few minutes. After a few hours the lateral pressure had fallen to zero. Barden's rheological model (Fig. 3) would have to be modified to take into account this drastic reduction of σ_{oct}. The latter confirms many previously observed phenomena and is likely to be the chief cause of the rapidity with which the pore-pressure is commonly observed to fall off in one dimensional tests on peat.

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5 April, 1968.

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Based on his long experience of the material and its engineering behaviour, Dr Hanrahan has raised a number of interesting points on the consolidation of peat.

His first comments refer to the effect of H on secondary consolidation, where there seems to be a wide divergence of general opinion. One empirical treatment has been suggested by Wilson et al (1965); another is by Hanrahan (1964) who claims that the H^2 law associated with primary consolidation also applies during the secondary consolidation of peat and his Fig. 8 gives empirical evidence in support of this. I fail to see the physical basis for such an H^2 law once the pore pressure in the *macro*-pores (i.e. the measurable pore pressure) is sensibly zero. Accurate mid-plane pore pressure measurements using transducers on samples of Irish and Canadian peats, back pressured to 20 lb/sq. in. to minimize the problems of gas, have revealed that the measurable (macro-) pore pressure excess is sensibly zero during secondary and hence that the long term deformation is not governed by *primary* pore pressure

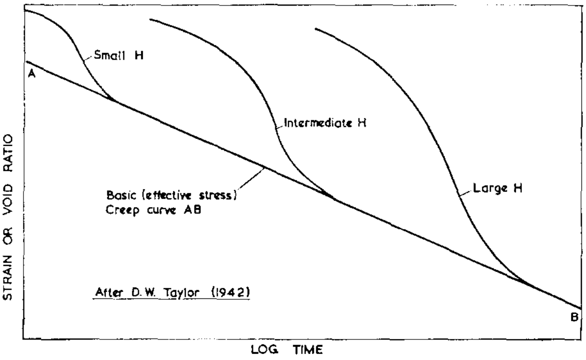

Fig. 1

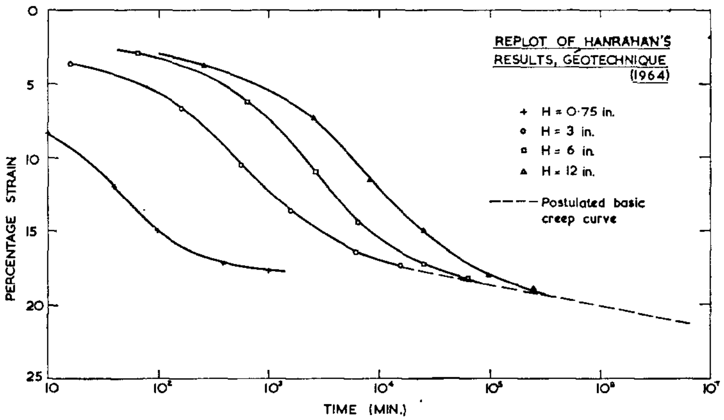

Fig. 2

dissipation. Even if secondary compression is due to pore pressure dissipation in the *micro*-pores, it is no longer related to the macro dimension H. I would expect the behaviour to be similar to that postulated by Taylor (1942) and shown in Fig. 1, with a basic (effective stress) creep curve AB independent of H and joined at various times according to the effect of H^2 on primary pore pressure dissipation.

To illustrate this basic behaviour the results presented by Hanrahan (1964) in his Fig. 8, curves A, have been replotted in Fig. 2 as compressive strain versus true time, after the manner of Taylor; the agreement is good.

Further confirmation is presented in Figs 3 and 4. Fig. 3 shows the results of samples of remoulded fibrous peat loaded from 0–3 lb/sq. in. The 11 in. thick sample ($H = 5{\cdot}5$ in.) was tested in a 20 in. diameter Rowe consolidation cell and the two 0·75 in. thick samples ($H = 0{\cdot}37$ in.) in 3 in. Casagrande oedometers. Fig. 4 is a particularly interesting result obtained on the same type of fibrous peat loaded from 3–6 lb/sq. in., this time with $H = 12$ in. in the 20 in. Rowe cell and $H = 0{\cdot}25$ in. in the Casagrande oedometers. In all the above cases the behaviour supports a basic creep curve as postulated by Taylor, although it is clear that the creep curve is not always linear with log t.

