M.I.T. Dorms,
Cambridge, Mass.

September 9, 1946

Professor George W. Swett
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts.

Dear Sir:

In partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering at the Massachusetts Institute of Technology, I herewith submit this thesis entitled :" Laboratory Investigation of Shearing Strength of Clay."

Yours respectfully,

Victor F. B. de Mello.

Victor F. B. de Mello

LABORATORY INVESTIGATION
OF
SHEARING STRENGTH OF CLAY

by

Victor F. B. de Mello

S.B., Massachusetts Institute of Technology,
(1946)

Submitted in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE IN CIVIL ENGINEERING
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
(1946)

Signature of Author........ Victor F. B. de Mello

Department of Civil Engineering, Sept. 9, 1946

Certified by ....

Thesis Supervisor

....

Chairman, Dept. Committee on Graduate Students

ACKNOWLEDGEMENT

The Author wishes to express his gratitude to Prof. Donald W. Taylor, Assistant Professor of Soil Mechanics at the Massachusetts Institute of Technology, and to Mr. Fred F. Flanders, Laboratory Technician : to Prof. Taylor for suggesting the investigation and for his kindly advice throughout its execution ; to Mr. Flanders for continued assistance in setting up apparatus and running the tests.

TABLE OF CONTENTS.

SCOPE

This investigation had as its main purpose a study of the correlation of shearing strength results obtained by the use of Cylindrical Compression Apparatus with pore pressure measurements, with results as obtained from Drained Direct Shear Tests. It thus would throw light on the degree to which the pore pressure measuring device (attached to the standard Cylindrical Compression Apparatus) could be accepted as reliable in the attainment of a True Mohr Strength Envelope.

In view of which, it was sought to obtain the true Strength Envelope, first by use of Cylindrical Compression apparatus with use of the pore pressure measuring device, and secondly, and quite separately, by use of Drained Direct Shear Tests. In order to avoid the scattering that is almost inevitable in any investigation using "Undisturbed Samples of Clay" ,the material used for all the tests was remoulded Boston Blue Clay.

The apparatus used for the Cylindrical Compression tests is the standard apparatus described in the Tenth Progress Report, "Cylindrical Compression Research Program on Stress-Deformation and Strength Characteristics of soils", Donald W.Taylor, M.I.T., May 1, 1944.

For the drained Direct Shear tests the standard strain-control machine was used, with a few modifications which will be discussed below.

CONCLUSIONS

There is little that can be said that is not quite apparent from the plot of the Mohr Strength Envelope.

(1) As far as can be deduced from this somewhat limited study, there is very good agreement between results obtained by the Cylindrical Compression tests with Pore Pressure measurements, and those of Drained Direct Shear tests. The pore-pressure pilot is therefore quite reliable in giving the pore pressures during a cylindrical compression test, so that the True Mohr Strength Envelope may be obtained from Undrained Cylindrical Compression tests.

(2) The effect of precompression in the remoulded Boston Blue Clay shows up as a straight line almost parallel to the ϕ line but displaced upwards by a small amount corresponding to the cohesion ; and near $\overline{\sigma}_F = \frac{1}{2}\sigma_c$ this 'cohesion' breaks down fairly rapidly, from then on the Strength Envelope following the ϕ line.

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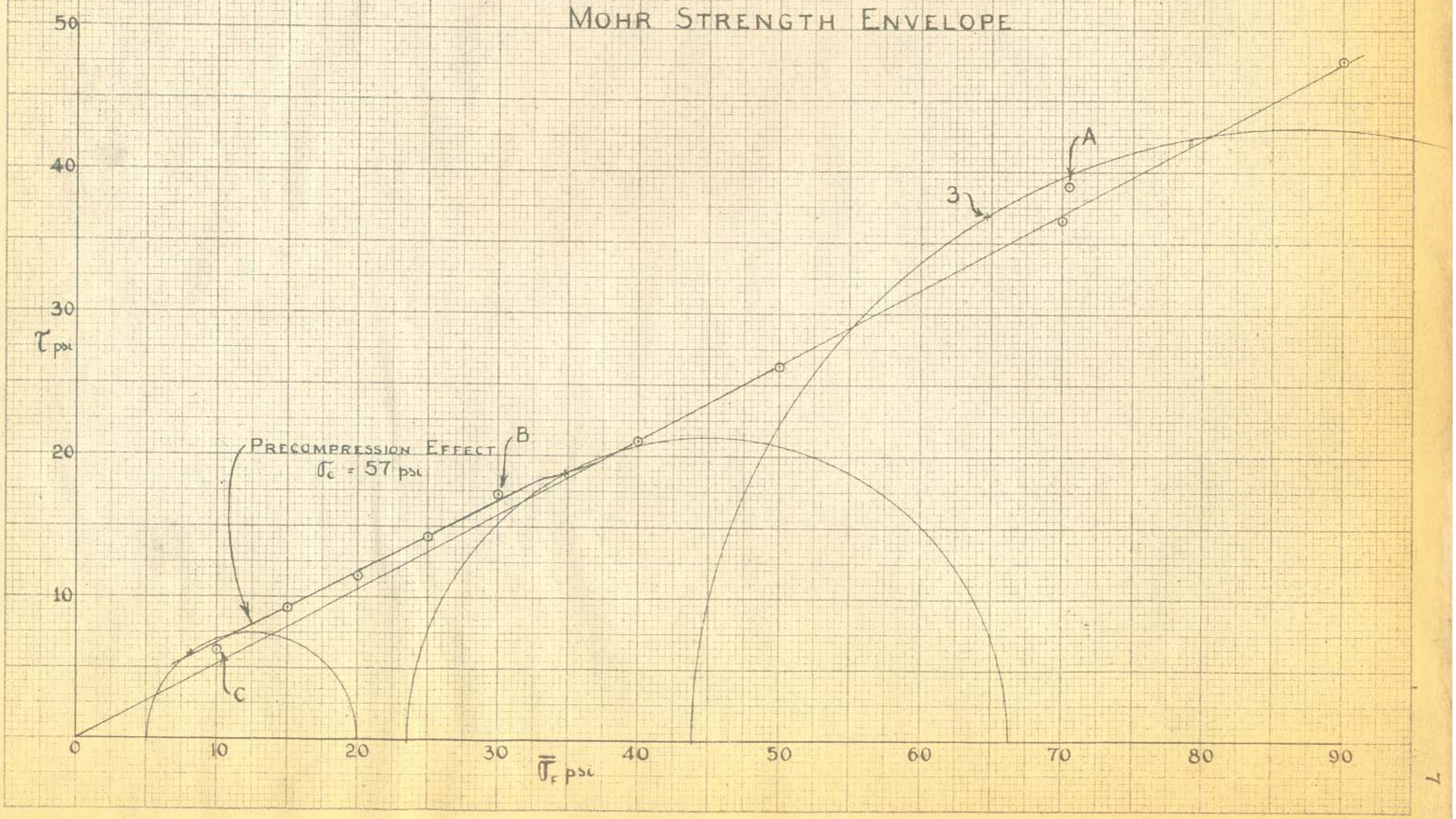
MOHR STRENGTH ENVELOPE



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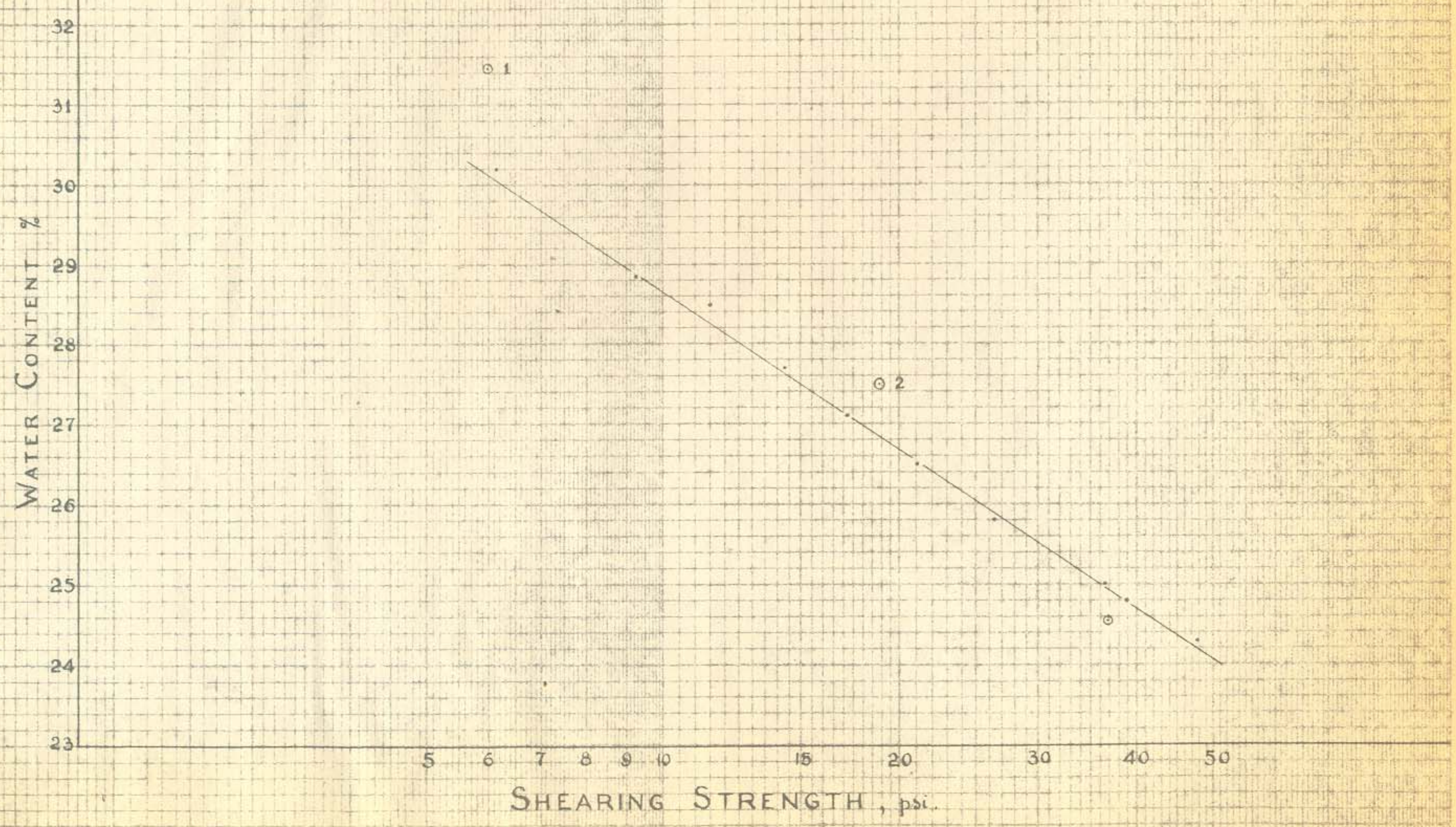


⊙ Cylindrical Compression tests
1, 2 best available approximations
of ω in failure plane.

Water Content vs.
Log. (Shearing Strength)
Remolded Boston Blue Clay

GENERAL DESCRIPTION.

The problem of determining the true Mohr Strength Envelope in undrained Cylindrical Compression tests on clays was successfully tackled with the development of the Pore-pressure measuring device. Previous to this the problem was evaded by use of the so-called "Apparent ϕ angle" : it being impossible to determine the intergranular pressure on the failure plane, it became customary to plot the shearing strength vs. the consolidation pressure. In the general run of clays, where the ϕ value is about 30, (outside the range of effects due to precompression), it became customary to think of ϕ_a as having about half the value of the true ϕ since $\bar{\sigma}_F = \bar{\sigma}_1 (1 - \sin\phi)$ and $\bar{\sigma}_1 \approx \sigma_c$.

As a result of the fairly extensive research program carried out at the M.I.T. Soil Mechanics Laboratory in cooperation with the U.S. Engineer Department, a method was developed for obtaining measurements of pore pressures in samples subjected to Consolidation or to Cylindrical Compression tests in a standard Cylindrical Compression machine. The development of this Pore pressure measuring device is detailed in the Tenth Progress Report of the above Research Program; a report submitted by Donald W. Taylor, Assistant Professor of Soil Mechanics, on May1, 1944. The same progress report gives a wealth of data on tests carried out with the use of the Pore-pressure measuring device: and it includes descriptions of test procedure. It thus becomes unnecessary to describe this type of test in this thesis. Three such tests were run on the same sample. Three tests are not quite sufficient to allow assertive conclusions on the "fine points". But it lay without the scope of this study, in time and available material, to attempt to conduct a more extensive series of tests. Neither do three tests quite establish a Mohr Strength Envelope. However, it was possible to run quite an extensive series of drained Direct Shear tests, the last few of which were so developed in technique as to take only three days. The idea of the investigation was therefore modified a little:- the results from the drained Direct Shear Tests were used to determine the Mohr Strength Envelope and the results of the three Cylindrical Compression Tests were plotted alomgside and their positions studied in relation to the Strength Envelope. Actually all the tests went to define just one Envelope...

The drained Direct Shear tests purport to be slow enough so that there is essentially complete consolidation: the normal pressure applied on the failure plane (horizontal) is therefore the intergranular pressure on that plane, and the plot of shearing strength vs. normal pressure gives the True Mohr Strength Envelope.

SAMPLE:- The Samples used were prepared from the same Boston Blue Clay used for the investigations described in Progress Reports # 9 and 10. The following is transcribed from Page 6, Ninth Progress Report.." It is a typical Boston Blue Clay obtained from a large open excavation in South Boston Harbour. This clay has a liquid limit of 50 and plastic limit of 24. Its natural water content is approximately 40% and its unconfined compressive strength about 700 pounds per sq. ft." On Page 7 of the same report is described the procedure used in remolding and thoroughly mixing the clay before consolidation. This achieved a high degree of homogeneity. This is worthy of specific mention here, because the remarkable agreement obtained in most test results is to a large extent due to this 'perfect' homogeneity.

The sample used for the Cylindrical Compresion tests had been cut from a large batch that, early in 1944, was consolidated to 4 Kg/sq.cm. in the large 15-inch diameter consolidometer then but recently designed and set up at the M.I.T. Soil Mechanics Laboratory. (Vide. Brief description, Page 9, Ninth Progress Report ; and Page 4, Tenth Progress Report). In the notation used by Prof. D.W.Taylor in his reports, the sample used was Sample C of Batch E25E2. The consolidation data is available at the Laboratory. The following data is of interest:-

Average $\frac{W_s}{V} = 1.467\ ^{gm}/_{cm^3}$. Average water content = 30.3%,

computed at the end of the consolidation process.

The samples for the direct shear tests were consolidated either in the 4.2-inch diameter consolidometer units or in the direct shear machine itself. The advantage in consolidating them in the consolidometer units was that a check water content could be obtained out of the shavings when cutting each sample down to the necessary 3-inch square. The water content thus determined averaged 30.3±0.1%. The smples were consolidated to the 57 psi. (4 Kg/cm^2.) using 6% friction ...Vide. Consolidation Research pamphlet, Fig. 14 on page 32. (Total friction as percent of total applied load at end of primary compression $\approx$12% .. average friction $\approx$6%).

In placing the remoulded clay into the containers (consolidation units, or direct shear machine) great care was exerted to avoid entrapping air bubbles. The usual procedure was employed ; viz., of taking the clay a little at a time and spreading it thin with a spatula on a large porcelain dish, thus getting rid of the existing air bubbles. The author wishes to point out, however, that in his opinion this does not accomplish much for it seems that most air bubbles are entrapped when transferring the clay into the container where it becomes next to impossible to "spread it"out in thin layers" to destroy the air bubbles. However this does not seem to be a point of major consequence.

TESTS AND TESTING PROCEDURE

Cylindrical Compression Tests. The apparatus used is what the author terms "standard" apparatus in that it has been thoroughly described in previous studies on Shear in Clays. The apparatus and testing procedure are well described in the Ninth Progress Report, and the additions made necessary by the pore-pressure measuring device are completely covered in the Tenth Progress Report.

The first test was run with no reconsolidation. Unfortunately it was run a little too fast for altogether adequate handling of the pore pressure measurements, which requires considerable practice. As the pore-pressure measuring device tends to be slow in registering changes, if the test is run relatively fast, the result is more or less that there is always a little lag, and consecutive readings will straddle the actual value. It is advisable to run these tests moderately slow unless and until one is quite adept. Anyway, by using the best interpolated curve from a plot, quite accurate pore pressure values are obtainable. Certainly of better degree of accuracy than obtains im the chamber pressure readings .. especially if due to a small leak in the stuffing-box the chamber pressure does not stay quite constant.

The observed and computed data for this test are given in Tables 1A, 1B, and 1C (Page 30-32) accompanied by the graphs (Page 33,34). The computations herein detailed were based on an assumption of uniform bulging throughout the lenght of the sample. The use of average area, over entire length of sample, computed from the assumption of constant volume, is somewhat in error, especially under larger compressive strains. In general there are "dead end" spaces : and most of the change of area (due to compression and consequent bulging) takes place in the middle portion of the cylinder. Hence obviously the values of $(\sigma_1-\sigma_3)$max. tend to be a little high : and so also the computed shearing strength.

The author has therefore adopted what he considers a much more logical procedure, based on an eye estimate of the fraction of the entire length over which most of the bulging seems to have taken place. This procedure is obviously only approximate: if precision is desired, actual measurements of the circumference of the sample at various levels may be undertaken. The computations involved in this correction of basic assumption are indicated in Table 6 (Pages 53-55). The procedure is only approximate indeed, but the approximation should infallibly bring the results closer to actual. The author was not quite aware of the degree to which this alteration in the basic assumption would modify results;. In the first test it affected the results by 2.2% : in the second test by 3.7% : and in the third test by 15% ; these figures are based on the corrective assumptions adopted. Being unaware of the importance of these alterations, the author failed to set due store by all possible measurements that might have helped in making the assumptions more precise. However, the one set of measurements (of circumferences) taken previous to the start of Test #3, checks pretty well with the results arrived at by computation based on these assumptions (Vide. Correction for Test #3, Page 55).

Since the same sample was to be used in subsequent tests care was exerted to avoid prolonging Tests #1 and #2, which were consequently stopped as soon as it became fairly sure that $(\sigma_1 - \sigma_3)$ max. had been reached.

