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MATERIALS AND RESEARCH DEPARTMENT

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By

F. N. Hveem

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Sacramento, California

This is an advance copy of a paper to be presented to the First Pacific Area National Meeting of the American Society for Testing Materials (1916 Race St., Philadelphia 3, Pa.) to be held in San Francisco, Calif., October 10 to 14, 1949. This advance copy is issued primarily to stimulate discussion. Discussion is invited and may be transmitted to the Executive Secretary. The paper is subject to modification and is not to be republished as a whole or in part pending its release by the Society through the Executive Secretary.

This paper is one of a group of three papers prepared by Members of the Triaxial Institute and should be considered in connection with the other current papers; "The History and Theory of Triaxial Testing, and the Preparation of Realistic Test Specimens - A Report of the Triaxial Institute" by Mr. V. A. Endersby, and "Application of the Triaxial Test to Bituminous Mixtures - California Research Corporation Method" by Mr. Vaughn Smith.

APPLICATION OF THE TRIAXIAL TEST TO BITUMINOUS MIXTURES - HVEEM STABILOMETER METHOD

F. N. Hveem*

Synopsis

A brief review of the development of the Stabilometer is given, together with a discussion of the underlying principles of the test and its relation to deformation of road surfaces, bases and supporting soils.

The test procedure is discussed giving pertinent details of the operation. Formulas for converting Stabilometer results into stability values and for computing "Resistance Values" are also included. Tables and charts giving test results on both stable and unstable materials are appended for illustration.

DEFINITION

The name "Stabilometer" is a coined word and was intended to apply only to the type of apparatus described herein. The term is not properly applied to other devices of different principle that have been proposed for measuring "stability".

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DEVELOPMENT

The Stabilometer has been employed as a routine test in the Laboratory of the Materials and Research Department, California Division of Highways, since 1930, the first models being simple metal cylinders split on one side and held together by compression springs which permitted expansion of the cylinders when subjected to internal pressures. In 1932, the design was changed to the present hydraulic type in which lateral pressure is transmitted through the walls of a rubber tube to an annular liquid cell. Lateral pressure is measured by means of a standard hydraulic pressure gauge. Fig. 1.

The Stabilometer was originally developed because of the pressing need for a means to evaluate the stability of the oil mix type of bituminous surfacing which was then a relatively new process, the first oil mix road surface in California having been constructed in 1926.

Attempts to apply stability tests such as the Hubbard-Field or other shear tests to the oil mix types gave values that were extremely low compared to standards thought necessary to assure stability in pavements of the sheet asphalt type. It was evident that dense graded mixtures using slow curing liquid asphalts similar to the present SC-2 grade (having a viscosity range from 100-200 sec. at 140 degrees F.) were capable of withstanding considerable amounts of traffic and the conclusion was inescapable that such satisfactory road surfaces must therefore possess the requisite "stability".

Examinations of failures on the road caused by instability of a bituminous surfacing indicate that the paving mixture tends to flow in a lateral direction giving the appearance of being squeezed out or pressed out beneath the wheels of heavy vehicles. It, therefore, seemed to be a fairly obvious and simple conclusion that the ability to resist lateral displacement is a characteristic of stable bituminous pavements. In view of the fact that all pavements represent very large areas compared to the area covered by a single vehicle tire, it is also evident that in order for the material beneath the tire to flow or "escape" in a lateral direction it must transmit pressures greater than the resistance of the surrounding mass of similar composition. By way of illustration; if a hole with a diameter corresponding to a tire print is bored in solid material such as concrete and filled with either clean sand or plastic clay, these materials will sustain a load covering the area of the hole simply through the influence of lateral support alone. Conversely, an isolated block of concrete or of stone would sustain any load which could be transmitted by a pneumatic tire simply because of the internal resistance or strength of the unit directly beneath the load. Therefore, assuming an adequate foundation, the capacity of a bituminous pavement to remain smooth and undistorted under traffic depends upon the ability of the pavement mass to <u>resist</u> plastic deformation.

