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Tests on a Very Large Shear Cell

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Versuche mit einem außerordentlich großen Schergerät
Essais sur une très grande cellule cisaillée
Ensayos con una rozadora grandisima

超大型シアーセルのテスト

特大剪力容器的测试

اجراء الاختبارات على خلية قصم ضخمة جدا

Summary

The design of storage bunkers requires data on the flow properties of the granular material being stored. Such data is usually gathered using a shear cell of which there are many designs. The Jenike Flow Factor Tester has become almost standard over recent years but the annular cell has the advantage of unlimited travel, ensuring that the material can be put into the critical state.

Most shear cells have an upper limit of particle size which can be handled in the cell, eight mesh being the upper limit for the Jenike cell. To gain information on the flow properties of materials which have large particles (say 50 mm) a large annular shear cell has been constructed, of average trough diameter 1020 mm, trough width 100 mm.

The Portishead annular shear cell (average diameter 250 mm, trough width 25 mm) is a device very similar to the large cell and the author was able to carry out a series of comparative tests using the same material in each. The large annular cell gave much higher strength values and the author speculates that a Janssen effect may be resulting from the difference in trough sizes.

The fact that the design of the two annular cells differed a little does not remove the concern over the differing strength values for there are important serious implications on the validity of the shear test methods in general. Mention is made of a previous work which showed poor agreement between a Portishead cell and a Jenike cell and in one case revealed cyclic behaviour in the annular cell.

1. Introduction

Over the last decade or so powder technologists have come to rely almost exclusively on the Jenike Flow Factor Tester [1, 2] for the determination of flow and frictional properties of granular materials. The Jenike cell is a simple shear box modified from soil mechanics practice to allow for the relatively low stresses involved.

One reason for the continued acceptance of the Flow Factor Tester is the outstanding fact that many successful hopper designs have been made using it in conjunction with Jenike's designs technique [3]. Another reason is the shear simplicity of the device.

However, other pieces of apparatus have been constructed over the years, especially torsion and ring shear machines. In general there are two important advantages in any type of torsion or ring shear apparatus. Firstly, there is no change in the area of cross-section of the shear plane as the test proceeds and secondly the powder sample may be sheared through an uninterrupted displacement of any magnitude, i.e., there is available unlimited strain.

2. Rotational Shear Machines

The simplest test of the kind is one where a simple cylinder is twisted and many such pieces of apparatus have been constructed [4, 5, 6, 7, 8, 9, 10, 11].

They all may be criticised on the grounds of the great non-uniformity of strain and stress within the sample. To combat that problem the ring or annular apparatus was invented on the principle that if the inner and outer radii of the sample do not greatly differ there is a closer approach to uniformity.

The earliest ring shear apparatus was probably that of Casagrande and Hvorslev [12]. Since then there have been many testing devices of the ring type.

Cooling and Smith [13, 14] used an unconfined annular disc loaded normally and twisted. This eliminated side friction problems but the normal load which could be applied was very small.

To reduce side friction problems, divided confining rings in various forms were introduced [11, 15—20].

Recently attempts have been made by chemical engineers to design rotational shear apparatus to measure flow properties of powders. That used by Novosad [21] and Bagster [22] is similar in principle to Hvorslev's apparatus whereas those of Carr and Walker [23] and Scarlett and Todd [24] are of somewhat less refined design but do have the advantage of simplicity.

3. Previous Ring Shear Results

In 1974 Bagster et al. [25] reported some results obtained from a ring shear cell of the type designed by Carr and Walker [23]. It was constructed because of the advantages

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of such machines mentioned above and because Walker appeared to have used results from his "Portishead" cell in successful experimentation on hoppers and in his theory of flow [26, 27]. A cross-section of the cell appears in Fig. 1.

Initially the aim was to use powder samples in both the Carr and Walker cell and a Jenike Flow Factor Tester and to compare the results.