It is interesting to follow the variations of $\bar{\sigma}_F$ and τ_F as the test progresses. In the precompression range the curve is somewhat different from the usual:and there is a little question as to which plane to use ... the 60° plane, failure plane for $\phi = 30°$ (which is close to the condition obtained with remolded Boston Blue Clay), or the 64° plane which is the actual failure plane in this case with considerable precompression effects. In Table 1C (Page 32) computed data is given for both, but the curve is plotted only for the 60 plane. This Table is given as a sample : for tests #2 and #3 only the graphs are given. This brief side-investigation merely follows a thought developed by Prof.D.W. Taylor in the afore-mentioned Tenth Progress Report

______________________________(Page 18,19)

The sample was then set to consolidate to 60 psi. The stop-cock allowing drainage at the bottom was opened;and connection was made to a burette (all air in the connections having been thoroughly boiled out) in order to obtain measurement of the total volume of water drained out in the consolidation process. Scattered pore-pressure readings were taken to study the progress of the consolidation process. This data is given in the Appendix (Page 56).

At the end of five days the pore pressure registered a small enough residual ($\approx$3psi) so that the second Test could be run. The height of the sample of course had changed during the consolidation process; but was indirectly obtainable through the number of revolutions of the counter corresponding to the travel necessary for the "compressing plate" to reach the top of the sample. The volume of the sample is best approximated by subtracting the volume of water drained out, from the original volume of the sample. (Vide, Computations and relevant comments, Table 6, Page 54). Thus the average area was obtainable.

The second test was thus run. The speed was better adjusted so that pore pressure readings were more easily handled. Since $\bar{\sigma}_1$ during the test reaches values higher than the $\sigma_c \approx 60$psi, effects of precompression should theoretically not exist.

In Table 2 the computations are carried out under the assumption of uniform bulging occurring over the entire length of sample ...and assuming that the area was still uniform as a result of the bulging occurring in Test #1. The corresponding graphs of pertinent characteristics are plotted in Pages 36-38.

Of course, similar to the adjustment undertaken in Test#1, there is a necessary adjustment of areas for Test #2. The computations for this are outlined in fair detail on Page 54 The speed of axial strain in this test is taken as the base speed to which results of all other tests are reduced. The Effect of an incrase of speed of shear is to increase the shearing strength; and so a "base speed" must be adopted in order to bring all shearing strength results to comparable values. Progress Report # 9 brings forth the conclusions on a very extensive program of research on the effect of speed of shear. The tests, on which those conclusions are based, were carried out on the same type of Boston Blue Clay, results being corrected to a base of 29% Water Content. The average curve of Compressive Strength vs. Time Rate of Axial Strain, per cent per min., is used by the author to reduce shearing strengths at any speed to shearing strength at the "base speed#. Since shearing strength $\tau = (\bar{\sigma}_1 - \bar{\sigma}_3)\frac{1}{2}\cos\phi$, therefore for ϕ const., $\tau \alpha (\bar{\sigma}_1 - \bar{\sigma}_3)$ And it is assumed that at other water contents (especially since most water contents were very close to 29%) the curve of compressive strength vs. time rate of axial strain is the same. This might at most involve very minor approximations.

Upon completion of Test #2 the chamber pressure was increased to 120psi., and the sample was allowed to consolidate (three-dimensional consolidation) ,bottom drainage being allowed. At the end of a couple of days ,however, the volume of water drained being quite appreciable and the pore pressure refusing to fall, the logical conclusion was reached ...namely that there was a leak. Upon inspection it was discovered that the leak was occasioned by the failure of the cement used in sticking the rubber nipple to the rubber gasket. The apparatus was dismantled, the pore pressure pilot carefully removed, and the sample carried to the humid room.. The only way to remove the gasket with least disturbance was to slit it down its length with a sharp razor-blade. A new gasket was prepared, the nipple cemented (with the same cement ..Goodrich Tyre Cement.. since no other was available at the moment, and, after all, this had behaved satisfactorily for some time). The gasket was put on with great care to avoid disturbance to the sample and to insure that the nipple was opposite the hole left by the removal of the pilot. The pilot was deaerated, the hole in the sample was filled with water, the sample was set up, and the pilot carefully inserted into the position it had previously occupied. The process of consolidation was started over. But unfortunately the same trouble developed a second time. Which leads the author to recommend discarding the use of the said Goodrich Tyre Cement. The sample was finally set up and the third test carried to successful conclusion, by using a Cement # 140 of the Glover Coating Co. (Boston). The sample may have suffered a little from the inevitable rough handling, but the process of consolidating to 120psi. should eradicate such effects. In fact, the use of a single sample in three consecutive tests involving three failures might be questioned,. But it is known from practice that consolidation to higher pressures erases the mark of any such previous failure: and in fact this was borne out in this particular work, for not only was the strength definitely not noticeably impaired, but also the failure plane was not the same in consecutive tests.

Before final consolidation to 120psi. pertinent measurements were taken of the sample : weight, height, and circumference at various levels. This data is presented in the Appendix (Page 58). The volume of the sample after consolidation is computed as outlined in Page 58, 59

The third test was thereupon successfully run. The data and computations are presented in Tables 3A and 3B (Pages 39-41), and in the plots (Pages 42-44). In this third test especially, however, the assumption of uniform bulging over the entire length of the sample is very erroneous. There is the effect of bulging due to the previous two tests (witness the measurements at the middle and at the ends). And, there is the effect of bulging occurring in this same test. By visual examination it is estimated that most of the bulging took place in the middle half of the length of the sample. Based on this estimate a recomputation of results is outlined in Table 6C (Page 55). Finally, important data for determination of water content etc.

werw obtained. The data and computations are presented in fair detail in the Appendix (Page 58).

The two calibration curves required for computations were (1) Proving Ring Calibration; (2) the Calibration curve of counter revolution vs. compressive strain. Both these were available and are here presented (Pages 60,61). Since the Proving Ring was used somewhat above capacity, new Proving Ring calibration data was obtained..

<u>Direct Shear Tests</u> :- The main purpose was to run the tests slow enough to insure fairly complete consolidation during the shearing process.. The choice still lay between a stress-control test and a strain-control one. The first test was attempted as a modified stress-control (since the machine available is strain-control) but it had to be given up as hopeless, because the author had to spend day and night beside the machine switching the motor on and off to keep the shearing load constant for some time. On further thought it became obvious that a strain-control test had vast advantages. It would be fairly easy to set up a system of pulleys etc. in order to maintain a constant shearing load ;and then the procedure would be to start by applying a certain small load, letting the sample consolidate, then adding some more,...and so on to failure. Which would involve a lot of worry on estimating the proper additions of load, there being absolutely no com control over strain. And towards the end of the test this

would mean almost continuous attention since with a shearing load almost equal to the maximum, shearing strain would certainly increase quite a bit if inadvertently neglected for some time. And strains *Had* to be controlled: it is fairly well accepted that beyond a certain horizontal displacement (about 0".3 for the 3"×3" sample) results become almost meaningless because not much is known about such fundamental characteristics as the cross-sectional area !!

In order to use the strain-control procedure the machine would merely require considerable slowing down... It was roughly computed that the speeds obtained by running the motor at its full speed in its present set-up, with the mere interposition of an additional 1:150 and 1:25 gear boxes, the speed would be satisfactory (the speed of horizontal displacement is about 0".002 per hour). It was recognised that the first part of the test could be run at a much higher speed: therefore the 1:25 gear box was not fixed in at all "permanently", but merely with clamps, so that it could be removed from action at will.

Samples: some samples were prepared in the consolidation units and some were consolidated in the direct shear machine itself. Most of the samples used in the range of precompression (consolidated to 57psi) were consolidated in the 4.2-inch consolidometers and then cut into the 3"×3" square for the Direct Shear box. This consolidation is standard procedure and will therefore not be described any further. The samples were on an average 5/8 - 3/4 inches thick. Many of the samples were set to consolidate in the Direct Shear machine itself and allowed a period of a couple of days for almost complete consolidation before starting the Direct Shear Test. 3"x 3" porous stones were directly under and above the clay sample.

It was necessary to surround the shearing plane with water to avoid drying out. Many ideas were tried out and finally a successful method was evelved which was quite easy to handle. Strips of manila-cover were cut to the appropriate size to fit around the bottom square leaving a 1/4-inch edge above ; were dipped in molten paraffin wax to avoid their absorbing water; and were then stuck to the sides of the bottom square by filling in molten wax into the space between the manila-cover and the aluminium box. This could be done only after the upper frame had been raised to be quite clear of the lower frame..for the running of the direct shear test.

The first test run took about 10 days. The author only ran the first 0"036 at the faster speed (motor at lowest speed and additional 1:150 gear ratio). And then the rest of the test, to about 0"279 at the slower speed (motor at full spedd; additional 1:150 and 1:25 gear ratios). The motor had its own rheostat control, so that in general four standard speeds were used...

(A) Motor at full speed; additional 1:150 gear ratio .. this averaged 0"032 per hour when the motor had warmed up.

(B) Motor at lowest speed; additional 1:150 gear ratio... this averaged 0".026 per hour.

(C) Motor at full speed; additional 1:150 and 1:25 gear ratios..this averaged 0".002 per hour with the motor well warmed up.

(D) Motor at lowest speed; additional 1:150 and 1:25 gear ratios..this averaged 0".0017 per hour. It was seldom used.

The author will henceforth refer to these standard speeds as A,B,C,D. Actually the speed did not remain constant at any of these settings; of course while the motor was warming up the speed varied a lot (showing a gradual increase). But although it is supposed to be a constant-speed motor, it was not quite well enough so.

The first test run took nine days but helped very much in experience necessary in cutting down the time in subsequent tests. The standard stress-strain curve was obtained and it was thus discovered that the test could be run at the highest speed up to about 0".150 horizontal displacement without developing a shearing stress higher than the shearing strength at the lower speed (especially speed C). The final procedure that was evolved cut down the time per test to about three days (for the shearing).

The proving ring dial was set up with a little traveling indicator to mark the maximum reached, if this happened to have occurred during the night or some odd time. Readings were taken of horizontal displacement, vertical displacement (indicating consolidation), time, and proving ring.

Table 4 (Page 45) and the graph on Page 46, are a sample of the complete details of any one test. It would be too laborious to present the data of all other tests in similar form, so the abbreviated form is adopted of showing pertinent data on a stress-strain plot.

Calibration curves were run for both proving rings used on the Direct Shear Machine. The calibration data is presented in tabular form on Pages 63,64.

The important result in each test is merely the shearing strength. The computations of these results are all presented in Table 5 (Page 47). Of course the results must be corrected for speed of strain. The speed of shearing strain is 3/2 the speed of axial strain as given in the Ninth Progress Report, for small strains, for the plane of maximum shear. (Page 27) Hence for comparison, 2/3 the speed of shearing strain had to be used... Several very good indirect checks on the average curve of Fig.VII (Ninth Progress Report) were obtained by obtaining the shearing strength at various speeds of strain and reducing them to the "base speed" by use of that curve. The results are indicated in Table V. The agreement is truly remarkable in most cases.

Two tests were run with a slightly different procedure; and although theory does not warrant the expectation of any difference in result, the actual results obtained indicate the existence of some difference (Points A,B.. Mohr Strength Envelope, Page 7). This will however be discussed in the following section.

DISCUSSION OF RESULTS

With the only exception of a few tests, the points that go to define the Mohr Strength Envelope (Page 7) show such remarkable agreement with the expectation based on theory that there is little that can be said in "discussion". It may be noted that in the range of precompression effect, the precompression effect shows up as a straight line almost parallel to the ϕ line, but displaced upwards by a small amount corresponding to the 'cohesion' or 'bond'. And indeed if this 'bond' due to precompression were something definite and constant, theory leads us to expect this: witness the strength envelopes fo metals or other highly cohesive materials. The precompression effect is therefore fairly constant up to a point where $\bar{\sigma}_r \approx 30$psi which would correspond to a $\bar{\sigma}_1$ of about 60psi (which is close to the σ_c): and then this artificial 'bond' rapidly breaks down and the Mohr Strength Envelope corresponds to the ϕ line passing through the origin..

The tests that show somewhat questionable results are indicated by the letters A,B,C, and the number 3. The author wishes to emphasize that although even the variation shown in these tests is of small enough order of magnitude that it could be blamed on the random 'scattering' intrinsic in any soil investigation, he will not accept that line of explanation which might imply 'escapism'. The samples were very homogeneous. The degree of care exerted in each and every test was the same .. the best that could be mustered with the knowledge and experience the possessed.. The technique in handling some of the early Direct Shear Tests was not so well developed as it subsequently came to be, from much that was learnt by experience; but,nevertheless that lack of technique should in no way have affected the results ...rather, it made the work more tedious for the author.

In tests noted A,B,C a slight difference in procedure is noted. Test C is the only one of the tests in the precompression range for which the consolidation was carried out in the direct shear machine itself, previous to running the shear test. Theoretically this does not lead one to expect any difference in the results : but it is just perhaps some of the 'finer points', that theory is forced to neglect, that may explain it. The plot of Water Content vs. log(shearing strength) does not show any discrepancy that might explain it.

Tests marked A and B were consolidated first to a pressure quite a bit higher than the $\bar{\sigma}_F$,although lower than the computed $\bar{\sigma}_1$. Test A for example was first consolidated to 120psi: then the normal load was released to 70.5psi just before starting the direct shear test. Now, for $\phi = 28^\circ$ and $\bar{\sigma}_F = 70.5$psi, $\bar{\sigma}_F = \bar{\sigma}_1(1-\sin\phi) \therefore \bar{\sigma}_1 = 133$psi, so theoretically this change of procedure should have made no difference. Similarly for Test B the sample was first consolidated to 60psi ; $\bar{\sigma}_1$ (computed) = 60psi. The effect of precompression perhaps may legitimately be expected to a small degree...

but not to such an extent that the result plots even higher than the 'average' curve drawn as the strength envelope in the range of that precompression effect. It is rather singular, further, that in both cases the result is somewhat higher than expected. A study of the readings of the vertical dial shows no appreciable compression or expansion of the sample near failure (0"0001 and 0"00015 compression in the period of about 3 hours between readings, in both cases) :so that no study of energy relations due to volume change is warranted. In all other direct shear tests just about the same compression existed at failure.

Finally Point 3 (representing Cylindrical Compressiom Test #3) deserves discussion. The point as plotted is already corrected as the author deemed most legitimate (Vide. Table 6C, Page 55). Of course this correction may have been too small or too big by a little.. but it's magnitude should be close to that indicated, amd minor variations in the assumptions will not brimg the point much closer to the expected value, anyway. The water content seems a little low, but that will not explain much. The author can think of several points, each of which may not explain away the whole difference, but all of which when considered together easily might:-

(1) Effect of the rubber. The rubber gasket was 0"025 thick instead of the customary 0"010 : and by the time the third test was well under way the area of the sample at the center was 12.2% bigger than the original area. This

excessive bulging, forcing the rubber to stretch, may have been responsible for part of the added strength.

(2) The development of the failure plane:- Quite early in the test (at about 7% strain) a disrinct failure plane started to develop cutting the plane of the pilot almost at rt. angles. As the test progressed, however, this failure plane did not develop, but others started to develop on planes more or less parallel to the plane of the pilot; and as the test was concluded there was no distinct failure plane, but a maze of little failure planes crossing each other in the middle portion of the cylinder (the portion that had bulged most). Perhaps if the pilot had not been there, the development of the first failure plane would have continued normally, and the shearing strength on this failure plane might have been less than the observed value, ... more nearly the true value.

The result of the first Cylindrical Compression Test does not indicate the existence of too much of the effect that might have been expected due to the 'two-year rest period' between the consolidation and the cylindrical compression test : the little added strength may be either due to that or due to any natural scattering.

Discussion of results in view of theoretical differences between Cylindrical Compression Tests and Direct Shear Tests.

(1) The fact that in cylindrical compression the failure

plane develops on the weakest plane, whereas in direct shear the failure plane is arbitrarily picked, and is therefore much more likely to give the average shearing strength : this is of no importance in these tests which use samples very carefully prepared with a view to perfect homogeneity .

(2) The effect $\bar{\sigma}_2$ (neglected in theory). In direct shear tests all that is known of $\bar{\sigma}_2$ values is that they fall somewhere between $\bar{\sigma}_1$ and $\bar{\sigma}_3$,. "It is generally believed, however, that the shearing strength may depend somewhat on $\bar{\sigma}_2$, being perhaps of the order of 10% greater when $\bar{\sigma}_2$ equals $\bar{\sigma}_1$ than it is when $\bar{\sigma}_2$ equals $\bar{\sigma}_3$. (Page 8. Supplement to Ninth Progress Report). It must be noted that no such difference is indicated in the series of tests undertaken : of course, no assertive conclusions can be made therefrom.

TABLE 1A

Counter revs.	Proving Ring	Pore u Press.	Chamber Press.	P.R. Load #	ΔL"	L"	Area sq.ins.
0	ins × 10^{-4} 1.0	psi 27.4	σ_3 30.0 psi	1.2	0	6.500	6.1625
10	5.2	28.3		6.0	0.0055	6.495	6.168
20	11.4	29.6		13.4	0.0141	6.486	6.175
30	16.3	30.0	?	19.2	0.0236	6.476	6.180
40	20.4	30.3		23.8	0.0334	6.467	6.190
50	23.8	30.7	↓	27.6	0.0443	6.456	6.200
60	26.6	30.5	31.0	30.9	0.0534	6.447	6.210
70	28.8	31.8		33.4	0.0634	6.437	6.22
80	31.0	31.3	?	36.0	0.0735	6.427	6.23
90	33.1	30.0	↓	38.3	0.0836	6.416	6.24
100	34.9	30.2	30.0	40.3	0.0938	6.406	6.245
120	39.8	30.3		45.8	0.1140	6.386	6.265
140	44.0	31.8		50.4	0.1343	6.366	6.28
160	48.3	30.7		55.2	0.1547	6.345	6.31
180	52.2	30.4	30.0	59.4	0.1750	6.325	6.33
200	56.1	29.8		63.6	0.1953	6.305	6.35
220	59.9	31.2		67.7	0.2157	6.284	6.37
240	63.2	30.0		71.5	0.2360	6.264	6.39
260	66.4	30.0		75.0	0.2566	6.243	6.415
280	69.5	29.1		78.6	0.2775	6.222	6.44
300	72.1	30.1		81.6	0.2975	6.202	6.45
20	74.8	29.7	30.0	84.7	0.3180	6.182	6.475
40	77.2	29.1		87.6	0.3385	6.162	6.50
60	79.2	28.3		89.8	0.3590	6.141	6.525
80	81.0	30.0		91.9	0.3795	6.120	6.545
400	82.8	28.9	30.0	93.8	0.4007	6.099	6.565
20	84.1	28.5		95.3	0.4210	6.079	6.585
40	85.8	27.8		97.2	0.4412	6.059	6.605
60	87.2	29.1		98.8	0.4615	6.039	6.630
80	88.5	27.1		100.2	0.482	6.018	6.65
500	89.6	26.3		101.4	0.503	5.997	6.675
20	90.5	25.9	30.0	102.3	0.524	5.976	6.70
40	91.1	27.0		103.1	0.5445	5.956	6.72
60	92.4	26.3		104.4	0.565	5.935	6.75
80	93.0	25.7		105.2	0.5855	5.915	6.765
600	93.6	25.1		105.9	0.606	5.894	6.80
20	94.4	26.3		106.7	0.627	5.873	6.815
40	95.2	24.9		107.7	0.648	5.852	6.84
60	95.3	24.9	30.0	107.8	0.669	5.831	6.86
80	95.4	24.1		107.9	0.690	5.810	6.88

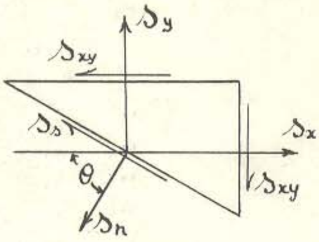
Time for 680 revs.= 16 mins ∴ 80 revs.(1.28% strain) in 1.88mins.