Perhaps the properties of plastic materials may be better visualized by extending the principles of hydrostatics rather than by an attempt to analyze the behavior through applying the theory of elasticity. If the mechanics of bituminous pavements or of granular soil materials is compared to the behavior of liquids under pressure, it will be recognized that one of the characteristics of liquids is the ability to transmit pressure equally in all directions. When masses of fine and coarse granular materials such as the mineral aggregates used in bituminous pavements or in granular bases (or even in the underlying basement soils) are combined with varying amounts of water or of asphalt or both, all such materials form combinations that will transmit some pressure in all directions but not in a uniform pattern or to an equal degree. Therefore, if a sample of a typical bituminous pavement or of granular base material is placed in a cylinder and subjected to a load under a tight fitting piston, a certain percentage of the vertical pressure will be transmitted to the side walls of the cylinder. The proportion of the vertical pressure thus transmitted in a lateral direction may vary considerably however, depending upon the character of the sand or rock particles and especially with the amount or type of lubricating liquid that is combined. The whole relationship and condition may be summarized by stating that the lateral pressure will vary inversely with the internal resistance of the mass. The internal resistance of bituminous paving mixtures has usually been referred to as "stability". If a specimen of soil or mineral aggregate with or without a bituminous binder is compacted in the form of a cylinder and subjected to vertical loading with means for measuring the lateral pressure developed in the process, then the relative tendency of the material to transmit lateral pressure will present an index to the stability or "resistance value" of the material in place on the roadbed.

As illustrated by Fig. 2, the Stabilometer has evolved through a series of types or models to its present form.

The Stabilometer test was first described in a paper published in the Proceedings of the Highway Research Board in 1934.(1) Further discussion was included in an article published by the American Road Builders' Association in 1939.(2)

As indicated in the earlier reports, the design of the instrument is such that it is possible to test specimens artificially compacted in the Laboratory or those cut from the pavement by means of a core drill. This latter feature has made it possible to establish a direct comparison between test results on artificially formed specimens and those fabricated by the usual construction methods involving rolling and traffic compaction. As soon as such comparisons were established, it became clearly evident that Laboratory compaction methods involving tamping under an impact hammer followed by direct confined compression consistently produced test specimens that were far more stable than were samples cut from the pavements composed of the same ingredients. This was true even though the tamped specimens developed the same density as the field cores. Therefore, a lengthy study was undertaken in order to establish a laboratory compaction technique that would reproduce in all respects the resistance properties of the mixture when compacted on the roadway. A great deal of time and effort was expended and it was finally established that compaction of the test specimen must be accomplished by means that did not employ a sharp impact or pounding action and still must permit movement or shifting of the particles during the compaction process. This latter requirement eliminates direct confined compression as a compaction method. Therefore, compaction must be accomplished by means that applies the compaction pressure to only a small portion of the specimen surface at one time. In other words, the compacting machine should subject the specimen to a sort of kneading action and the area of the compaction foot should not exceed three or four square inches when applied to a specimen having an end area of approximately twelve square inches, for example. It might be stipulated then that the tamper foot should not have an area exceeding one-third of the area of the upper surface of the test specimen. (The compaction foot finally adopted in this Laboratory is approximately one-fourth the area of the specimen surface.) Compaction is accomplished by the application of 150 loads or thrusts of the tamper shoe developing a pressure not exceeding 500 p.s.i. The compaction thus produced is designed to simulate the effects of construction rolling plus about one year's traffic and has been found to check well with pavement samples. It is essential that the particles of aggregate be given an opportunity to move or shift during the compaction process. California Standard Specifications now require that construction operations develop a density in the newly laid pavement equal to 95 per cent of the density of the laboratory test specimen. The compacting apparatus used is shown in Fig. 4 and is the first of a series of such compactors. At the present time it is known that there are five compaction machines in existence on the Pacific Coast, all of different mechanical design but all capable of subjecting a test specimen to similar kneading action by applying a succession of relatively low or moderate loads through a tamper foot much smaller than the area of the specimen. The second compactor was constructed in the Laboratory of the California Research Corporation at Richmond, the load being applied by a weighted vertical ram lowered onto the specimen by means of a cam mechanism and utilizes a tamper foot approximately one square inch in area. A third compactor was constructed in the Laboratory of the California Division of Highways employing a hydraulic mechanism to operate a tamper foot of three square inches in area. A fourth has been constructed in the Laboratory of the Shell Oil Company at Martinez using a pneumatic cylinder employing compressed air as the motive power. The latest compactor was designed by a subcommittee of the Triaxial Institute and has been constructed in the shops of the University of California. The construction of a sixth compactor using this same design is now underway in this Laboratory. Thus, there is now a considerable agreement on the part of members of the Triaxial Institute that the method of fabricating the test specimen is of paramount importance and there is also agreement that a special compacting machine is necessary in order to produce test specimens that are a reasonably close model of bituminous pavements constructed and compacted on the road.

