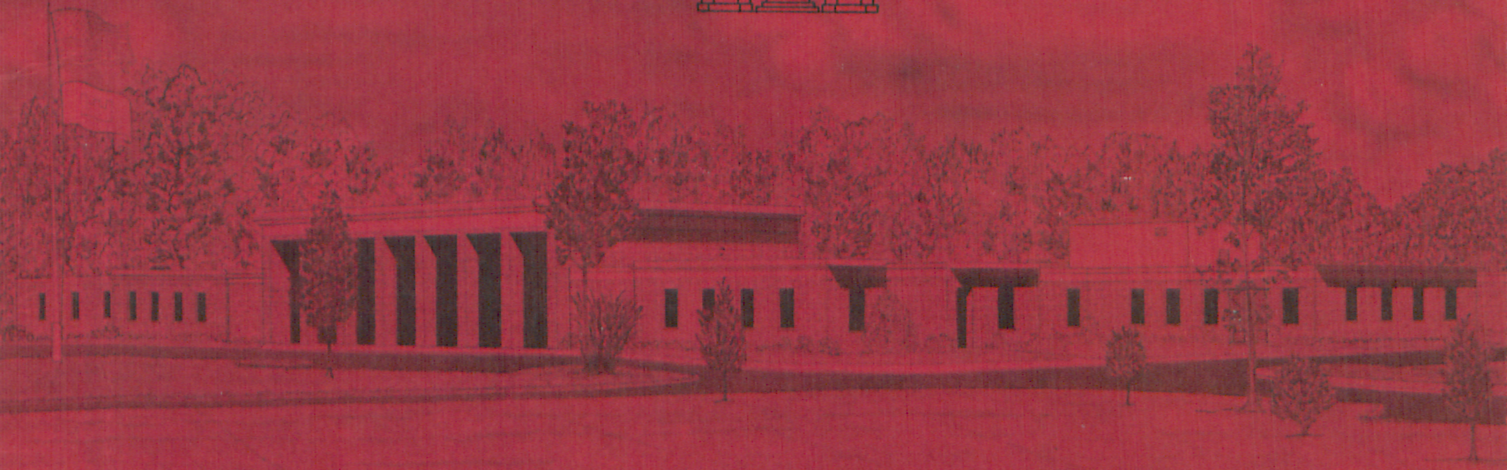
CONTRACT REPORT S-71-5

THE EFFECT OF RATE OF DISPLACEMENT ON MEASURING THE RESIDUAL STRENGTH OF CLAYS

by

D. P. LaGatta



August 1971

Sponsored by Office, Chief of Engineers, U. S. Army

Conducted for U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

Under Contract No. DACW39-69-C-0028

By Harvard University, Cambridge, Massachusetts

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ARMY-MRC VICKSBURG, MISS.

FOREWORD

The work described in this report was accomplished under a modification to Contract DACW39-69-C-0028, "Research Study on Residual Shear Strength of Soils," between the U. S. Army Engineer Waterways Experiment Station (WES) and Harvard University. The contract was sponsored by the Office, Chief of Engineers, under Engineering Study (ES) 545, "Residual Shear Strength of Soils."

The investigation, which supplemented the principal work under the contract as reported in Contract Report S-70-5, "Residual Strength of Clay and Clay-Shales by Rotation Shear Tests," dated June 1970, had as its objective the study of the feasibility of expediting the measurement of residual drained shear strengths of clay-shales and stiff clays.

The work was performed and the report prepared by Dr. Daniel P. La Gatta at Harvard University. Only limited distribution is made of this report since definitive conclusions cannot be drawn on the effect of displacement rate in view of the limited number of materials tested and of tests performed.

The contract was monitored by Mr. J. R. Compton, Chief, Embankment and Foundation Branch, under the general supervision and guidance of Messrs. S. J. Johnson, Special Assistant, and J. P. Sale, Chief, Soils Division, WES.

Contracting Officers were COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE, successive Directors of the WES during conduct of this study and the preparation and publication of this report. Technical Directors were Messrs. J. B. Tiffany and F. R. Brown.

SUMMARY

Rotation shear tests were performed with a rotation shear device, developed for the purpose of measuring residual shear strengths of clays and clay shales,* on 2 mm thick annular specimens of remolded Bearpaw shale and remolded London clay. Rates of displacment in comparative tests, expressed in peripheral velocities of the annular specimens, were 2.8×10^{-1}, 5.6×10^{-2}, 5.6×10^{-3}, and 5.6×10^{-4} cm per min. Results of this limited investigation indicated the following: (a) rates of displacement in the range tested have a negligible effect on the residual shear strength of remolded Bearpaw shale; residual friction angles varied generally from 3.5 to 4.0 deg; and (b) the residual angle of internal friction of the London clay increased from about 7.5 deg at the slowest rate of displacement of 5.6×10^{-4} cm per min to 9.2 deg at the fastest rate of 2.8×10^{-1} cm per min. It was found difficult to make readings when the test was performed at the fastest rate, and it was considered that in testing London clays a rate of displacement of 5.6×10^{-2} cm per min was acceptable, since it caused the residual strength to be only about 8 percent higher than that for the lowest rate, and because at this rate of displacement, the test could be performed in one working day.

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* This device is described in Contract Report S-70-5, "Residual Strength of Clay and Clay-Shales by Rotation Shear Tests," June 1970, D. P. La Gatta

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PURPOSE AND SCOPE

The purpose of this investigation was to determine a method of expediting the measurement of the residual S strength of a remolded clay.

Rotation shear tests were performed on 2 mm thick annular specimens of remolded Bearpaw Shale and remolded London Clay. The testing rates used resulted in the velocity of the outside diameter (7.11 cm) of the specimen to be 2.8×10^{-1}, 5.6×10^{-2}, 5.6×10^{-3} and 5.6×10^{-4} cm/min. These velocities resulted in the time required for one revolution of the specimen to be 80, 400, 4000, and 40,000 minutes.

INTRODUCTION

The S strength of a clay is measured in a specimen which has been consolidated to the desired effective stress and then sheared slowly enough to insure that the induced pore pressures are negligible. The residual strength is the constant shearing resistance at which a material undergoes continuous deformation at constant velocity under a constant state of effective stress. The author has previously shown (La Gatta, 1970) that the use of 2 mm thick rotation shear specimens permits the residual S strength to be measured in 2 to 4 days. Results of this earlier investigation also indicated that the residual S strength might be measured in less than 2 days if one were not concerned that the pore pressure induced during the early stages of the test were not zero.

When the residual strength has been reached the soil has presumably reached a critical void ratio (Casagrande, 1936), it undergoes no further volume change on the failure plane (if drainage is permitted), and the soil is in the critical state (Poulos, 1969; La Gatta, 1970). At the critical state, the induced pore pressure is zero; hence, when a constant shearing resistance is measured in a test which permits drainage, the pore pressure must be zero regardless of the rate of speed at which the specimen is being sheared.

The significance of this reasoning is that it would permit tests designed to measure the residual S strength to be performed at rapid shearing rates. During the early stages of such a test, when the shear strains tend to induce volume change, the induced pore pressure would not be zero. Eventually, however, if drainage is permitted, and the test continued to a constant shearing resistance any pore pressure induced during the early stages of shearing will have dissipated and the constant shearing resistance measured should represent the residual S strength of the material.

TEST PROCEDURE

A detailed description of the rotation shear machines used in this investigation has been presented by La Gatta, 1970.

All tests were performed on annular specimens of remolded clay. The specimens had an outside diameter of 7.11 cm, an inside diameter of 5.08 cm and an initial thickness (before consolidation) of 2 mm. The inner periphery of the annulus was supported by a Teflon disc and the outer periphery was confined by a rotating, unsplit, Teflon ring. When a constant shearing resistance was achieved during a test, the outer confining ring was removed momentarily to eliminate the error in the measured shearing resistance due to friction from this ring.

After an initial stress of 0.12 kg/cm^2, each specimen was consolidated in increments by doubling the previous stress to a final effective stress of 4.0 kg/sq cm. For convenience, the vertical loading was completed in 24 hours.

SOIL DESCRIPTION

Bearpaw Shale - The Bearpaw shale used in this investigation was obtained from the Canadian Praire Farm Rehabilitation Administration. The one-cubic-foot block sample was taken between a depth of 6 to 7 feet in an excavation designated as TP 4102 in the west bank of Coteau Creek, downstream from Gardiner Dam.

The material is a grayish black, firm, slickensided clay. At its natural water content, which ranged between 30% and 36%, the clay could be remolded by hand with moderate effort.

A cube of shale with a volume of approximately 10 cc disintegrates into a pile of silt and sand-sized particles in about one hour when placed in distilled water. The clay exhibits no reaction to HCL.

The undisturbed block was easily separated along numerous shiny surfaces into irregular shaped pieces varying in size from a few cubic centimeters to 100 cc. The larger pieces were generally slab-shaped, their largest surfaces were shiny and usually oriented horizontally.

Approximately one-fifth of the block was dissected, revealing three distinct types of shiny surfaces. The most common surfaces were classical slickenside; i.e., they had numerous shallow striations, indicating that movement had taken place along the surface. The slickensides generally had wide shallow undulations perpendicular to the axis of movement. The undulations dipped into the surface of the slickenside parallel to the axis of movement, so that they were not continuous along the surface. The block could be easily separated along these surfaces, which were very shiny.

The second most common type of shiny surface was also undulating but contained no striations. The block was easily separated along these surfaces which were similar in both size and shine to the slickensides.

The third type of shiny surface was usually large (50 to 100 sq cm), very flat and smooth and had no striations. The block could not be easily separated along these surfaces and they were not as shiny as the other two types of surfaces.

Fig. 1 shows a series of scanning electron microphotographs of a naturally occurring slickenside (i.e., a surface with striations). The clay used for these photographs had been air-dried and then coated with a 100 angstrom thick layer of gold. The photographs were taken perpendicular to the slickensided surface. Photo A shows the surface, including a crack which presumably occurred during drying. The cause of the small circular protuberances are not known, but a number of the shiny surfaces had small (but visible to the unaided eye) growths on them, which appear to be crystalline growth, possibly the result of weathering.

Photo B is an enlargement of the area within the white square shown in Photo A. This photograph was taken with the electron beam scanning down into the crack, approximately perpendicular to the slickenside. Horizontal layering may be observed near the surface of the slickenside.

Photograph C is an enlargement of the area within the white circle shown on Photograph B. The clay particles seen in this photograph are oriented approximately parallel to the surface of the slickenside.

Atterberg Limits for this clay are shown below and the results are plotted on the Plasticity Chart in Fig. 2.

Treatment	L_w	P_w	P_i
undried	83.1	24.2	63.9
air-dried	104.5	25.3	79.2
oven-dried	90.2	25.4	64.8

At the plastic limit the soil was very tough, irrespective of the method of treatment. At a water content below the plastic limit, the clay acquired a high gloss when rubbed with the thumbnail.

The result of a hydrometer test using a 0.01 N solution of sodium metaphosphate is shown in Fig. 3. The specific gravity of the solids is 2.75.

<u>London Clay</u> - The London Clay was obtained from Professor A. W. Bishop of Imperial College, London, and comes from a reservoir site at Wraysbury, South Buckinghamshire. The sample was a five-inch-long section from a four-inch-diameter undisturbed sample taken at a depth of about 40 ft.

The soil is a brown, stiff, medium to highly plastic clay.* At its natural water content of about 28%, the soil can be remolded with moderate effort and easily trimmed with a knife. The sample appears to be essentially homogeneous at first inspection, with a few small (1 to 2 cc) pockets and lenses (less than 0.5 mm thick) of fine sand. When trimming undisturbed test specimens (La Gatta, 1970), it became clear that there was silt or fine sand scattered throughout the sample. There were several zones which felt more "gritty" (when trimmed with a knife) than the bulk of the sample. No slickensides or fissures were observed in the sample.

Pieces of the undisturbed soil immersed in distilled water swelled without disintegration. After swelling for 48 hours, the soil could be easily remolded to a smooth paste.

Air-dried chunks of the undisturbed soil slaked to discrete pieces ranging in size from 3 mm down to being barely distinguishable to the unaided eye. The larger pieces had a well-defined laminar structure but had a basically bulky shape. After being submerged for 30 minutes, the air-dried soil was very easily remolded between the fingers to a smooth paste.

This sample of the London Clay (undisturbed state) effervesced strongly when treated with hydrochloric acid.