The physical basis is clear and if the basic creep curve is independent of H then so is the scaling law for secondary.

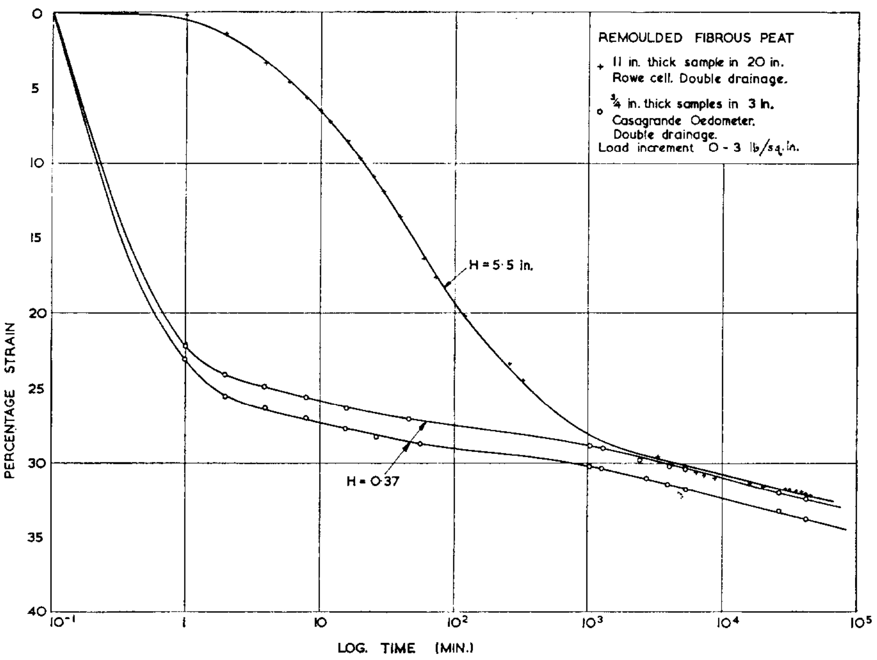

Fig. 3

It can further be seen that if the creep curve is not very steep, as in Figs 2 and 3, then the results when plotted on an H^2 time scaling basis, after Hanrahan, will still be in reasonable agreement—particularly when one considers the scatter of natural peat results. However, when the creep curve is steeper, as in Figs 1 and 4, and the difference in H is great, then it can be clearly seen that scaling time according to H^2 will result in poor agreement in the secondary stages.

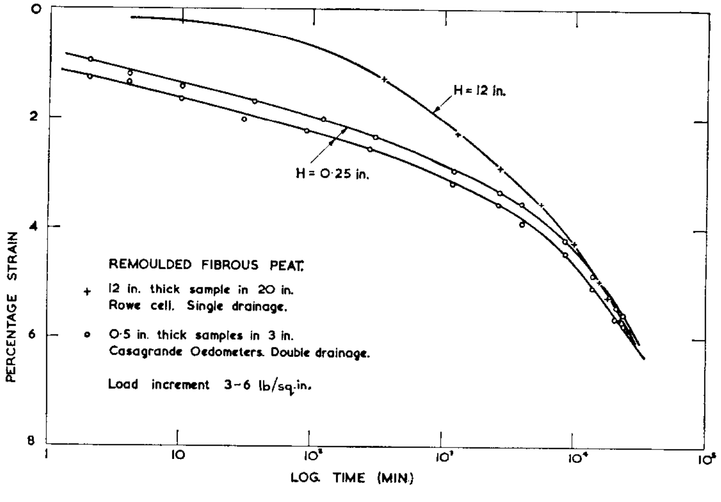

Fig. 4

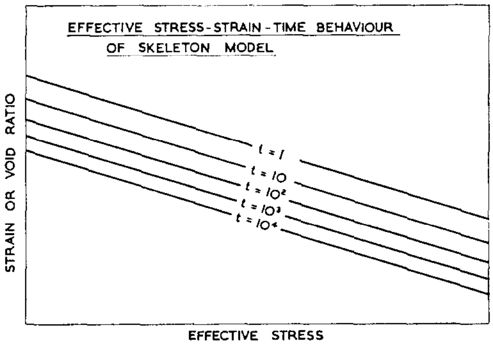

Fig. 5

I should therefore like to modify my original observation on page 19, concerning the complexity of the scaling law for secondary, and suggest that C_α be treated as essentially independent of H, in general agreement with Taylor's concepts. The main effect of H is on the relative proportions of primary and secondary compression (see Fig. 1).

