Comparison of Alternative Methods of Measuring the Residual Strength of a Clay

J. T. ANAYI, J. R. BOYCE, AND C. D. ROGERS

This paper describes a series of drained tests on Lias clay at various normal stresses in both a reversible shear box and a modified Bromhead ring shear apparatus. The residual failure envelopes were found to be curved at normal stresses below 150 kN/m² (22 lb/in.²). At normal stresses above this value, the modified Bromhead ring shear tests produced lower values of residual shear strength than reversal shear box tests. The results indicate that residual failure surfaces are not developed at normal stresses below 30 kN/m² (4.4 lb/in.²).

When a soil is subjected to shear strain, the shear resistance steadily increases. For any applied effective normal pressure, the limit to the resistance that the soil can offer is known as the peak shear strength. In some cases an experimental test is stopped just after this point and the strength measured is referred to as the shear strength of the soil. If shearing is continued beyond the maximum value of shear strength, the resistance of a clay decreases until a constant value is reached, which is known as the residual strength.

Residual strength is defined by Skempton (*1*) as the minimum constant shear strength attained in a soil (for a slow rate of shearing) at large displacement. He demonstrated that the displacements necessary to cause such a strength are usually far greater than those corresponding to the peak strength and the fully softened state (critical state in overconsolidated clay) as shown in Figure 1. In such a soil the postpeak drop in drained shear strength may be considered as taking place in two stages: first, at a relatively small displacement, the strength decreases to the fully softened or critical state owing to an increase in water content (dilatancy); and second, after large displacements, the strength falls to the residual value owing to the orientation of platey clay minerals parallel to the direction of shearing. The postpeak drop in strength of normally consolidated clay is due only to particle reorientation.

The drained residual strength of cohesive soil has been studied extensively by many investigators. The first major understanding of residual strength was presented by Skempton (*2*) who showed that the strength along any discontinuity in a clay mass is governed by the residual-strength of the clay. Lupini et al. (*3*) have presented an extensive review of previous work on residual strength. They concluded that three modes of shearing are associated with residual strength:

- Turbulent mode, which usually occurs when soils have a high proportion of rotund particles or have platey particles in which particle orientation does not occur.
- Sliding mode, which corresponds to the case in which a low strength shear surface of strongly orientated, low-friction platey particles forms.
- Transitional mode, which involves both turbulent and sliding modes.

The transition from one mode to another is related to the packing and porosity of the rotund particles present.

It is generally accepted (*2–4*) that the residual shear strength of a soil is independent of stress history effects and specimen size. Rate of displacement has only a small effect. Essentially the decrease in strength to its residual value is related to the orientation of clay particles in the shear zone. This orientation process is largely independent of the speed of shearing.

If this is the case, the application of a large deformation at a high rate of shearing followed by a reduction in the rate of shearing should reduce the time required to mobilize the residual strength in laboratory tests. However, the question of developing pore pressure will arise at a high rate of shearing. This problem will be discussed later in relation to the results of this work.

MEASUREMENT OF THE RESIDUAL STRENGTH OF CLAY

Two types of apparatus can be used to measure residual shear strength: the shear box and the ring shear apparatus. Each of these is discussed in turn. The triaxial test is not used to any great extent in measuring residual strength, because of the complex stress distribution across the failure plane that is produced if the test is continued beyond the peak.

Shear Box

The shear box apparatus is the oldest form of shear test. Generally the soil is held in a box that is split at midheight. A vertical pressure is applied, followed by a horizontal shear force so as to cause relative displacement between the two parts of the box. The magnitude of the shear force

Loughborough University of Technology, Loughborough, Leicestershire LE11 3TU, England.

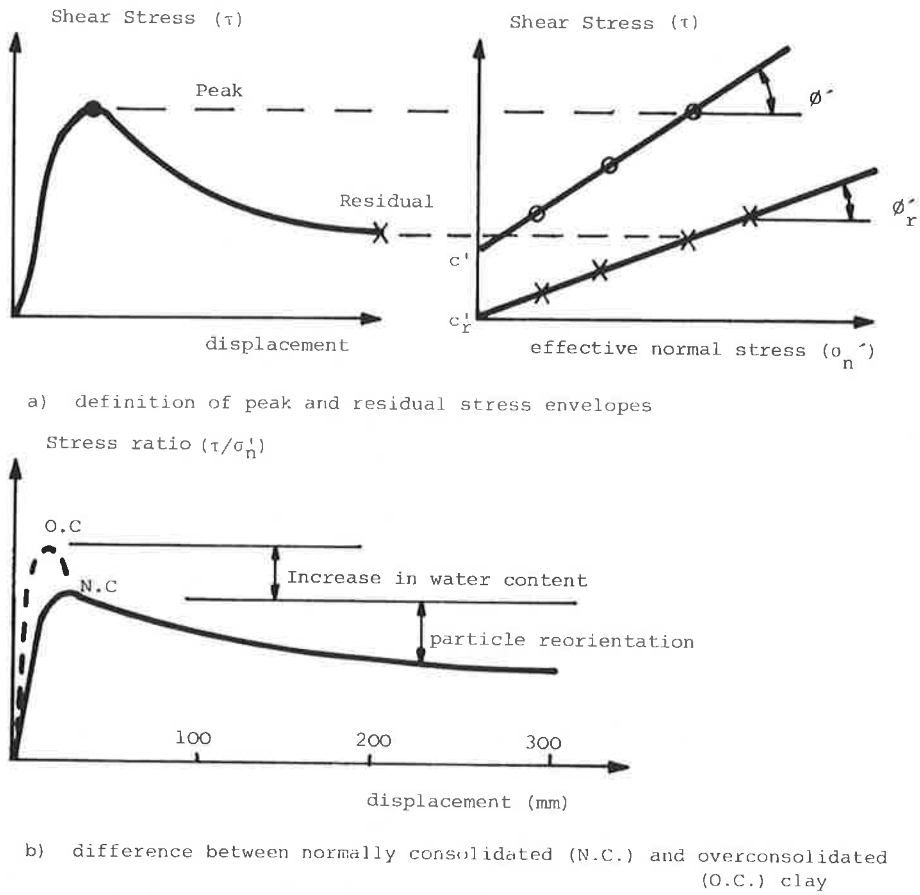

FIGURE 1 Shear stress versus displacement for a typical clay.

is recorded as a function of the shear displacement. The vertical load is usually applied by dead weights, whereas the shear force is often applied by a motor acting through gears so that the test is strain controlled.