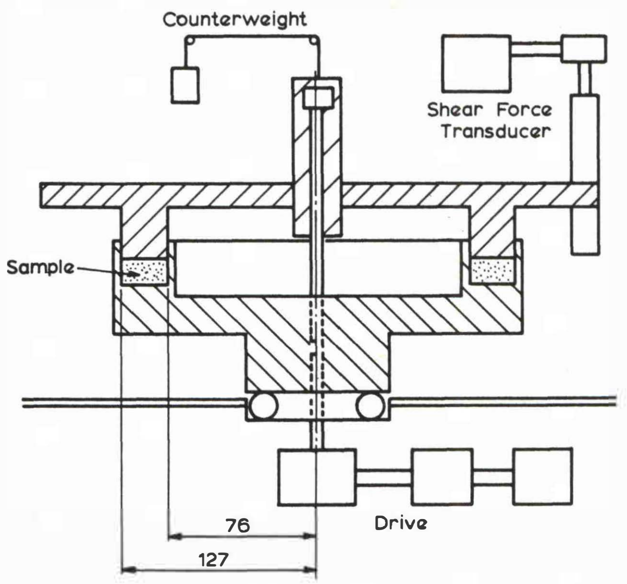

Fig. 1: Schematic section of Portishead cell

The first sample selected for comparison was an air-dry zinc oxide powder. Then this was charged into the Portishead cell and loaded with a selected normal load, the resulting shear stress-strain behaviour did not conform to the expected rise to a steady value. Indeed the shear strength did not become steady after a large number of revolutions of the cell, Fig. 2.

Each stress oscillation actually corresponded to a revolution of the cell and examination of the powder in the annulus revealed some portions of the powder to be very much more compacted than others. Obviously a peak of shear strength corresponds to a coincidence of hard portions in both upper and lower parts of the cell. Many attempts were made to fill the cell more uniformly and indeed the amplitude of the oscillations could be reduced but never eliminated.

It was noticed that zinc oxide was very compressible and it is possibly a combination of cohesiveness and compressibility (the latter no doubt influencing the former) which enables any uneven cell charging to result in grossly uneven consolidation. Figs. 3 and 4 illustrate schematically how uneven charging or uneven loading can lead to non-uniform consolidation, which in turn can lead to a great variation in measured powder strength.