Speed of compressive strain=0.68% per min.
To reduce shearing strenght to speed of strain of 0.365% per min.
use proprotion 48.65 → 47.7 ....

TABLE 1B

Strain %	$\sigma_1 - \sigma_3$ psi	σ_1 psi	$\bar{\sigma}_1$ psi	$\bar{\sigma}_3$ psi	$\bar{\sigma}_1/\bar{\sigma}_3$	u^*	$\bar{\sigma}_1^*$	$\bar{\sigma}_3^*$
0	0	30.0	2.6	2.6	1.0	27.4	2.6	2.6
0.085	0.98	31.15	2.9	1.9	1.53			
0.216	2.17	32.50	2.9	0.7	4.14	29.4	3.1	0.9
0.363	3.10	33.60	3.6	0.5	7.20			
0.514	3.86	34.53	4.2	0.4	10.50	30.5	4.0	0.2
0.682	4.45	35.28	4.6	0.1	46.0			
0.821	4.97	35.97	5.5	0.5	11.0	30.9	5.1	0.1
0.975	5.37	36.12	4.3	-1.0	-4.3			
1.130	5.77	36.27	5.0	-0.8	-6.25	30.9	5.4	-0.4
1.287	6.14	36.39	6.4	0.3	21.3			
1.442	6.45	36.45	6.3	-0.2	-31.5	30.8	5.65	-0.8
1.754	7.30	37.30	7.0	-0.3	-23.3			
2.068	8.01	38.01	6.2	-1.8	-3.45	30.65	7.35	-0.65
2.380	8.74	38.74	8.0	-0.7	-11.41			
2.692	9.37	39.37	9.0	-0.4	-22.5	30.5	8.4	-0.5
30005	10.00	40.00	10.2	0.2	51.0			
3.32	10.62	40.62	9.4	-1.2	-7.83	30.3	10.3	-0.3
3.63	11.20	41.20	11.2	0	∞			
3.945	11.70	41.70	11.7	0	∞	30.0	11.7	0
4.27	12.20	42.20	13.1	0.9	14.57			
4.575	12.65	42.65	12.6	-0.1	-126	2955	13.1	0.45
4.895	13.1	43.1	13.4	0.3	44.67			
5.21	13.5	43.5	14.4	0.9	16.0	29.25	14.25	0.75
5.525	13.8	43.8	15.5	1.7	9.12			
5.84	14.05	44.05	14.1	0	∞	28.85	15.2	1.15
6.16	14.35	44.35	15.5	1.1	14.1			
6.485	14.6	44.6	16.1	1.5	10.73	28.35	15.25	1.65
6.795	14.8	44.8	17.0	2.2	7.73			
7.10	14.95	44.95	15.9	0.9	17.68	27.75	17.2	2.25
7.42	15.08	45.08	18.0	2.9	6.2			
7.745	15.2	45.2	18.9	3.7	5.11	27.0	18.2	3.0
8.06	15.29	45.29	19.4	4.1	4.73			
8.375	15.35	45.35	18.4	3.0	6.13	26.5	18.85	3.5
8.70	15.47	45.47	19.2	3.7	5.19			
9.01	15.55	45.55	19.8	4.3	4.60	25.8	19.75	4.2
9.33	15.58	45.58	20.5	4.9	4.18			
9.65	15.64	45.64	19.3	3.7	5.22	25.25	20.4	4.75
9.96	15.75	45.75	20.9	5.1	4.10			
10.29	15.70	45.70	20.8	5.1	4.08	24.55	21.15	5.45
10.61	15.65	45.65	21.5	5.9	3.64	24.1	21.55	5.9

* values obtained by use of best interpolated u curve.
ΔL and P.R.Load values obtained from calibration curves.
A figured on the basis of constant volume , average area over entire length.



$$s_n = \frac{s_x + s_y}{2} + \frac{s_x - s_y}{2}\cos 2\theta - s_{xy}\sin 2\theta$$

$$s_s = \frac{s_x - s_y}{2}\sin 2\theta + s_{xy}\cos 2\theta$$

which reduce to

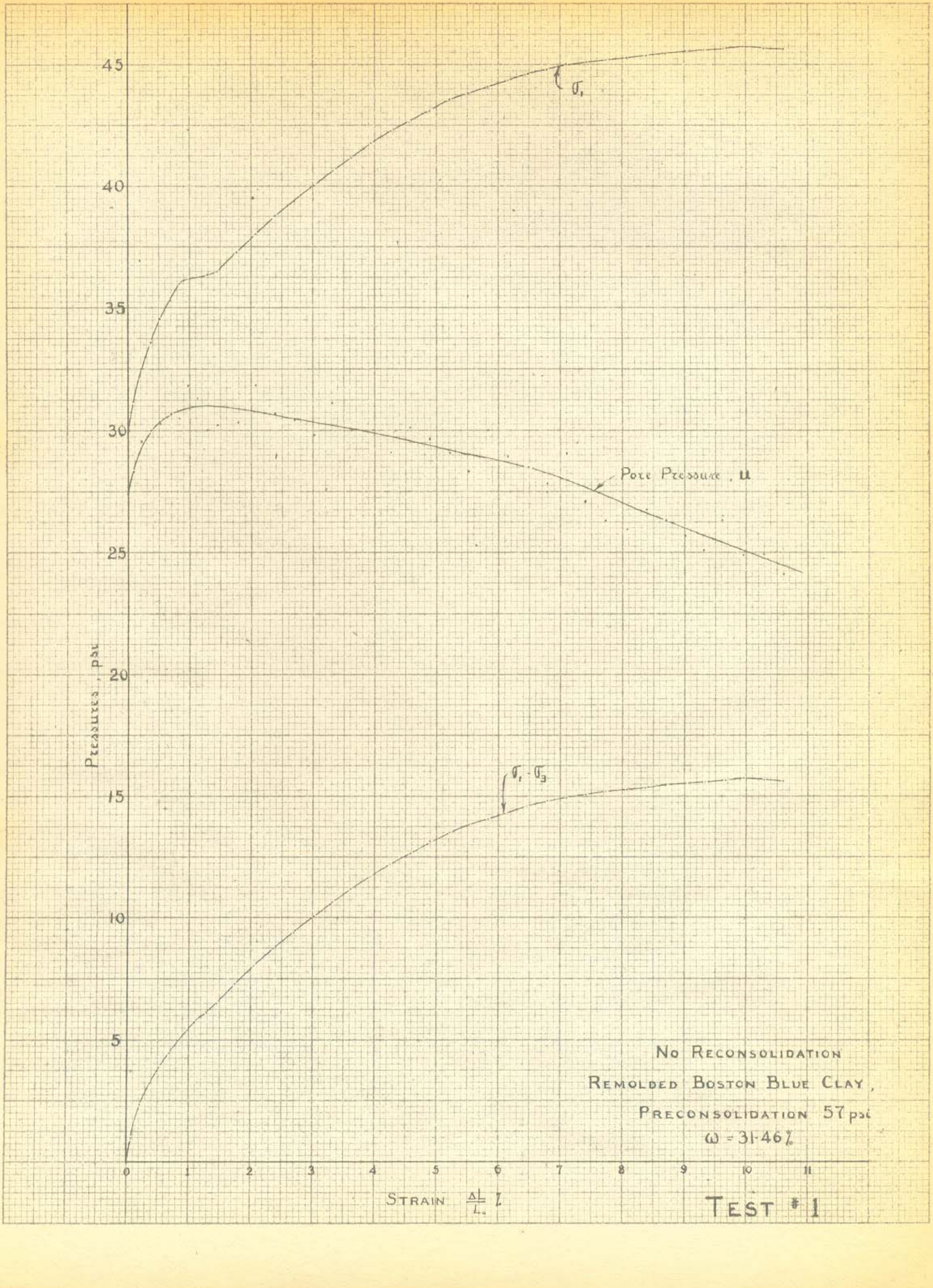
$$\bar{\sigma}_\theta = \frac{\bar{\sigma}_1 + \bar{\sigma}_3}{2} + \frac{\bar{\sigma}_1 - \bar{\sigma}_3}{2}\cos 2\theta$$

$$\tau_\theta = \frac{\bar{\sigma}_1 - \bar{\sigma}_3}{2}\sin 2\theta$$

TABLE 1C

STRAIN	$\frac{\bar{\sigma}_1 + \bar{\sigma}_3}{2}$	τ_θ	$\bar{\sigma}_\theta$	τ_θ	$\bar{\sigma}_\theta$
		ON 60° PLANE		ON 64° PLANE	
		$\cos 2\theta = -0.500$; $\sin 2\theta = +0.866$		$\cos 2\theta = -0.614$; $\sin 2\theta = +0.787$	
0	2.6	0	2.6	0	2.6
0.216	2.0	0.95	1.45	0.86	1.33
0.514	2.1	1.65	1.15	1.50	0.93
0.821	2.6	2.16	1.35	1.97	1.06
1.130	2.5	2.51	1.05	2.28	0.72
1.442	2.42	2.79	0.81	2.54	0.44
2.068	3.35	3.46	1.35	3.15	0.89
2.692	3.95	3.85	1.73	3.50	1.21
3.320	5.00	4.59	2.35	4.17	1.74
3.945	5.85	5.07	2.92	4.60	2.25
4.575	6.77	5.47	3.61	4.98	2.88
5.210	7.50	5.85	4.12	5.31	3.35
5.840	8.17	6.07	4.66	5.53	3.85
6.485	8.45	5.89	5.05	5.35	4.27
7.100	9.72	6.50	5.98	5.88	5.12
7.745	10.60	6.58	6.80	5.98	5.93
8.375	11.17	6.64	7.34	6.04	6.45
9.010	11.97	6.73	8.09	6.12	7.19
9.65	12.57	6.77	8.66	6.16	7.76
10.29	13.30	6.80	9.38	6.18	8.47
10.61	13.72	6.77	9.81	6.16	8.90

using values of U picked from best interpolated curve

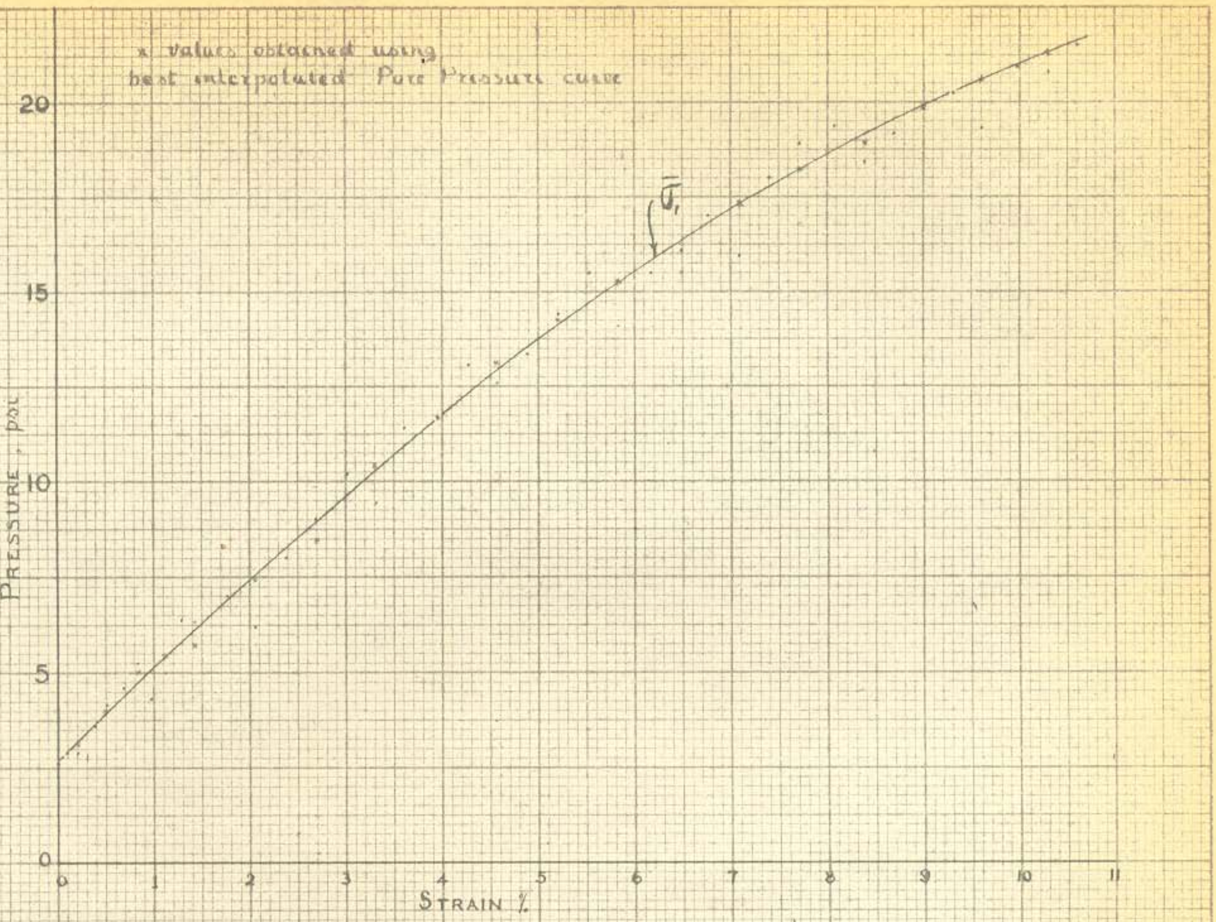


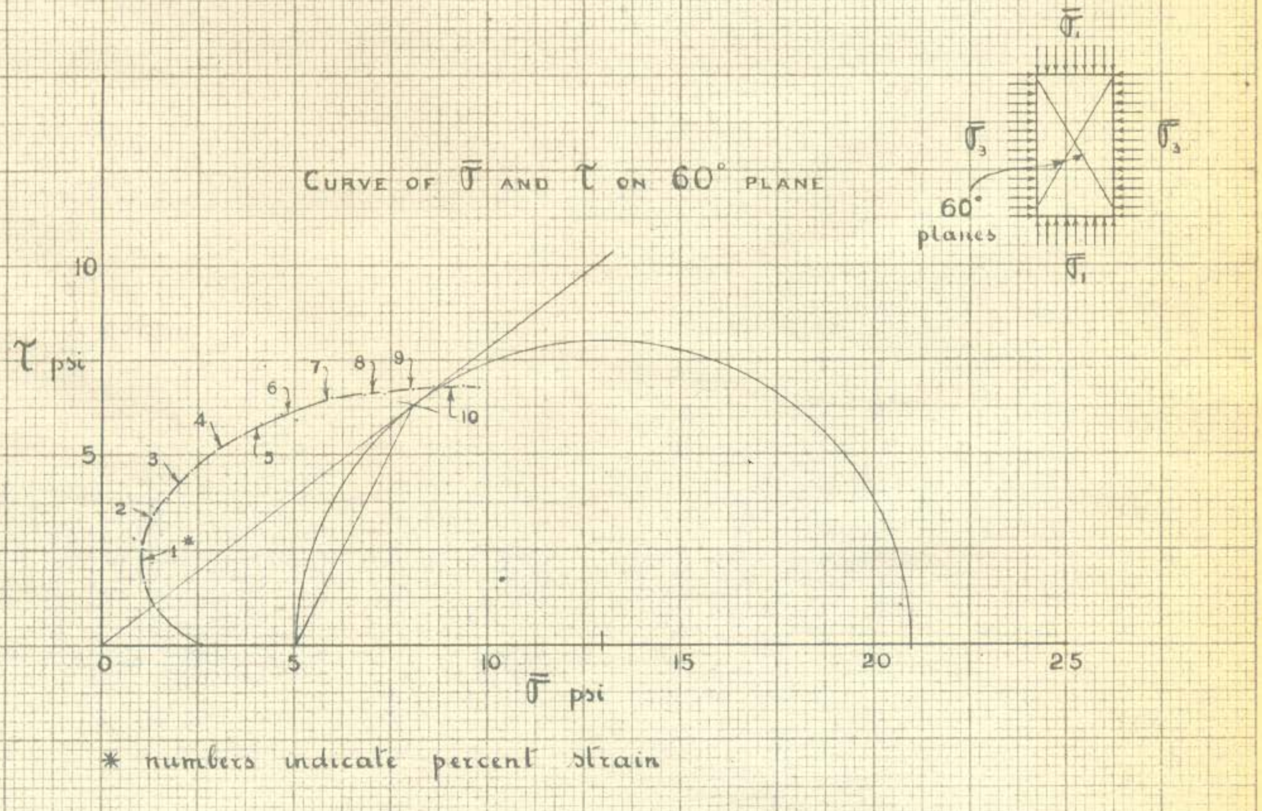
NO RECONSOLIDATION
REMOLDED BOSTON BLUE CLAY,
PRECONSOLIDATION 57 psi
$\omega = 31.46\%$

TEST #1

FORM 2T TECHNOLOGY STORE, H. C. S. 40 MASS. AVE., CAMBRIDGE, MASS.