At Loughborough the standard shear box has been modified to enable the direction of travel to be reversed automatically. When this equipment is used, the strength along the shear plane formed in the specimen is made to approach a lower limiting value, or residual value, by repeated reversals of the direction of travel of the shear box.

In many ways, the most satisfactory method of measuring residual strength is to obtain undisturbed samples that contain a natural slip surface and to test them in the shear box such that failure occurs by sliding along the existing slip plane. Skempton (*1*) has shown that when tests are satisfactorily carried out on undisturbed samples containing a fully developed slip or shear surface, the residual strength is reached at a relatively small displacement since all water content changes and particle orientation effects have already been brought about by the shearing movements in nature. The strength on such surfaces is defined as the field residual value. In principle, it should be the same as the strength calculated from back analysis of a landslide in which movement has been reactivated along a pre-existing slip surface. Skempton and Petley (*5*) have shown from their investigation of slip surface samples that, in the second run of a test (after reversing the travel of the box), the strength returns closely to the first-run value.

Drained tests were performed in a shear box by Calabresi and Manfredini (*6*) at the University of Rome on intact samples from Santa Barbara. The samples were sheared along different types of structural discontinuities of jointed overconsolidated clay. Calabresi and Manfredini concluded that along joints and bedding planes the same peak value of friction angle as that of an intact clay occurs, but that cohesion is very low, if not negligible. The residual strength is the same in both cases, but along these discontinuities, is usually reached after a smaller displacement. Along the faults, the shear strength is already at its residual value. The intact clay seems more brittle when sheared along planes parallel to the bedding planes, and this may have some influence on the development of progressive failure.

The magnitude of shear displacement available in the shear box is usually small, so more than one travel is needed to obtain the residual strength of any soil. This is achieved by returning the split box to its starting position after completing the extent of its travel and shearing again. This process can be repeated a number of times until a steady (residual) value of shear strength is observed. However, this procedure has the obvious disadvantage that the particle orientation developed during travel in one direction may be partly destroyed when the direction of travel is reversed.

The development of residual shear strength can be facilitated by the use of a precut shear plane. However, care must be taken to consolidate the specimen under the selected normal load for an appropriate period after the shear plane has been formed. This method has the advantage that the shear surface is a plane, whereas in other shear box tests the shear surface may undulate giving greater values of recorded strength.

Ring Shear Apparatus

All previous work on residual strength of soil has found the ring or torsion shear test to be very useful because there is no change in area of cross section as the test proceeds and the sample can be sheared through an uninterrupted displacement of any magnitude.

Bishop et al. (*7*) stated that any measurement of the residual strength of a soil should satisfy the requirements that the normal and shear stresses at failure should be as uniform as possible in the apparatus used, which must be capable of transmitting the desired combination of normal and shear stresses to the sample. The Bishop ring shear apparatus was built by the Norwegian Geotechnical Institute and Imperial College (*7*). The sample in the ring shear has the following dimensions:

Outside diameter	152.4 mm (6 in.)
Inside diameter	101.6 mm (4 in.)
Initial thickness	19.0 mm (0.75 in.)

It can be subjected to a maximum normal stress of 1,000 kN/m^2 (145 $lb/in.^2$) and a maximum shear stress of 500 kN/m^2 (72 $lb/in.^2$). The annular sample is laterally confined between two pairs of rings and is loaded normally through annular platens. Drainage is by means of a porous ceramic annulus screwed into each platen. Fins are provided on the exposed face of each ceramic annulus to minimize the risk of slip occurring at the soil-ceramic interfaces. The lower confining rings and the loading platen are screwed to the base plate. The upper and lower confining rings are held together by locking screws, which are removed before shear commences. A perspex water bath serves to prevent the sample from drying out during testing. The sample is sheared by steadily rotating the lower half while the upper half reacts against a torque arm. The shear torque is determined from the readings on two opposed tangential proving rings mounted on rigid columns. This machine is the most sophisticated device for measuring the residual strength of soil. However, it is complicated and expensive and is therefore used mainly for academic work at Imperial College (University of London).

The Harvard Ring Shear apparatus is described by La Gatta (*8*). The machine is designed to test disc-shaped specimens with a diameter of 71.1 mm (2.8 in.) or annular specimens of outside diameter 71.1 mm and inside diameter 50.8 mm (2.0 in.). The specimen thickness may vary from 1 to 25 mm (0.04 to 1.00 in.). Specimens can be undisturbed or remolded. In general, the shearing unit consists of a turntable, two loading platens containing porous stainless steel discs to allow drainage, a vertical spacer, a moment transfer plate, and a top plate. The vertical stress is applied by means of a loading yoke and counterbalanced lever system. Three miniature extensometers can be attached to the top plate to measure any tilting during consolidation or shear. Shear stresses are computed from the geometry of the test specimen and the moment acting on the sample.

The expensive and time-consuming nature of ring shear tests to determine the residual strength of soils has prevented the test from becoming a routine procedure in commercial laboratories. However, in 1979 a new simple, robust, and inexpensive apparatus was developed at Kingston Polytechnic, and it is now commercially available. A general view of this apparatus, which is described by Bromhead (*9*), is shown in Figure 2. An annular soil sample 5 mm (0.2 in.) thick with inner and outer diameters of 70 mm (2.76 in.) and 100 mm (3.94 in.) respectively is confined radially between concentric rings. It is compressed vertically between porous bronze loading platens by means of a lever loading system and dead weights. Rotation is imparted to the base plate and lower platen by means of a variable speed motor and gearbox driving through a worm drive. This causes the sample to shear, the shear surface forming close to the upper platen, which is artificially roughened to prevent slip at the platen-soil interface. The settlement of the upper platen during consolidation or shear can be monitored by means of a sensitive dial gauge bearing onto the top of the load hanger. Torque transmitted through the sample is measured by a pair of matched proving rings or load cells bearing on a cross arm. A remolded sample is kneaded into the annular cavity, and the sample is consolidated to the desired normal effective stress. When settlement of the upper platen has stopped, the sample is considered to be fully consolidated and it is then sheared at the appropriate rate.

FIGURE 2 Bromhead ring shear apparatus.

CURRENT WORK AT LOUGHBOROUGH

Aims and Research Philosophy

The aims of the research program at Loughborough are

- To compare the conventional methods of measuring residual strength of clay using the reversible shear box and the ring shear apparatus.
- To find the best method of measuring residual strength of clay and to investigate the laboratory factors that affect the measured value of residual strength.
- To define the actual shape of the residual failure envelope using the recommended method for particular clays.