Dr Hanrahan's next point is that peat may never reach final equilibrium. Whatever the truth here, the creep rate will decrease to negligible values after a large number of years. Thus if we are concerned with engineering structures an arbitrary life of say 50 to 100 years can be specified and 'final' compression established by extrapolating the basic creep curve to this time. I would agree with Dr Hanrahan that the effect of load increment is greatly affected by the duration of the previous loading. This effect was discussed under thixotropy and the quasi-preconsolidation phenomenon. Since the Paper was written Bjerrum (1967) presented his Rankine Lecture which dealt in detail with this most important practical problem. It can be seen from Fig. 5 that the proposed rheological model provides behaviour in general agreement with the idealization proposed by Bjerrum (1967) in his Fig. 14 and hence incorporates the (quasi-preconsolidation) effects of $\Delta p/p$ and increment duration referred to by Dr Hanrahan.

Dr Hanrahan next suggests that the one-dimensional consolidation test, because of undefined stress boundary conditions, is little better than an empirical test. While all soil tests have boundary problems, I feel Dr Hanrahan is perhaps going too far with this observation, and would not accept that much research equipment including the Rowe consolidation cell can be dismissed so lightly. X-ray results of Burland (1967) have shown that, provided care is taken with boundary lubrication, the uniformity of strain in one-dimensional consolidation of kaolin increases as the pressure increases and becomes almost uniform above about 4 lb/sq. in. Sirwan (1965) had shown by the same techniques that the first load increment, however small, induced more consolidation near the drainage faces than the middle of the sample and thereafter there was slightly more consolidation in the middle than at the ends until it became uniform.

Dr Hanrahan introduces a particularly interesting point when he refers to the drop in the lateral total stress during the one-dimensional consolidation of peat. It is clear that the lateral total stress σ_x must fall as the pore pressure falls in a (one dimensional) oedometer test, but will stay constant in a (three dimensional) consolidation test in the triaxial cell, as has been discussed in some detail by Rowe (1959) and Akai and Adachi (1965). However, provided the problem is one dimensional vertical and is properly formulated in terms of one dimensional stress–strain relations then there would appear to be no reason for the lateral stresses to appear explicitly in the equations.

The variation in the bulk total stress $\theta=\sigma_x+\sigma_y+\sigma_z$ is recognized as the source of much complexity in Biot type treatments of truly three dimensional consolidation based on linear elastic theory (Gibson and Lumb, 1953; Davis and Poulos, 1968), and in a generalization of the rheological model to three dimensional triaxial conditions (Barden, 1968) consideration has been given to the effects of the term $\partial\theta/\partial t$. However, the proposed *one dimensional model* does not require modification for the reason suggested by Dr Hanrahan.

The reduction in the lateral stress has been measured on Irish peat tested in a 10 in. Rowe cell containing a number of total stress transducers set in both the base and the side wall. However, in tests conducted to date the reduction in lateral stress has not been as marked as reported by Hanrahan, the K_0 value stabilizing at a value of about 0·3 and remaining sensibly constant over a period of weeks. In the majority of tests on peat the measured pore pressure dissipation is much faster than suggested by rates of settlement and this is in agreement with viscosity effects (see Figs 5 and 6 of the Paper). It is therefore suggested that while a drop in θ can be important, particularly in three dimensional cases, the main reason for the rapid fall off in pore pressures in peat is the dominant effect of structural viscosity. These tests include samples of remoulded Irish fibrous peat generously supplied by Dr Hanrahan.

I should like to thank Dr Hanrahan for his discussion and express complete agreement that, mainly because of its large strain behaviour, the compression of peat merits further investigation of stress and strain distribution, possibly incorporating X-ray techniques.

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AN APPARATUS FOR FORMING UNIFORM BEDS OF SAND FOR MODEL FOUNDATION TESTS

(Walker, B. P. & Whitaker, T., *Géotechnique* **17**, No. 2, 161–167)

I have conducted some foundation studies on sand and wish to offer the following comments on this topic, which is of vital interest to research workers in foundation engineering everywhere.

The problem of forming a relatively big sand bed at a desired density which is uniform throughout and which is reproducible without difficulty has confronted research workers in