80 MASS. AVE., CAMBRIDGE, MASS.
TECHNOLOGY STORE, H. C. S.
FORM 21





* numbers indicate percent strain

TEST #1

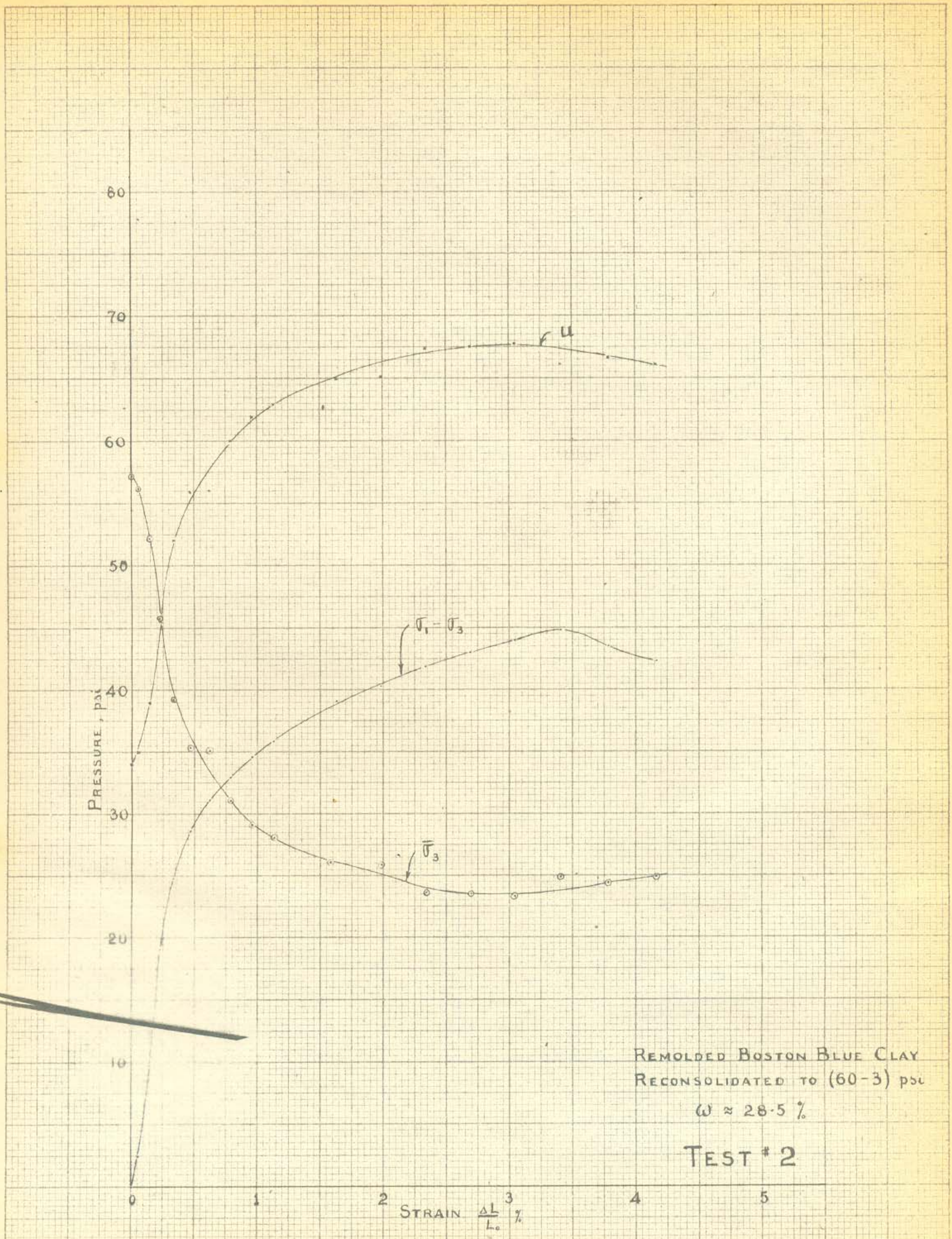
TABLE 2

Counter revs.	Proving Ring	Pore Press. u	Chamber Press.	P.R. Load #	ΔL"	L"	Area sq. ins.
0	ins × 10^{-4} 1.6	34.0 psi	σ_3 91.2 psi	1.9	0	5.640	6.700
10	14.1	35.0		16.6	0.00322	5.637	6.703
20	58.0	39.0		65.8	0.00797	5.632	6.708
30	112.2	45.5		127.7	0.01204	5.628	6.71
40	146.0	52.0		166.4	0.01862	5.622	6.715
50	168.1	55.8	91.1	192.2	0.0263	5.614	6.72
60	182.2	56.0		209.0	0.0352	5.605	6.74
70	194.1	60.0		222.4	0.0443	5.596	6.75
80	204.1	61.9	91.0	233.8	0.0539	5.586	6.76
90	212.0	62.9		243	0.0629	5.577	6.77
120	232.2	64.9		266.2	0.0921	5.548	6.805
140	239.8	65.1	91.0	275.2	0.1120	5.528	6.835
160	250.5	67.4		287.4	0.1318	5.508	6.853
180	258.3	67.5		296	0.1518	5.488	6.89
200	265.0	67.7		303.8	0.1719	5.468	6.90
220	271.1	66.1		310.6	0.1920	5.448	6.93
240	264.0	66.6		302.6	0.2135	5.426	6.96
260	258.0	66.1	91.0	295.8	0.2350	5.405	6.99

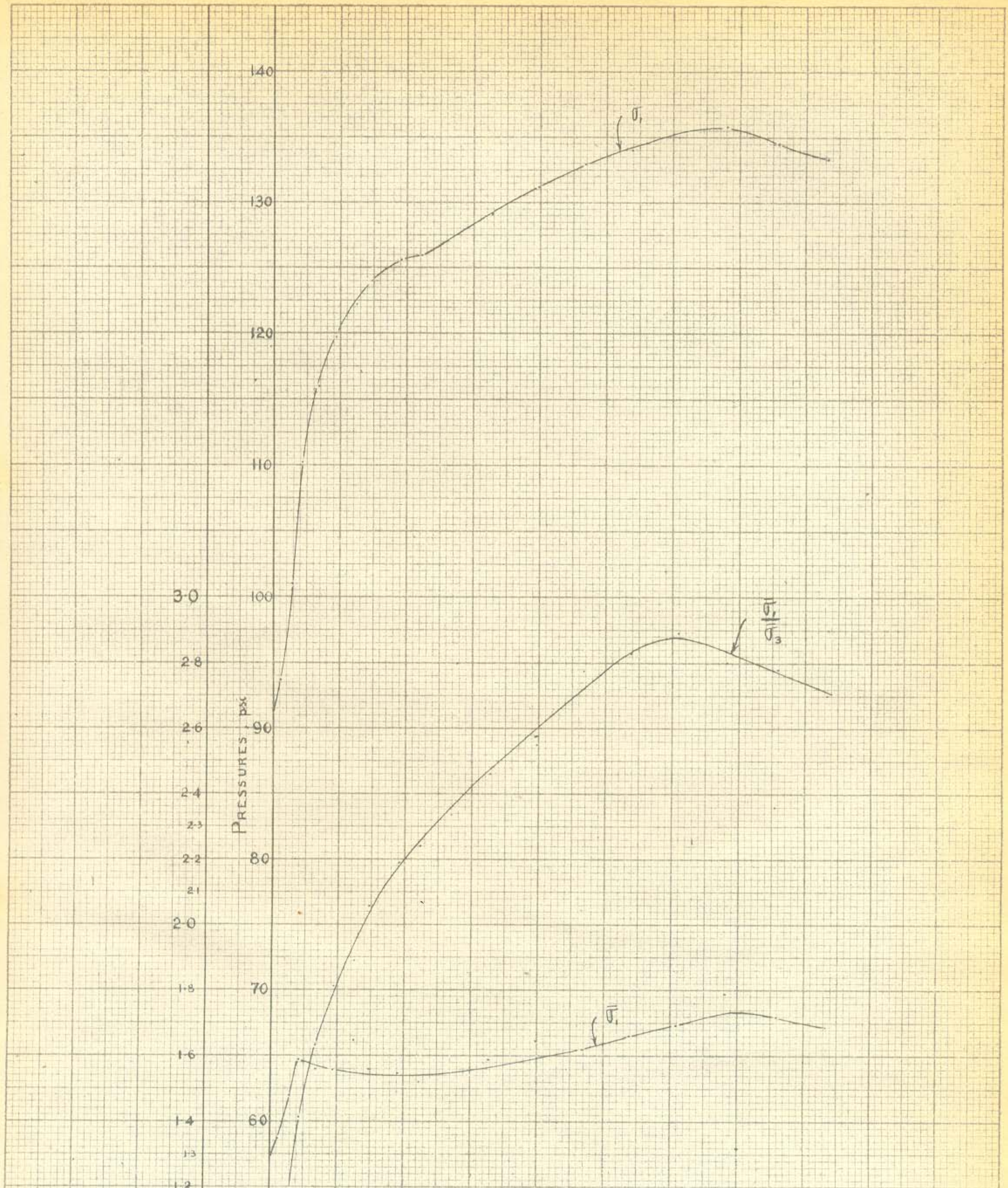
Counter revs.	Strain %	$\sigma_1 - \sigma_3$ psi	σ_1 psi	$\bar{\sigma}_1$ psi	$\bar{\sigma}_3$ psi	$\bar{\sigma}_1/\bar{\sigma}_3$
0	0	0.284	91.4	57.4	57.2	1.000
10	0.057	2.475	93.7	58.7	56.2	1.045
20	0.141	9.805	101.0	62.0	52.2	1.188
30	0.213	19.02	110.2	64.7	45.7	1.416
40	0.330	24.78	116.0	64.0	39.2	1.632
50	0.466	28.60	119.7	63.9	35.3	1.810
60	0.624	31.05	122.2	66.2	35.1	1.887
70	0.785	32.95	124.0	64.0	31.1	2.058
80	0.955	34.58	125.6	63.7	29.1	2.19
90	1.114	35.9	125.9	63.0	28.1	2.24
120	1.632	39.1	129.1	64.2	26.1	2.46
140	1.985	40.25	131.2	66.1	25.9	2.55
160	2.335	41.9	132.9	65.5	23.6	2.775
180	2.690	43.0	134.0	66.5	23.5	2.83
200	3.045	44.0	135.0	67.3	23.3	2.89
220	3.405	44.8	135.8	69.7	24.9	2.80
240	3.785	43.5	134.5	67.9	24.4	2.78
260	4.165	42.3	133.3	67.2	24.9	2.70

200 revs. of counter in 10 mins.
∴ 60 revs. (1.095 % strain) in 3 mins.
∴ rate of axial strain 0.365 % per min.
This speed is taken as the base to which all others are reduced.

40 MASS. AVE., CAMBRIDGE, MASS.
TECHNOLOGY STORE, H. C. S.
FORM 27



80 MASS. AVE., CAMBRIDGE, MASS.
TECHNOLOGY STORE, H. C. S.
FORM 2 T



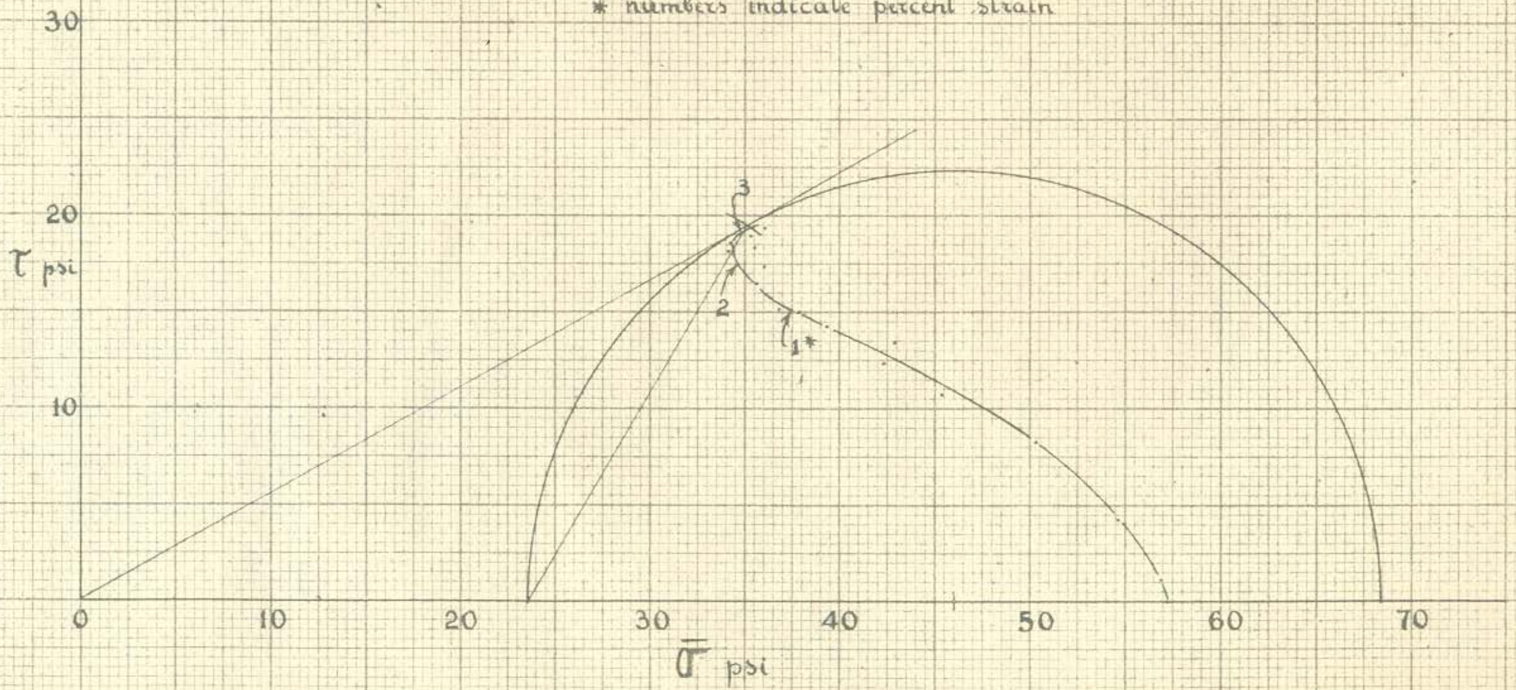
TEST # 2

FORM 2T TECHNOLOGY STORE, H. C. S. 40 MASS. AVE., CAMBRIDGE, MASS.

MOHR DIAGRAM (USING BEST INTERPOLATED U VALUE)

CURVE OF $\bar{\sigma}$ AND τ ON 60° PLANE

* numbers indicate percent strain



TEST #2

TABLE 3A

Counter revs.	Proving Ring	Pore u Press.	Chamber Press.	P.R. Load #	ΔL"	L"	Area sq.ins.
	ins $\times 10^{-4}$	psi					
0	1.5	13.1	σ_3 130 psi	0	0	5.75	6.28
10	21.0	13.2	128	23.5	0.0021	5.75	6.28
20	40.7	13.5		46	0.0099	5.74	6.29
30	52.1	16.8	130	59.1	0.0190	5.73	6.30
40	81.2	20.8		92.3	0.0270	5.72	6.31
50	132	25.9	128.7	151.4	0.0306	5.72	6.31
60	200	34.7		229	0.0333	5.72	6.31
70	255.2	44.1		289	0.0376	5.71	6.325
80	297.8	53.5	129	335.5	0.0436	5.71	6.325
90	329.1	58.8	127.5	369.7	0.0506	5.70	6.34
100	352.0	63.9	128.4	394.5	0.0586	5.69	6.35
20	381.5	74.1	130	427.7	0.0762	5.67	6.365
40	407	77.3	128.4	456	0.0944	5.66	6.375
60	421.3	82.8	128.5	472.5	0.1136	5.64	6.405
80	445	82.8	128	498	0.1319	5.62	6.425
200	462.1	87.8	130	516.3	0.1509	5.60	6.45
20	488.8	86.3	128.2	545.4	0.1689	5.58	6.47
40	492.8	88.3	128.5	549.9	0.1891	5.56	6.49
60	506.1	87.0	128.5	564.3	0.2085	5.54	6.52
80	519.5	90.5	130	577.5	0.228	5.52	6.545
300	531.7	87.5	128	590.2	0.2475	5.50	6.57
20	542	89.0	129	600.8	0.267	5.48	6.59
40	552.1	86.5	127.4	612.3	0.2867	5.46	6.61
60	561.1	89.2	130	622.2	0.3065	5.44	6.645
80	570	86.1	128	631.2	0.3265	5.42	6.665
400	578.4	87.3	128.5	640.1	0,3462	5.40	6.69
20	585.1	83.9	127.3	647.2	0.3665	5.38	6.71
40	592.2	86.5	130	655	0.3865	5.36	6.735
60	598.3	83.3	128	661.4	0.4065	5.34	6.765
80	603	84.5	128.8	666.5	0.427	5.32	6.79
500	607.5	81 ?	127.8	671.6	0.447	5.30	6.815
20	610.8	84.1	130	675	0.4675	5.28	6.84
40	613.3	80.1	128	678	0.488	5.26	6.865
60	612.9	80.8	128.4	680.7	0.508	5.24	6.895
80	618	77.8	127.2	682.9	0.529	5.22	6.925
600	620.1	81.0	130	685	0.5495	5.20	6.950
20	621.2	77.5	128.2	686.2	0.570	5.18	6.975
40	621.5	79.1	129.5	686.5	0.591	5.16	7.00
60	621.7	76.4	127.4	686.7	0.612	5.14	7.025
80	621.3	79.7	130.5	686.3	0.633	5.12	7.055
700	621.2	77.0	128.3	686.2	0.654	5.10	7.08
20	620.5	79.0	129.1	685.5	0.675	5.08	7.105
40	620	77.4	127.4	684.8	0.696	5.05	7.15

continued

TABLE 3A

Counter revs.	Proving Ring ins x 10^{-4}	Pore u Press. psi	Chamber Press.	P.R. Load #	ΔL"	L"	Area sq.ins.
740	620	77.4	σ_3 127.4 psi	684.8	0.696	5.05	7.15
60	621.4	80.7	130	686.4	0.717	5.03	7.175
80	624.4	78.2	128	689.2	0.7375	5.01	7.20
800	627.3	80.2	129.2	692.3	0.7575	4.99	7.24
20	629.6	77 ?	127.5	694.6	0.778	4.97	7.265
40	632.8	80.9	130	697.8	0.799	4.95	7.30
60	636.2	78.7	128.2	701.3	0.8195	4.93	7.325
80	638.6	80.1	129	704	0.840	4.91	7.35
900	640.9	77.5	127	706.5	0.860	4.89	7.39
20	643.6	80.6	130.4	709.4	0.8805	4.87	7.42
40	645.9	78.0	128	711	0.901	4.85	7.45
60	648.4	79.7	129	714.8	0.922	4.83	7.475
80	651	77.8	127.2	717.7	0.942	4.81	7.505
1000	653.1	82.0	130	720	0.963	4.79	7.54
20	---						
40	658.3	80.0	129	726	1.003	4.75	7.60
60	660.2	77.8	127.1	728	1.023	4.73	7.63
80	661.8	80.6	130	729.8	1.043	4.71	7.66
1100	663	79.0	128	731	1.064	4.69	7.70

