Conclusions
1. Determinations of the minimum porosity without grain breakdown are commonly neglected in favour of more severe treatments. As part of a research programme on natural sands, a new technique has been devised to obtain values of minimum porosity.
2. The new technique carried out dry gives a denser packing than slow pour for fine sands. Carried out wet its greater effectiveness can extend into the medium and coarse sand ranges.
3. The new technique has a potential application for the preparation of dense samples, particularly of fine sands, for laboratory testing.

Acknowledgements
The authors wish to express their thanks to SN Palmer and YL Wong for their help with testing and discussion. Palmer undertook the research into the most effective method for the slow pour tests. The authors also acknowledge the financial support given by the Science & Engineering Research Council.

Appendix 1: Apparatus
One of the principal objectives of the design was to minimise vibration contamination from sources other than the cam. To this end, the entire assembly was bolted to a heavy steel base plate. The cam was mounted on a remote shaft supported by two ballbearing races and belt driven by the DC motor. A DC, rather than AC, motor was fitted as this type runs much more smoothly at very low speeds. The cam rotates against a ballbearing race mounted on the end of the relay shaft, thus avoiding excessive friction. The relay shaft is in two sections (not appreciable from the diagram) each supported by a long brass bush. The latter half of the shaft is spring-loaded ensuring contact with the cam at all times, avoiding ‘bounce’. The shaft was made in two parts to prevent unwanted vertical vibration from the cam being transmitted to the pot.

The pot vibrates horizontally on three PTFE feet fitted to its base, and is linked to the relay shaft by a quick-release slotted flange and clamp nut arrangement. An adapter plug may be inserted inside the pot to support a small (60mm by 60mm) shear box when loose material is to be reconsolidated for testing.

The camshaft and motor shaft are of the same diameter, allowing the pulley wheels to be exchanged to provide very low frequencies if required.

References

Model tests of footings above shallow cavities
Abir Al-TabbaaA, Lisa RussellB and Michael O’ReillyC

Racehorses stabled on Doncaster’s turb last month over hidden soil cavities which give an immediate perspective to a BSc research project carried out at a Bristol University.

Introduction
Subsurface cavities present problems in many areas of ground engineering. These range from the potential dangers of building over large cavities created as solution features or during mining, to the trafficking of areas in which small cavities have been caused by dessication and internal erosion processes operating immediately below the ground surface.

A dramatic example of the consequences of near surface cavities was the series of incidents which occurred during Doncaster Racecourse last month a few days before the classic St Leger race was due to be run. Four horses fell in two separate accidents. It was discovered after excavation near drainage runs on the course that the dry weather had caused near-surface cavities to be formed. These had been broken into by the high point loading of galloping horses whereas the larger loaded areas of tractor tyers ‘had not even made an impression’. Such cavities are said to be common on the dirt tracks used for horse racing in the United States. 

A Geotechnical engineer, Ora Arup & Partners
B ICE editor, New Civil Engineer
C Chartered engineer and barrister

GROUND ENGINEERING · OCTOBER · 1989
Analysis of the deformation and failure of cavitated ground when subjected to surface loading cannot easily be accomplished unless simplifying assumptions are made. Model tests, on the other hand, may provide a method by which the effect of cavities can be studied with greater confidence, and produce experimental data against which analytical solutions may be compared and calibrated. In this paper the results of model tests performed using an artificial cohesive-frictional soil (Al-Tabbaa and Russell (1983)\textsuperscript{a}), are presented. In these tests a strip footing loads ground containing a single cavity. It is hoped that the results may provide some insight into the mechanisms involved.

**Experimental apparatus**

Plane strain model footing tests were performed in the apparatus shown in Fig. 1. An artificial soil consisting of dry uniform medium sized sand cemented by the addition of 4\% of plaster of Paris and 2\% water by weight. Density of the mixture used was 1550kg/m\(^3\) and results of triaxial tests performed on it are presented in Fig. 2. After the soil had been compacted and set in the apparatus an unlined circular cavity was hand bored, following which load was applied to the footing using a standard deformation controlled triaxial rig.

Variables investigated were the depth to the cavity axis D, width of the cavity W and the offset dimension x, as shown in Fig. 3. All loads imposed were purely vertical, although in many situations (eg the horse trafficking example given above) the problem involves the consideration of inclined loading. During the tests the width of the footing was kept at B = 75mm.

**Fig. 1. The apparatus.**

**Fig. 2. Triaxial test results on artificial soil.**

**Fig. 3. Variables considered.**

**Fig. 4(a) Average footing pressure versus settlement for different depth of cavity at W/B = 1.0. (b) Relationship between maximum pressure, depth and width of cavity.**
Fig. 5. Photographs of a test in which cavity is vertically below footing taken at the start and at the end of the test.

The average footing pressure imposed is denoted by q in the limiting case of loading ground with no cavity the failure pressure was found to be 650kN/m$^2$ and this value was denoted by Q.

Results
Effect of depth and width of cavity
Fig. 4(a) shows the average footing pressure-settlement behaviour, q vs δ, for a cavity of width equal to that of the footing, W = B, with the cavity at three different depths. As expected, the deeper the cavity the stiffer and stronger is the response. A range of cavity dimensions was tested and the combined results of varying the depth and the width of the cavity are shown in Fig. 4(b) which indicates the relationship between the failure footing pressure ratio q/$Q$ and the width and depth of the cavity.

It may be seen from this, for instance, that for a footing 75mm wide with a cavity 75mm diameter directly beneath it, a cavity at a depth of 350mm or greater will have an insignificant effect on the failure pressure of the footing. Fig. 5 shows a photograph of the failure mechanism during a typical test. The failure planes are highlighted by the displacement of the black grid which was sprayed onto the face of the section before testing.

Effect of cavity offset
Fig. 6(a) shows the results of tests for various cavity offsets while maintaining a constant width ratio W/B = 1 and depth ratio D/B = 1.3. The offset is normalised with respect to the footing width B. As expected the closer the void is to the line of the footing the less stiff and weaker is the system. Fig. 6(b) shows q/$Q$ vs x/B from Fig. 6(a). This figure shows that for this particular depth and width of cavity the strength of the soil scarcely increases unless the cavity is shifted more than 0.5 the footing width from the centre of the footing. A pronounced increase in capacity occurs at values of shift between 0.5 and 1.5 of the width of the footing. At shifts greater than about 1.5 the failure pressure approaches that for ground without a cavity. Fig. 7 shows a

Fig. 7. Photographs of a test in which cavity is offset taken at the start and at the end of the test.

Fig. 8. Comparison of pressure-settlement relationship between circular and square cavities at two different depths.

Effect of shape of cavity
The results presented so far deal solely with circular cavities. In Fig. 8 two comparisons between circular and square section cavities are illustrated. As expected the square section (which produces a larger void for the same dimension W) is weaker, but the difference between the two is not very great.

Conclusion
In many situations it may be necessary to load ground containing near-surface cavities. This short contribution shows the results of a series of tests in which the response of a footing on artificial soil containing a cavity was investigated. The results indicate how the depth, size and offset of the cavity affect the stiffness and strength of the system and it is hoped may provide some assistance in understanding such problems.

Acknowledgements
The tests presented here were performed by the two first named authors as part of an undergraduate project at Bristol University under the supervision of Dr WJ Larnach, whose guidance is greatly appreciated.

References
1 The Times, 18 September 1989, p38.
2 BCCI television report, 16 September 1989, on the postponement and transfer of the 1989 St Leger to Ayr Racecourse.
3 Al-Tabbaa A and Russell LJ (1983), 'The behaviour of footings over voids', BSc research project, University of Bristol.