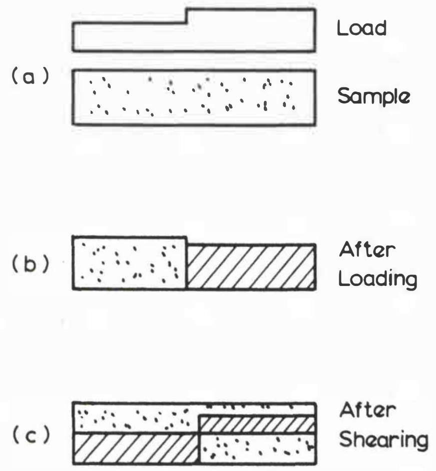

Fig. 3: Uneven charging producing inhomogeneities in cell after loading

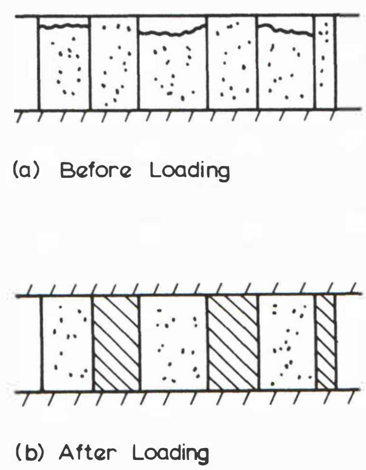

Fig. 4: Uneven loading producing inhomogeneities in cell after shearing

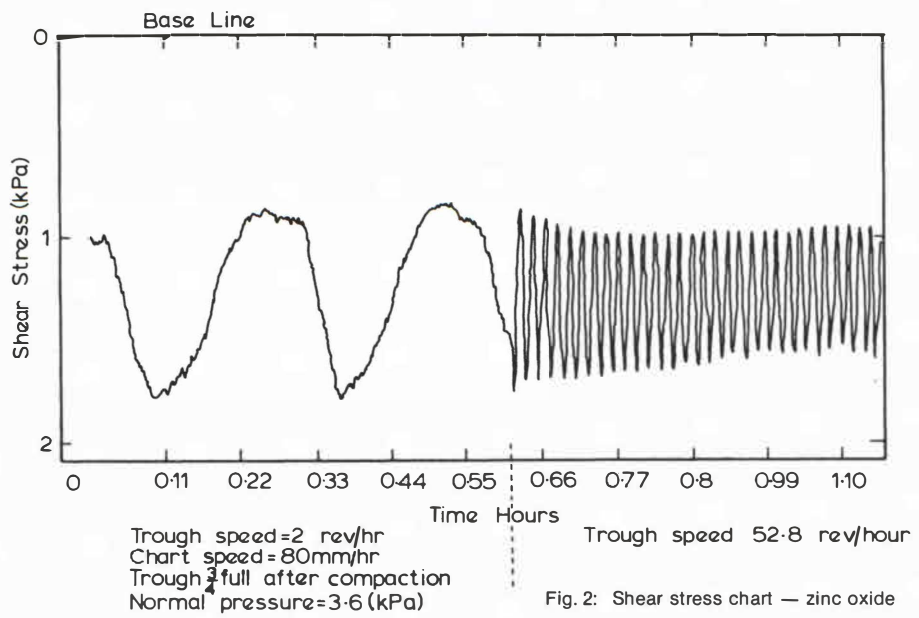

Fig. 2: Shear stress chart — zinc oxide

A sample of —18 mesh coal from Ravensworth, New South Wales, was also tested at three different moisture contents, 9.2, 16.3 and 26.2 % wet basis.

The 9.2 % water sample gave a steady value of shear stress as the cell rotated. The 16.3 % sample gave steady values only if the normal stress was kept low. At high normal stress oscillations occurred. The 26.2 % sample produced oscillations at all normal stresses. The occurrence of hard smooth portions among softer ones was noticed in those samples producing oscillations of stress.

The values of unconfined compressive strength f_c for the 16 % water coal as found on the Jenike cell are plotted in Fig. 5, together with values from the Portishead cell for low stresses (where stress oscillations did not occur). Obviously the Jenike cell measured greater shear strength, a fact observed consistently with other samples as well.

Examination of Fig. 4 provides a possible reason for the results from the Jenike machine being greater than those of the ring machine. Any heavily consolidated and hence strong regions made in sample preparation (i.e. pre-consolidation) in the Jenike cell may not be broken until sheared. In the annular cell the unlimited travel will break such regions prior to shearing the sample. In other words, whereas self-consistent experimental stress results may be obtained from the simple shear cell, any homogenetics of the nature found here will have an influence on strength measured which will not be evaluated.

4. The Large Ring Machine

The point of major concern above is that in taking two shear cells operating on the sample physical (or soil mechanical) principles, great discrepancies should be found.

The new contribution here is the result of taking yet another shear cell of the annular type and comparing the performance with that of the Portishead cell and the Flow Factor Tester.

The shear cell in question was constructed by the Electricity Commission of New South Wales based on the principle of operation of the Portishead machine but with some constructional modifications. Fig. 6 is a schematic cross-section of the large annular apparatus. The channel dimensions (given in millimeters in Figs. 1 and 6) are large because the original intention was to be able to study the flow properties of run-of-mine coal with a top size of 50 mm.