Most of the work to date has been carried out on samples of clay taken from a site near Rugby, England. The soil is generally a blue, fissured, highly overconsolidated clay known as Lias clay, with layers of limestone occurring in the clay strata. The average water content of these samples was found to be 16 percent. This type of clay has the following index properties: liquid limit, 52 percent; plastic limit, 25 percent; plasticity index, 27 percent. Chandler (*10*) has mentioned that Lias clay is of Jurassic age and is heavily overconsolidated, having been subjected in the past to a maximum overburden in excess of 1,000 m (3,300 ft). Consequently, in its unweathered state, it has a natural water content well below its plastic limit. As a result of weathering, its water content near the surface typically rises to around the plastic limit. The material used in this work was taken from a recently exposed quarry face about 12 m (40 ft) below the surface. The material is therefore hard, but highly fissured as a result of stress relief, and has a natural moisture content somewhat below the plastic limit. Figure 3 shows a photograph of the material in an air-dried condition.

A conventional shear box and a Bromhead ring shear are being used in this work, each being connected to a data acquisition system. In each case, modifications have been made to improve the standard equipment.

The shear box (Figure 4) was modified by introducing a reversing switch, which changes the direction of shearing when the limit in either direction is reached. At the same time, a message is relayed to the data acquisition system.

The main modification to the Bromhead ring shear apparatus was to include small vanes on the top and bottom platens (Figure 5) so that shearing would occur at the midheight of the sample instead of near the top platen. To allow for this, the initial sample thickness was increased from 5 to 10 mm (0.2 to 0.4 in.).

Laboratory Testing

Reversal Shear Box

Lias clay samples were prepared by breaking the air-dried material with a pestle and mortar to form a powder passing

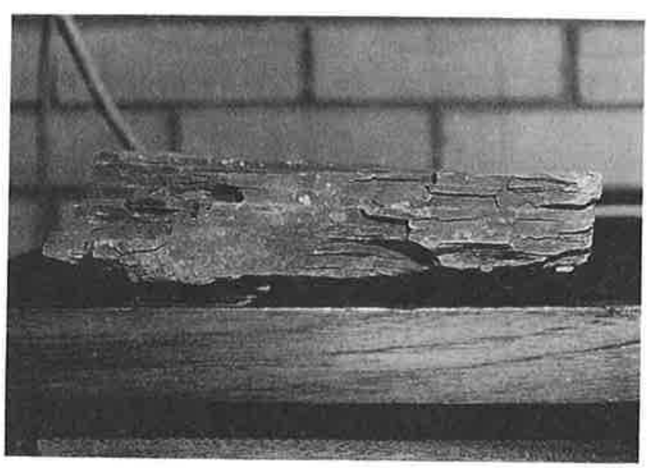

FIGURE 3 Lias clay.

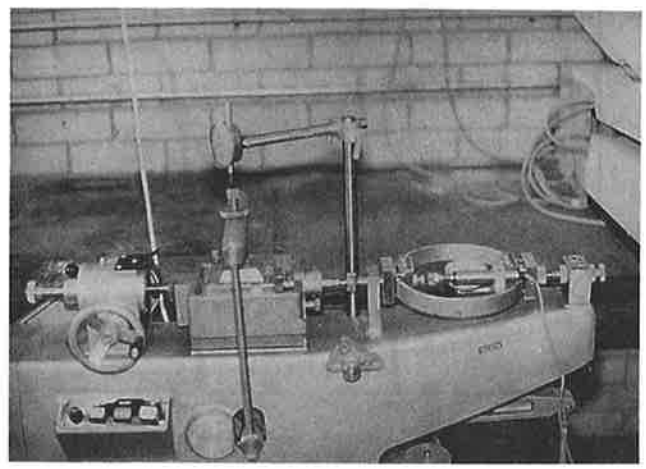

FIGURE 4 Shear box.

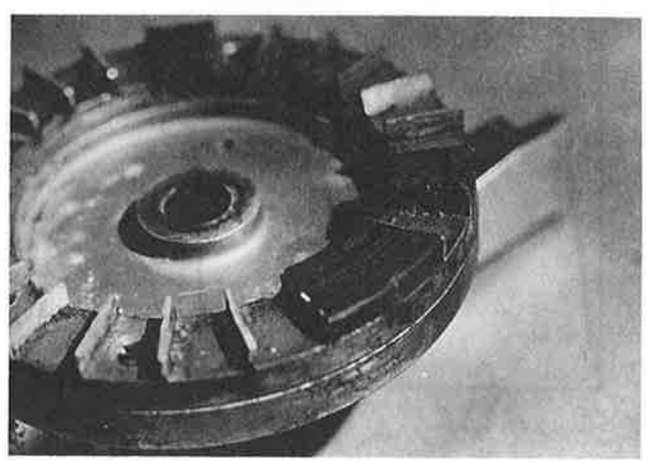

FIGURE 5 Top platen of modified Bromhead ring shear showing vanes.

a 425 m (No. 36) sieve. Distilled water was then added, and the clay thoroughly mixed at a water content near its liquid limit. The clay was then allowed to dry out to a moisture content near the plastic limit. A sample was kneaded into the mold of the shear box after boiling the porous plates for 30 min in distilled water to remove air bubbles.

A series of tests was conducted using various possible techniques to determine which method gave the quickest reliable measurement of the residual strength of the clay. The techniques employed were as follows:

- Formation of shear plane
  - Intact sample subject to slow shearing
  - Precut sample subject to slow shearing
  - Intact sample subject to fast shearing for several reversals followed by slow shearing.
- Rate of shearing
  - 0.24 mm/min (9.4×10^{-3} in./min)
  - 0.024 mm/min (9.4×10^{-4} in./min)
  - 0.0096 mm/min (3.8×10^{-4} in./min)
- Sample size
  - 60 mm (2.36 in.) square
  - 100 mm (3.94 in.) square
- Sequence of normal loads on each sample
  - Single stage
  - Multi-stage

The results of these tests gave rise to certain general conclusions:

1. An intact sample subject to slow shearing with forward and backward reversals forms an undulating shear surface that may lead to high measured values of residual