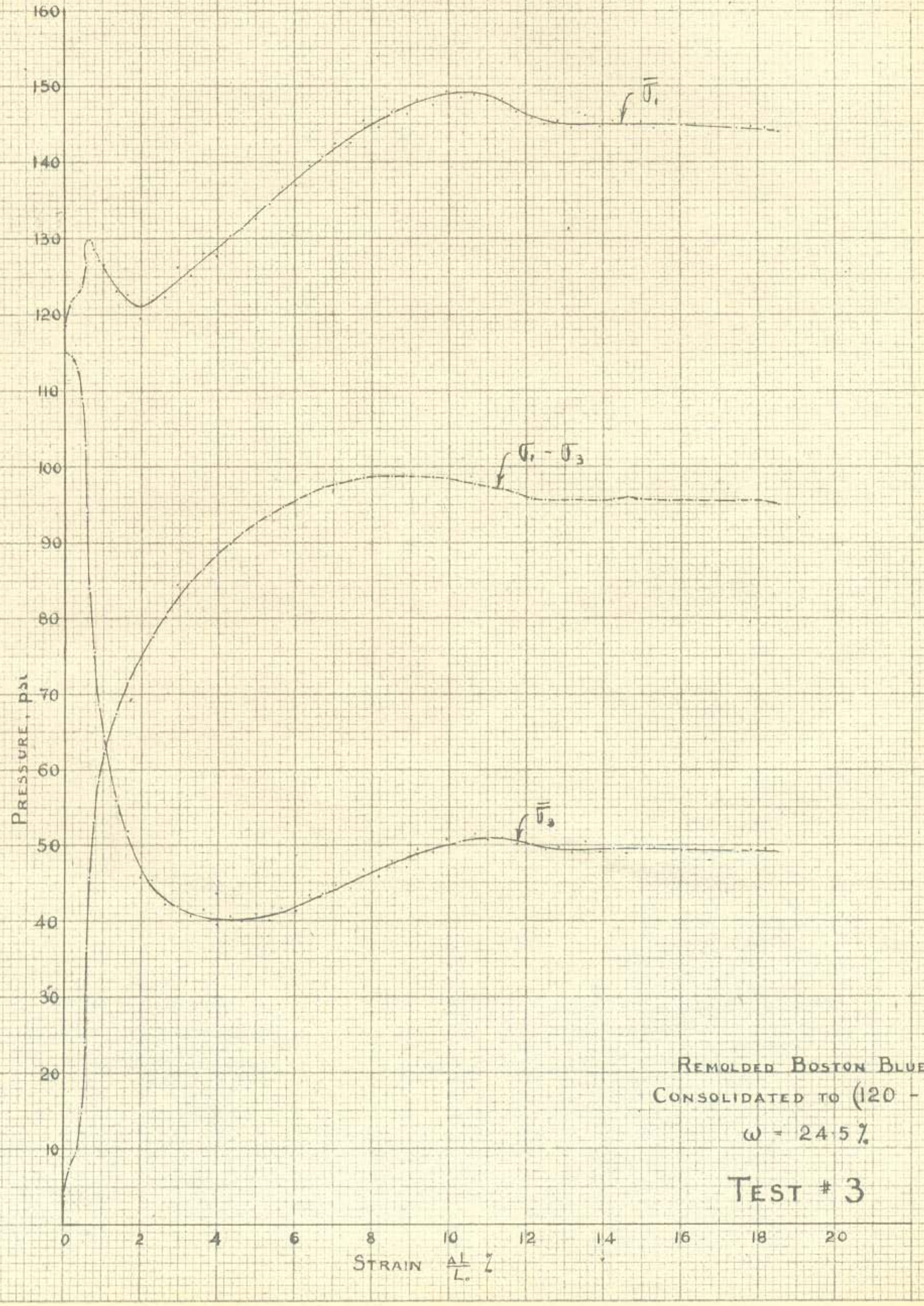
TABLE 3B

Counter revs.	Strain %	$\sigma_1 - \sigma_3$ psi	σ_1 psi	$\bar{\sigma}_1$ psi	$\bar{\sigma}_3$ psi	$\bar{\sigma}_1 / \bar{\sigma}_3$
0	0	0	130	117	117	1.00
10	0.036	3.74	131.7	118.5	115	1.03
20	0.172	7.32	135.3	121.8	114.5	1.063
30	0.33	9.58	139.4	122.6	113.0	1.084
40	0.47	14.61	144.6	123.8	109	1.135
50	0.533	24.0	152.7	126.8	102.8	1.232
60	0.58	36.3	164.4	129.7	94	1.378
70	0.655	45.7	173.8	129.7	84	1.543
80	0.76	53.0	182	128.5	75.5	1.702
90	0.88	58.4	185.9	127.1	68.7	1.85
100	1.02	62.1	190.5	126.6	64.5	1.963
20	1.325	67.2	197.2	123.1	55.9	2.2
40	1.64	71.5	199.9	122.6	51.9	2.36
60	1.975	73.8	202.3	119.5	45.7	2.615
80	2.29	77.5	205.5	122.7	45.2	2.715
200	2.625	80.1	210.1	122.3	42.1	2.905
20	2.94	84.3	212.5	126.2	41.9	3.01
40	3.29	84.9	213.4	125.1	40.3	3.10
60	3.63	86.5	215.0	128	41.5	3.085
80	3.97	88.2	218.2	127.7	39.5	3.23

TABLE 3B

Counter revs.	Strain %	$\sigma_1 - \sigma_3$ psi	σ_1 psi	$\bar{\sigma}_1$ psi	$\bar{\sigma}_3$ psi	$\bar{\sigma}_1/\bar{\sigma}_3$
80	3.97	88.2	218.2	127.7	39.5	3.23
300	4.3	89.8	217.8	130.3	40.5	3.22
20	4.65	91.25	220.2	131.2	40	3.28
40	4.99	92.6	220	132.5	40.9	3.24
60	5.34	93.6	223.6	134.4	40	3.36
80	5.68	94.7	222.7	136.6	41.7	3.28
400	6.03	95.7	224.2	136.9	41.2	3.325
20	6.38	96.4	223.4	139.5	43.4	3.22
40	6.72	97.3	227.3	140.8	43.5	3.24
60	7.08	97.7	225.7	142.4	44.7	3.19
80	7.43	98.25	227	142.5	44.3	3.22
500	7.78	98.5	226.3	145.3	46.8	3.105
20	8.14	98.7	228.7	144.6	45.9	3.15
40	8.50	98.7	226.7	146.6	47.9	3.06
60	8.84	98.7	227.1	146.3	47.1	3.11
80	9.20	98.7	225.9	148.1	49.4	3.00
600	9.55	98.6	228.6	147.6	49	3.01
20	9.91	98.5	226.7	149.2	50.7	2.945
40	10.29	98.1	227.6	148.5	50.4	2.95
60	10.64	97.8	225.2	148.8	51.4	2.895
80	11.00	97.3	227.8	148.1	50.8	2.915
700	11.37	97.0	225.3	148.3	51	2.91
20	11.73	96.5	225.6	146.6	50.1	2.925
40	12.11	95.8	223.2	145.8	50.1	2.91
60	12.48	95.7	225.7	145.0	49.3	2.94
80	12.81	95.6	223.6	145.4	49.8	2.92
800	13.18	95.6	224.8	144.6	49	2.95
20	13.52	95.6	223.1	146.1	50.5	2.90
40	13.9	95.6	225.6	144.6	49.1	2.95
60	14.25	95.8	224.0	145.3	49.5	2.94
80	14.6	96.0	225.0	144.9	48.9	2.96
900	14.96	95.7	222.7	145.2	49.5	2.935
20	15.31	95.6	226	144.4	49.8	2.90
40	15.68	95.5	223.5	145.5	50	2.91
60	16.02	95.6	224.6	144.9	49.3	2.94
80	16.39	95.6	222.8	145.0	49.4	2.935
1000	16.74	95.5	225.5	143.5	48	2.99
20...						
40	17.47	95.5	224.5	144.5	49.0	2.95
60	17.80	95.5	222.6	144.8	49.3	2.935
80	18.15	95.3	225.3	144.7	49.4	2.93
1100	18.51	95.0	223	144	49	2.94

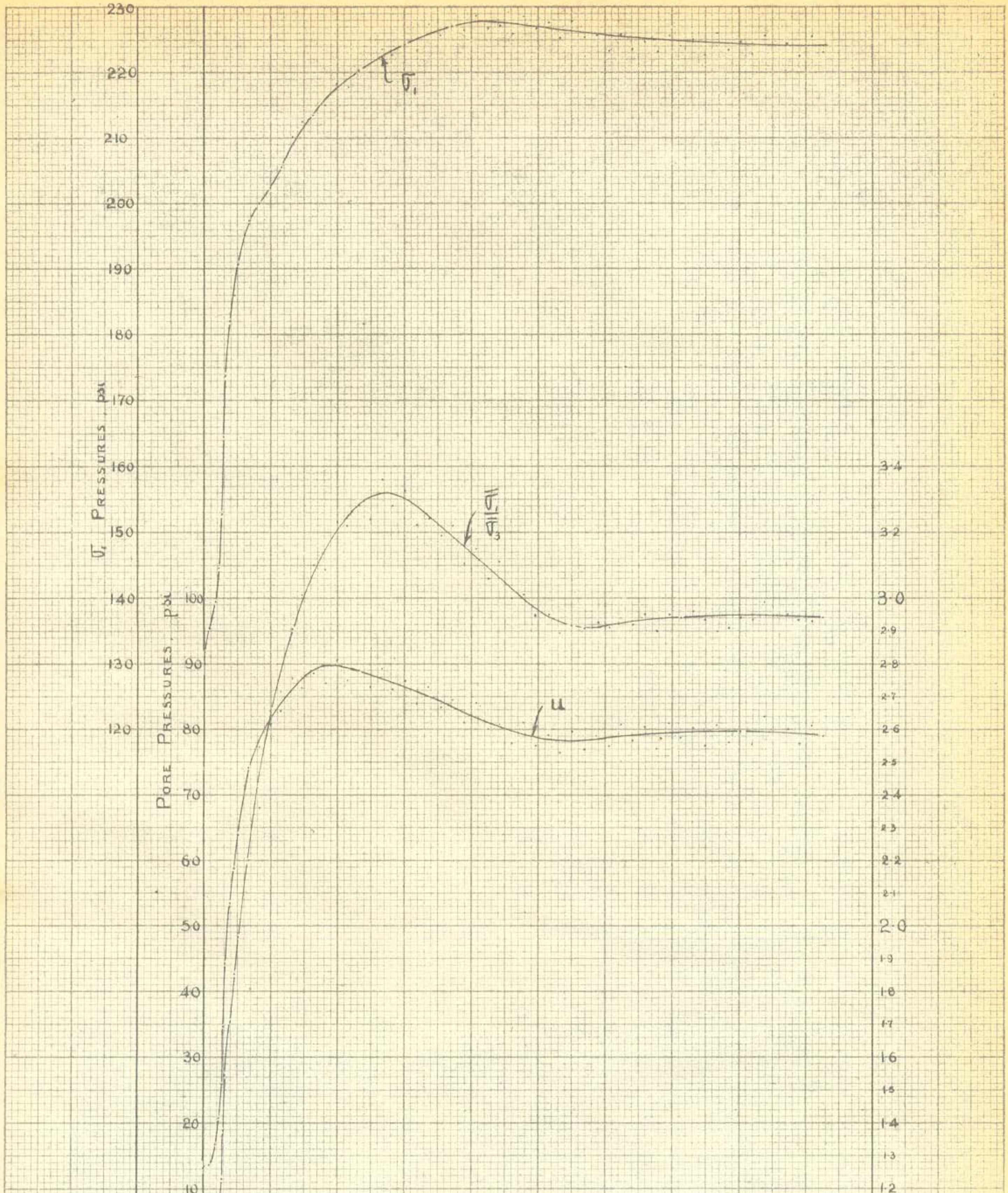
1.065 % strain in 60 revs. , in 3 mins.
∴ speed of axial strain = 0.355 % per min.
negligible correction for speed.



Remolded Boston Blue Clay
Consolidated to (120 - 1·7) psi
ω = 24·5 %

Test # 3

80 MASS. AVE., CAMBRIDGE, MASS.
TECHNOLOGY STORE, H. C. S.
FORM 2 T



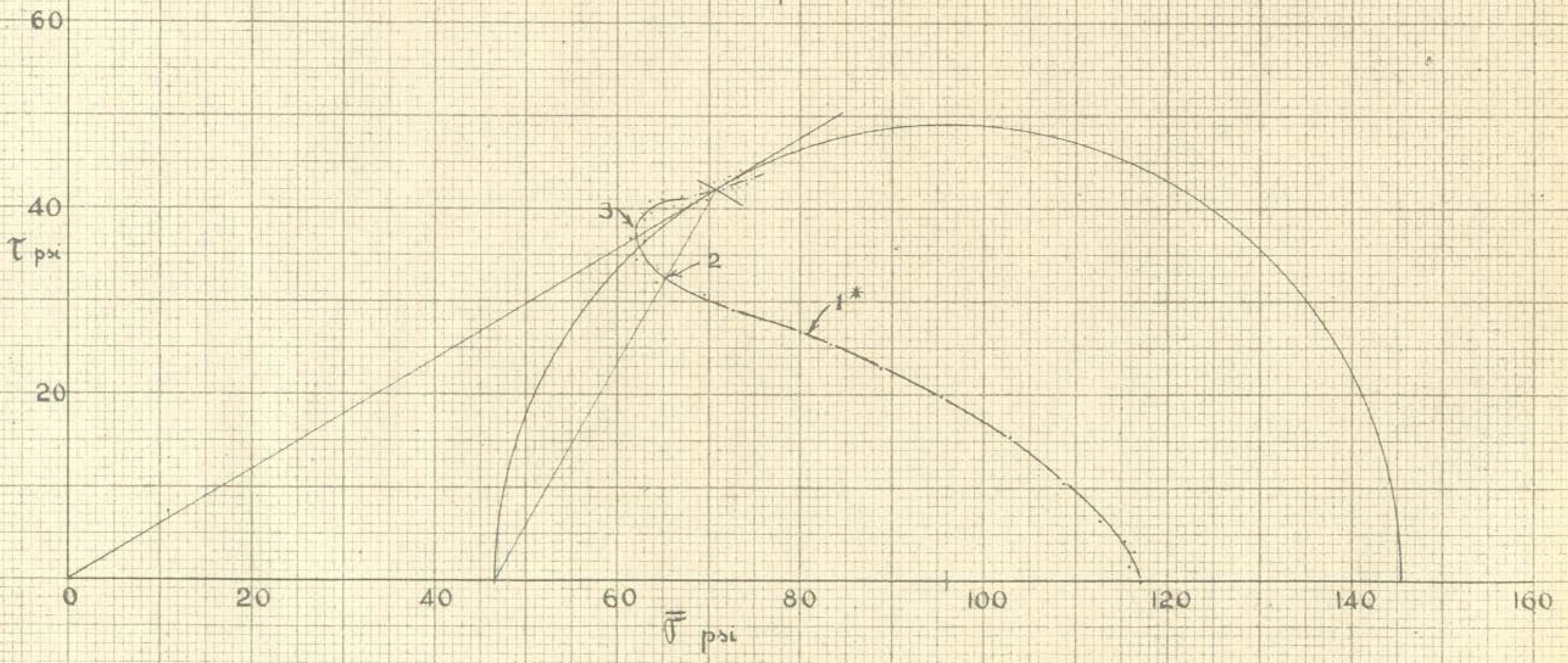
40 MASS. AVE., CAMBRIDGE, MASS.
TECHNOLOGY STORE, H. C. S.
FORM 2 T

FORM 2-T TECHNOLOGY STORE, H. C. S. 40 MASS. AVE., CAMBRIDGE, MASS.