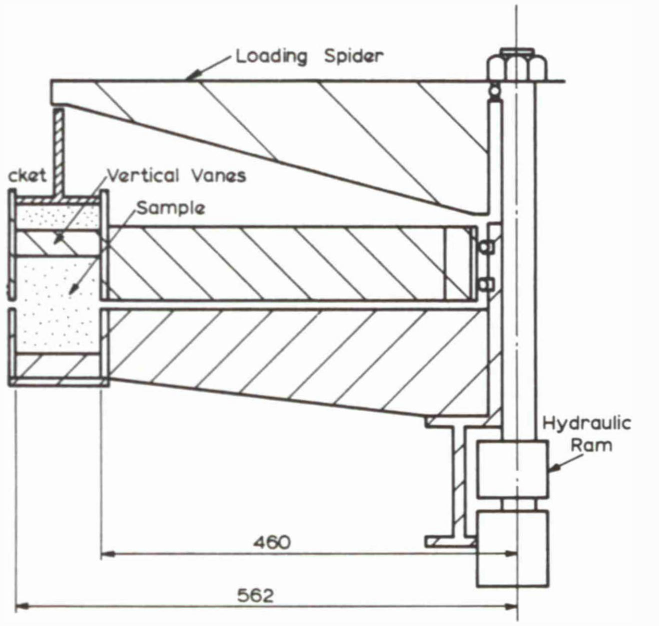

Fig. 6: Schematic section of large ring shear cell

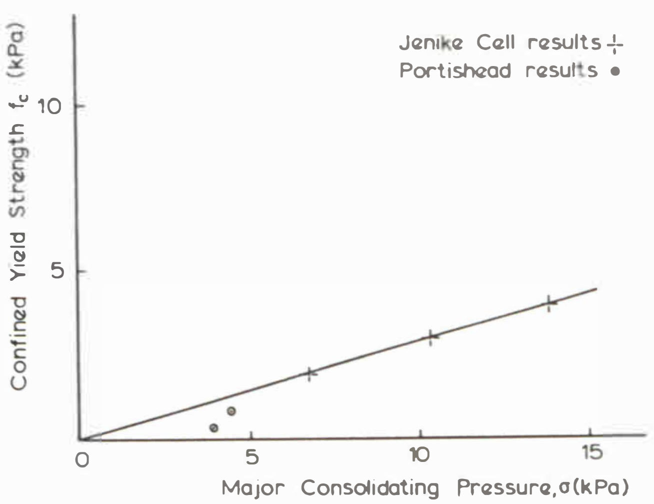

Fig. 5: Comparison of unconfined yield strength — Portishead and Jenike cells. Ravensworth coal, moisture content 16.3 %

A major difference between the Portishead cell and the large one is that the former had the lower annular trough rotating with the upper one restrained and the corresponding torque measured, while the large cell rotates the top trough. The large cell provides normal loading with a hydraulic ram (very low normal loads necessitated a back-loading with weights carried over a pulley). Both normal and tangential loads are recorded from calibrated force transducers. Fig. 7 is a general view of the machine.

For comparative purposes a relatively fine material had to be selected which would be suitable both for the Portishead cell (channel width 25 mm) and the large cell. A New South Wales Wyee coal was crushed and the minus eight mesh portion taken.

Fig. 8 shows a result of a comparative test among the large annular cell, the Portishead cell and the "standard" Flow Factor Tester; all with the same consolidating pressure.

In contrast with the previous comparison between the Jenike cell and the Portishead machine (Fig. 5) where the former produced much stronger parameters, the agreement here is excellent. (It may be that the Wyee coal being somewhat less compressible than the Ravensworth coal of Fig. 5 does not have the same tendency to produce strong regions). However, the large cell shows strengths very much greater than the other machines.

It could be that the prominent vertical vanes in the large cell are providing additional strength to the material (Fig. 6) but these vanes do not extend into the region of split between the upper and lower troughs.

Another possibility which was investigated was that the smaller cell, having a smaller distance between inner and outer walls, may bear more of the normal loading on the walls and so less on the shear plane, resulting in smaller