Having provided means for preparing a test specimen in which the compaction pressures, arrangement of particles, density and film thickness of asphalt are all fairly typical of actual pavement conditions, the next step is the conduct of the test.

The Stabilometer test is accomplished by placing the compacted test specimen within the Stabilometer shell where it is supported upon the base column and surrounded by the closely fitting rubber tubing. A series of photographs are included, Fig. 3 A,B,C,D,E,F, illustrating the sequence of operations involved. The total lapsed time to perform the test ranges from five to six minutes. With the test specimen in place and the follower or loading piston resting on the upper surface of the test specimen, the Stabilometer is placed on the platen of a testing press and the specimen subjected to a load applied at the rate of 0.05 inches per minute. Continuous readings of the Stabilometer dial are recorded; typically at each 1,000 pounds of total load. For comparative purposes "stability" is reported under a total load of 5,000 pounds which is equivalent to approximately 400 p.s.i. on a specimen four inches in diameter. The test is not carried out to reach any yield point or "failure" point.

The process of testing a sample of road material in the Stabilometer is based on the premise that a sample should be subjected to pressures sufficient to represent the combined effects of traffic loads frequently repeated over a long period of time. Under the conditions of the test, a load ranging from three to four hundred p.s.i. seems to furnish a reasonable duplication of the cumulative long time effects from pneumatic tired traffic. Therefore, as stated above, a sample is subjected to a slowly applied load culminating in a pressure of 400 p.s.i. and the Stabilometer reading under each 1,000 pounds of total load is recorded. After reaching the maximum load, the displacement value of the Stabilometer system is measured and recorded. This displacement value represents the volume of liquid expressed in cubic inches (or in the number of "turns" or revolutions of the calibrated pump handle) required to increase the pressure in the apparatus from five to one hundred p.s.i. This measurement is made with the specimen in place and any influence caused by the specimen will be reflected in the displacement measurement. It has been found that the magnitude of the lateral expansion or the volume displaced by the specimen while undergoing the test must be taken into account when evaluating the lateral pressure developed. In other words, two test specimens of the same asphaltic mixture will give different lateral pressures depending upon the range of movement permitted to the specimen and this range or volumetric expansion is evaluated in each case by the displacement measurement. Therefore, the displacement is measured after the completion of the test by turning the displacement pump handle in a clockwise direction, thus forcing a volume of liquid into the Stabilometer sufficient to develop a pressure of 100 p.s.i. The exact amount of liquid required is indicated by the number of turns of the pump and may be read on the Ames dial gauge provided.

In the conduct of this test, the specimen becomes in effect an integral part of the Stabilometer system and therefore, any lateral surface voids on the specimen or air entrained in the Stabilometer liquid will influence the lateral displacement required to develop a given pressure.

As specimens differ in the degree of smoothness or roughness of the exterior surface, it is necessary to measure the actual displacement for each test. The specimen is held firmly in place during the displacement measurement by retaining a vertical pressure of about 1,000 pounds. This is employed simply to prevent the test specimen from being deformed or squeezed upward while the displacement measurement is being carried out. Early studies indicated that the significance of test results was impaired when the total displacement in the instrument was at a very low value. Under such conditions it was difficult to establish a differential between specimens of high and low stability. Therefore, a standard initial displacement was adopted corresponding to two turns of the hand pump when a "dummy" specimen such as a smooth cylinder of brass or wood is in place. All compacted specimens of bituminous materials give a displacement value somewhat higher than is recorded for the smooth unyielding dummy specimen. To repeat; it is necessary that the conditions of compressibility within the entire Stabilometer system must be evaluated for each specimen. While in a sense the displacement value is a correction for the test specimen itself, fundamentally it is a correction for the entire Stabilometer system as air voids anywhere in the system will have the same effect on the instrument reading.

The foregoing discussion and test procedure imply that the tendency of the specimen to transmit vertical pressures in a horizontal direction is an inverse measure of the ability of the specimen to resist deformation. Following the idea that plastic materials form a class of substances intermediate between liquids and rigid solids, an arbitrary scale for reporting stability was established many years ago in which the value of zero corresponds to a liquid having no measurable internal resistance to slowly applied loads and at the other extreme, 100 corresponds to a hypothetical solid that will transmit no measurable amount of pressure or movement.

CALCULATING RELATIVE STABILITY

Stabilometer values were converted to this arbitrary stability scale by the following empirical formula:

$$\text{Relative Stab.} = S = \frac{22.2}{\frac{P_h D_2}{P_v - P_h} + .222} \qquad (1)$$

P_v = vertical pressure. (Typically 400 p.s.i.)