MOHR DIAGRAM

CURVE OF $\bar{\sigma}$ AND τ ON 60° PLANE

* numbers indicate percent strain



TEST #3

TABLE 4

Time	Horiz. Dial	Vert. Dial	Proving Ring	P.R. Load #	τ psi	Strain %	Rate of Strain % per min
(motor at full speed ; 1:150 additional gear ratio)							
1/10p.m.	0	955	0	0	0		
1/42	1.8	958	60	30	3.33	0.06	0.00188
1/47.5	3.0	959	68.5	34.2	3.80	0.10	0.00690
2/00	6.1	961	81.7	40.8	4.54	0.203	0.00845
2/37	21.0	966	106	52.4	5.82	0.700	0.01342
3/00	31.5	964	111.5	55.0	6.11	1.050	0.01522
3/35	49.3	962	118.1	58.1	6.46	1.643	0.01695
4/00	61.2	952	122.2	60.1	6.68	2.040	0.01589
5/36	115.0	920	134.0	65.8	7.31	3.833	0.01869
(motor at lowest speed ; 1:150 additional gear ratio)							
5/37	115.6						
7/49	173.3	885	141.8	69.7	7.75	5.777	0.01458
(motor at full speed ; 1:150 25 additional gear ratio)							
7/52.5	174.8						
8/00	175.5	883	135.0	66.3	7.37	5.850	0.00307
10/59p.m.	178.8	879	138.7	68.1	7.57	5.960	0.000615

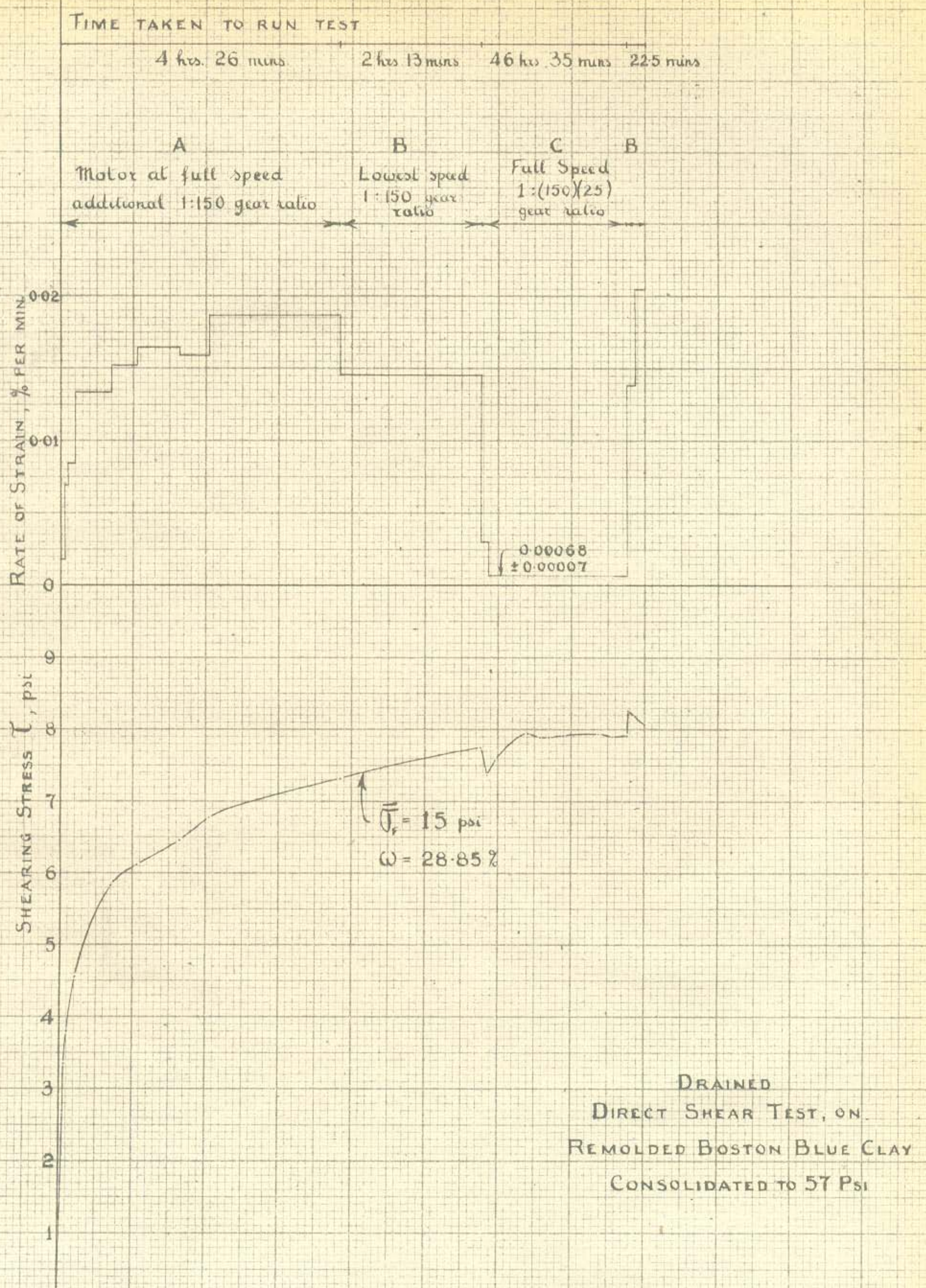
9/16a.m.	192.3	872	145.2	71.4	7.93	6.410	0.000729
12/48p.m.	197.2	867	144.5	71.0	7.89	6.573	0.000769
4/05	200.9	866	144.5	71.0	7.89	6.697	0.000625
9/02	206.8	863	145.0	71.2	7.91	6.893	0.000663

9/12a.m.	221.6	857	145.2	71.4	7.93	7.387	0.000675
1/09p.m.	226.8	854	144.8	71.1	7.90	7.560	0.000730
6/24	232.8	852	145.0	71.2	7.91	7.760	0.000635
(motor at lowest speed ; 1:150 additional gear ratio)							
6/33	233.1		151.0	74.3	8.26		
6/40	236.0	851	149.5	73.6	8.18	7.867	0.01385
6/46.5	240.0	850	147.5	72.5	8.06	8.000	0.02048

P.R.Load obtained by use of calibration curve for the proving ring.

τ psi based on assumption of constant cross-sectional area (9 sq.ins.)

Rate of strain computed as average between any two successive sets of readings. This becomes necessary because the motor unfortunately does not keep at constant speed, although supposed to.



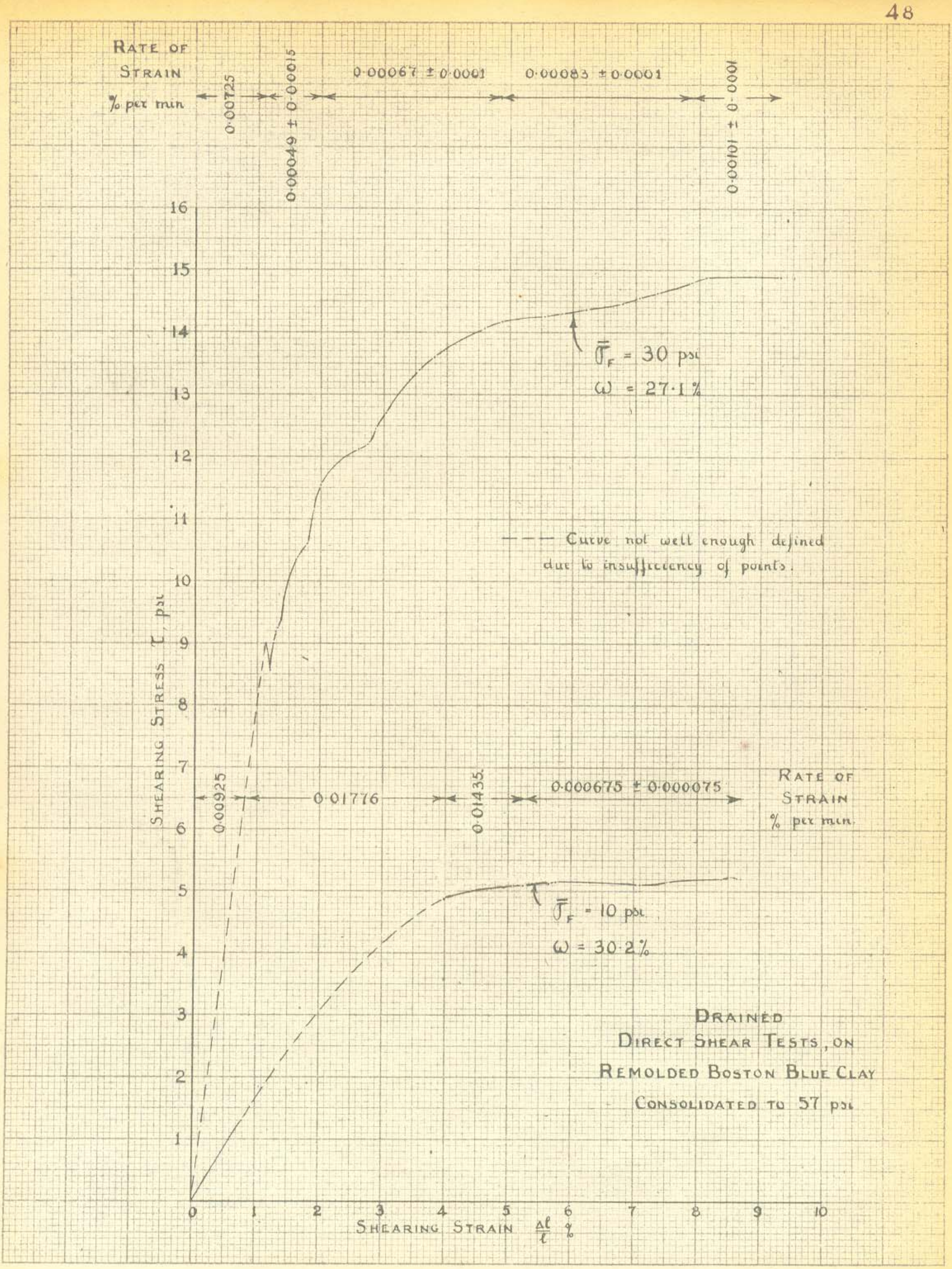
DRAINED
DIRECT SHEAR TEST, ON
REMOLDED BOSTON BLUE CLAY
CONSOLIDATED TO 57 PSI

FORM 2 T TECHNOLOGY STORE, H. C. S. 40 MASS. AVE., CAMBRIDGE, MASS.

TABLE 5

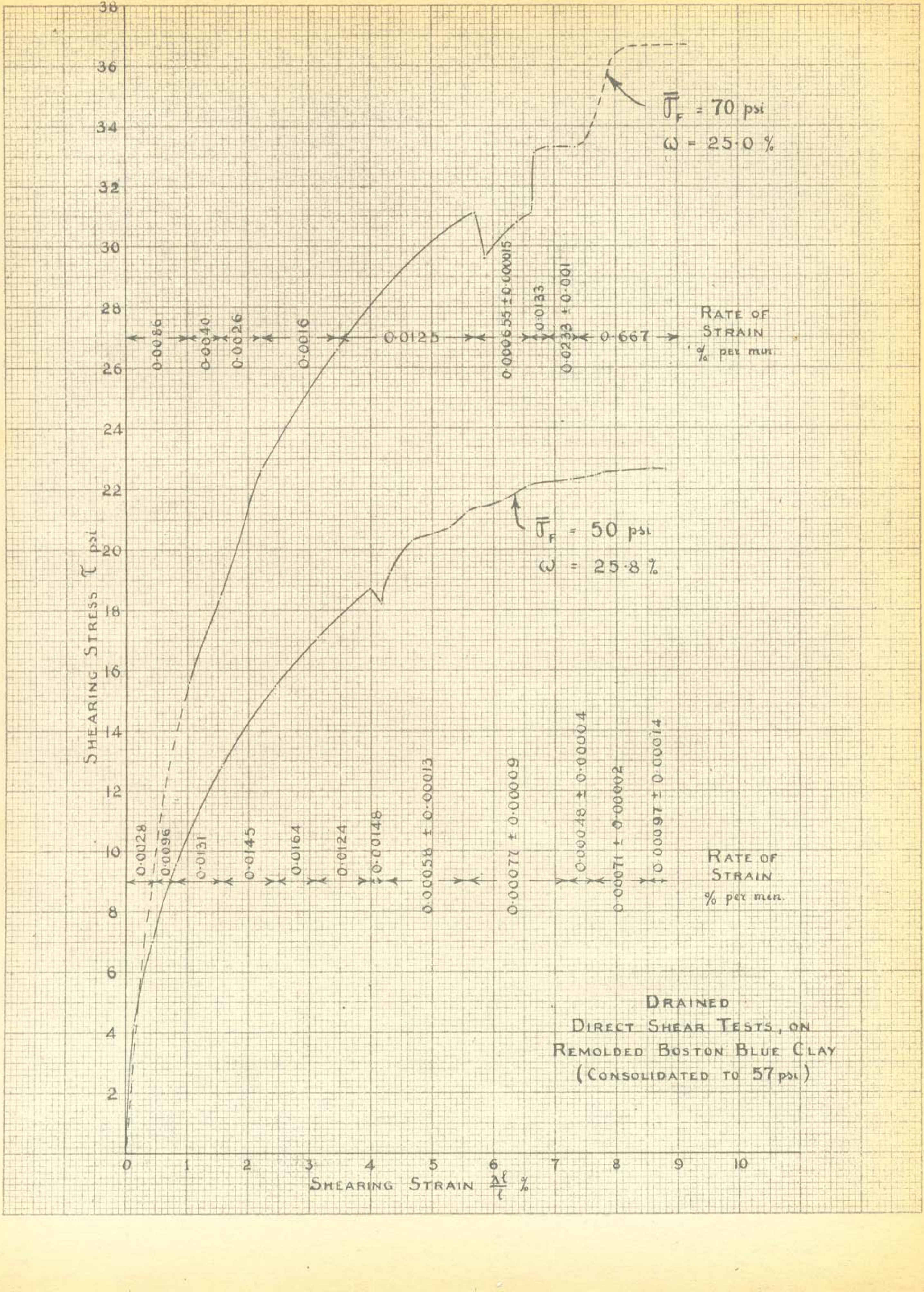
$\bar{\sigma}_F$ psi	Rate of Shearing Strain % per min	×2/3 = Speed comparable to that of axial strain in cylindrical compression	Proportion, to reduce τ_{max} to base speed *	Shearing Strength at actual speed psi	Shearing Strength at base speed psi
10	0.000675 ± 0.000075	0.000475	40.7 → 47.7	5.24	6.14
15	0.00073 ± 0.00006	0.000487	40.7 → 47.7	7.93	9.25
	0.015 ± 0.002	0.0090	43.0 → 47.7	8.26	9.17
20	0.000724 ± 0.000020	0.000482	40.7 → 47.7	9.80	11.50
25	0.00086 ±	0.00057	40.85 → 47.7	12.25	14.3
30	0.00101 ± 0.00010	0.00070	41.0 → 47.7	14.88	17.2
40	0.000712 ± 0.000020	0.000475	40.7 → 47.7	17.95	21.05
50	0.00097 ± 0.00014	0.00070	41.0 → 47.7	22.66	26.35
70	0.667 ±	0.445	47.9 → 47.7	36.7	36.6
	0.023 ±	0.01535	43.7 → 47.7	33.33	36.4
	0.000655 ±	0.000436	40.6 → 47.7	31.1	36.5
70.5	0.00077 ± 0.00003	0.00050	40.75 → 47.7	33.1	38.7
	0.0158 ± 0.004	0.01055	43.4 → 47.7	35.4	38.9
90	0.000725 ± 0.000020	0.000485	40.7 → 47.7	40.8	47.85

* Obtained by use of fig. VII, P. 44, Ninth Progress Report



DRAINED
DIRECT SHEAR TESTS, ON
REMOLDED BOSTON BLUE CLAY
CONSOLIDATED TO 57 psi

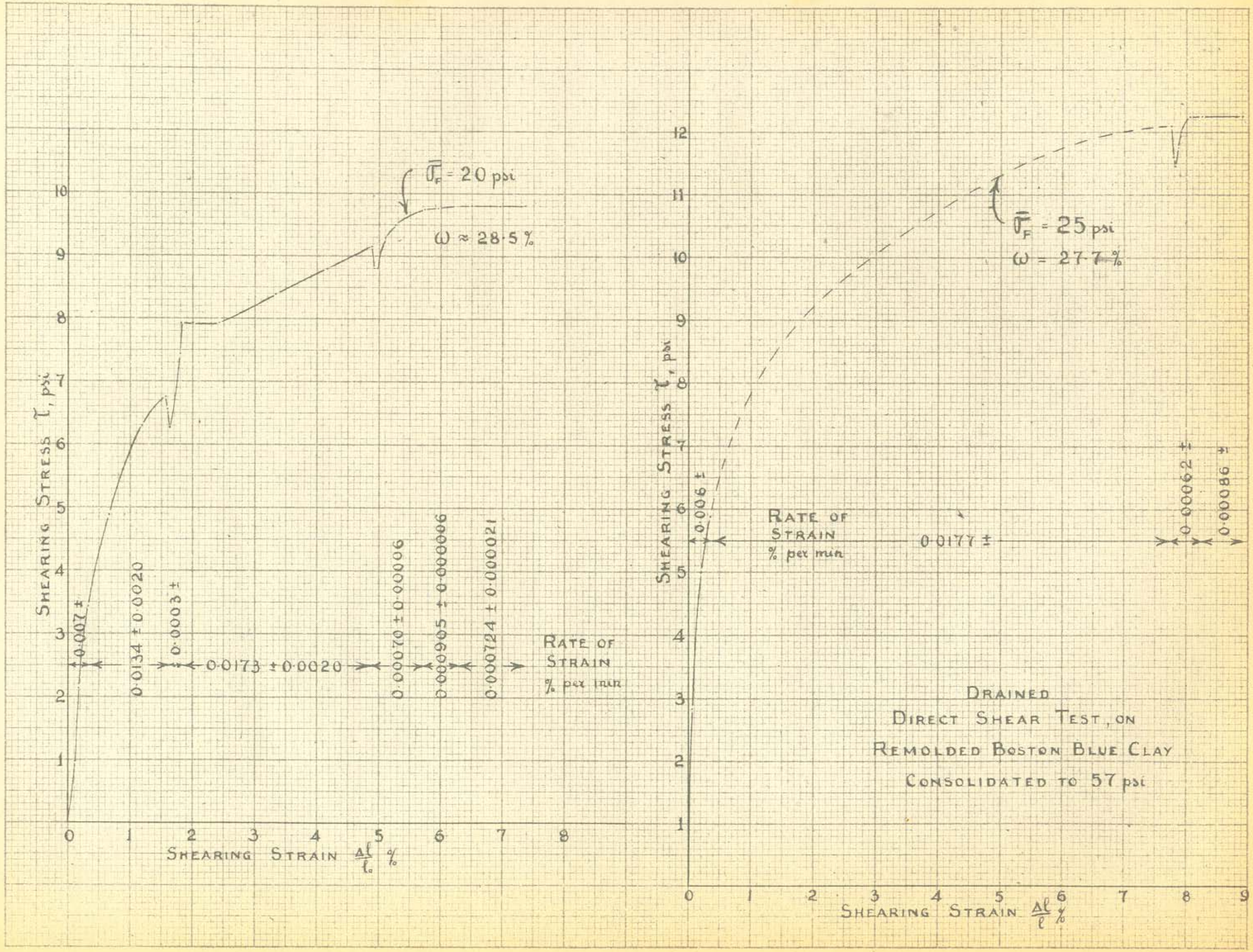
40 MASS. AVE., CAMBRIDGE, MASS.
TECHNOLOGY STORE, H. C. S.
FORM 1 T



DRAINED
DIRECT SHEAR TESTS, ON
REMOLDED BOSTON BLUE CLAY
(CONSOLIDATED TO 57 psi)

