To ensure an unaltered water content during the simple compression tests, it is advisable to surround the specimen with a thin rubber skin. Specimens without any skin are likely to lose or gain water during the test, depending on the temperature and the relative humidity of the air which surrounds the specimen. Fig. 3 shows the relation between the temperature T, the relative vapor pressure, and the increase of weight for a specimen of the Parisian clay in a stiff plastic state, and Fig. 4 shows the same relation for the same clay with the water content close to the shrinkage limit.

In dense sands and clays the application of the shearing force at a constant vertical pressure produces an increase of the voids ratio and in loose sands and soft clays the application of shearing force is associated with a decrease of the void ratio. This fact is illustrated by Fig. 2 and 5. The limit between dense and loose state is tentatively placed at a void ratio of $\varepsilon=0.8$, corresponding to a volume of voids of 44.5 per cent.

If a load is applied on a limited area of the horizontal surface of a soil deposit, the zone of maximum shear is located beneath the rim of the loaded area, as shown in Fig. 6. If the increase of the shearing stresses produced by an increase of the load is associated with an important decrease of the void ratio, the settlements along the rim of the loaded area are likely to be greater than those of the central part of this area (Fig. 6 bis).

No. D-11 A RING SHEARING APPARATUS FOR THE DETERMINATION OF THE SHEARING RESISTANCE AND PLASTIC FLOW OF SOILS

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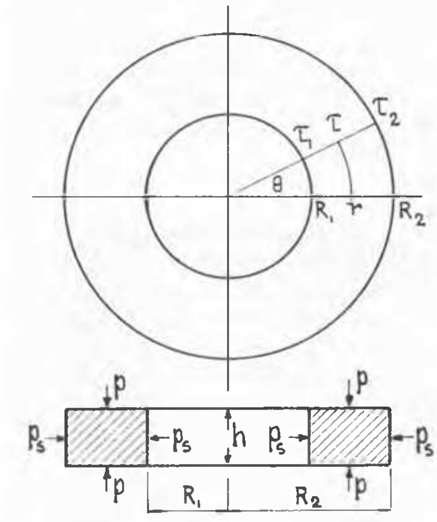
ABSTRACT

The paper contains the results of a successful attempt to investigate the shearing resistance of two very different clays after failure. The tests were made by means of a "ring shearing apparatus" on specimens with the shape of annular rings. The clays were tested in a remoulded state. The paper also contains a detailed description of the apparatus and theory of the distribution of the shearing stresses over the plane of shear for different stages of the test.



CIRCULAR RING IN TORSION

FIG 1.

Method of testing. Fig. 1 shows a vertical section through the specimen. In this figure the following symbols were used:

τ_1 , τ , τ_2 = shearing stresses acting at the points where shown,

R_1, R_2 = inner and outer radius of the specimen,

p, p_s = vertical and horizontal pressure acting in the specimen

h = thickness of the sample, and

θ = angular displacement between the upper and the lower surface of the specimen in radians.

The subsequent figures and the text contain in addition the following notations:

$n = \frac{R_1}{R_2}$ = ratio between inner and outer radius,

$\gamma = \frac{\theta}{h} r$ = average unit shearing strain,

τ_a = average shearing stress,

T_s = time between beginning of the shearing test to the instant of failure, at constant increase of shearing force,

S = Weight on the scales required to subject the specimen to a twisting moment M,