The liquid and plastic limits of the soil remolded from its natural water content were 71.5 and 22.4, respectively. These results are plotted on the

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* In the letter of transmittal, the soil is referred to as the Blue London Clay.

Plasticity Chart in Fig. 2. At the plastic limit the soil was tough. At a water content below the plastic limit, it acquired a medium shine when rubbed on the thumbnail. The remolded, air-dried soil had a high, dry strength. The results of a hydrometer test using a 0.01 N solution of sodium metaphosphate as dispersant are shown in Fig. 3. The specific gravity of the solids was 2.72.

TEST RESULTS

Remolded Bearpaw Shale - The shear stress versus displacement curves for the eight tests in this series are shown in Figs. 4 to 7 and are summarized in Fig. 8.

The residual shear strength results are summarized in Table 1. These results are plotted in Fig. 9 which shows that there is practically no effect of the rate of displacement on the residual strength of remolded Bearpaw Shale.

Remolded London Clay - The shear stress versus displacement curves for seven of the eight tests on London Clay are shown in Figs. 10 to 13 and are summarized in Fig. 14. The rate of peripheral displacement was constant for any given test and varied from 2.8×10^{-1} cm/min. to 5.6×10^{-4} cm/min. Test 8 (Fig. 15) was initially sheared at a rate of displacement of 5.6×10^{-3} cm/min until the residual strength had been reached, then the rate of displacement was reduced to 5.6×10^{-4} cm/min.

The results of these tests are summarized in Table 2 and plotted in Fig. 16 which shows the residual strength varies from a high of 8.9^{o} at a rate of peripheral displacement of 2.8×10^{-1} cm/min to a low of 7.6^{o} at a rate of peripheral displacement of 5.6×10^{-4} cm/min.

Fig. 17 shows the range of all test results from this investigation superimposed on the residual strength line of the London Clay measured by La Gatta (1970). The results of this investigation at a rate of peripheral displacement of 5.6×10^{-3} cm/min show good agreement with the earlier measurements.

CONCLUSIONS

The results of this investigation show that rates of displacement between the range of 2.8×10^{-1} cm/min and 5.6×10^{-4} cm/min have a negligible effect on the residual strength of remolded Bearpaw Shale (Fig. 9).

The residual strength of the London Clay increased about 18% when the rate of displacement was increased from 5.6×10^{-4} cm/min to 2.8×10^{-1} cm/min. The error in residual strength of the London Clay due to the effect of rate of displacement is reduced to about 8% when the rate of displacement is reduced to 5.6×10^{-2} cm/min. At this rate of displacement, the test may be performed in one working day.

Because of the difficulty in taking the readings when a test is performed at a rate of displacement of 2.8×10^{-1} cm/sec and the possible error in the measured residual strength at this testing rate, it is recommended that routine tests on 2 mm thick specimens be performed at a rate of peripheral displacement of 5.6×10^{-2} cm/min.

REFERENCES

Casagrande, A., 1936. "Characteristics of Cohesionless Soils Affecting the Stability of Slopes and Earth Fills," Journal of the Boston Society of Civil Engineers, Vol. 23, No. 1, pp 13-32.

Poulos, S. J., 1969. Personal communication.

La Gatta, D. P., 1970. "Residual Strength of Clays and Clay-Shales by Rotation Shear Tests," Harvard Soil Mechanics Series No. 86, 204 pages.

TABLE 1

ROTATION SHEAR S TESTS ON REMOLDED BEARPAW SHALE

NORMALLY CONSOLIDATED ANNULAR SPECIMENS: $\bar{\sigma}_v$ = 4.0 kg/sq cm

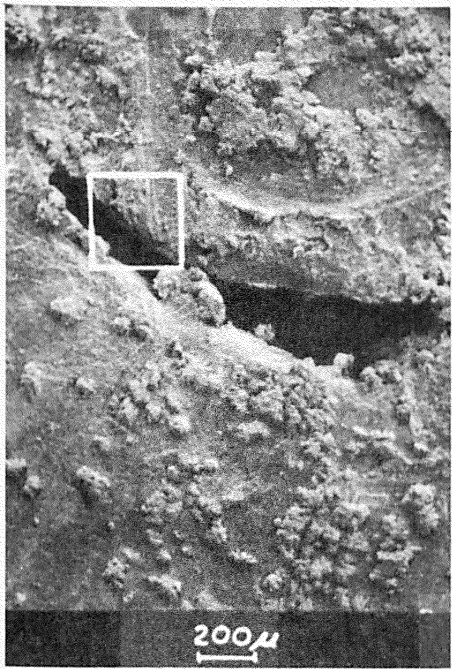
Test No.	Initial Water Content %	e_i	e_c	Rate of Peripheral Displacement cm/min	τ_r kg/cm^2	$\tau_r/\bar{\sigma}_v$	δ_r cm	T_r min
1	127.5	3.51	1.07	2.8×10^{-1}	0.260	0.065	50	180
2	124.4	3.42	1.05	2.8×10^{-1}	0.244	0.061	40	140
3	121.8	3.35	1.07	5.6×10^{-2}	0.277	0.069	20	360
4	127.9	3.58	1.18	5.6×10^{-2}	0.250	0.062	20	360
5	124.0	3.41	1.06	5.6×10^{-3}	0.312	0.078	15	2700
6	123.6	3.40	0.83	5.6×10^{-3}	0.250	0.062	12	2150
7	126.9	3.48	1.10	5.6×10^{-3}	0.261	0.065	17	3040
8	118.4	3.26	0.89	5.6×10^{-4}	0.265	0.066	20	35,800

TABLE 2

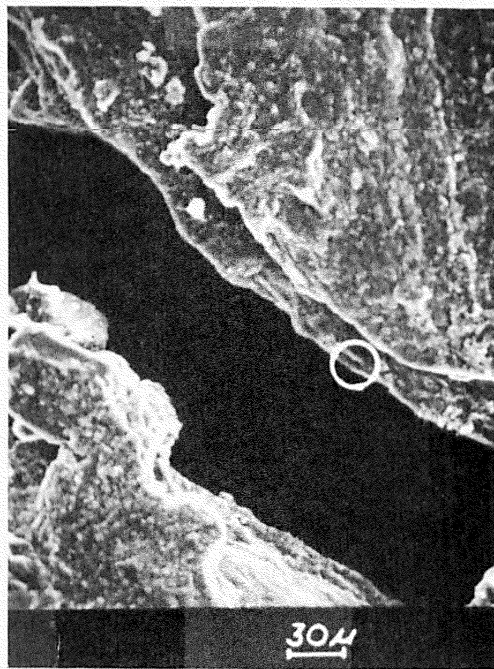
ROTATION SHEAR S TESTS ON REMOLDED LONDON CLAY

NORMALLY CONSOLIDATED ANNULAR SPECIMENS: $\bar{\sigma}_v$ = 4.0 kg/sq cm

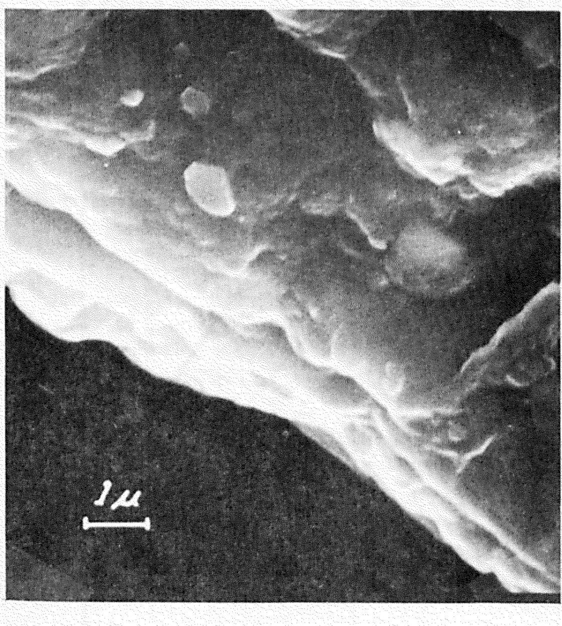
Test No.	Initial Water Content %	e_i	e_c	Rate of Peripheral Displacement cm/min	τ_r kg/cm^2	$\tau_r/\bar{\sigma}_v$	δ_r cm	T_r
1	57.1	1.55	0.577	2.8×10^{-1}	0.660	0.155	10	36
2	56.4	1.54	0.600	2.8×10^{-1}	0.642	0.161	10	36
3	55.2	1.50	0.547	5.6×10^{-2}	0.580	0.145	10	180
4	59.2	1.61	0.526	5.6×10^{-2}	0.564	0.141	10	180
5	58.2	1.58	0.564	5.6×10^{-3}	0.572	0.143	10	1800
6	58.0	1.58	0.512	5.6×10^{-3}	0.605	0.151	15	2700
7	57.4	1.56	0.544	5.6×10^{-4}	0.530	0.132	10	18,000
8	57.8	1.57	0.526	5.6×10^{-4} 5.6×10^{-3}	0.540 0.605	0.135 0.151	10 --	18,000 ------



Photograph A



Photograph B



Photograph C

MICROPHOTOGRAPHS OF A
SLICKENSIDE IN BEARPAW SHALE

FIG. 1

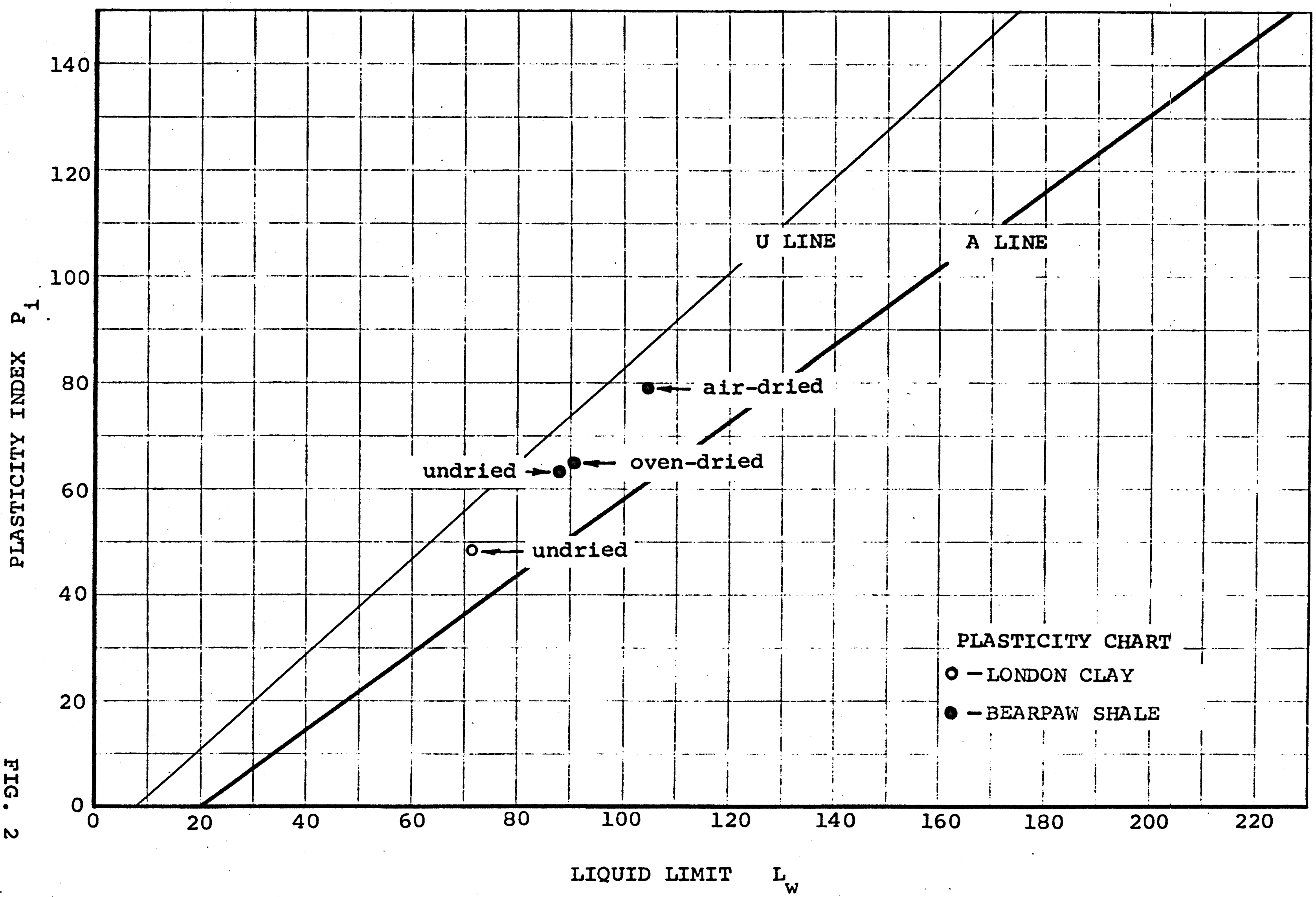

PLASTICITY INDEX P_i
LIQUID LIMIT L_w
0
20
40
60
80
100
120
140
160
180
200
220
U LINE
A LINE
air-dried
oven-dried
undried
undried
PLASTICITY CHART
LONDON CLAY
BEARPAW SHALE