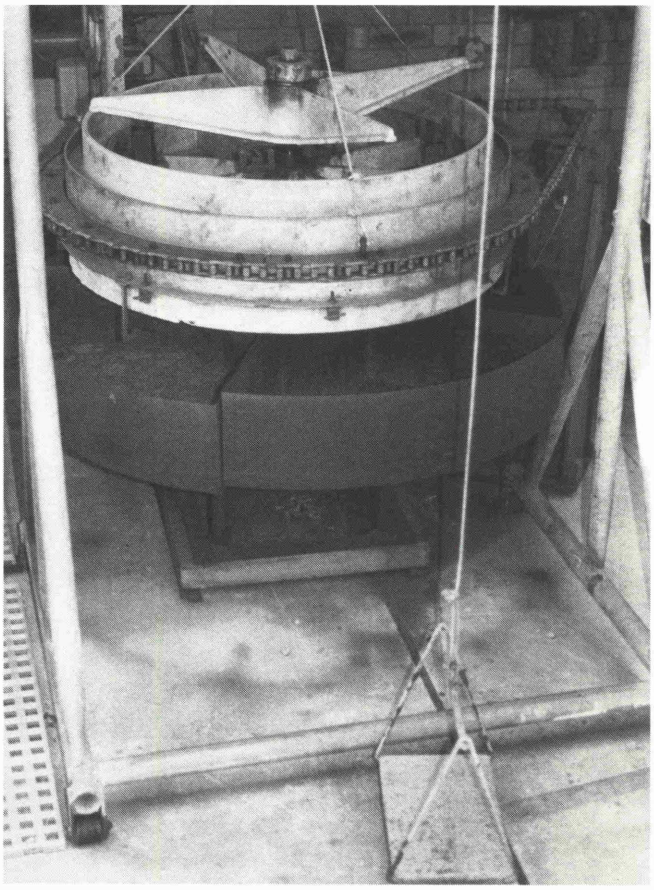

Fig. 7: General view of large shear cell

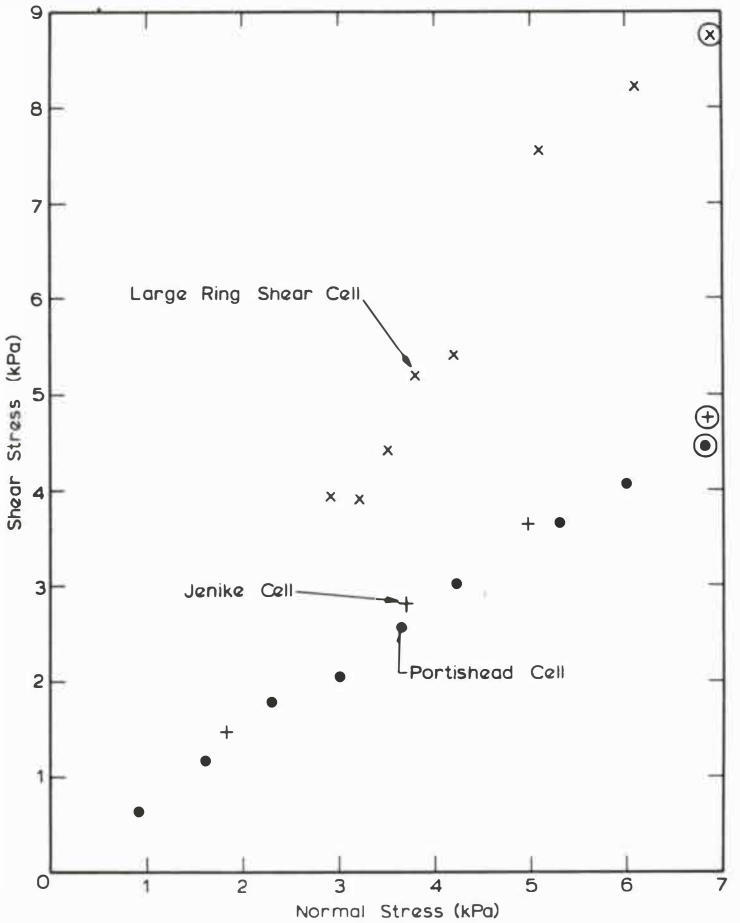

Fig. 8: Yield loci by various devices

measured strengths. The Janssen equation (e.g. [28]) was applied to both cell shapes and it was readily established that with the cross-sectional geometry of either cell the walls produce an insignificant reduction of normal load on the shear plane.

5. Conclusion

Great discrepancies in powder strength have been found in comparison between and among shear machines which are similar in principle of operation.

A possible at least partial explanation may lie in the inherent non-homogeneity of samples for such samples have strength characteristics which are functions of sample size [Endersby, 29]. With the samples used in the experiments described in the present study the actual particle size is much smaller than the shear cells but the size of the various over and under consolidated (or hard and soft) portions is in some cases of the same order as that of the cell dimensions. Hence, a larger cell may suffer as much or even more from the existence of non-homogeneity.

In view of the importance of the results from shear cells further work is necessary to establish the cause (and effect) of the differences between the performance of machines which are intended to work on the same principles.

References

[1] Jenike, A.W., Elsey, P.J. and Woolley, R.H., "Flow properties of bulk solids", Proc. Am. Soc. Testing Mat., Vol. 60 (1960) 1168.

[2] Jenike, A.W., "Storage and flow of bulk solids", Bull. 123, Eng. Expt. Station, Univ. Utah, 1964.

[3] Wright, H., "An evaluation of the Jenike bunker design method" Trans. A.S.M.E., J. Eng. Ind., Vol. 95, series B (1973) 48.

[4] American Society of Civiel Engineers, "Progress report of the special committee to codify present practice on the bearing value of soils for foundations, Appendix A", Proc. Am. Soc. Civ. Engrs., Papers and Discussions, 1917, 1174—1191.

[5] Streck, O., "Fortschritte auf dem Gebiet der Baugrundforschung", Zentbl. Bauverw., No. 9 (1928)

[6] Franzius, O., Streck, A. and Hinderks, A., "Hydraulic laboratory practice", Am. Soc. Mech. Engrs., p. 599 (1929).

[7] Langer, C., "Propriétés mécaniques et physiques des terrains cohérents", Compte rendu des recherches effectuées durant l'Annee, p. 19 (1938).

[8] Tiedemann, B., "Über die Schubfestigkeit bindiger Böden", Bautechnik, 15 (1937) 400 and 433.

[9] Ghani, M.A., "Determination of shear stress in a fine cloddy soil with 'guarded' shear head", Proc. 2nd Intern. Conf. Int. Soc. Terrain-Vehicle Systems, Toronto, p. 279 (1966).

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