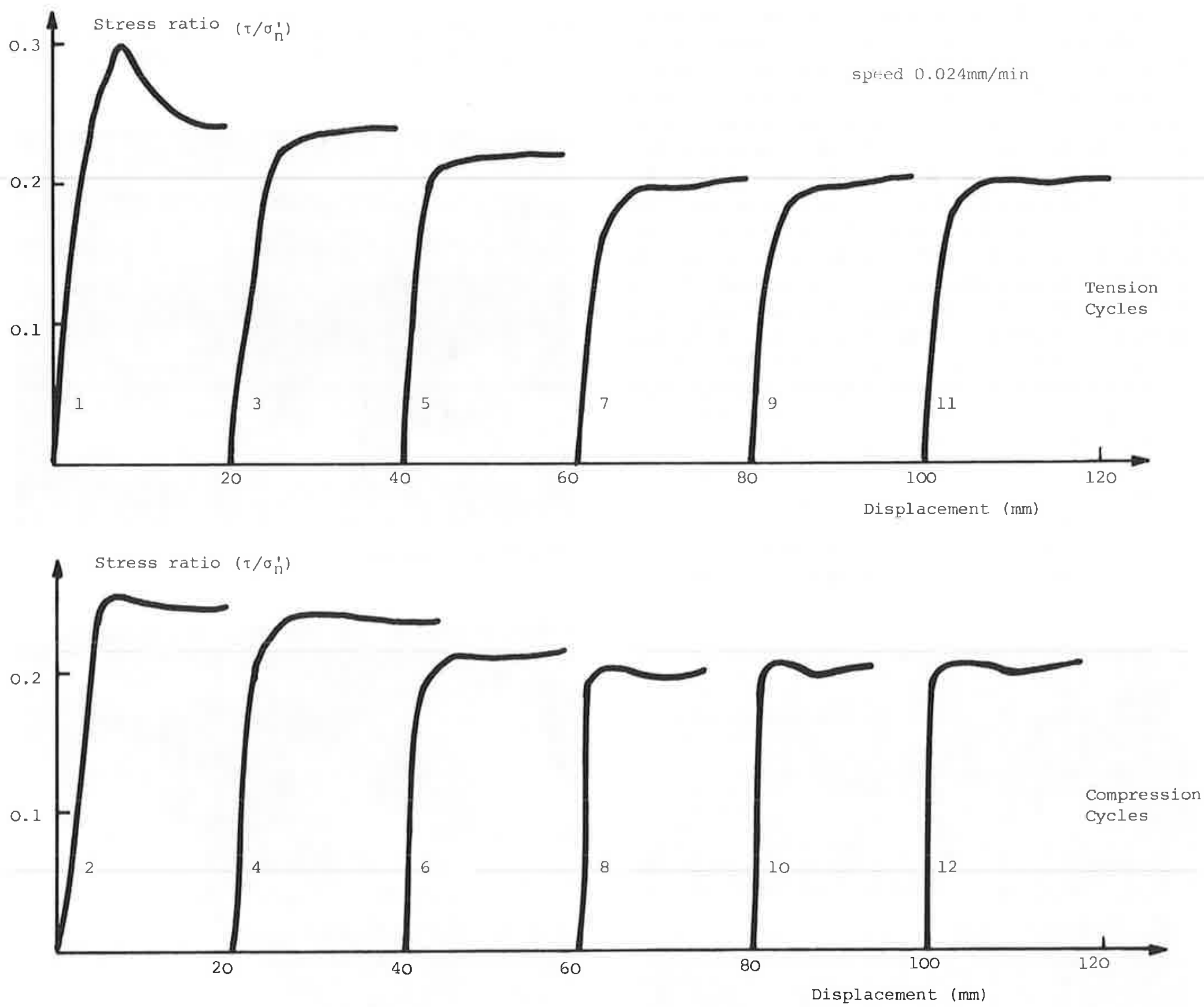

FIGURE 6 Stress-strain curves for reversal shear box test on Lias clay (continuous slow shearing).

strength. The topography of the shear surface can be seen when the sample is examined after the test has been finished. Carrying out the test also takes longer than the other methods do, and there is a problem of excessive soil being extruded at the end of the box. Typical results are shown in Figure 6.

The samples with a precut plane were prepared in two separated half thicknesses (10 mm each) and then put together in the shear box. Experience has shown this method to be easier than cutting the sample with a wire saw.

Fast shearing followed by slow shearing involved first subjecting the sample to several reversals under undrained conditions (300 mm or 11.8 in. displacement at 1.2 mm or 0.047 in./min). Then the rate of shearing was reduced to 0.024 mm/min, and several more reversals were carried out. The readings of the first slow traverse were not taken into consideration to ensure that all the pore water pressure had dissipated. The next traverse was considered to be sheared under drained shearing displacement. This method gave a steady shearing strength in the following cycles and was considered the best method because it gave the lowest value of residual shear strength, was less time consuming, and did not require operator skill in preparing precut samples. Typical results are shown in Figure 7.

2. Rate of shearing was found to have no effect, but a rate of 0.024 mm (9.4×10^{-4} in.) per min is recommended to ensure drained conditions.

3. Figure 8 shows the results of two multi-stage tests using the 60 mm (2.36 in.) square shear box and the 100 mm (3.94 in.) square shear box. The results for the larger sample are slightly lower; the reason for this difference is not known.

4. Multi-stage testing involves the establishment of the residual strength condition at one normal stress, followed by the measurement of residual strength at other normal stresses on the same sample. This technique saves time because the displacement required at each new value of normal stress is only about 20 mm (0.78 in.). There is also less soil extrusion, especially if the normal stress is reduced.