FIG. 2

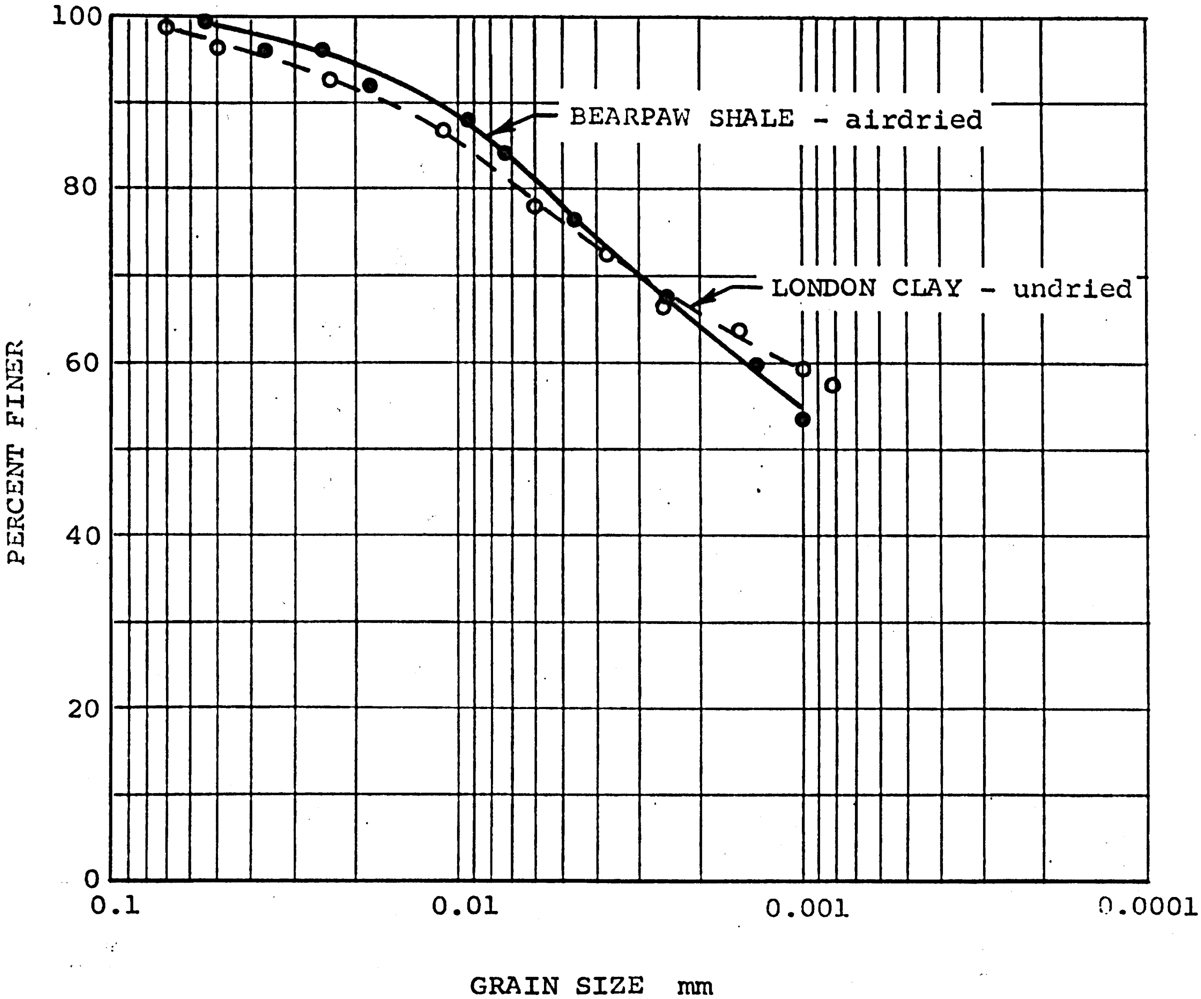
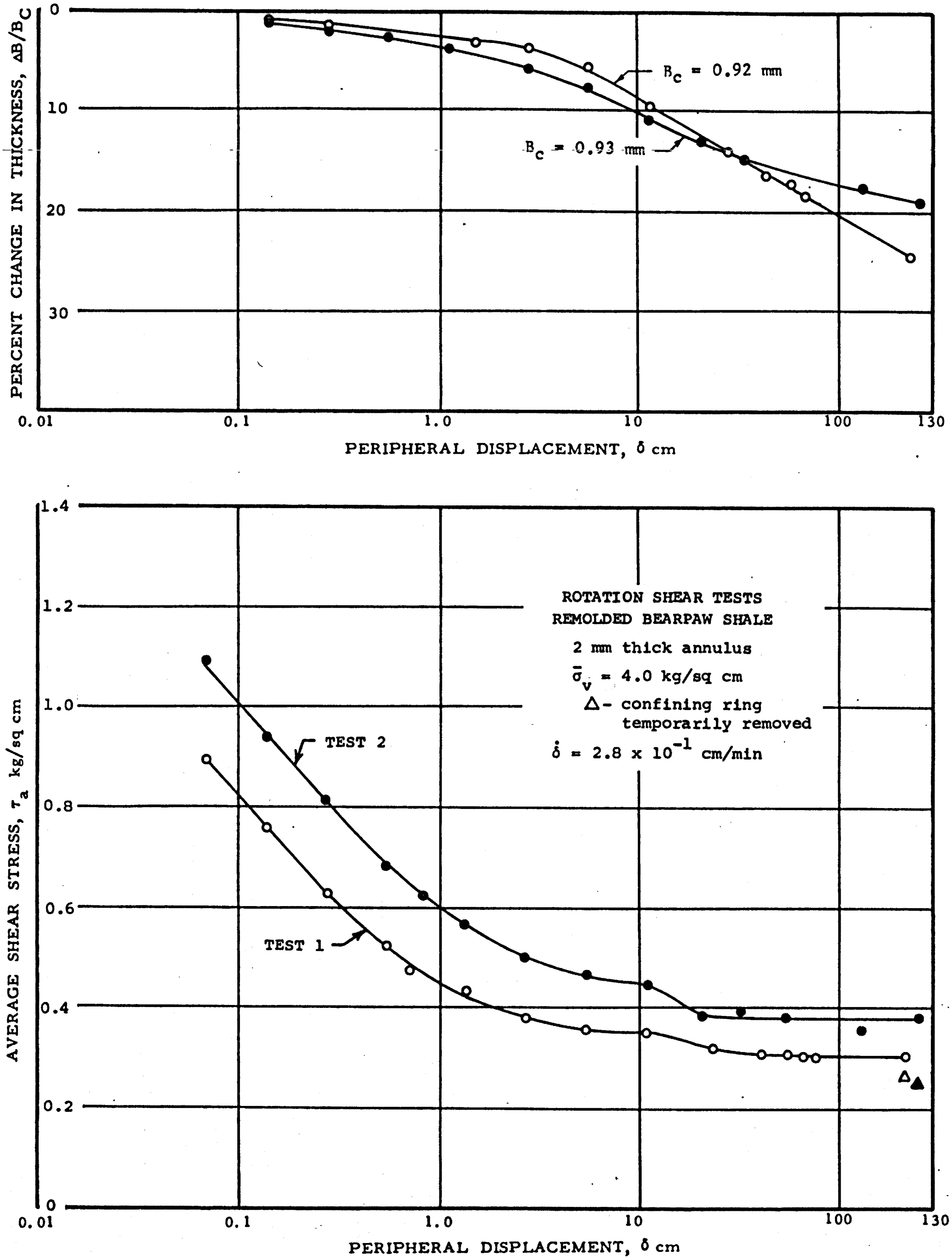
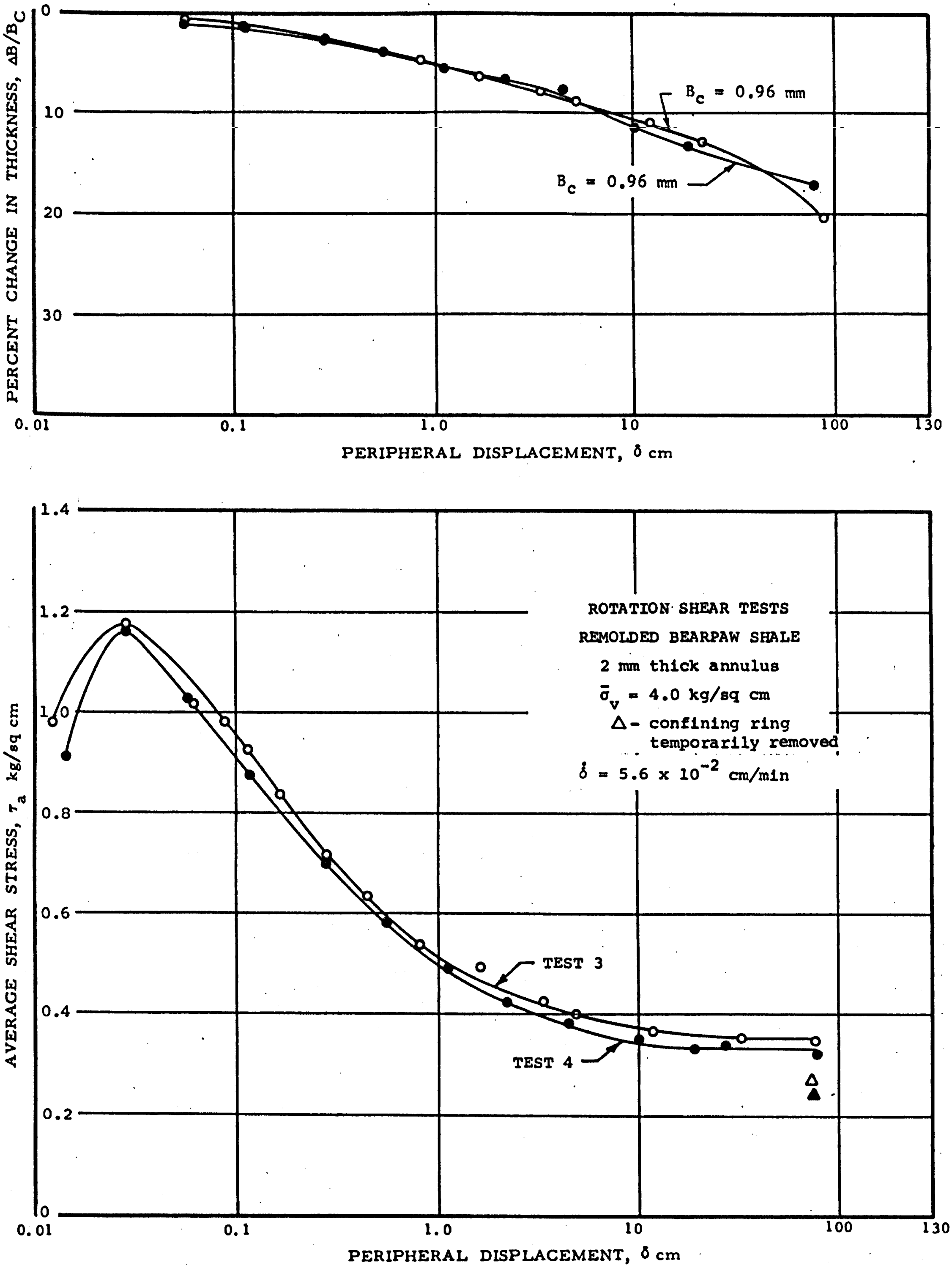

100
80
60
40
20
0
PERCENT FINER
0.1
0.01
0.001
0.0001
GRAIN SIZE mm
BEARPAW SHALE - airdried
LONDON CLAY - undried