M = twisting moment acting on the specimen,

$$F_1(\theta) = M + \frac{\theta}{3}\frac{dM}{d\theta} \quad \text{and}$$

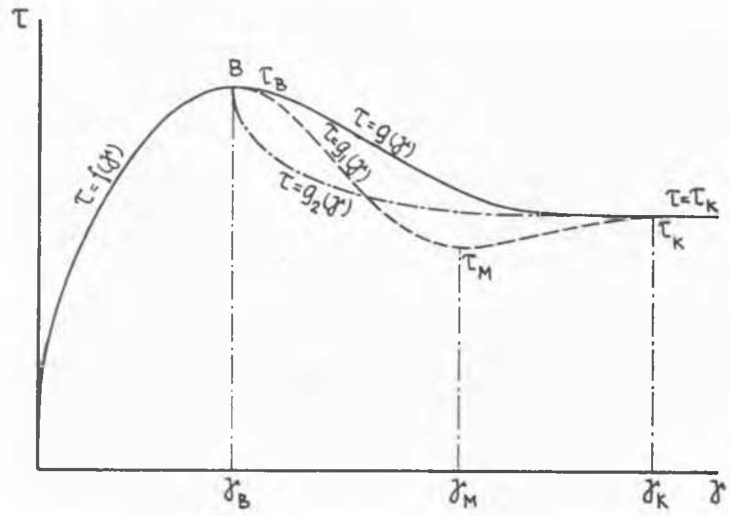
$$f_1(\theta) = F_1(\theta) + n^3 F_1(n\theta) + n^6 F_1(n^2\theta) + \ldots\ldots$$ = two functions obtained by theory.

The theory of the distribution of the shearing stresses is based on the following assumptions: a. the pressures p and p_s are uniformly distributed and remain constant throughout the test. b. All horizontal sections remain plane throughout the test. c. The unit angular strain increases in simple proportion to the distance from the center of rotation. d. The friction between the side walls and the specimen can be neglected.

Fig. 2 shows the different types of relations which were found to exist between the shearing stress and the unit strain γ. Fig. 3 is an assembly drawing of the apparatus and Fig. 4a and b are photographic views of the container. The internal diameter of the specimen is about equal to 6 and the external diameter equal to 12 cm. The thickness h of the specimen is normally about 2 cm. The apparatus is constructed so that the tests can be made in three different ways:

1. The circular side walls remain stationary throughout the test ("fixed rings")
2. Both rings are free to rotate during the tests ("free rings")
3. Both rings are attached to the piston which rests on the top surface of the specimen in such a manner that they follow the rotary movement of the piston, but not its vertical movements ("restrained rings").

Fig. 5 and 6 illustrate the influence of the method of testing on the deformation of the specimen.



STRESS-STRAIN CURVES FOR PURE SHEAR.

FIG. 2.

Review of some Test Results. One series of tests was made with an Austrian silty clay, "Wiener Tegel", and with a Danish plastic clay, "Little Belt Clay". The physical characteristics of these clays as well as results of tests with the Krey shearing apparatus combined with Terzaghi shearing boxes are described in another paper.

The following summary of tests made with the ring shearing apparatus concerns only tests made with testing arrangement 1. By all these tests the load increment was approximately two per cent of the maximum shearing load, while the time intervals between load applications were varied from 5 minutes at the start to 30 or 60 minutes at the end of the test. The total duration of the tests varied between 10 and 14 hours equivalent to $T_s = 17$ to 22 hours by a constant rate of load application.