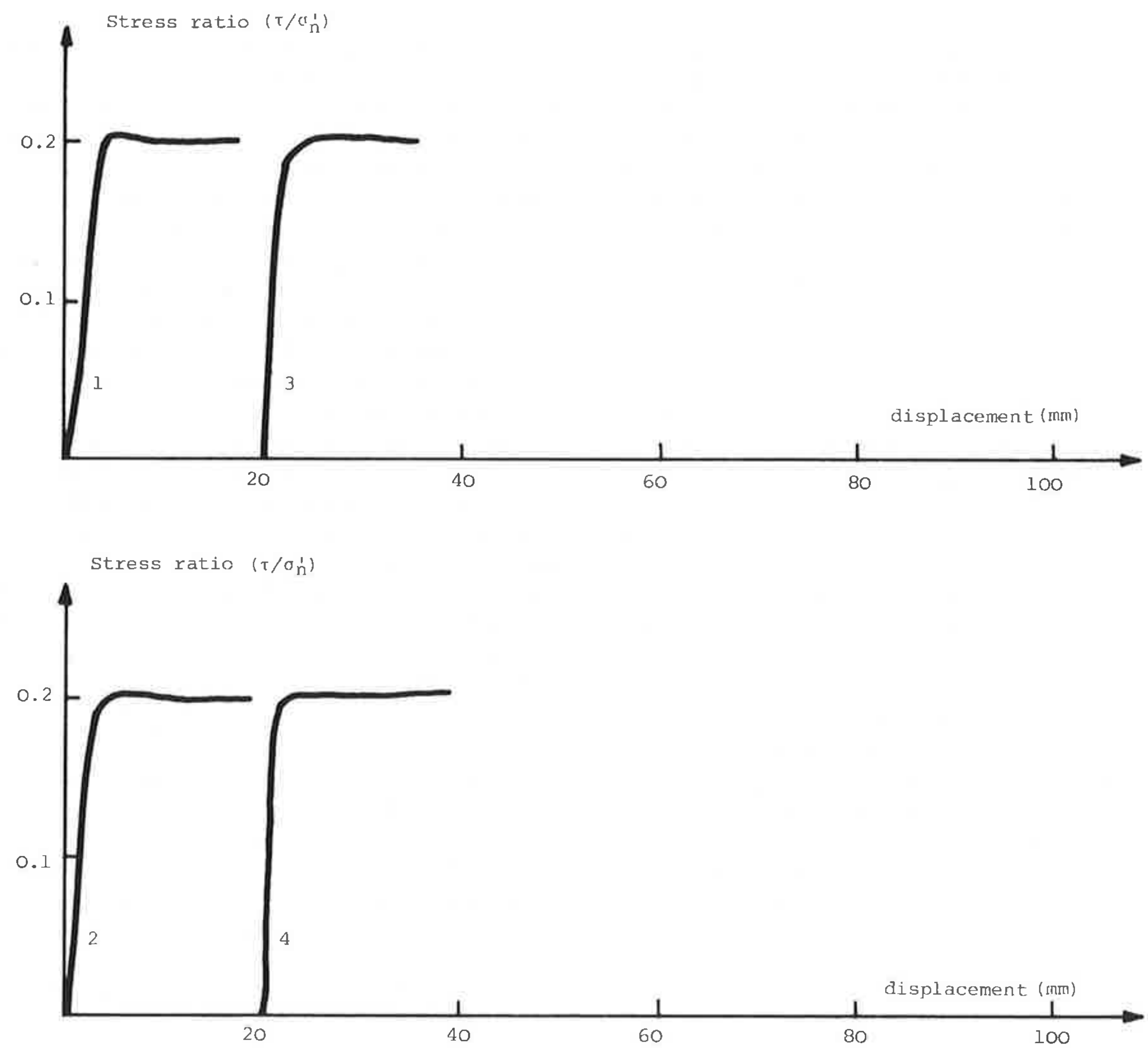

FIGURE 7 Stress-strain curves for reversal shear box test on Lias clay (fast shearing followed by slow shearing).

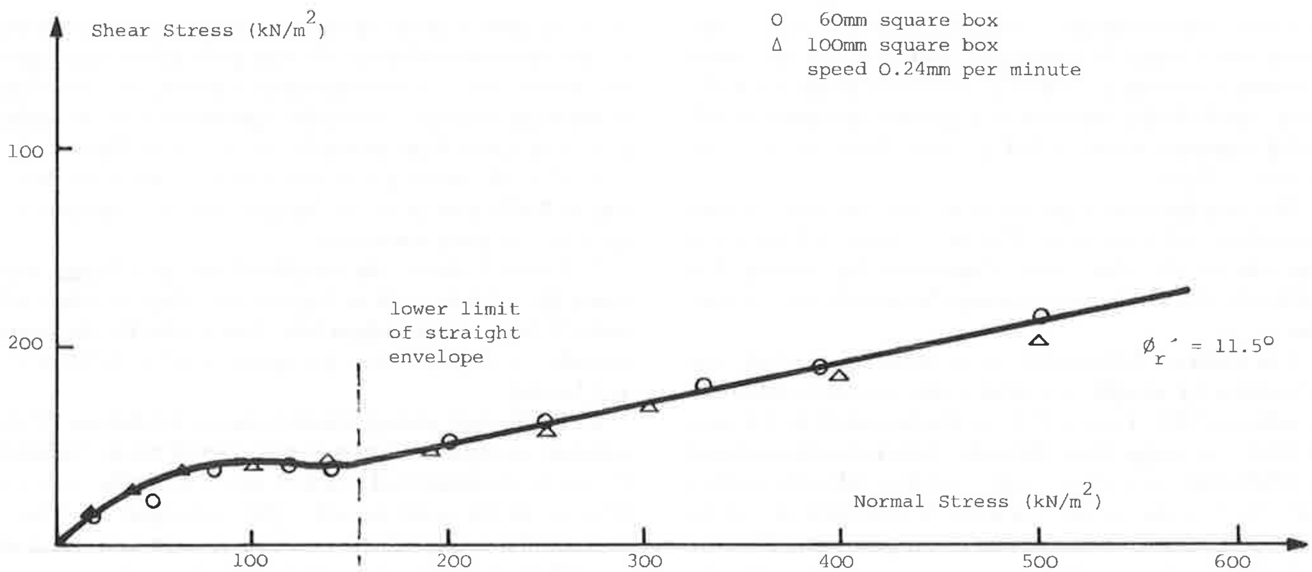

FIGURE 8 Residual strength envelope for Lias clay (reversal shear box tests).

As a result of this series of tests, the recommended technique for reversal shear box tests is to use a 100 mm (3.94 in.) square sample, with the residual shear plane formed by fast shearing, followed by residual strength measurement at a rate of about 0.024 mm (9.4×10^{-4} in.) per min. Multi-stage testing can be used if the sample appears to be in good condition after the previous measurement.

Ring Shear

Lias clay was again used in these tests. The samples were prepared in the same way and kneaded into the lower platen of the Bromhead apparatus at a moisture content near the plastic limit.

Many trial tests were carried out using the original apparatus designed by Bromhead (*9*) and performed in the manner recommended by Bromhead. The sample was left overnight under normal load for full consolidation, and then four or five revolutions were applied to the sample, which produced a failure surface just below the top platen. The sample was left again for the moisture content to equalize before slow shearing. As soon as shearing commenced, the readings of the two proving rings started to become unbalanced, and in some cases, one ring reached zero. Attempts were made to overcome this imbalance in shear forces by carefully equalizing the two proving rings before shearing. Also, small pieces of rubber were introduced between the tip of each proving ring and the torque arm to reduce the stiffness of the proving ring system. It was hoped that this would reduce the effect of any small eccentricity of rotation. In all these trials, no satisfactory measurement of residual strength was achieved.