FIG. 3



PERCENT CHANGE IN THICKNESS, ΔB/B_C
0
10
20
30
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm
B_c = 0.92 mm
B_c = 0.93 mm
AVERAGE SHEAR STRESS, τ_a kg/sq cm
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
ROTATION SHEAR TESTS
REMOLDED BEARPAW SHALE
2 mm thick annulus
σ̄_v = 4.0 kg/sq cm
Δ- confining ring temporarily removed
δ̇ = 2.8 x 10^-1 cm/min
TEST 2
TEST 1

FIG.4



PERCENT CHANGE IN THICKNESS, ΔB/B_C
0
10
20
30
0.01
0.1
1.0
10
100
130
B_c = 0.96 mm
B_c = 0.96 mm
PERIPHERAL DISPLACEMENT, δ cm
AVERAGE SHEAR STRESS, τ_a kg/sq cm
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
ROTATION SHEAR TESTS
REMOLDED BEARPAW SHALE
2 mm thick annulus
$\bar{\sigma}_v$ = 4.0 kg/sq cm
Δ - confining ring temporarily removed
$\dot{\delta}$ = 5.6 x 10^{-2} cm/min
TEST 3
TEST 4
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm

FIG. 5

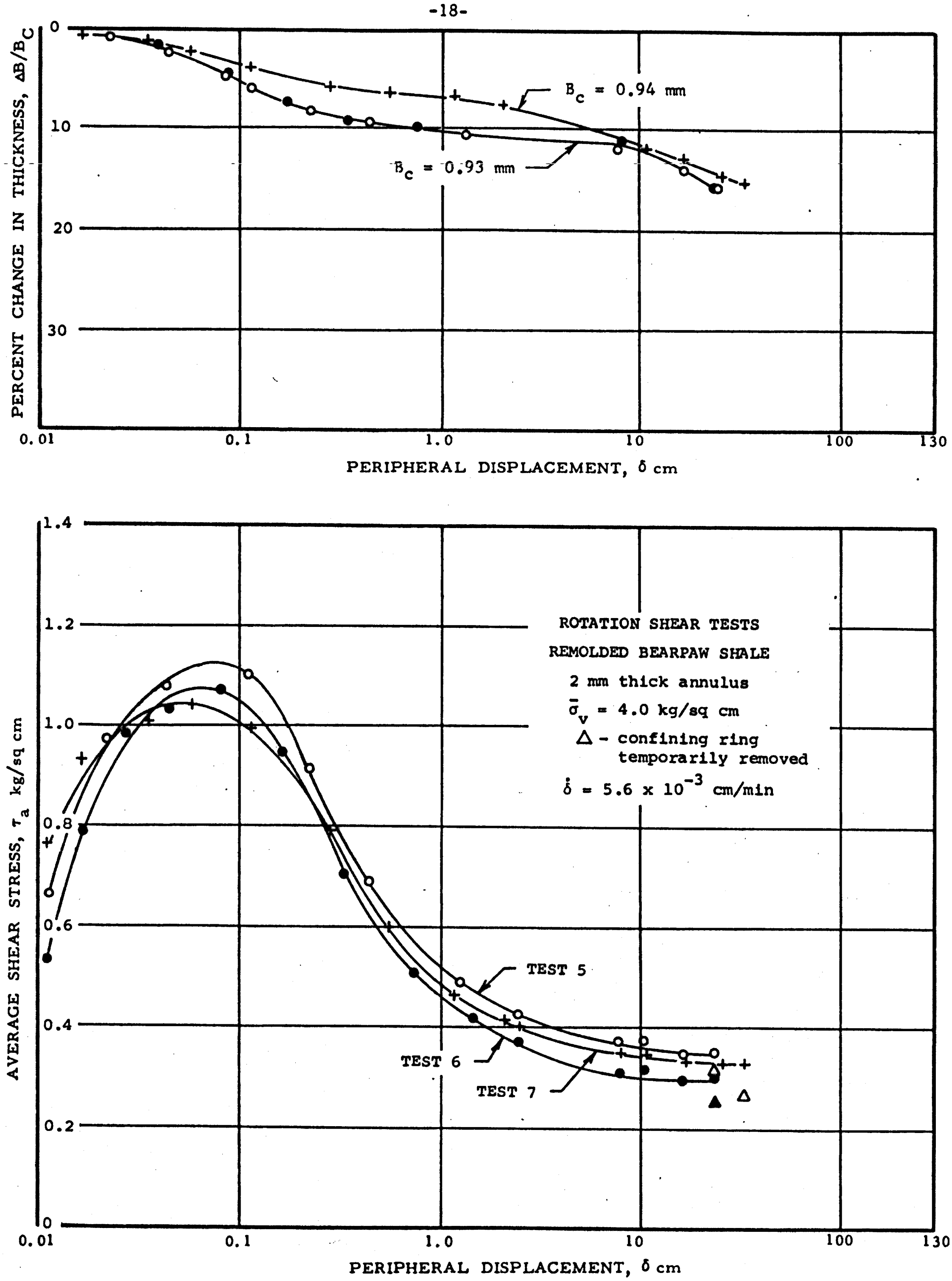
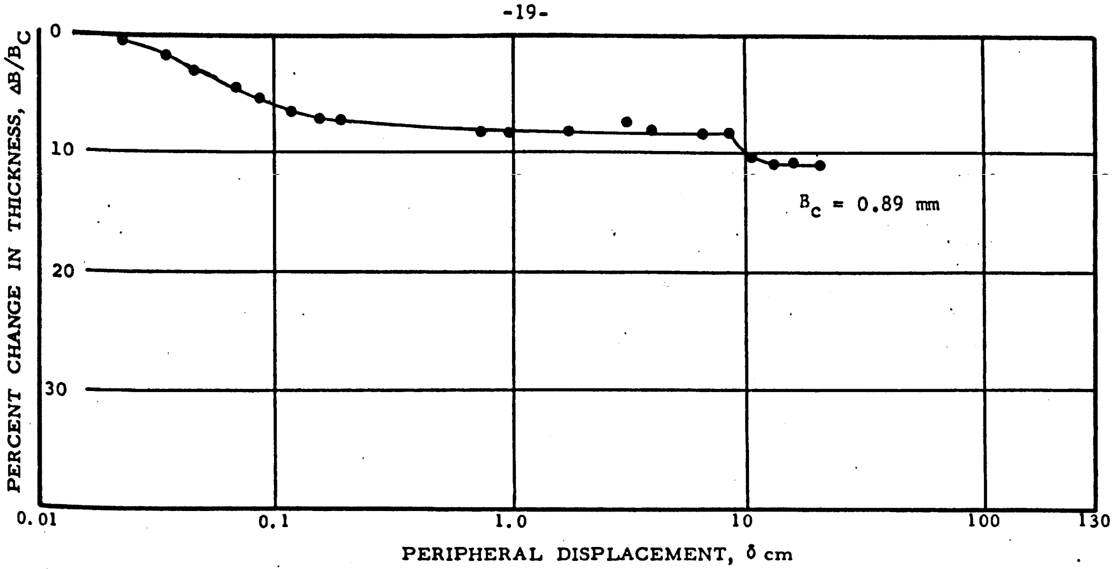

PERCENT CHANGE IN THICKNESS, $\Delta B/B_C$
0
10
20
30
B_c = 0.94 mm
B_c = 0.93 mm
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm
AVERAGE SHEAR STRESS, τ_a kg/sq cm
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
ROTATION SHEAR TESTS
REMOLDED BEARPAW SHALE
2 mm thick annulus
$\bar{\sigma}_v$ = 4.0 kg/sq cm
Δ - confining ring temporarily removed
$\dot{\delta}$ = 5.6 x 10^{-3} cm/min
TEST 5
TEST 6
TEST 7
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm

FIG. 6


PERCENT CHANGE IN THICKNESS, ΔB/B_C
0
10
20
30
0.01
0.1
1.0
10
100
130
B_c = 0.89 mm
PERIPHERAL DISPLACEMENT, δ cm

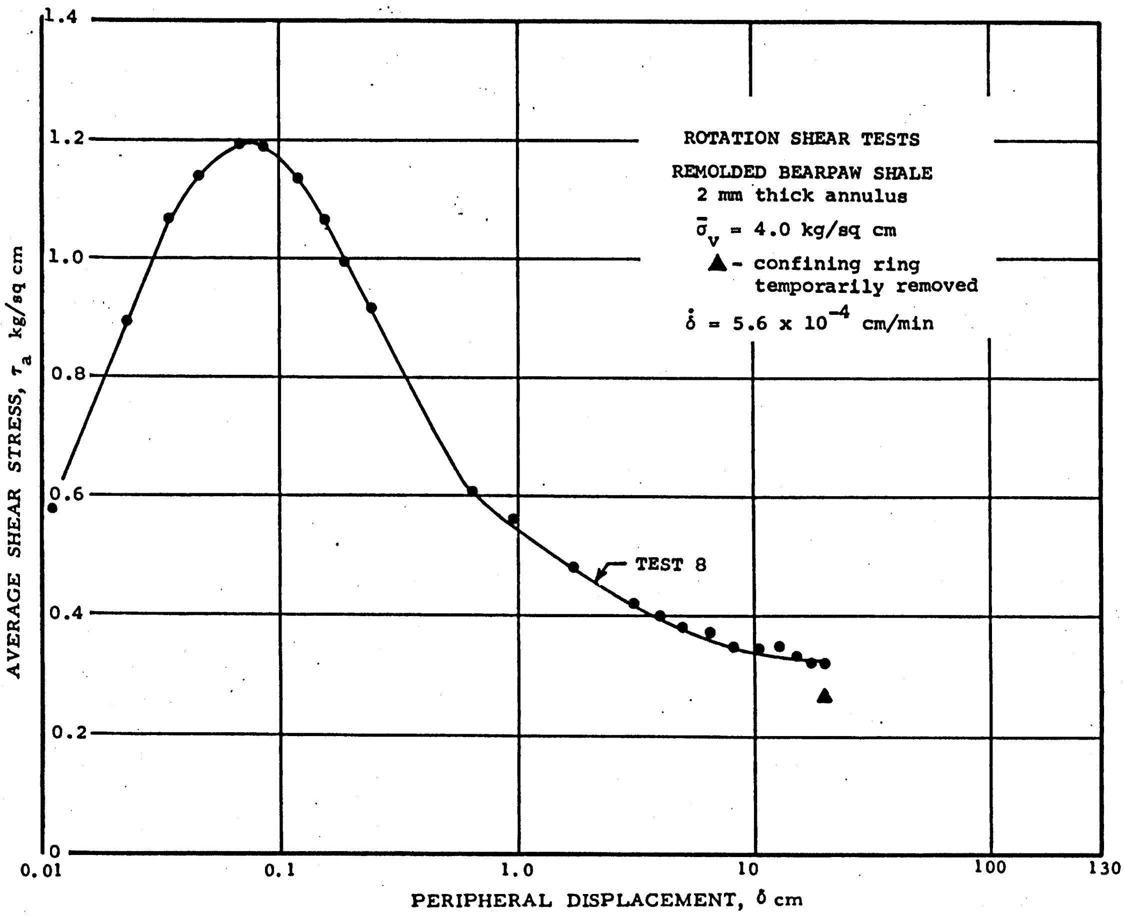
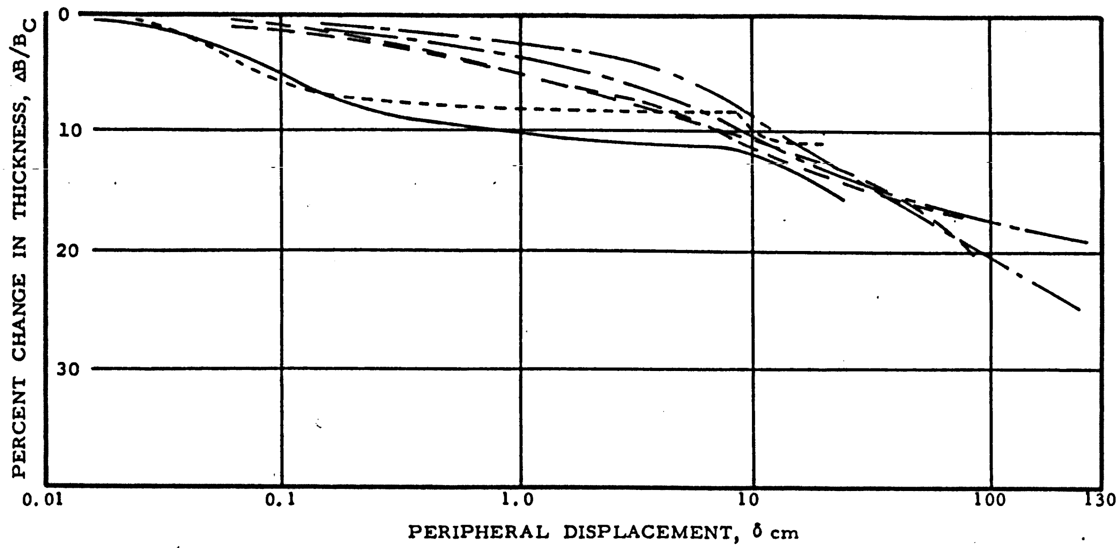