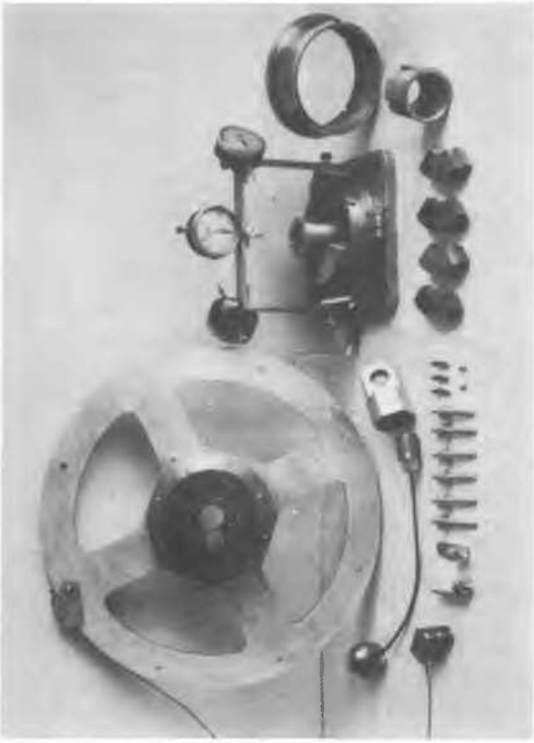
In Fig. 7 is shown an example of the tests with Wiener Tegel. On account of the rapid internal readjustments after failure and the thixotropic properties of the soil, the moment or S curve after failure can only be determined approximately and best by comparing the results of several tests brought to a stop at various values of θ. From the $f_1(\theta)$ curve the τ_2 curve has been computed and drawn to the same scale as the τ_a curve. The maximum values of τ_2 and τ_a are nearly the same, although not occurring for the same value θ, but the minimum value of these stresses differ considerably. After failure the shearing resistance decreases rapidly to 72% of its maximum value, thereafter slowly to increase to 83%. If the movement is now brought to a stop by a further decrease of the shearing load and the test repeated after a rest period, a regain in the shearing resistance is observed, this recovery increases with the length of the rest period and surpasses quickly the original maximum - after five days 110% is reached - but the minimum value of the shearing resistance after each failure remains constant at 83%.

In Fig. 8 a similar example of tests with Little Belt Clay is shown. In this case the decrease of the shearing resistance takes place much more slowly, but is astonishingly large; the minimum 40% is first reached for $\theta = \pm 1.5$, corresponding to a linear displacement of 9 cm along the outer surface of the test specimen. The recovery of the shearing resistance is also very slow; after a four day rest period the shearing resistance is still only 50% of the maximum value. For this clay the maximum and minimum values of τ_2 and τ_a are nearly identical.

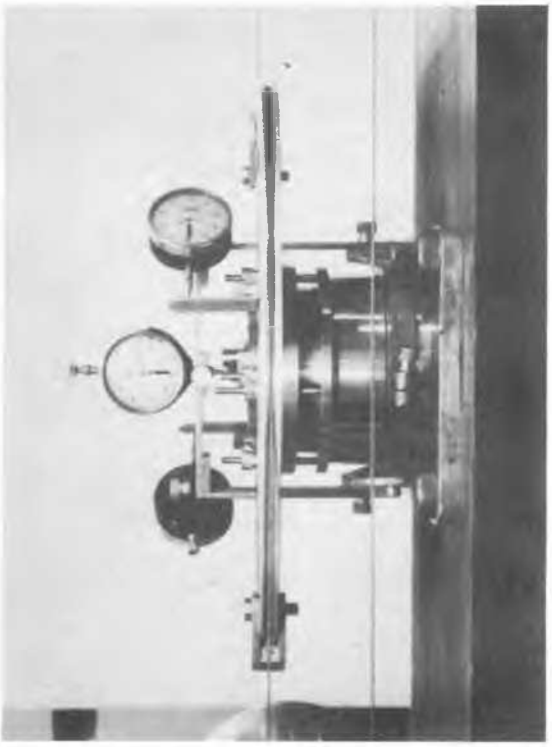
Stress-strain curves for a large number of tests, also with the Krey-Terzaghi apparatus, are shown in Fig. 9. It is here to be noted that the change in rate of load application, mentioned above, also influences the curves.

Investigation of the slow plastic flow before failure requires tests extended over several months. Such tests have not yet been completed, but shorter preliminary tests with both clays indicate that, even at 25% of the maximum shearing load and five days after the load application, the movements are still progressing, although at a steadily decreasing rate. It was further noted that in several cases the maximum velocity of displacement first occurs some time after the load application and that failure may occur up to 20 hours after placing the last load increment. The ultimate shearing resistance after failure (τ_K in Fig. 2) depends to some extent not only on the momentary velocity of displacement, but also, due to thixotropic properties of clays, on the preceding maximum velocity and the time that has passed since this velocity was reached.