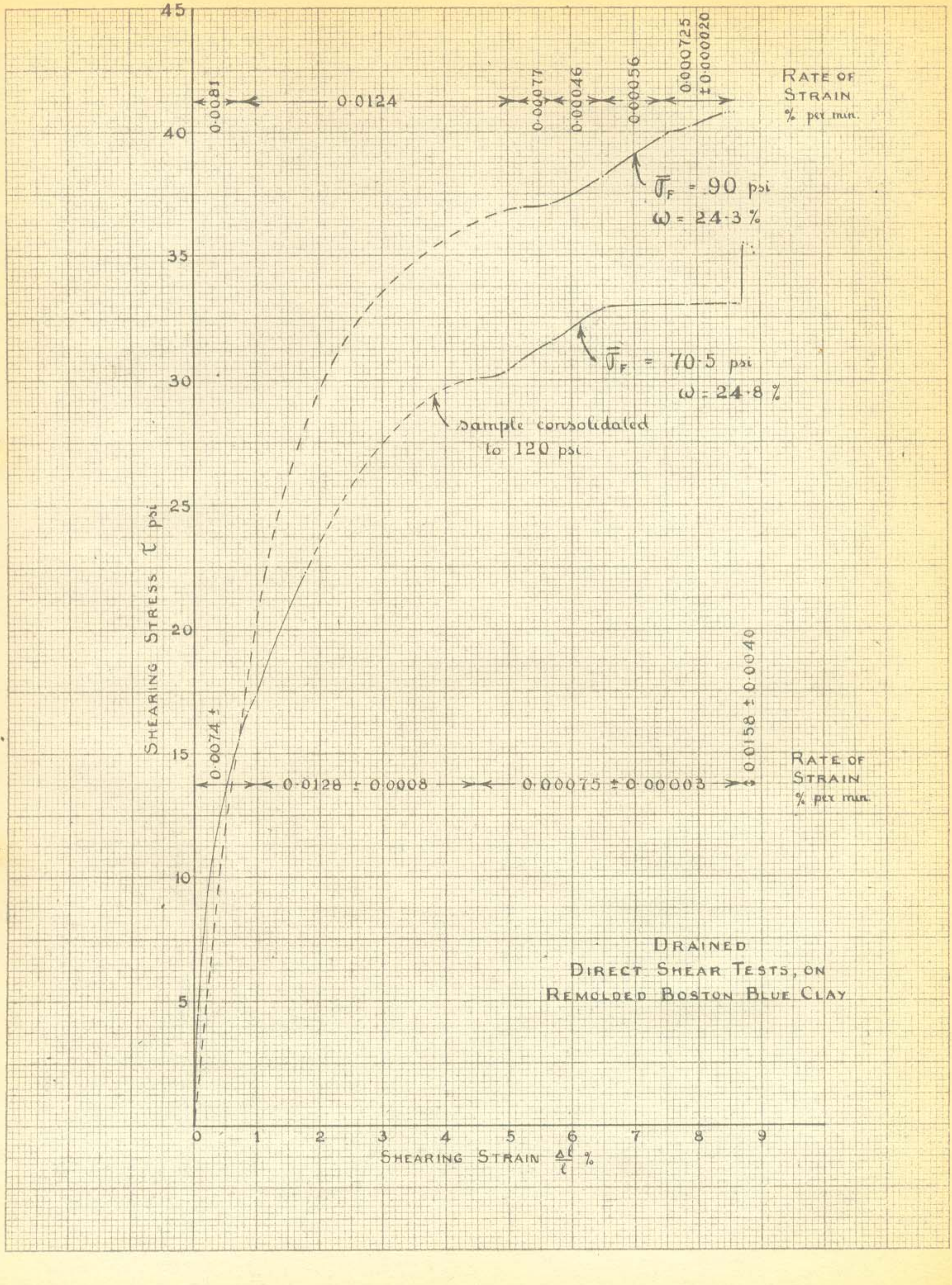
40 MASS. AVE., CAMBRIDGE, MASS.
TECHNOLOGY STORE, H. C. S.
FORM 2 T

FORM 2 T TECHNOLOGY STORE, H. C. S. 40 MASS. AVE., CAMBRIDGE, MASS.

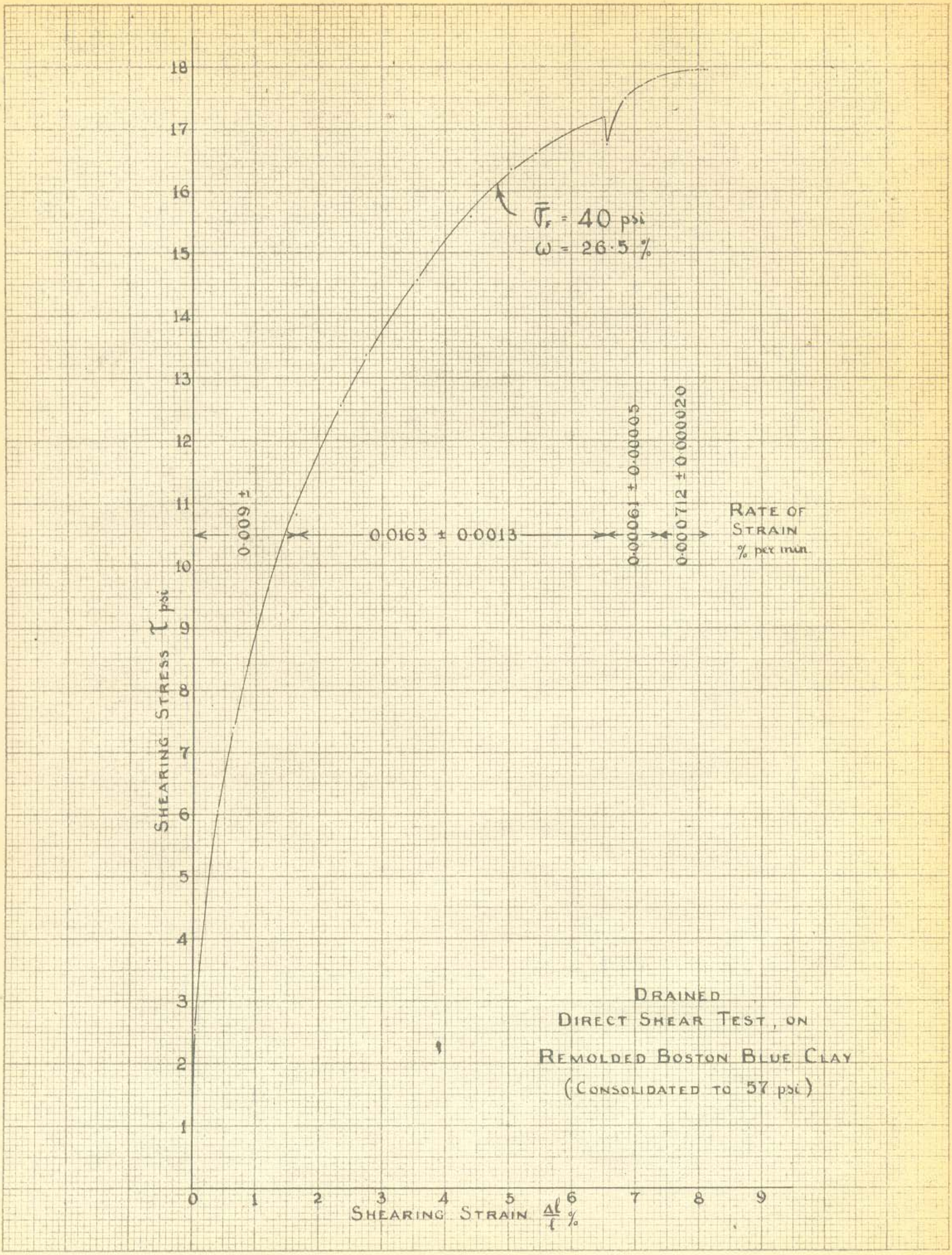


Drained
Direct Shear Test, on
Remolded Boston Blue Clay
Consolidated to 57 psi

FORM 2 T - TECHNOLOGY STORE, H. C. S. 40 MASS. AVE., CAMBRIDGE, MASS.



DRAINED
DIRECT SHEAR TESTS, ON
REMOLDED BOSTON BLUE CLAY



Drained
Direct Shear Test, on
Remolded Boston Blue Clay
(Consolidated to 57 psi)

Form 2T Technology Store M.I.T.C.S. 40 Mass. Ave., Cambridge, Mass.

TABLE 6

Correction for computations in the Cylindrical Compression Tests, discarding the assumption of uniform bulging throughout the length of the sample, and replacing it by the more sound and legitimate assumption of the bulging due to compression taking place only in the middle portion of the sample ; the fraction representing this "middle portion" is estimated by eye in each of the three cases. It obviously does not represent accurately the true conditions, but should logically bring the result much closer to its proper value.

TABLE 6A

for Test #1; assumption that effective length of sample is 4/5 of the cylinder length. L = 5.″200 ; A = 6.1625 □″

Strain %	ΔL″	L″	A □″	P.R. Load #	$\sigma_1 - \sigma_3$ psi	σ_1 psi	$\bar{\bar{\sigma}}_1$ psi	$\bar{\bar{\sigma}}_3$ psi
9.01	0.585	4.615	6.95	105.2	15.14	45.14	19.34	4.20
9.65	0.627	4.573	7.01	106.7	15.20	45.20	19.95	4.75
9.96	0.648	4.552	7.05	107.0	15.27	45.27	20.37	5.10
10.29	0.669	4.531	7.08	107.8	15.21	45.21	20.66	5.45
10.61	0.690	4.510	7.12	107.9	15.15	45.15	21.05	5.90

$$\sin\varphi = \frac{\bar{\bar{\sigma}}_1 - \bar{\bar{\sigma}}_3}{\bar{\bar{\sigma}}_1 + \bar{\bar{\sigma}}_3} = \frac{15.27}{25.47} = 0.599 \quad \therefore \varphi = 36^\circ 48'$$

$$\bar{\sigma}_F = \bar{\sigma}_3(1 + \sin\varphi) = \bar{\sigma}_1(0.401) = 8.17 \text{ psi}$$

$$\tan\varphi = 0.748 \quad \therefore \tau_F = \bar{\sigma}_F \tan\varphi = 6.11 \text{ psi}$$

and correcting for speed $48.65 \rightarrow 47.7$; $\tau_F = 5.99$ psi

To draw Mohr Diagram corrected for speed :

$$\tan\varphi = \frac{5.99}{8.17} = 0.733 \ ; \ \varphi = 36^\circ 15' \quad \therefore \theta = 45^\circ + \frac{\varphi}{2} = 63^\circ 7.'5$$

$$\therefore \tan\theta = 0.5068$$

$$\bar{\bar{\sigma}}_3 = 8.17 - (5.99)(0.5068) = 5.14 \text{ psi}$$

$$\bar{\bar{\sigma}}_1 = 8.17 + \frac{5.99}{0.5068} = 19.98 \text{ psi}$$

Correction for Test #2

Volume correction :- Volume of water drained in consolidation was 2.37 cu.ins.. It is usually found that only about 2/3 of the amount thus measured is actually drained from the sample, the rest being water that seep~~e~~s into the sample through the rubber gasket ..which is perhaps permeable , however little.

The test data available is too scant to allow any definite assertion on this score ; had there been no leakage at all, the total volume of water drained, in consolidations for Tests # 2 and # 3, could have been checked against the drop of water content. (But the cement used to attach the nipple to the rubber gasket gave way .. twice over .. during the process of consolidation after Test # 2 :so this was not possible). The only way of checking is by computing the water content for Test # 2 under each assumption :- (1) no appreciable seepage through the rubber gasket ; (2) seepage through the rubber as outlined above: and then deciding which is the more reasonable from a study of the plot of water content vs. logarithm of shearing strength..

Maybe it is due to the fact that the rubber used was 0"025 thick rather than the 0"010 used in previous investigations, based on which the above assertion was made : maybe it is due to something else.. But the fact is that in this test the assumption of <u>no</u> appreciable seepage through the rubber gasket seemes much better.

Volume = 40.05 - 2.37 = 37.68 cu.ins.

Original area = $\frac{37.68}{5.64}$ = 6.69 sq.ins.

Ratio of area at middle to average area due to bulging occurring in Test # 1 = $\frac{7.12}{6.88}$ = 1.035

Assume bulging to take place in 3/4 height of sample:- 4"230

Using value of pore pressure from best interpolated curve.

TABLE 6B

Strain %	$\Delta L''$	L''	$A^{\square''}$	P.R. Load #	$\sigma_1 - \sigma_3$ psi	σ_1 psi	$\bar{\sigma}_1$ psi	$\bar{\sigma}_3$ psi
3.045	0.172	4.058	6.97	303.8	43.6	135.3	67.9	23.6
3.405	0.192	4.038	7.01	310.6	44.3			
3.785	0.213	4.017	7.05	302.6	43.0			
4.165	0.235	3.995	7.08	295.8	41.8			

Using the correction factor for Area at middle since failure plane developed near the middle:- $\sigma_1 - \sigma_3 = 42.8$, $\sigma_1 = 133.8$, $\bar{\sigma}_1 = 66.4$ psi

$\sin\phi = \frac{42.8}{90.0} = 0.475 \;\therefore\; \phi = 28^\circ 22'$; $\tan\phi = 0.5398$

$\bar{\sigma}_F = (1.475)(23.6) = (0.525)(66.4) = 34.8$ psi

$\tau_F = (0.5398)(34.8) = 18.8$ psi

Correction for Test #3

Volume correction :- Computing the volume by measuring the average circumference and height of sample (before final consolidation to 120 psi) and then subtracting the volume of water drained out during consolidation, V = 36.12 cu.ins. ; Computing it by use of the water content (at the end of Test#3) V = 35.9 cu.ins.... Here again this is an indication that there is no appreciable seepage through the rubber gasket.

Using Volume = 36.0 cu.ins.; Original area = $\frac{36.0}{5.75}$ = 6.26 sq.ins.

Ratio of area at middle to aver. area in Test #2 = $\frac{7.08}{6.99}$ = 1.012

Due to Tests #1 and #2 combined , $\frac{\text{Area at Middle}}{\text{Aver. Area}}$ = 1.035 × 1.012
= 1.049

Which checks with measurements
of circumference : $\frac{(23.85)^2}{(23.32)^2}$ = 1.05

Using value of pore pressure from best interpolated curve.

Assume bulging to take place in 1/2 height of sample:- 2"88

TABLE 6C

Strain %	ΔL"	L"	A□"	P.R. Load #	$\sigma_1-\sigma_3$ psi	σ_1 psi	$\bar{\sigma}_1$ psi	$\bar{\sigma}_3$ psi
6.38	0.366	2.514	7.18	647.2	90.2	218.6	134.4	43.8
6.72	0.386	2.494	7.24	655.0	90.4			
7.08	0.406	2.474	7.30	661.4	90.6			
7.43	0.427	2.453	7.36	666.5	90.6			
7.78	0.447	2.433	7.42	671.6	90.5			
8.14	0.467	2.412	7.48	675.0	90.3			

Using the correction factor for Area at middle since failure plam s developed near the middle :-

$\sigma_1-\sigma_3 = 86.4$; $\sigma_1 = 214.4$; $\bar{\sigma}_1 = 130.2$; $\bar{\sigma}_3 = 43.8$ psi.

$\sin\phi = \frac{86.4}{174} = 0.4965$ $\therefore$ $\phi = 29^\circ 46'$; $\tan\phi = 0.5719$

$\bar{\sigma}_F = (1.4965)(43.8) = (0.5035)(130.2) = 64.7$ psi

$\tau_F = (0.5719)(64.7) = 36.9$ psi.

The values obtained in these computations are used in the final study of the correlation with results as obtained from the Brained Direct Shear Tests...

APPENDIX

Miscellaneous data obtained in the various tests and used in computing the results thereof...

Observations made in connection with the Cylindrical Compression tests .

At start :- length of cylinder = 6.50″

circumference = 8.8047″ ∴ diameter = 2.80″

whence, Area = 6.1625 □″ and Volume = 40.056 cu.ins.

Weight of cylinder (+ gasket, ring, rubber stopper) = 1314 gm.

Weight of gasket, ring, and rubber stopper = 36.1gm.

Water content determinations :-

Watch glass	I	II	III	IV	V
Wt. of dish wet sample	28.495	24.035	38.665	37.580	39.635
Wt. of dish dry sample	26.734	22.500	37.330	35.969	38.278
Wt. of clean dish	21.123	17.590	33.075	30.876	33.993
Water content =	$\frac{1.761}{5.611}$	$\frac{1.535}{4.910}$	$\frac{1.335}{4.255}$	$\frac{1.611}{5.093}$	$\frac{1.357}{4.285}$
=	31.38%	31.25%	31.38%	31.65%	31.65%

Average water content = 31.46%

Process of reconsolidation to 60 psi for Test # 2

Day	Time	Pore Pressure psi	Burette readings		Volume of water drained out ② - ①
			①	② resetting	
6-10-46	5.15 p.m.	60.0	----	45.55	-----
6-11-46	10.10 a.m.	36.8	25.45	48.35	20.10 cc.
6-11-46	4.10 p.m.	36.3	46.20	46.20	2.15
6-12-46	9.05 a.m.	25.7	39.85	48.20	6.35
6-13-46	10.00 a.m.	13.4	42.55	48.50	5.65
6-14-46	9.15 a.m.	7.0	45.75	49.50	2.75
6-15-46	9.25 a.m.	3.6	47.90	50.00	1.60
6-15-46	1.30 p.m.	3.0	49.80	-----	0.20
					38.80 cc.

The height of the sample in Test # 2 was obtained by noting the number of counter revolutions corresponding to the necessary travel of the "compressing head" to reach the top of the sample..

Process of consolidation to 120 psi for Test #3

Readings corresponding to those detailed in the table above were taken ; at the end of three days, after draining about 30 cc., the pore pressure still was above 110 psi ..., which was a clear indication of a leak .The cement used in attaching the nipple to the rubber gasket had failed.

The sample was very carefully removed and taken to the humid room. The pilot was carefully extracted. The rubber gasket was cautiously removed after being slit down its length with a sharp razor-blade. A new gasket was put on, avoiding ,as far as possible, any disturbance to the sample. The pilot was carefully inserted in the same place it had previously occupied.