Continuous monitoring of the tests suggested that there was some remolding taking place at the top of soil sample. This remolding might have happened because of the small clearance between the top platen and the lower platen (sample container), which is necessary for correct functioning of the apparatus. From these observations, ideas for modifications were developed. The concept adopted was to hold the top and bottom surfaces of the sample adjacent to the platens by means of vanes distributed uniformly on the top and bottom platens (Figure 5). Each platen was modified by the addition of 24 vanes, 3.0 mm (0.12 in.) high. Tests using this modified apparatus gave similar readings on each proving ring with a maximum difference of 3–4 percent, which can be attributed to the difference in stiffness of the two proving rings.

Two series of tests were carried out using the modified ring shear. In the first series, tests were performed on Lias clay using one normal stress and two different rates of shearing, 0.17 mm (0.0067 in.) per min and 0.017 mm per min. No significant differences were observed in the results for the two rates of shearing. In the second series, two sets of multi-stage tests were conducted to find the residual failure envelope at a rate of 0.017 mm per min.

The results showed the following features:

- Testing a sample under any given normal stress requires about 300–350 mm (12–14 in.) displacement to reach the residual state. When the sample is sheared again under a higher or lower normal stress, the displacement required to reach the residual stress is only 20–30 mm (0.8–1.2 in.). The multi-stage method is therefore much quicker.
- Only a little soil was extruded from the edge of the sample, so the problems of nonuniform stress distribution and decrease in sample thickness were not encountered.
- Each sample could be tested successfully under four different normal stresses using the multi-stage method.

• It was found that at low normal stresses, 30 kN/m^2 (4.4 $lb/in.^2$) or less, no residual state developed and no minimum shearing resistance was reached.

The total time required to establish the complete residual strength envelope using the recommended multi-stage method is not more than 15 days. With the modified apparatus there is the possibility of some side friction between the soil and the sample container. This friction is not believed to introduce significant errors, but it is hoped the apparatus will be modified again soon to eliminate this possibility.

Results

Reversal Shear Box

Figure 6 shows typical load displacement curves for the Lias clay using a 100 mm (3.94 in.) shear box at a shearing rate of 0.024 mm (9.4×10^{-4} in.) per minute. Each of the numbered shear stages represents a change of shear direction. The curves have a brittle peak characteristic at the early stages of testing (cycles 1 and 2), followed by the usual continuous drop in shear strength after the peak. The curves then show a tendency for the strength to drop a little at each reversal until after about six reversals a constant strength, defined as the residual state, is reached. This is defined as the residual state.

It seems that it is not sufficient to stop the test when a constant load value is obtained over a small displacement. The test should be stopped only when two consecutive compression or tension runs produce the same strength, within about 3 percent. It should be noted that the tension and compression loads seldom correspond exactly. This is thought to be due to the shape of the shear surface, and observations from these curves and others show that this variation between tension and compression runs can be as high as 5 percent. It seems that after a constant value of shear strength is attained in the fifth or sixth cycle, the curves sometimes show a saddle shape (curve 10 in Figure 6). Definition of the strength that represents the residual state is then difficult. The saddle shape indicates that after a minimum value is obtained, some increase in shear load may occur, and this increase may reach as much as 10 percent of the minimum value of shear strength. It is thought that this increase is due to the undulating shear surface.

The saddle shape does not appear in the sequence of curves in Figure 7, which represents the series of slow compression and tension cycles for a sample that has first been subject to fast forward and backward shearing as described earlier. The other obvious features of the curves in the latter case are that the number of reversals required to define the minimum shear strength of the clay is much reduced and that the peak strength observed in the first cycle is much smaller. A shortcoming of this method is that the peak strength cannot be determined, because it occurs during the fast shearing stage when the extent of pore pressure dissipation is uncertain.

Ring Shear

Typical load-displacement curves for Lias clay are shown in Figures 9 and 10. In continuous slow shearing (Figure 9), a displacement of more than 200 mm (8 in.) is necessary to reach the residual state, which takes more than 8 days at a speed of 0.017 mm/min. The test time can be reduced by using a variable rate of shearing as shown in Figure 10. As soon as the peak is reached, the rate of shearing is increased by 25 times for about 250 mm (10 in.). The rate of shearing is then reduced to the slower rate. No readings taken during the fast shearing are considered in determining the residual strength. Readings in the second slow stage were started after 8 hours to allow sufficient time for pore pressures to dissipate. In multi-stage tests, fast shearing is required only for the first normal stress.

Figure 11 shows a typical residual strength envelope for Lias clay, using the modified Bromhead ring shear at two different rates of shearing 0.017 mm/min and 0.17 mm/min (0.0067 in./min). The multi-stage method of testing was used for both rates of shearing.

DISCUSSION

The majority of investigators have shown that the shape of the residual failure envelope is curved for most clays. Skempton (*1*) states that for most clays, the relationship between residual strength and normal effective pressure is nonlinear. Thus when comparing the residual strength of one clay with another on the basis of other soil properties (clay fraction, liquid limit, plastic limit, etc.), it is best to fix a standard pressure that corresponds to the point on the envelope that shows a transition from a curved to a straight line.

Many investigators have tried to define this pressure. Skemption and Petley (*5*) stated it was 200 kN/m^2 (29 $lb/in.^2$), and the same finding was recorded by Hawkins and Privett (*11*). Townsend and Gilbert (*12*) gave an alternative figure of 150 kN/m^2 (22 $lb/in.^2$). Clay particles have a tendency to orientate themselves in a direction perpendicular to the direction of the major principal stress. Thus the shear strength of the clay in this direction is a minimum in comparison with shear strength in other directions. The mechanisms of shearing in both the ring shear and the shear box involve shearing on such a plane, consequently the shearing resistance along these planes should be at a minimum. The curved shape of the residual strength envelopes may be explained by the lesser degree of orientation of the clay at low normal stresses.