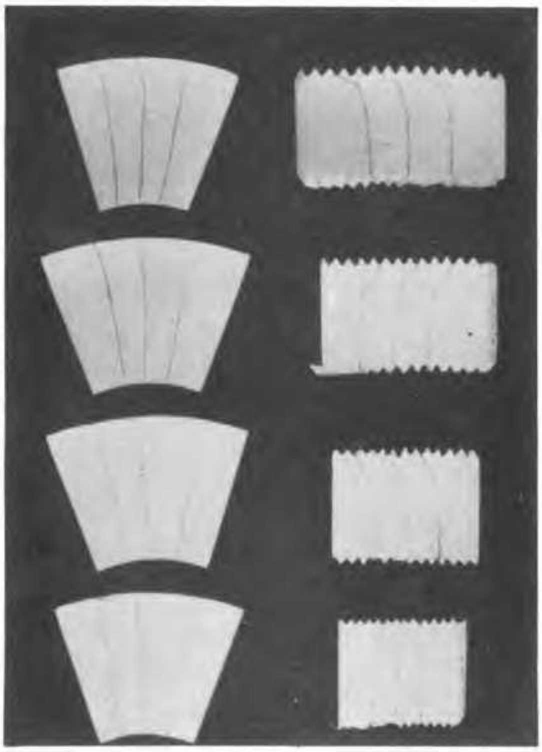
A summary of the test results and a comparison with results of corresponding shearing tests with the Krey-Terzaghi apparatus is given in the next table. Overconsolidation, in this instance, refers to samples which have been preconsolidated at 5 kg/cm^2, then unloaded to 1 kg/cm^2 and allowed to swell before being tested at this pressure. The shearing resistance is here denoted by s, and its maximum value during the first test with the ring shearing apparatus is used as basis of comparison ($s_{max} = \max \tau_2 = 100\%$).



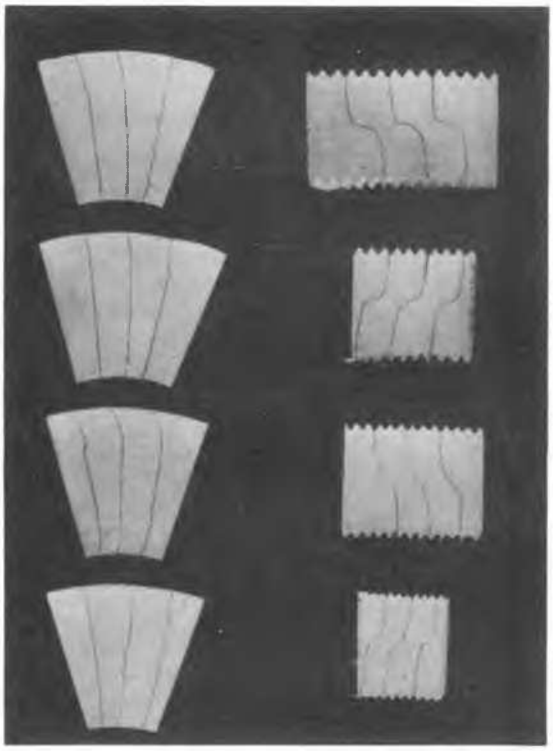
Ring Shearing Apparatus
Dismanteled
Fig. 4a