P_h = horizontal pressure. (Stabilometer reading in p.s.i.)

D_2 = displacement on specimen

(P_h was taken at the instant P_v was 400 p.s.i.)

It will be noted that three factors are involved in determining the relative stability; first, the test load or vertical pressure (P_v); second, the horizontal pressure (P_h) developed as indicated by the Stabilometer reading; third, the volume of liquid which must be displaced (D_2) to change the pressure on the Stabilometer dial from five pounds to one hundred pounds. For a bituminous paving mixture having a small amount of cohesion or tensile strength such as would ordinarily be obtained with an SC-2 or SC-3 liquid asphalt, a value of S equal to or greater than 35 would be considered satisfactory. However, it is evident that mixtures containing asphalts of low penetration have characteristics of hardness or toughness quite different from the oil mix type. In order to evaluate this property, the Cohesiometer(1) was developed to measure the cohesive strength of the asphalt films. This is accomplished by bending or breaking the same cylindrical test specimen as used in the Stabilometer. The Cohesiometer test is comparable to a cantilever beam test and Cohesiometer values have a linear relationship to Modulus of Rupture Values when applied to rigid or non ductile substances.

Within recent years, Stabilometer tests are being applied to native soils and granular bases in order to evaluate the supporting power and thus determine the thickness of pavement or surfacing required. The ability of such materials to resist distortion has been designated "the Resistance Value" and while the two extremes of zero or 100 also correspond to the liquid and solid state respectively, the intermediate values have a different order of correspondence as compared to the older "stability" scale.

When calculating the Resistance Values of soils or untreated granular bases, the following formula is used:

$$R = 100 - \frac{100}{\frac{2.5}{D_2}\left(\frac{P_v}{P_h} - 1\right) + 1} \qquad (2)$$

Where R = the Resistance Value

The other symbols have the same significance as in equation (1). However, P_h will be taken when P_v is at 160 p.s.i. The R value may be used to compute the thickness and/or strength of pavement necessary to carry traffic loads.[3]

Both of the foregoing equations neglect the cohesion or tensile strength of the soil or bituminous surface and under certain conditions it is desirable to have an over-all evaluation in which the tensile strength is included.

For bituminous surfacings, we are now calculating a Resistance Value combining both friction and tensile strength as reflected by Stabilometer and Cohesiometer readings.[1] The formula is as follows:

$$R_t = 100 - \frac{100}{\frac{2.5}{D_2}\left(\frac{P_v}{P_h} - 1\right) + 1} + .05c_1 \qquad (3)$$

Where c_1 = cohesiometer value in grams per lineal inch of specimen width. This is an index to the tensile strength of the specimen.

When calculated by the above formula, a value of R_t equal to or greater than 90 is sufficient and generally necessary for a bituminous pavement subjected to pneumatic tired traffic.

Since the development of the Stabilometer, instruments embodying the same principles have been constructed in many laboratories, many of which have been designated as "apparatus for measuring triaxial shear". So far as fundamental principles of the apparatus are concerned there is no difference between the Stabilometer and the "triaxial versions". However, there has been a rather general and consistent difference in the theoretical approach or concept and consequently in the methods of conducting the test. As stated before, the Stabilometer is employed to measure the ability of the compacted specimen to transmit pressure and the entire range of plastic materials may be evaluated by this process. Sands or similar cohesionless granular materials may also be tested in the Stabilometer without difficulty. In most conventional triaxial tests, however, the test is conducted on the assumption that there is a definite point of "failure" and a typical procedure is to apply a series of lateral pressures or degrees of lateral support to the specimen and then determine the vertical load required to cause "failure" in the specimen. The specimen is subjected to several stages or steps in magnitude of load and of lateral support.

Judging from reports, it appears that some of the investigators have been baffled by the problem of deciding on the most significant value to be selected for the lateral support. To quote Mr. E. S. Barber, "Field correlations may make it possible to determine an effective lateral pressure to use in evaluating such (granular) materials."[(4)]

The data obtained in the triaxial shear test is commonly used to determine the angle of friction and cohesion by employing the Mohr circle analysis. In accord with conventional theories of soil mechanics, the test specimen in the triaxial shear apparatus must be quite tall in relation to the diameter. It is commonly believed that the test specimen must be from two to two and one-half times the diameter in order for the shear planes to develop normally. This concept may have some justification when applied to the stability of embankments or pressures against retaining walls. There seems to be no reason for such requirement for routine testing when the test specimen represents a relatively shallow depth of pavement and even in the base courses and basement soils beneath the pavement any lateral movement caused by limited load areas will involve only a relatively shallow depth of the material. The use of the tall specimen seems to offer no special advantages as a practical test procedure and has definite disadvantages in the time, care and volume of material required to fabricate and test a suitable specimen.