The process of consolidation was started over again. However, the same trouble arose again after a couple of days.

This time a new cement was tried. The gasket and nipple being (supposedly) pure rubber, the Glover Coating Co. (in Boston) recommended the use of their Cement # 140 instead of the Goodrich Tyre Cement which had been the cause of so much trouble. This new cement was found to be entirely satisfactory.

Weight of sample + gasket = 1412.8 gm.

Measurements taken on sample : height = 6.00 ins.

Circumference at five levels : 23.05; 23.35; 23.85; 23.30; 23.05 cms.

Average circumference = 23.32 cms.

Whence : diameter = 2.92″ - 2(thickness of rubber) = 2.87″

Height of sample after consolidation = 6.00″ - 242revs. = 5.75″

Day	Time	Pore Pressure psi	Burette readings		Volume of water drained out
			①	② resetting	② - ①
7-3-46	4.00 p.m.	110	-----	50.00	-----
7-4-46	10.00 a.m.	78.4	29.55	50.00	20.45 cc.
7-5-46	9.25 a.m.	42.0	37.40	50.00	12.60
7-5-46	10.15 p.m.	27.0	46.10	50.00	3.90
7-6-46	9.45 a.m.	19.0	47.60	50.00	2.40
7-7-46	9.30 a.m.	9.0	47.25	50.00	2.75
7-8-46	9.15 a.m.	4.5	48.65	50.00	1.35
7-9-46	9.45 a.m.	1.7	49.25	-----	0.75
					44.20 cc.

Volume during Test #3 = $\frac{\pi(2.87)^2}{4} \times 6 - \frac{44.2}{(2.54)^3}$

$= 38.82 - 2.70 = 36.12$ cu.ins.

Water content determinations at end of test :-

Weight (with top cover, pilot, gasket) = 1391.8 gms.

top cover, pilot, gasket = 184.5

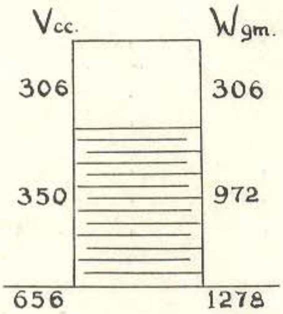
Weight of wet sample = 1207.3 gms.

Dividing the sample into three portions :-

Dish		I	II	III	Σ
Wt. of dish wet sample		516	599.8	422.2	1538
Wt. of dish dry sample		436.4	502.8	361.7	
Wt. of dish		108.7	108.8	115.1	-332.6
Water content	=	$\frac{79.6}{327.7}$	$\frac{97}{394}$	$\frac{60.5}{246.6}$	1205.4 gms
	=	24.3%	24.6%	24.5%	

Calculation of water content for Test #2.

Volume at start = 656 cc.; water content = 31.46%



Wt.of wet sample = 1314-36.1 = 1278 gms.

(whence $\delta \approx 2.78$)

Check on dry wt. of sample :-

= 327.7 + 394 + 246.6 = 968.3 gms.

For Test #2:- wt.of water = 306-38.8 = 267gm

$$\therefore \omega = \frac{267}{972} = 27.5\%$$

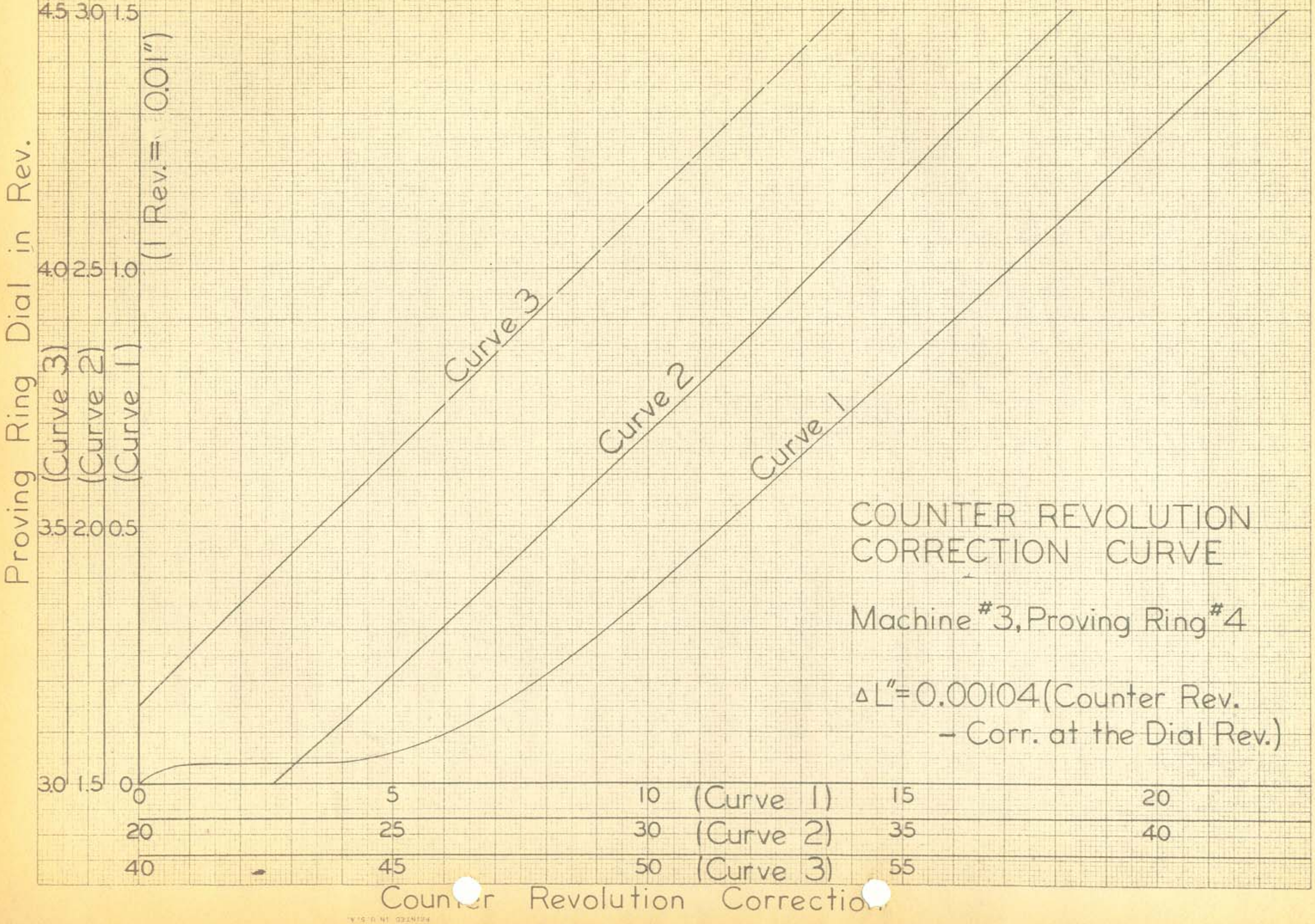
Or, assuming that only about 25 cc. are actually drained out of the sample: wt.of water = 306-25 = 281 gms.

$$\therefore \omega = \frac{281}{972} = 28.9\%$$

Check on the volume for Test #3, computing from water content

Wt. of water = (970)(24.5%) = 238 gms.

$\therefore$ total volume of sample = 350+238 = 588 cc. = 35.9 cu.ins.



COUNTER REVOLUTION
CORRECTION CURVE

Machine #3, Proving Ring #4

$\Delta L'' = 0.00104$ (Counter Rev.
– Corr. at the Dial Rev.)

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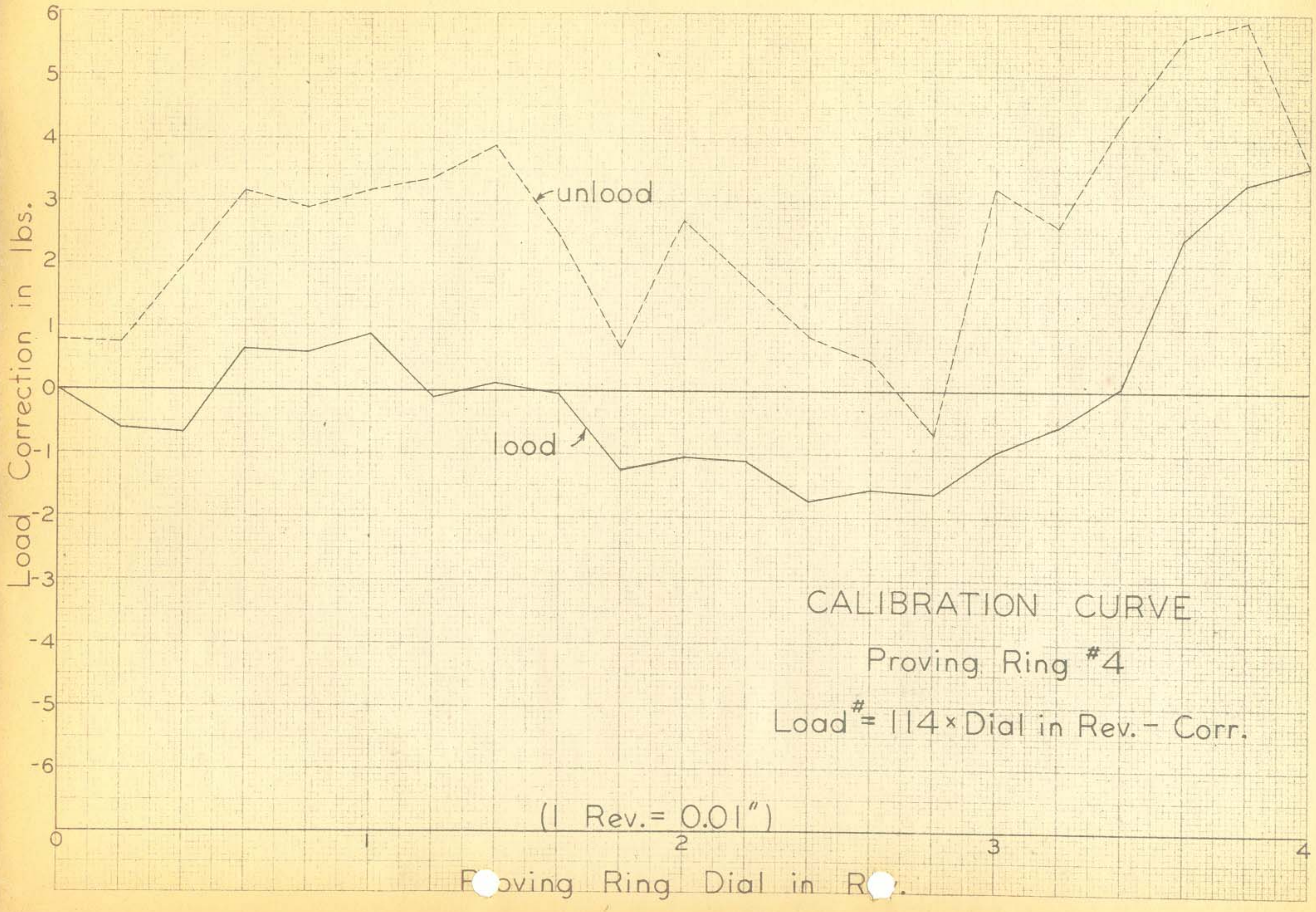

CALIBRATION CURVE

Proving Ring #4

Load# = 114 × Dial in Rev. – Corr.

CALIBRATION OF PROVING RING #4, CYL. COMP. MACHINE

# Load	Proving Ring Reading					
	Unload	Load	Unload	Load	Unload	Load
740	671.2	671.0	671.3	671.0	671.2	671.0
720	653.5	653.0	654.0	653.1	653.8	653.1
700	637.0	634.7	636.5	635.1	636.7	635.0
680	617.5	615.0	616.7	614.9	616.9	614.9
660	600.5	597.0	600.0	597.1	600.2	597.1
640	582.2	578.2	582.5	578.5	582.3	578.4
620	563.3	558.8	563.6	559.4	563.5	559.2
600	545.2	541.0	544.5	541.5	544.7	541.3
580	522.5	521.7	524.0	522.0	523.8	522.0
560	504.3	520.0	505.8	502.0	505.6	502.0
540.	486.6	483.6	487.7	484.0	487.5	483.9
520	468.8	465.4	469.4	465.9	469.2	465.7
500	450.0	446.8	450.5	446,8	450.3	446.8
480	429.5	428.0	430.5	428.0	430.3	428.0
460	412.9	410.5	413.6	410.5	413.4	410.5
440	396.0	392.5	396.5	393.1	396.3	392.9
420	378.0	374.4	377.9	374.4	377.9	374.4
400	360.4	356.4	360.0	356.7	360.2	356.6
380	341.5	339.0	342.0	339.0	341.8	339.0
360	324.0	320.0	323.5	320.1	323.7	320.1
340	305.6	301.3	304.8	301.5	305.0	301.4
320	287.6	283.8	287.1	284.0	287.3	284.0
300	269.6	265.5	269.6	265.5	269.6	265.5
200	177.2	173.0	176.4	173.0	176.5	173.0
100	91.5	88.0	90.7	88.0	90.8	88.0

CALIBRATION OF LIGHT PROVING RING, DIRECT SHEAR MACHINE

Load #	Proving Ring Reading					
	Unload	Load	Unload	Load	Unload	Load
250	511.4	511.0	511.1	511.1	511.2	511.0
240	491.3	490.5	491.0	490.7	491.2	490.6
230	471.0	469.8	470.9	470.0	470.9	469.9
220	452.7	451.1	452.6	451.3	452.6	451.2
210	432.0	430.7	432.0	430.9	432.0	430.8
200	411.3	409.5	411.3	409.9	411.3	409.7
190	390.8	389.0	391.0	389.4	390.9	389.2
180	371.2	369.0	371.5	369.5	371.4	369.3
170	350.9	348.5	350.9	348.7	350.9	348.6
160	330.5	328.0	330.5	328.2	330.5	328.1
150	310.0	307.8	310.2	307.8	310.1	307.8
140	289.0	286.3	289.3	286.7	289.1	286.5
130	268.2	265.9	268.5	266.0	268.4	266.0
120	248.2	245.8	248.2	246.0	248.2	245.9
110	227.8	224.2	227.0	224.4	227.4	224.3
100	205.0	202.5	204.8	202.5	204.9	202.5
90	184.4	182.5	183.8	182.9	184.0	182.7
80	164.2	162.3	163.6	162.1	163.8	162.2
70	143.8	142.4	143.2	142.2	143.4	142.2
60	123.7	122.0	123.1	121.9	123.3	121.9
50	102.2	100.8	101.9	100.9	102.0	100.9
40	81.1	80.0	80.9	80.0	81.0	80.0
30	61.0	60.0	60.9	60.1	60.9	60.1
20	40.4	40.0	40.2	40.0	40.3	40.0
10	20.4	20.3	20.4	20.1	20.4	20.1

CALIBRATION OF HEAVY PROVING RING, DIRECT SHEAR MACHINE

# Load	PROVING RING READING					
	Unload	Load	Unload	Load	Unload	Load
1000	197.2	196.8	197.0	196.8	197.0	196.8
980	193.0	192.7	192.7	192.7	192.9	192.7
960	189.1	188.8	188.8	188.8	189.0	188.8
940	184.9	184.5	184.5	184,4	184.8	184.5
920	180.7	180.0	180.2	180.0	180.3	180.2
900	176.6	176.0	176.1	176.0	176.3	176.0
880	172.9	172.3	172.4	172.3	172.6	172.4
860	169.0	168.3	168.5	168.3	168.7	168.4
840	165.0	164.5	164.7	164.5	164.9	164.5
820	161.1	160.4	160.9	160.5	161.0	160.5
800	157.3	156.6	156.9	156.6	157.1	156.7
780	153.2	152.5	152.9	152.6	153.1	152.6
760	149.2	148.5	148.9	148.6	149.0	148.6
740	145.5	144.8	145.0	144.8	145.0	144.8
720	141.8	140.9	141.3	141.0	141.5	141.0
700	138.0	137.0	137.6	137.1	137.7	137.1
680	134.0	133.2	133.7	133.3	133.9	133.3
660	130.0	129.4	129.8	129.5	129.9	129.5
640	126.3	125.6	125.9	125.6	126.0	125.6
620	122.4	121.7	121.9	121.7	122.0	121.8
600	118.5	117.7	118.0	117.8	118.1	117.8
580	114.4	113.8	113.9	113.9	114.0	113.7
560	110.4	109.6	109.9	109.9	110.0	109.7
540	106.7	106.0	106.2	106.2	106.2	106.0
520	103.0	102.3	102.5	102.5	102.5	102.3
500	99.2	98.5	98.8	98.8	98.8	98.5
480	95.2	94.8	95.0	95.0	95.0	94.9
460	91.4	90.9	91.0	91.1	91.0	90.9
440	87.5	87.0	87.2	87.3	87.2	87.1
420	83.8	83.1	83.3	83.5	83.4	83.2
400	80.0	79.3	79.5	79.7	79.5	79.3
380	76.0	75.4	75.8	76.8	75.9	75.6
360	72.0	71.3	71.9	719.	71.8	71.6
340	68.0	67.4	67.8	67.8	67.9	67.6
320	64.0	63.4	63.8	63.8	63.8	63.5
300	60.0	59.2	59.8	59.8	59.8	59.4
280	55.9	55.1	55.9	55.8	55.8	55.4
260	51.8	51.0	51.8	51.6	51.6	51.1
240	47.8	47.2	47.8	47.7	47.9	47.3
220	44.0	43.5	43.8	43.9	43.9	43.6
200	40.1	39.8	39.8	40.0	40.0	39.8
180	36.1	35.8	36.2	36.2	36.0	35.9
160	32.2	31.8	32.1	32.3	32.3	31.9
140	28.3	27.8	28.4	28.3	28.2	27.9
120	24.2	23.8	24.3	24.2	24.2	23.9
100	20.2	19.9	20.2	20.2	20.2	20.0
80	16.2	15.9	16.2	16.3	16.3	16.0
60	12.2	12.0	12.2	12.3	12.2	12.0
40	8.1	8.0	8.1	8.4	8.1	7.9
20	4.2	4.0	4.2	4.2	4.1	3.9

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Note on symbols used.

The symbols and notations used are the same as those used in the reports of the "Cylindrical Compression Research Program on Stress-deformation and Strength Characteristics of soils ". They are in general agreement with those adopted by the American Society of Civil Engineers.