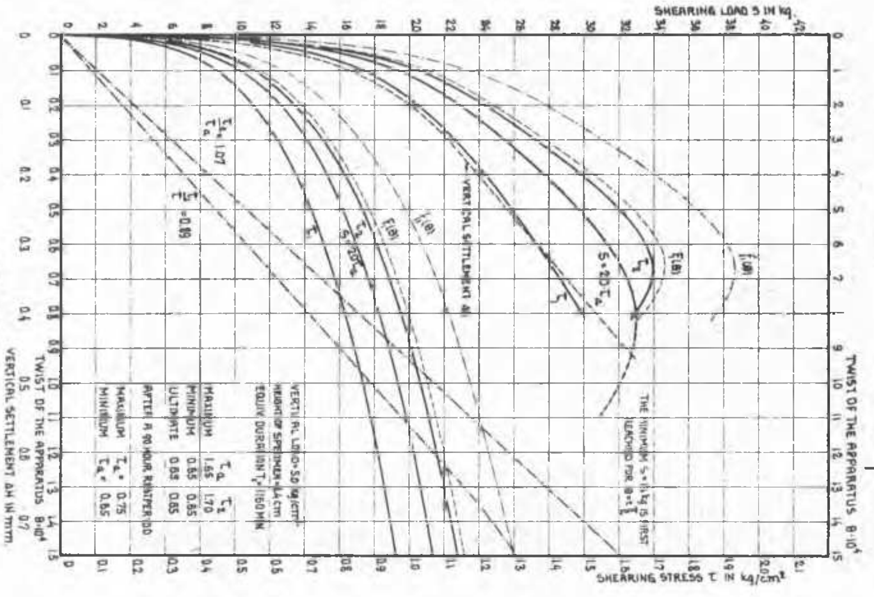
Ring Shearing Apparatus
Free Rings
Fig. 4b



Internal Displacements
Fixed Rings
p=2,0 T=898 H=2,1 e=5,0 e'=9,0
Fig. 5



Internal Displacements
Free Rings
p=2,0 T=635 H=2,1 e=5,0 e'=9,2
Fig. 6

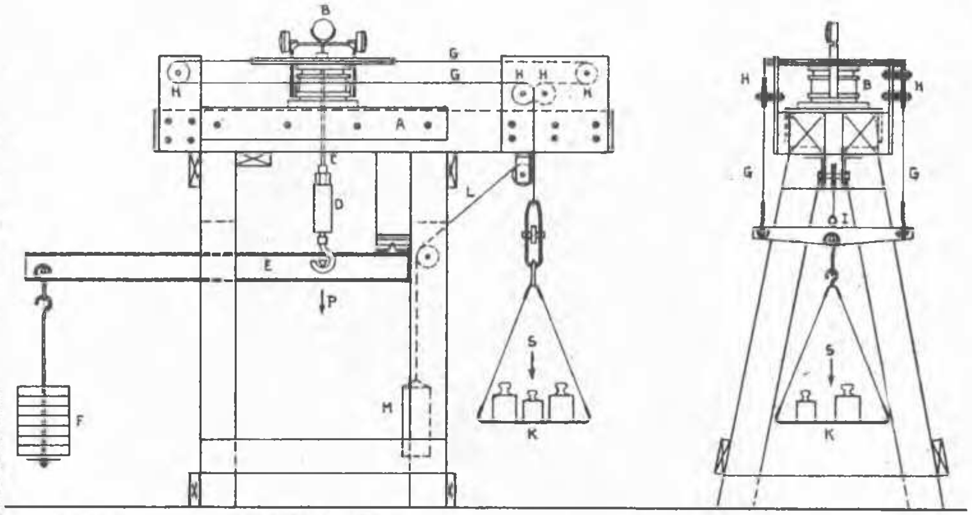


LITTLE BELT CLAY

SHEARING TEST WITH RING SHEARING APPARATUS - FIXED RINGS.