It is a common assumption that the intercept of the Mohr envelope on the vertical axis is a measure of cohesion. This concept is debatable to say the least. In the viewpoint of the writer, neither the Stabilometer nor the triaxial shear apparatus furnishes a suitable measure of the magnitude of cohesive forces. This property had best be evaluated by other means. It appears, however, that the angle of friction can be calculated from the test results on the relatively short Stabilometer specimen as indicated by Mr. L. E. McCarty.[5][6] Mr. McCarty has shown that a specimen having a height/diameter greater than 2 is not essential for developing fundamental data on the angle of friction and cohesion.

In order to illustrate the application of the Stabilometer test, four samples of bituminous mixtures were selected and the test data are shown on four charts, Figs. 5, 6, 7, 8. The four samples were submitted from a recently constructed project with the request that the Laboratory determine the causes for distortion and roughening of the pavement represented by Samples C and D. Samples A and B were taken from stable sections.

These samples are identified and the test results tabulated in Table I.

EXAMPLES OF TEST RESULTS ON STABLE AND UNSTABLE MATERIALS

Chart, Fig. 5, has been prepared showing the Stabilometer readings recorded for these four samples. This is accomplished by plotting the Stabilometer reading in pounds per square inch against the applied load in pounds per square inch. Under the conditions of the test, the vertical and horizontal pressures will be identical on a specimen having no internal friction or resistance. (The relative stability for bituminous pavements is evaluated under a test load of 400 p.s.i.)

TABLE I

TEST RESULTS ON SAMPLES OF BITUMINOUS PAVEMENT REPRESENTING BOTH STABLE AND UNSTABLE AREAS ON THE SAME PROJECT

Test No.	Identification letter used on Charts and in following discussion	Percentage Passing #200	Percentage of Moisture in Material	Percentage of Asphalt by Extraction	Cohesiometer Value at 140 degrees	*Stabilometer Value	Comments on Condition of Road
57649	A	10	1.0	4.3	74	45	Condition good. No sign of failure
57650	D	15	2.7	5.5	129	6	Condition poor. Bumps bladed off
57651	C	10	1.2	5.5	124	19	Condition poor. Bumps bladed off
57652	B	9	1.1	5.1	135	40	Condition very good. Best looking mix to date.

*Stabilometer Tests were made on the samples as received without drying.

Chart, Fig. 6, shows the "stability" value calculated by means of equation (1). The Cohesiometer values have also been superimposed indicating that Cohesiometer values or tensile strengths tend to increase with an increase in the liquid content, which is a typical trend in the majority of cases. Based on Stabilometer tests, specimens A or B would be considered to be satisfactory, however, it will be noted that the stability falls very rapidly with a slight increase in asphalt or water content beyond the amount found in specimen B. Therefore, it has been considered good practice to specify a somewhat lower asphalt content in order to provide some latitude for variation during construction.

Chart, Fig. 7, has been prepared to show the corresponding resistance value calculated from equation (2). Either the R value or the stability value places the four specimens in about the same relative order. However, the tensile strength is also a factor in the performance of a bituminous pavement and Chart, Fig. 8, has been prepared to show the resistance value calculated according to equation (3) which represents the combined influence of internal friction and tensile strength. Under this evaluation, specimen B appears slightly superior and the additional toughness imparted by the higher asphalt content undoubtedly would account for the comment from the field engineer that specimen B was "Best looking mix to date." However, the asphalt content in this specimen is dangerously close to the upper limit for stability and slight errors in plant proportioning or in the introduction of an excessive amount of moisture would render all or portions of the mix unstable as indicated by the steep decline in the curve.

It must be emphasized that the four specimens tested are not of identical composition as they were taken from different points on the roadbed and as will be seen in Table I, there is some variation in the percentage of fines which probably contributes to the low Stabilometer value on specimen D.

It should also be noted that there is no difference in asphalt content between specimens C and D. The chief distinction is in the fact that specimen D contains about twice as much moisture as specimen C.

The test results on the above samples were selected because the actual quality of the materials could be attested by known performance under traffic. The four samples also serve to illustrate the variations caused by differences in asphalt content and the similar influence of varying amounts of moisture.