The results presented here for Lias clay show that residual shear strength is not developed at low normal pressure, notably at a pressure of 25 kN/m^2 (3.6 $lb/in.^2$), even if it is sheared over a displacement of more than 500 mm (20

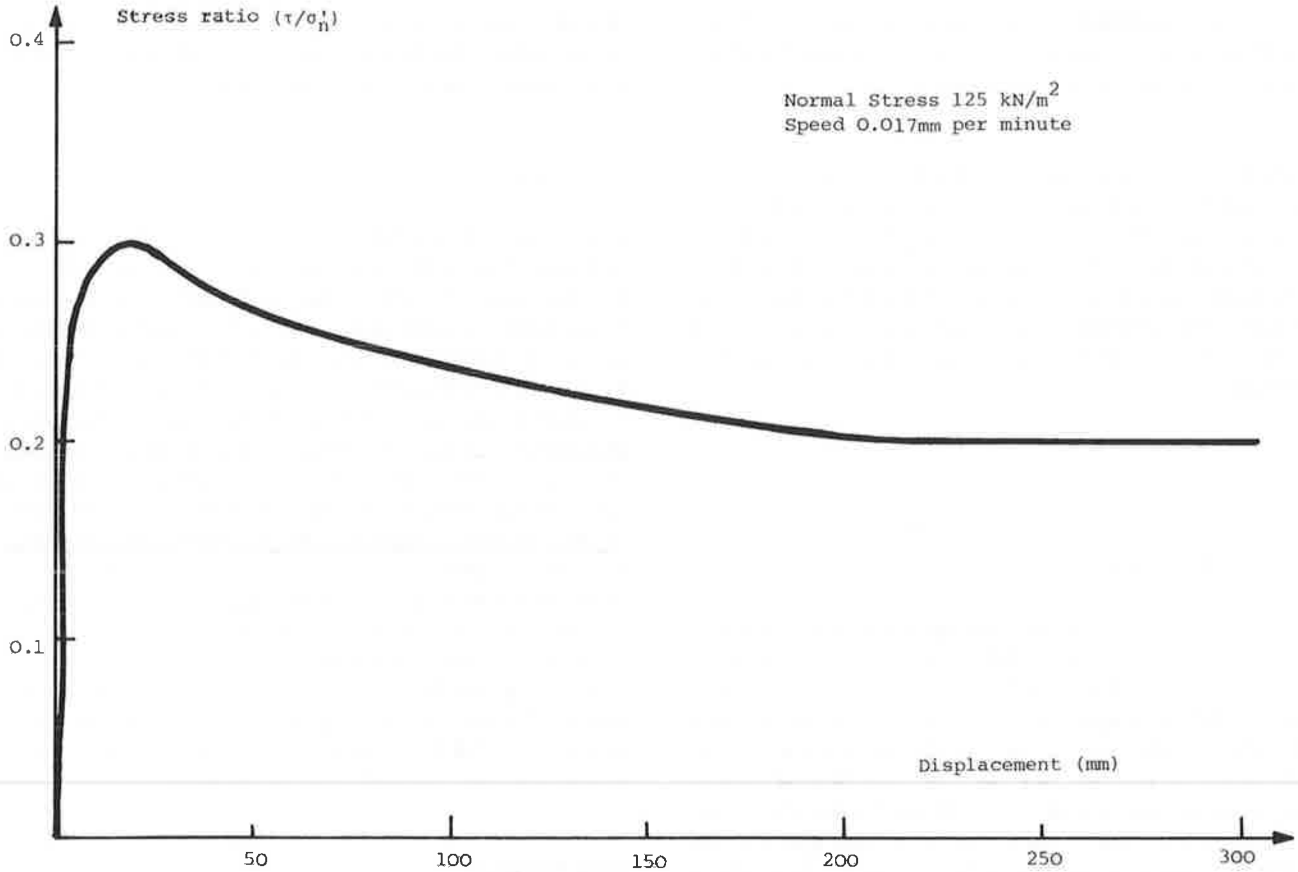

FIGURE 9 Stress-strain curve for Lias clay in ring shear apparatus at constant rate of shearing.

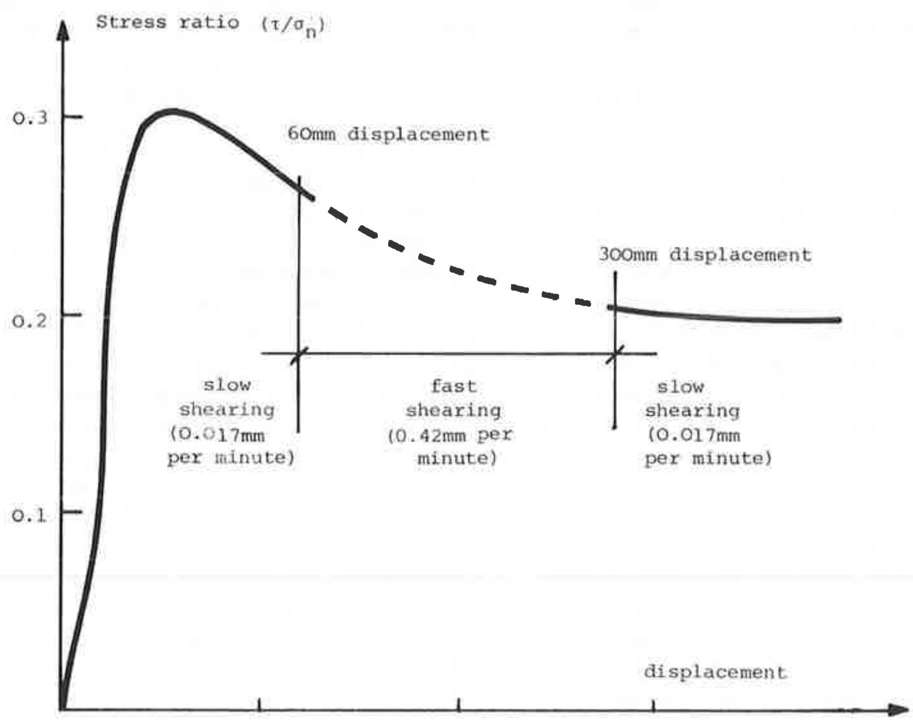

FIGURE 10 Stress-strain curve for Lias clay in ring shear apparatus at variable rate of shearing.