FIG. 8

WIEN 24-II-1936

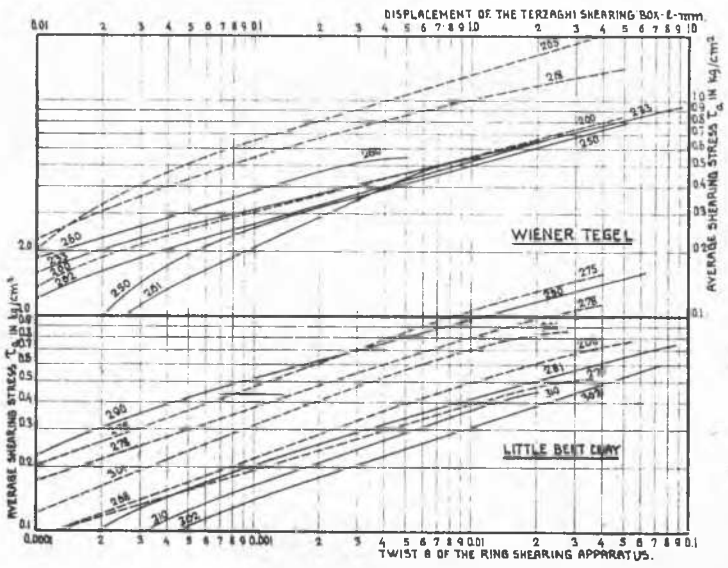


RING SHEARING APPARATUS

GENERAL ARRANGEMENT.

SCALE 1:10.

FIG. 3



WIENER TEGEL

Nº	p	T_s	h	m
200	2	664'	2.4	0.265
205	5	634'	2.35	0.310
218	5-0-3	645'	2.4	(0.260)
233	2	1300	2.1	0.245
250	2	11 DAYS	2.1	0.278
262	2	25 DAYS	1.0	0.295
260	5-1-1	483'	2.0	0.316
261	5-0-1	11 DAYS	2.05	0.465

LITTLE BELT CLAY

Nº	p	T_s	h	m
288	2	1000'	1.7	(0.371)
275	5	683'	1.9	(0.355)
277	5-0-1	817	1.8	0.304
301	5-2-2	1072	1.75	(0.375)
278	5-0-3	1013'	1.85	(0.332)
281	2	2600'	1.6	(0.305)
302	2	983'	1.6	0.335
290	5	1160'	1.4	0.275
310	5-1-1	823'	1.5	0.355

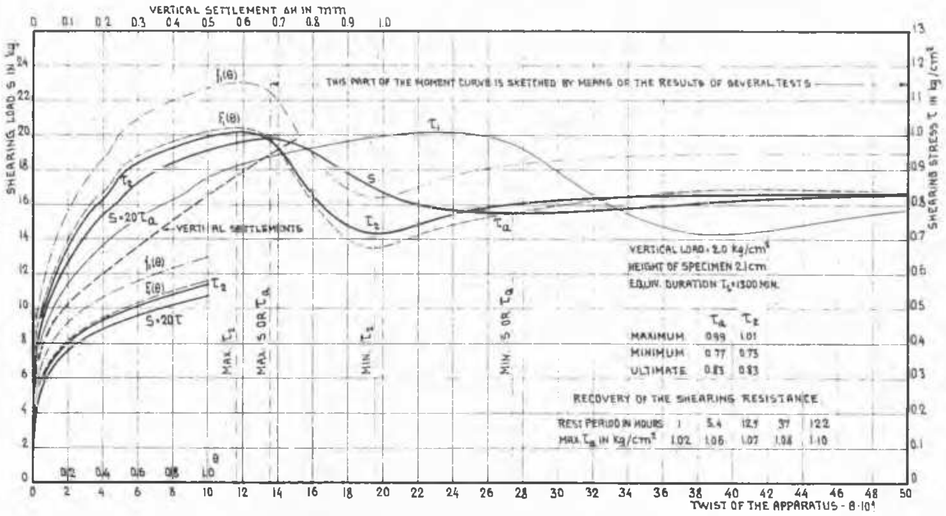
-------- TERZAGHI SHEARING BOX

———— RING SHEARING APPARATUS

STRESS-STRAIN CURVES FOR PURE AND SIMPLE SHEAR.