AVERAGE SHEAR STRESS, τ_a kg/sq cm
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0.01
0.1
1.0
10
100
130
ROTATION SHEAR TESTS
REMOLDED BEARPAW SHALE
2 mm thick annulus
σ̄_v = 4.0 kg/sq cm
▲ - confining ring temporarily removed
δ̇ = 5.6 x 10^-4 cm/min
TEST 8
PERIPHERAL DISPLACEMENT, δ cm

FIG. 7


PERCENT CHANGE IN THICKNESS, ΔB/B_C
0
10
20
30
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm

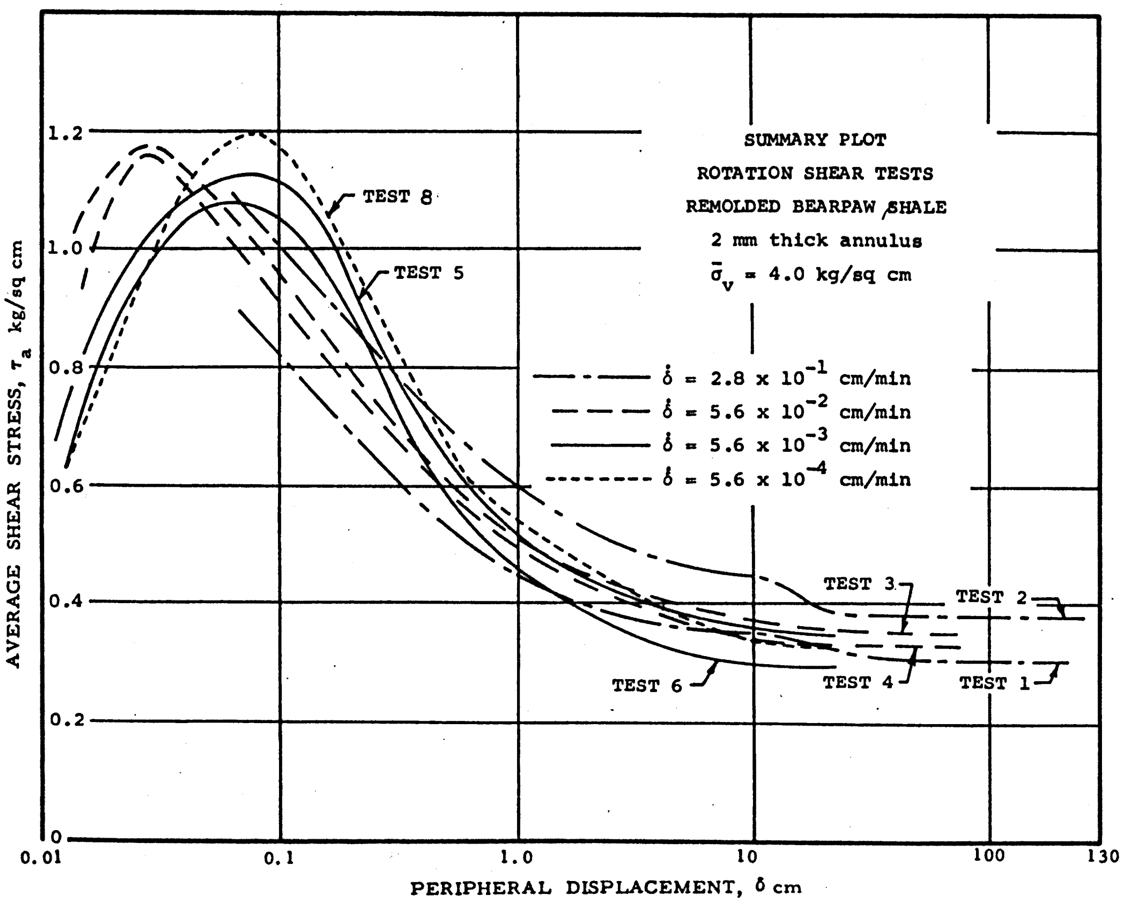
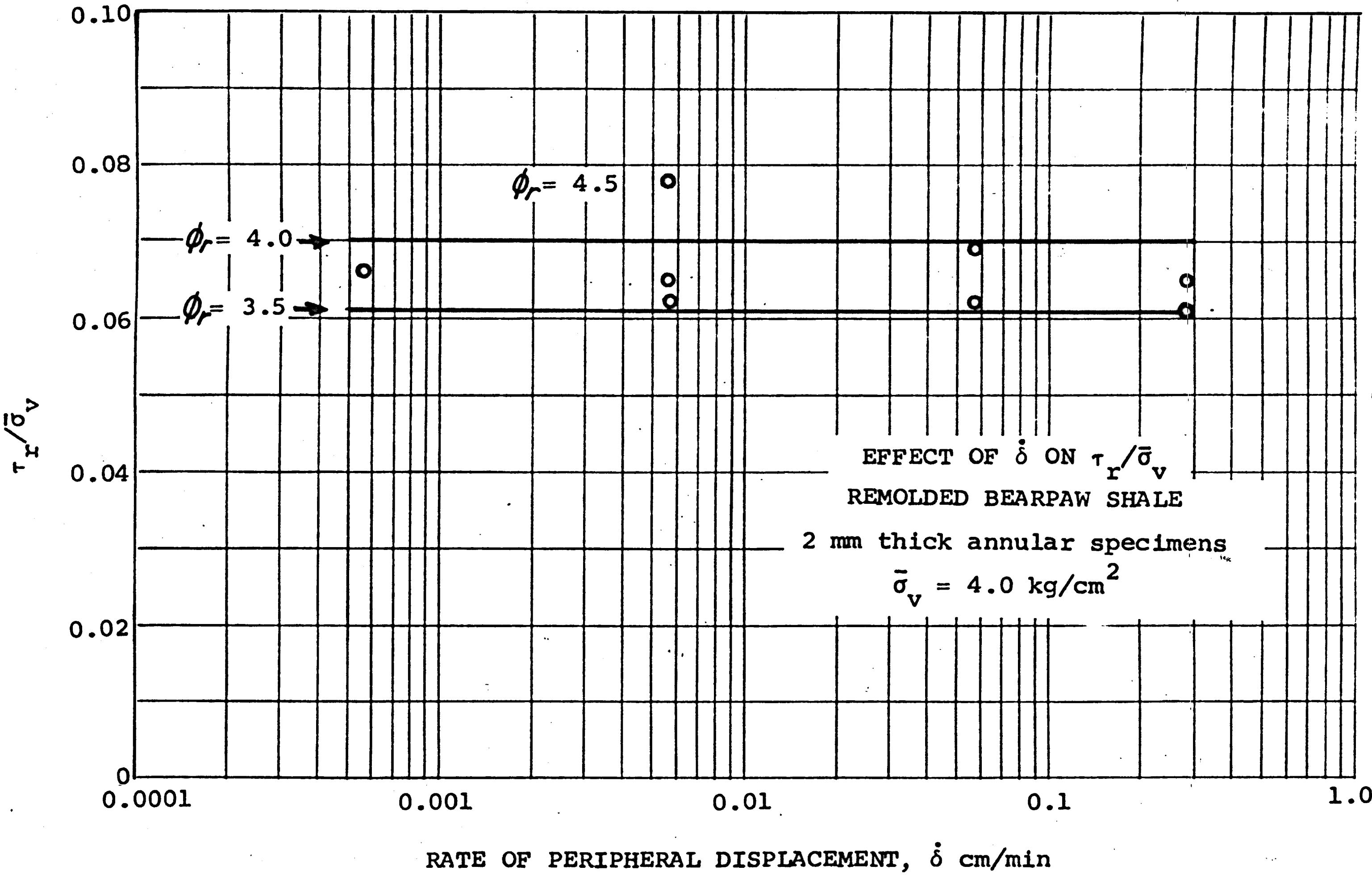
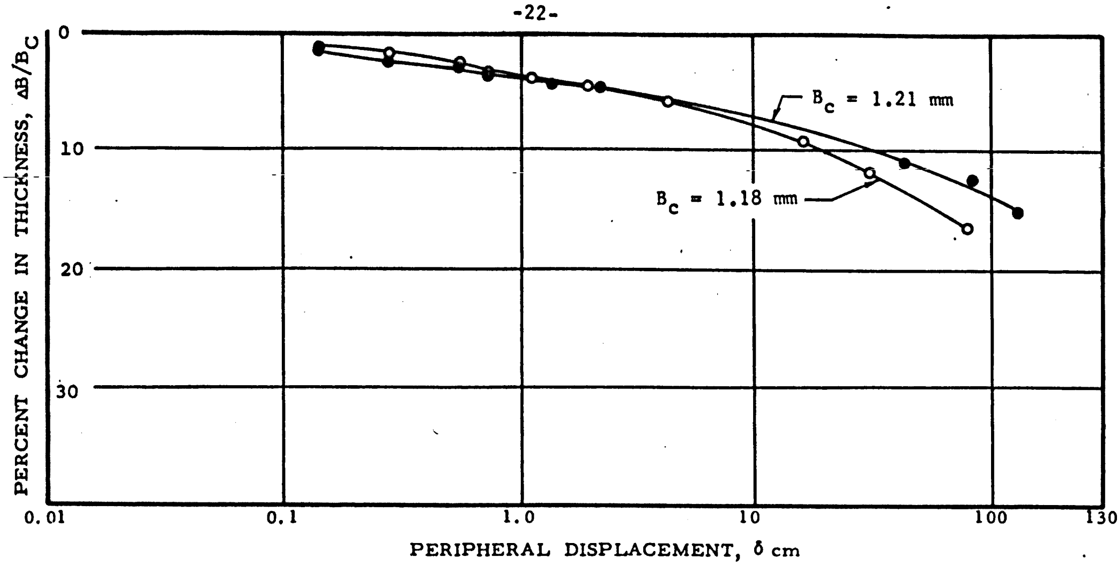

AVERAGE SHEAR STRESS, τ_a kg/sq cm
1.2
1.0
0.8
0.6
0.4
0.2
0
SUMMARY PLOT
ROTATION SHEAR TESTS
REMOLDED BEARPAW SHALE
2 mm thick annulus
σ̄_v = 4.0 kg/sq cm
δ̊ = 2.8 x 10^-1 cm/min
δ̊ = 5.6 x 10^-2 cm/min
δ̊ = 5.6 x 10^-3 cm/min
δ̊ = 5.6 x 10^-4 cm/min
TEST 8
TEST 5
TEST 3
TEST 2
TEST 6
TEST 4
TEST 1
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm

FIG. 8

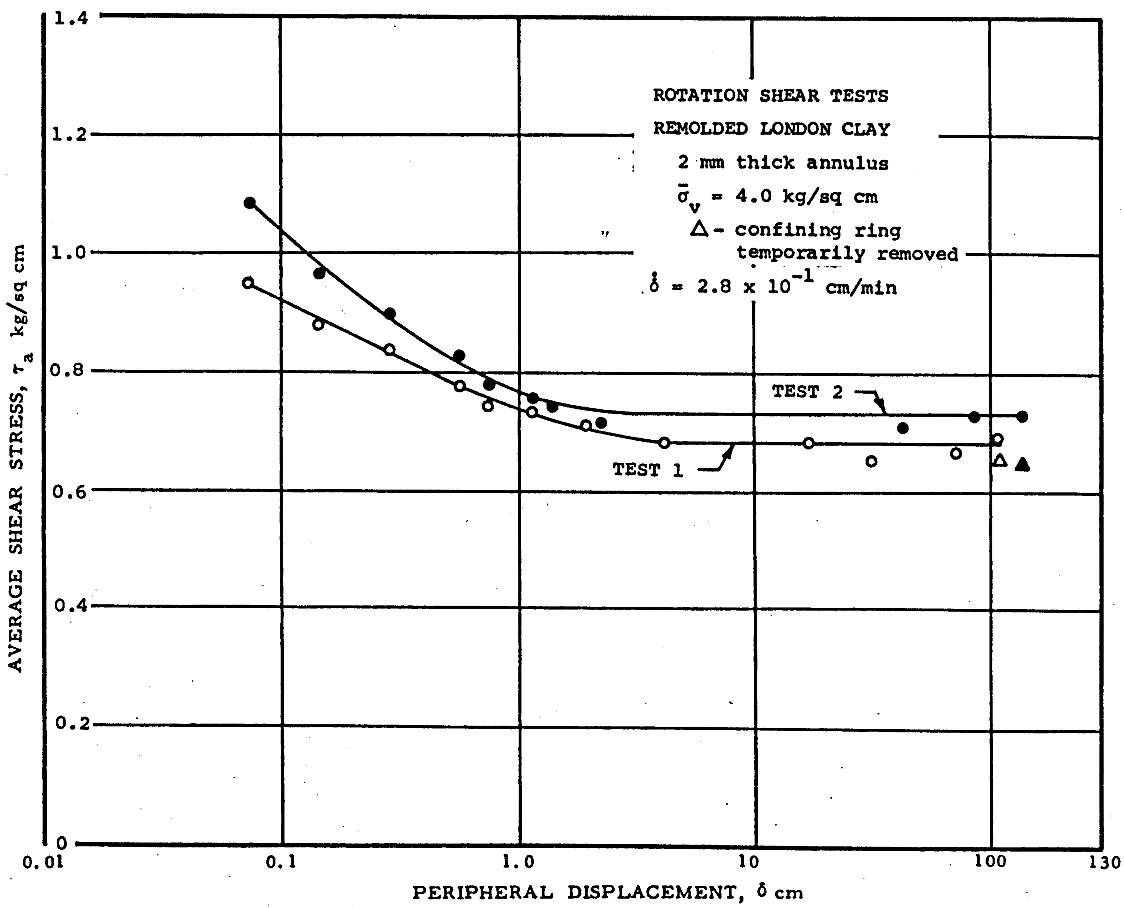


EFFECT OF $\dot{\delta}$ ON $\tau_r/\bar{\sigma}_v$
REMOLDED BEARPAW SHALE
2 mm thick annular specimens
$\bar{\sigma}_v$ = 4.0 kg/cm^2
ϕ_r = 4.5
ϕ_r = 4.0
ϕ_r = 3.5
$\tau_r/\bar{\sigma}_v$
0.10
0.08
0.06
0.04
0.02
0
0.0001
0.001
0.01
0.1
1.0
RATE OF PERIPHERAL DISPLACEMENT, $\dot{\delta}$ cm/min

FIG. 9

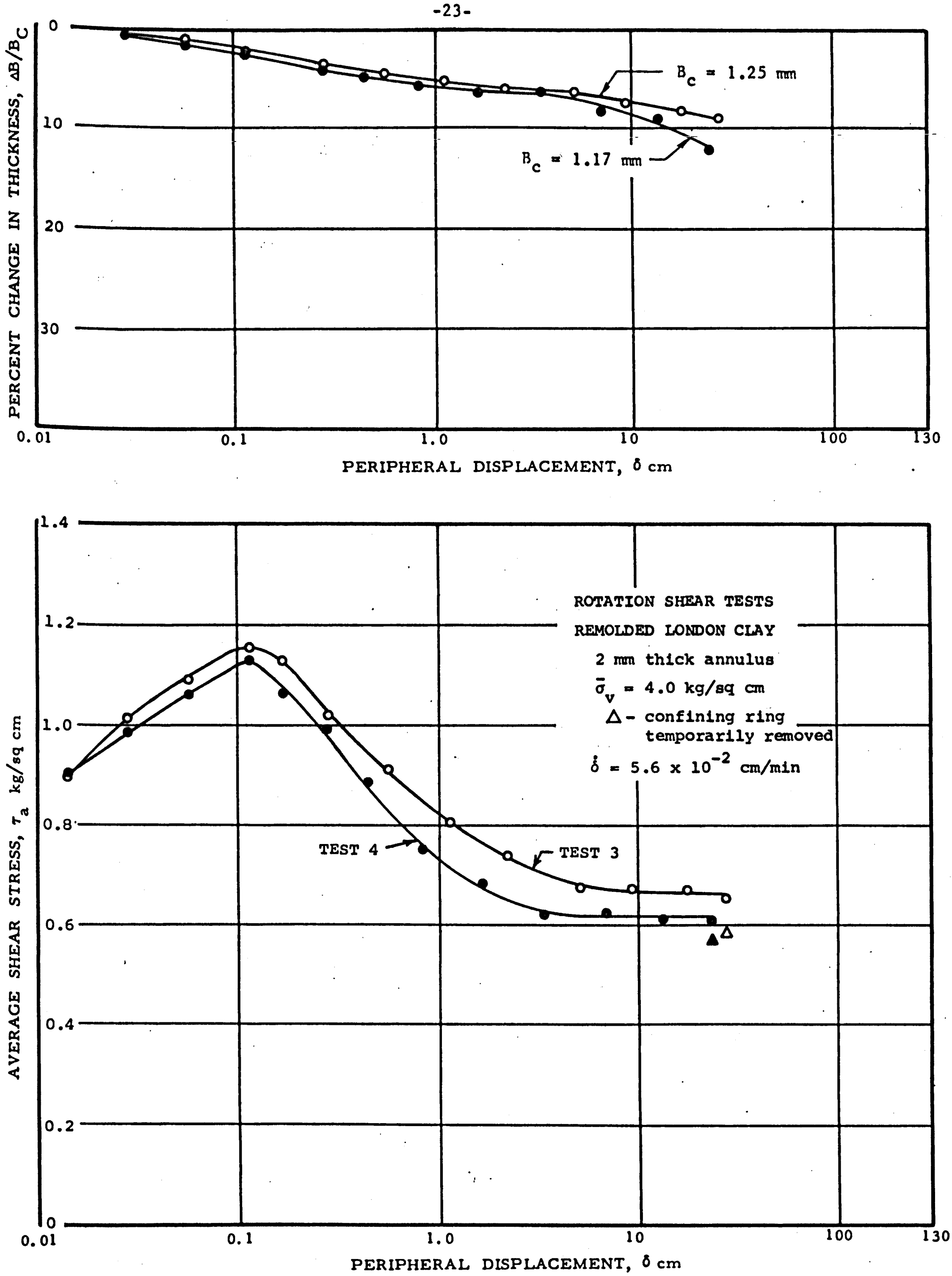


PERCENT CHANGE IN THICKNESS, ΔB/B_C
0
10
20
30
B_c = 1.21 mm
B_c = 1.18 mm
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm



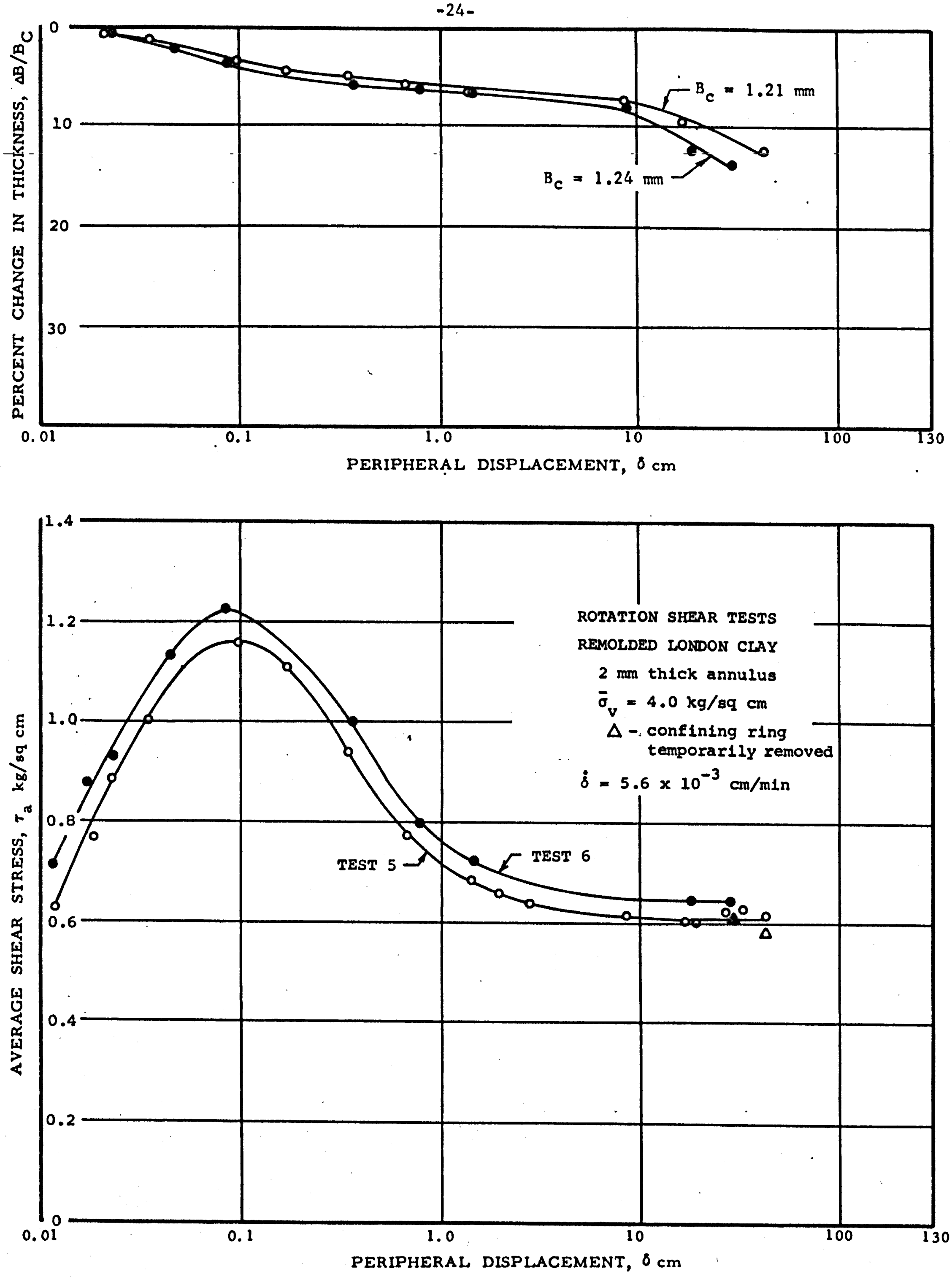
AVERAGE SHEAR STRESS, τ_a kg/sq cm
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
ROTATION SHEAR TESTS
REMOLDED LONDON CLAY
2 mm thick annulus
$\bar{\sigma}_v$ = 4.0 kg/sq cm
Δ - confining ring temporarily removed
$\dot{\delta}$ = 2.8 x 10^{-1} cm/min
TEST 2
TEST 1
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm