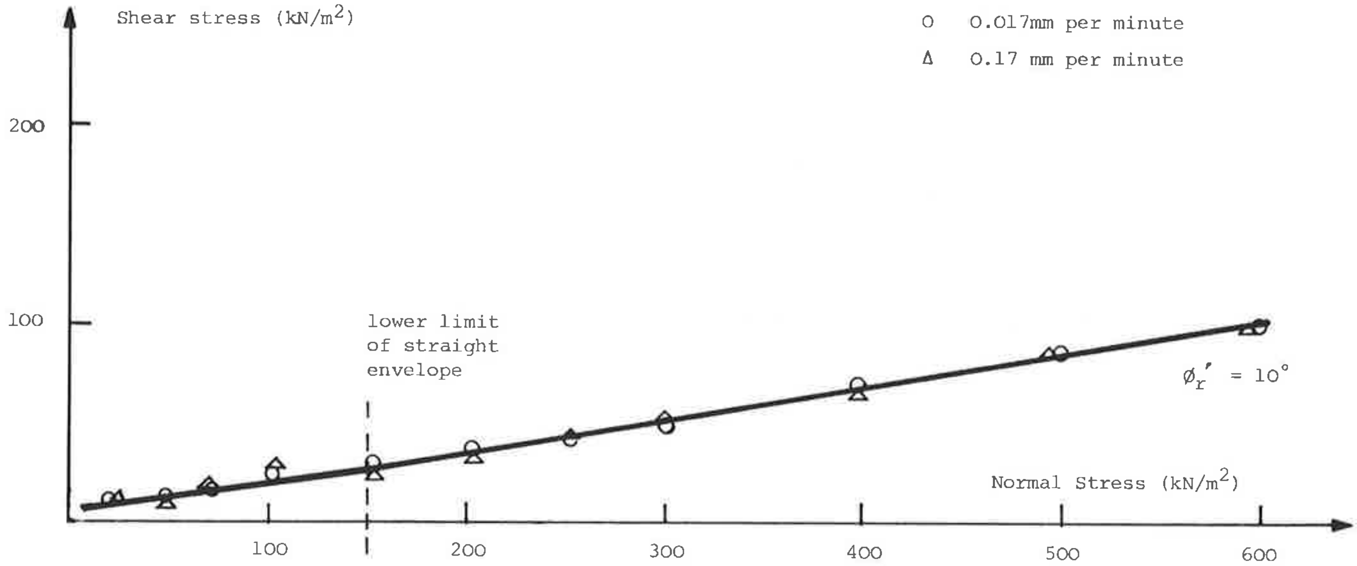

FIGURE 11 Residual strength envelope for Lias clay in ring shear apparatus.

in.). This finding is supported by results of Skempton (*1*) for London clay. These results shown that there is a considerable percentage difference between back analysis and test results at an average normal pressure of 30 kN/m^2 (4.4 $lb/in.^2$).

CONCLUSIONS

From the tests described above on remolded Lias clay, the following conclusions are drawn:

- The shape of the residual failure envelope is curved. This curvature is most pronounced at an effective normal stress below about 150 kN/m^2 (22 $lb/in.^2$). Such an effective stress seems enough to produce full clay particle orientation. Any increase of normal stress beyond this point will not result in any increase in the measured residual strength coefficient (τ_r/σ_n'). Small normal pressures of 25 kN/m^2 (3.6 $lb/in.^2$) were found to be inadequate to develop the residual failure surface for either test method.
- The use of fast shearing, to generate a failure surface, followed by slow shearing, for strength measurement, is the best technique for determining residual strength in both the shear box and the ring shear. This technique is preferred because it saves time and reduces the possibility of producing an undulating shear surface, which may lead to a greater shear resistance being measured.
- The shear box and ring shear both produce similar failure envelopes. However the measured value of residual strength angle, ϕ_r' seems smaller in the ring shear than the shear box. This difference is due to mechanical problems associated with the shear box, although larger samples may reduce this problem to some extent.
- Rates of shearing in the range of 0.01–0.2 mm/min were found to have no significant effect on the measured residual strength.
- In both of the devices, the initial moisture content and initial consolidation pressure were found to have no appreciable effect on the measured residual strength of the clay.
- In the ring shear apparatus, a displacement of over 200 mm (8 in.) is required to attain the residual state under the first normal stress. Under subsequent normal stresses, in the multi-stage method, the residual state can be attained at a displacement of only 20–30 mm (0.8–1.2 in.).

ACKNOWLEDGMENTS

The senior author is grateful to Boyce and Rogers for their helpful supervision and support throughout the work. Acknowledgments are extended to the staff of the Civil Engineering Laboratories at Loughborough University for their help and assistance in building the computer readout system and making modifications to the equipment.

REFERENCES

1. A.W. Skempton. Residual Strength of Clay in Landslides, Folded Strata and the Laboratory. *Géotechnique*, Vol. 35, No. 1, 1985, pp. 1–18.
2. A.W. Skempton. Long-Term Stability of Clay Slopes. Fourth Rankine Lecture. *Géotechnique*, Vol. 14, No. 2, 1964, pp. 75–102.
3. J.F. Lupini, A.E. Skinner, and P.R. Vaughan. The Drained Residual Strength of Cohesive Soils. *Géotechnique*, Vol. 31, No. 2, 1981, pp. 181–213.
4. A.W. Skempton and J.N. Hutchinson. Stability of Natural Slopes. *Proc., 7th International Conference Soil Mechanics*

and Foundational Engineers, Mexico City, State of the Art Volume, 1969, pp. 291–340.
5. A.W. Skempton and D.J. Petley. The Strength Along Structural Discontinuities in Stiff Clay. *Proc., Geotechnical Conference*, Oslo, Vol. 2, 1967, pp. 29–46.
6. G. Calabresi and G. Manfredini. Shear Strength-Characteristics of the Jointed Clay of Santa Barbara. *Géotechnique*, Vol. 23, No. 2, 1973, pp. 233–244.
7. A.W. Bishop, G.E. Green, V. K. Garga, A. Andresen, and J. D. Brown. A New Ring Shear Apparatus and Its Application to the Measurement of Residual Strength. *Géotechnique*, Vol. 21, No. 4, 1971, pp. 273–328.
8. D.P. LaGatta. Residual Strength of Clay and Clay Shales by Rotation Shear Tests. *Harvard Soil Mechanics Series*, Harvard University, Cambridge, Mass., No. 86, 1970.
9. E.N. Bromhead. A Simple Ring Shear Apparatus. *Ground Engineering*, Vol. 12, No. 5, 1979, pp. 40–44.
10. R.J. Chandler. Lias Clay: The Long Term Stability of Cutting Slopes. *Géotechnique*, Vol. 24, No. 1, March 1974, pp. 21–38.
11. A.B. Hawkins and K.D. Privett. Measurement and Use of Residual Shear Strength of Cohesive Soils. *Ground Engineering*, Vol. 18, No. 8, 1985, pp. 22–29.
12. F.C. Townsend and P.A. Gilbert. *Effects of Specimen Type on the Residual Strength of Clays and Clay Shales.* STP 599. American Society for Testing and Materials, Philadelphia, Pa., 1976, pp. 43–65.

Publication of this paper sponsored by Committee on Soil and Rock Properties.