FIG. 9

WIEN 29-II-1936



WIENER TEGEL - SHEARING TEST WITH THE RING SHEARING APPARATUS - FIXED RINGS

FIG. 7

WIEN 28-III-1935

Ring Shearing Apparatus with Fixed Rings	Wiener Tegel Natural Consolidation	Wiener Tegel Over-Consolidation	Little Belt Clay Natural Consolidation	Little Belt Clay Over-Consolidation
k = τ_2/τ_a (before failure)	1.06-1.07	1.07-1.11	1.07-1.08	1.08-1.09
k' = max τ_2 /max τ_a	1.02-1.03	1.00-1.01	1.02-1.03	1.00-1.01
k'' = min τ_2/min τ_a	- 0.92 -	- 1.00 -	- 1.00 -	-1.00 -
s max) First test	100%	100%	100%	100%
s min)	71-74	75-80	39-40	39-41
s' max) After several tests	107-110	109-111	45-50	- 42 -
) and a rest period				
s' min) of five days	82-90	82-85	- 40 -	- 34 -
Terzaghi Shearing Box				
s max) First test	96	110	101	112
s min)	80-84	95-98	70-75	80-85

As will be seen from this table, the maximum and minimum values of τ_2 are nearly identical with those of τ_a, except where a temporary minimum is concerned as for Wiener Tegel. As such a temporary minimum is primarily of theoretical interest, it suffices in most practical cases to determine τ_a. In comparison with the Krey-Terzaghi apparatus, the ring shearing apparatus furnishes nearly the same values for s_{max} in case of natural consolidation of the sample, but 10 to 12% lower values in case of strong overconsolidation. Probable causes for this difference have already been mentioned, but the case should be further investigated. Especially to be noted are the large decreases of shearing resistance after failure and the large differences in these minimum values of the shearing resistance, as determined by the two types of apparatus. The cause of these differences is that the minimum values of the shearing resistance cannot be reached during the limited horizontal movement of the Krey or similar types of apparatus.

Conclusion. The ring shearing apparatus is primarily suited for the testing of remoulded soils and is especially adapted for the investigation of the plastic flow before and after failure and of the temporary or permanent decrease of the shearing resistance after failure. Tests with remoulded samples of two soils, approximately representing the upper and lower limit of the true clays, show that the decrease in shearing resistance after failure depends to a large extent on the displacement after failure and may be as large as 30%, respectively 66% of the original maximum value of the shearing resistance. Furthermore, by bringing the plastic flow to nearly a full stop, a rapid and complete recovery of the shearing resistance takes place in case of the silty clay, while this recovery by the fine plastic clay is very slow and probably also incomplete.

The tests were made under the supervision of Professor Terzaghi. The ring shearing apparatus used in this investigation, was designed by the author.

AN INVESTIGATION OF JÜRGENSON'S SQUEEZE-TEST

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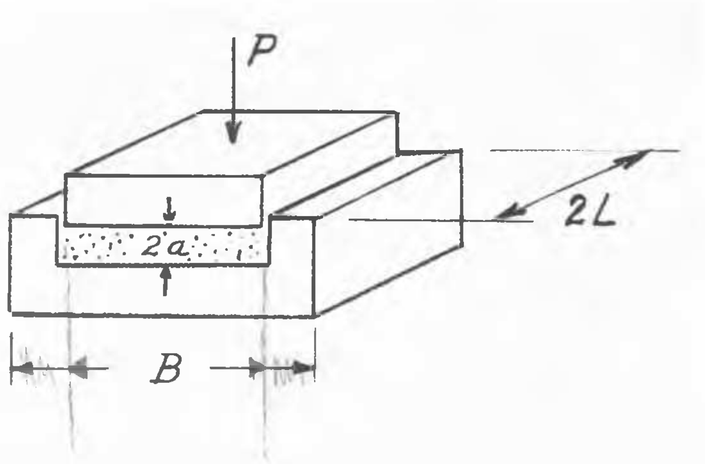
Symbols.

P = total load on sample
s = shearing stress
2a = thickness of sample
B = width of sample along open faces
2L = length of sample along closed side walls



Reference. Jürgenson, The Shearing Resistance of Soils. Journal Boston Society of Civil Engineers, July 1934.

Tentative Conclusions. The squeeze test can be used for determining shearing resistance of clays, provided the squeeze box is calibrated by direct shearing, or unconfined compression tests.

Calibration is necessary, because at the