FIG. 10



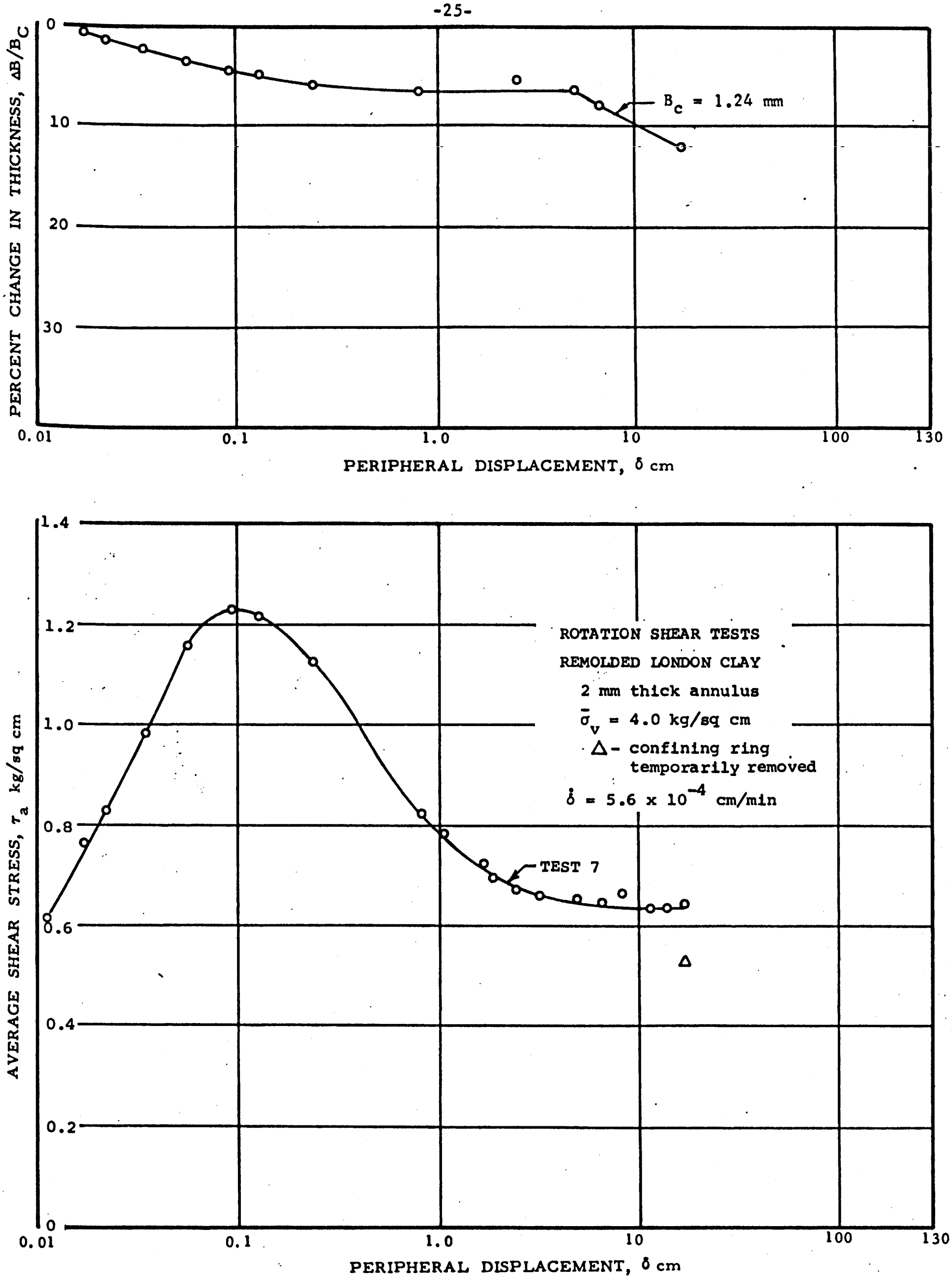
PERCENT CHANGE IN THICKNESS, ΔB/B_C
0
10
20
30
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm
B_c = 1.25 mm
B_c = 1.17 mm
AVERAGE SHEAR STRESS, τ_a kg/sq cm
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
ROTATION SHEAR TESTS
REMOLDED LONDON CLAY
2 mm thick annulus
σ̄_v = 4.0 kg/sq cm
Δ - confining ring temporarily removed
δ̇ = 5.6 x 10^-2 cm/min
TEST 4
TEST 3

FIG. 11



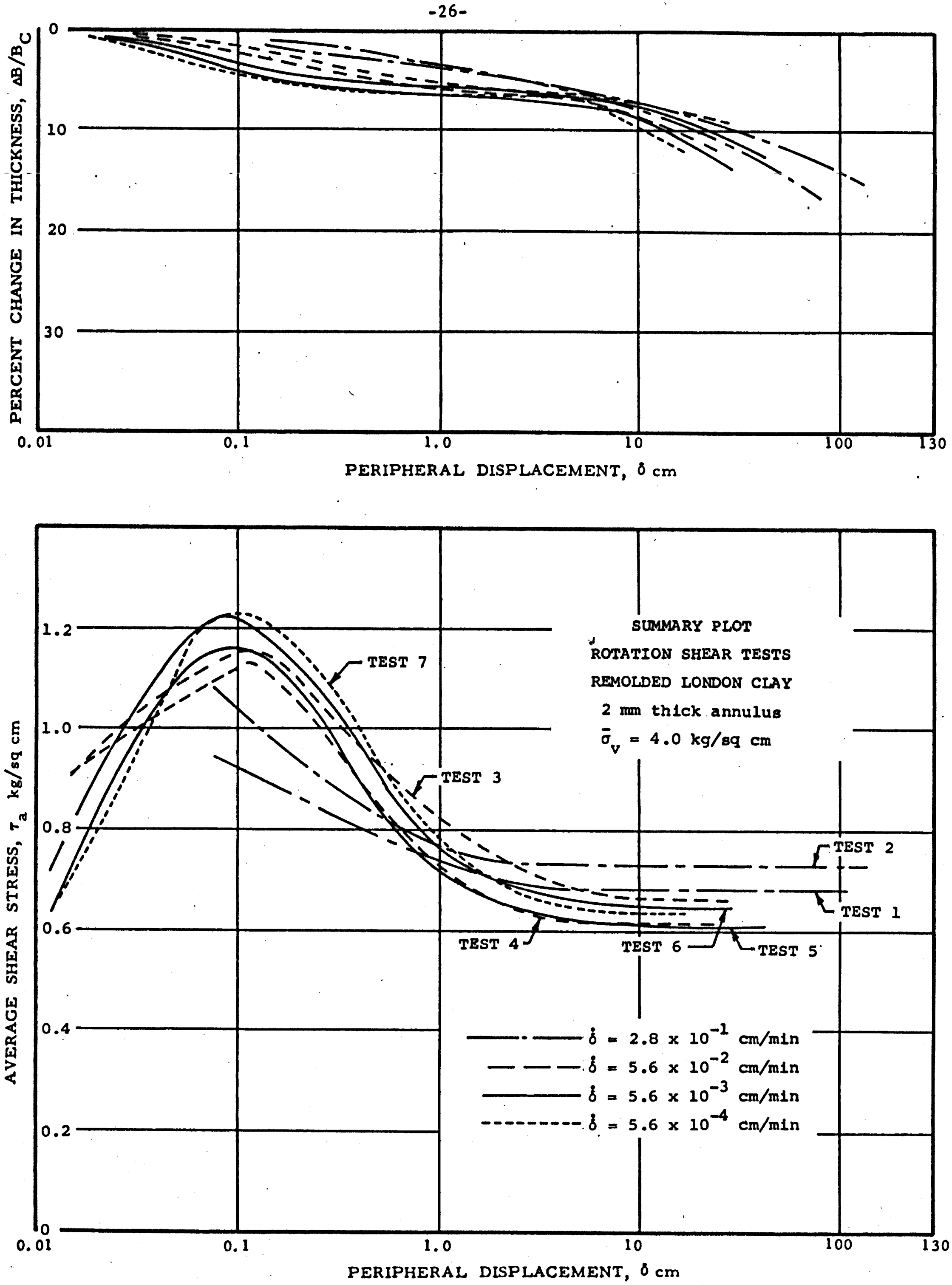
PERCENT CHANGE IN THICKNESS, ΔB/B_C
0
10
20
30
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm
B_c = 1.21 mm
B_c = 1.24 mm
AVERAGE SHEAR STRESS, τ_a kg/sq cm
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
ROTATION SHEAR TESTS
REMOLDED LONDON CLAY
2 mm thick annulus
σ̄_v = 4.0 kg/sq cm
Δ - confining ring temporarily removed
δ̇ = 5.6 x 10^-3 cm/min
TEST 5
TEST 6

FIG. 12



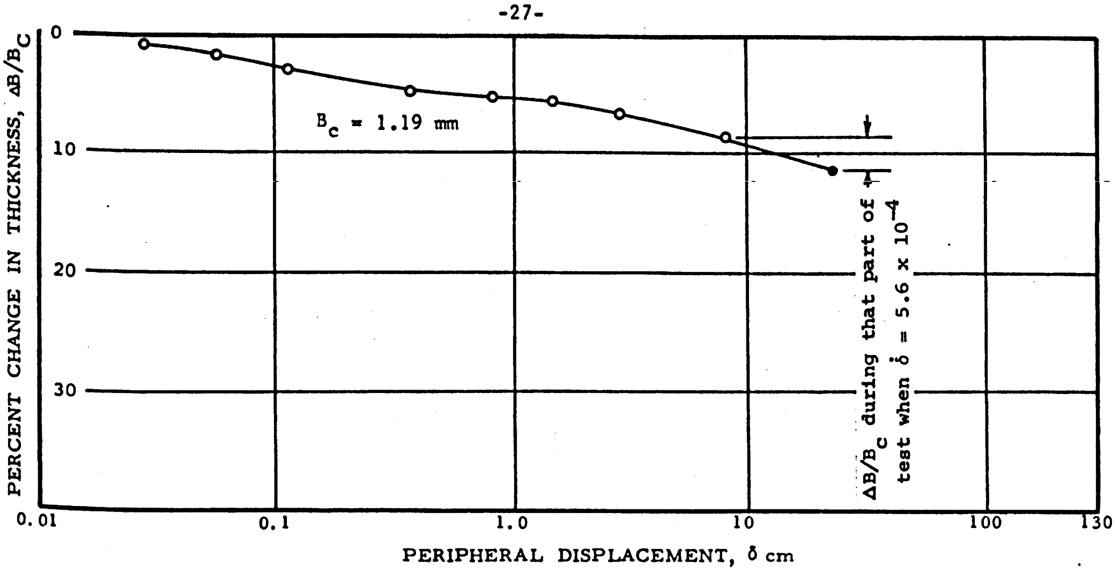
PERCENT CHANGE IN THICKNESS, ΔB/B_C
0
10
20
30
B_c = 1.24 mm
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm
AVERAGE SHEAR STRESS, τ_a kg/sq cm
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
ROTATION SHEAR TESTS
REMOLDED LONDON CLAY
2 mm thick annulus
σ̄_v = 4.0 kg/sq cm
Δ - confining ring temporarily removed
δ̇ = 5.6 x 10^-4 cm/min
TEST 7
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm

FIG.13



PERCENT CHANGE IN THICKNESS, $\Delta B/B_C$
0
10
20
30
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm
AVERAGE SHEAR STRESS, τ_a kg/sq cm
1.2
1.0
0.8
0.6
0.4
0.2
0
SUMMARY PLOT
ROTATION SHEAR TESTS
REMOLDED LONDON CLAY
2 mm thick annulus
$\bar{\sigma}_v$ = 4.0 kg/sq cm
TEST 7
TEST 3
TEST 2
TEST 1
TEST 4
TEST 6
TEST 5
$\dot{\delta}$ = 2.8 x 10^{-1} cm/min
$\dot{\delta}$ = 5.6 x 10^{-2} cm/min
$\dot{\delta}$ = 5.6 x 10^{-3} cm/min
$\dot{\delta}$ = 5.6 x 10^{-4} cm/min

FIG. 14


0
10
20
30
PERCENT CHANGE IN THICKNESS, ΔB/B_C
B_c = 1.19 mm
ΔB/B_c during that part of test when δ̇ = 5.6 x 10^-4
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm

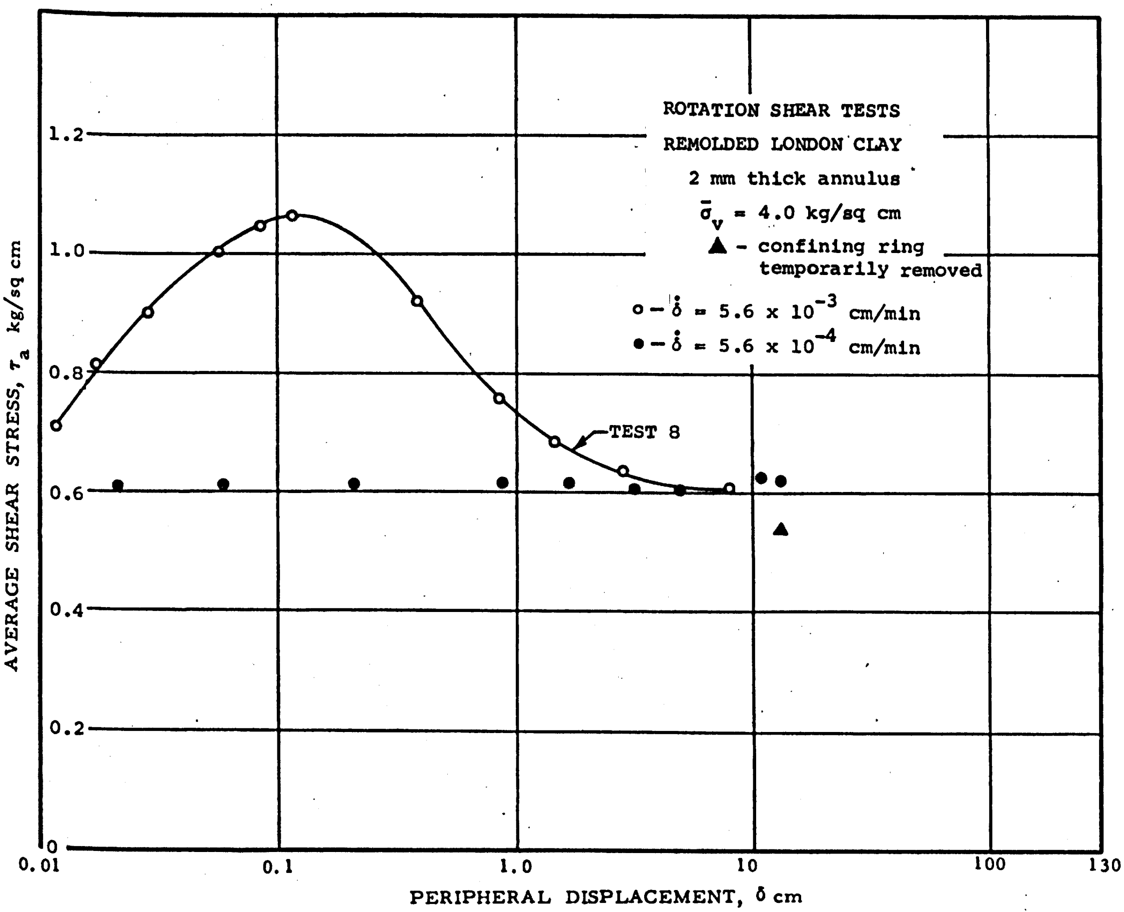
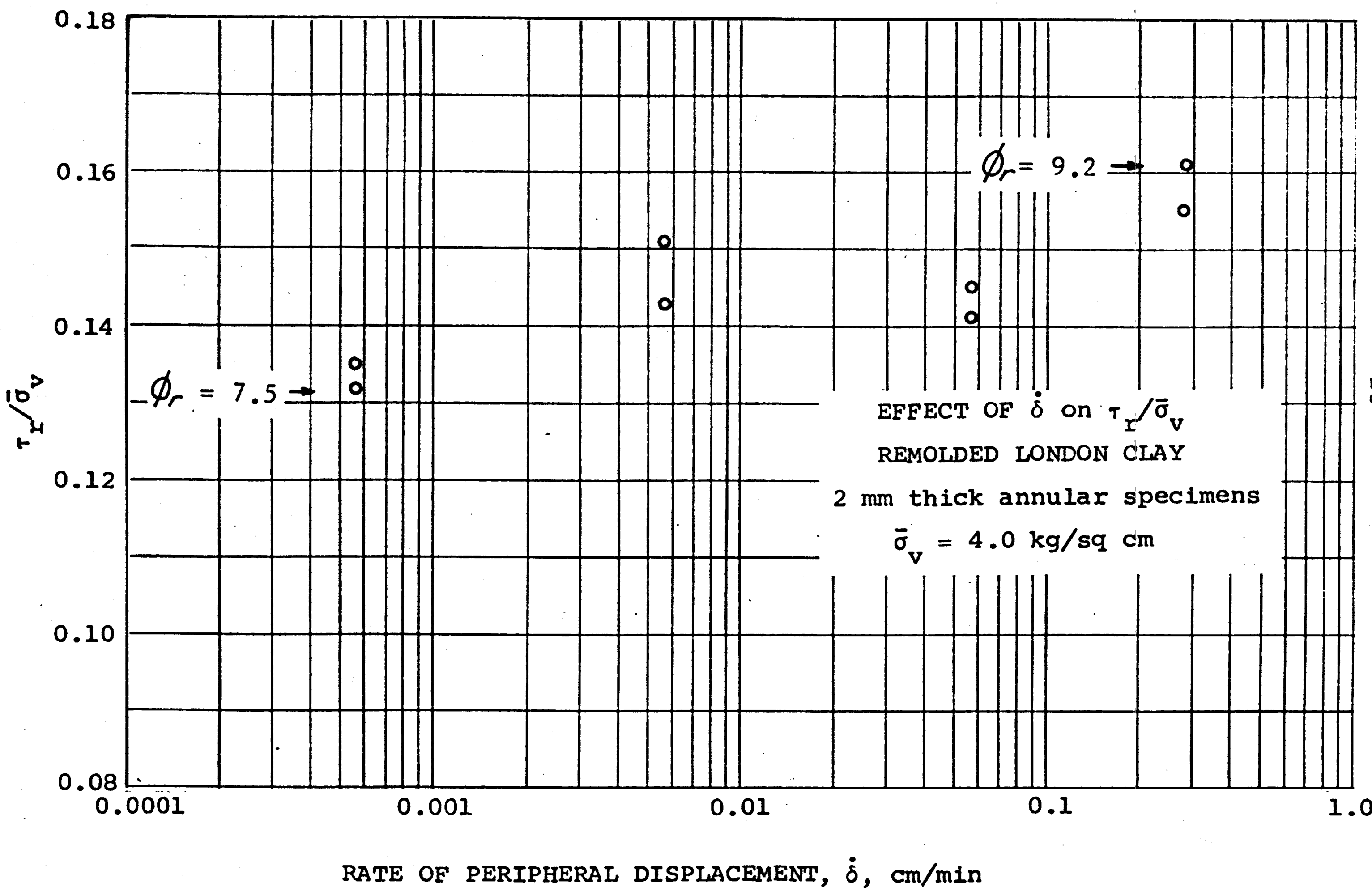

ROTATION SHEAR TESTS
REMOLDED LONDON CLAY
2 mm thick annulus
σ̄_v = 4.0 kg/sq cm
▲ - confining ring temporarily removed
○ - δ̇ = 5.6 x 10^-3 cm/min
● - δ̇ = 5.6 x 10^-4 cm/min
TEST 8
AVERAGE SHEAR STRESS, τ_a kg/sq cm
0
0.2
0.4
0.6
0.8
1.0
1.2
0.01
0.1
1.0
10
100
130
PERIPHERAL DISPLACEMENT, δ cm

FIG. 15



0.18
0.16
0.14
0.12
0.10
0.08
$\tau_r/\bar{\sigma}_v$
0.0001
0.001
0.01
0.1
1.0
$\phi_r = 7.5$
$\phi_r = 9.2$
EFFECT OF $\dot{\delta}$ on $\tau_r/\bar{\sigma}_v$
REMOLDED LONDON CLAY
2 mm thick annular specimens
$\bar{\sigma}_v$ = 4.0 kg/sq cm
RATE OF PERIPHERAL DISPLACEMENT, $\dot{\delta}$, cm/min

FIG. 16

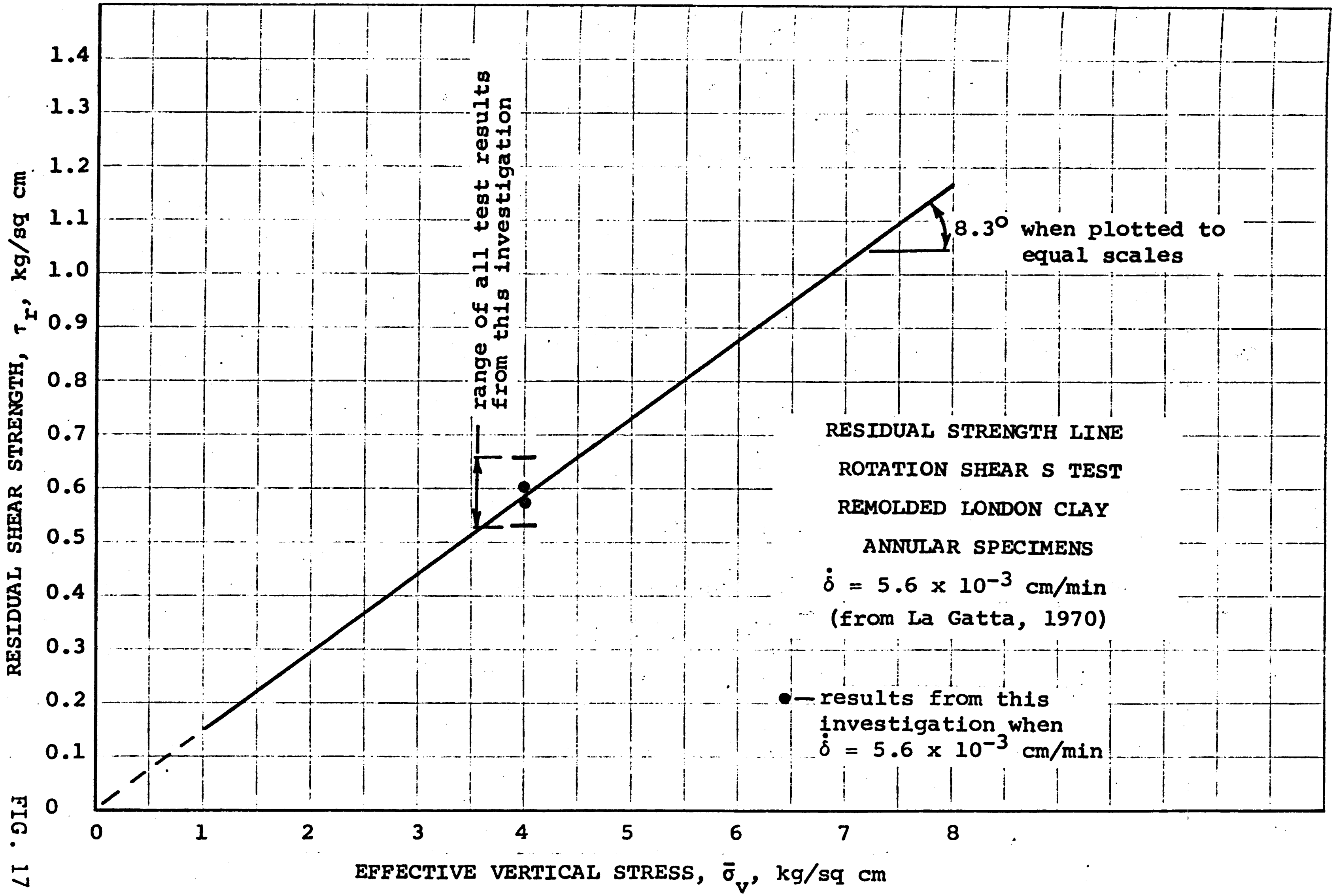

RESIDUAL SHEAR STRENGTH, τ_r, kg/sq cm
EFFECTIVE VERTICAL STRESS, $\bar{\sigma}_v$, kg/sq cm
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
0
1
2
3
4
5
6
7
8
range of all test results from this investigation
8.3° when plotted to equal scales
RESIDUAL STRENGTH LINE
ROTATION SHEAR S TEST
REMOLDED LONDON CLAY
ANNULAR SPECIMENS
$\dot{\delta} = 5.6 \times 10^{-3}$ cm/min
(from La Gatta, 1970)
results from this investigation when $\dot{\delta} = 5.6 \times 10^{-3}$ cm/min

FIG. 17

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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Prepared under contract for U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi	Office, Chief of Engineers, U. S. Army Washington, D. C.

13. ABSTRACT Rotation shear tests were performed with a rotation shear device, developed for the purpose of measuring residual shear strengths of clays and clay shales, on 2-mm-thick annular specimens of remolded Bearpaw shale and remolded London clay. Rates of displacement in comparative tests, expressed in peripheral velocities of the annular specimens, were 2.8 X 10^{-1}, 5.6 X 10^{-2}, 5.6 X 10^{-3}, and 5.6 X 10^{-4} cm per min. Results of this limited investigation indicated the following: (a) rates of displacement in the range tested have a negligible effect on the residual shear strength of remolded Bearpaw shale; residual friction angles varied generally from 3.5 to 4.0 deg; and (b) the residual angle of internal friction of the London clay increased from about 7.5 deg at the slowest rate of displacement of 5.6 X 10^{-4} cm per min to 9.2 deg at the fastest rate of 2.8 X 10^{-1} cm per min. It was found difficult to make readings when the test was performed at the fastest rate, and it was considered that in testing London clays a rate of displacement of 5.6 X 10^{-2} cm per min was acceptable, since it caused the residual strength to be only about 8 percent higher than that for the lowest rate, and because at this rate of displacement, the test could be performed in one working day.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Bearpaw shale						
Clays						
Clay-shales						
London clay						
Residual shear strengths						
Rotation shear tests						

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