SUMMARY

It may be stated that the Stabilometer is an instrument capable of measuring the most important elements of internal resistance in a wide variety of granular or plastic materials with or without bituminous binders ranging from cohesionless sands to wet clays and will also produce significant values on test specimens of soil cement mixtures.

The entire test procedure can be completed within an elapsed time of six minutes and the test specimen is not ruptured or destroyed in the process so that the same briquette may be used to determine the tensile strength or cohesive resistance if desired.

The principal and outstanding advantage of the Stabilometer is the speed with which tests may be performed. This is a matter of paramount importance in any laboratory where cost of testing is a consideration and where test results must be made available as soon as possible for job control purposes.

The test has been in use for more than fifteen years and a large mass of data exists to demonstrate the correlation between test results and performance of soils, base materials and bituminous surfaces under motor vehicle traffic.

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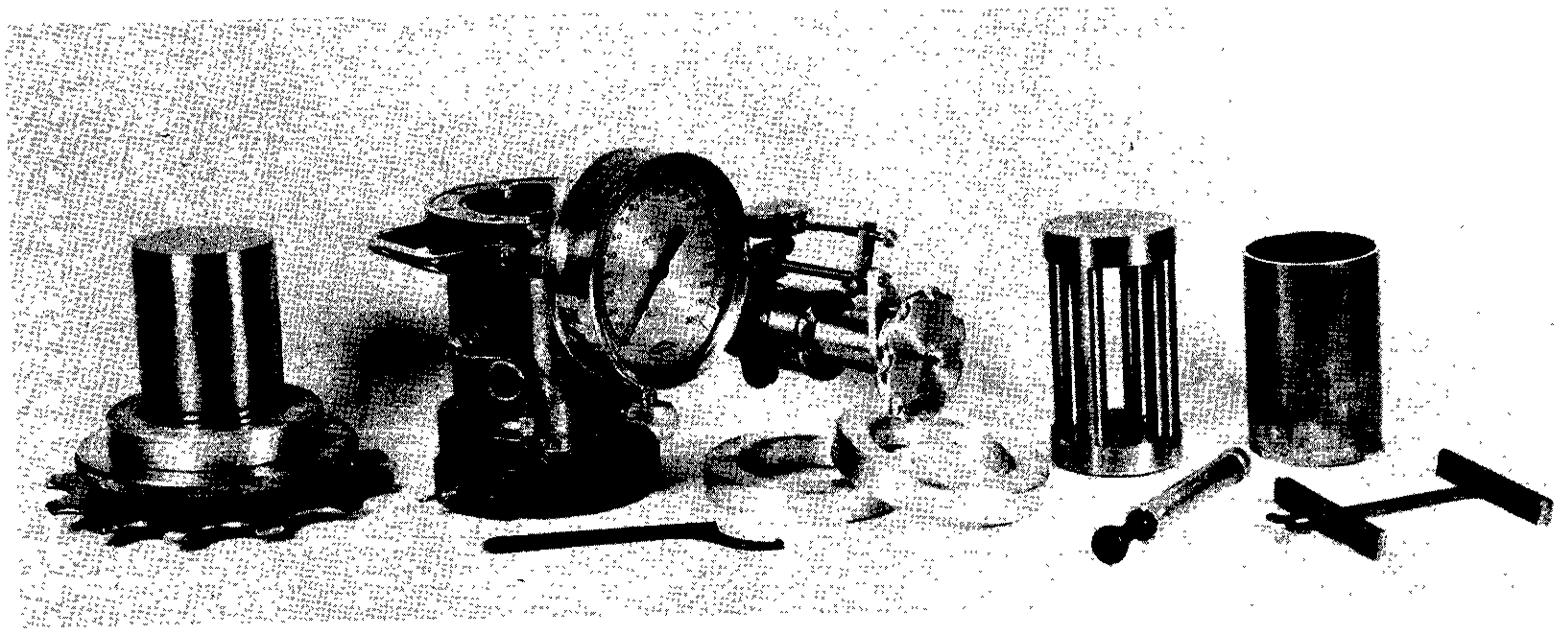


Fig. 1
Complete Stabilometer Assembly

At extreme left, base column with adjustable stage.
Second, the main unit containing the liquid cell and gauges.
Right of center, aluminum bushing rings for use with tall specimen.
Cage type piston or follower for applying load to the test specimen.
On the right, brass cylinder 4 in. O.D. for use as dummy specimen.
Miscellaneous items include spanner wrench for tightening pump gland, small air pump for adjusting initial displacement and clamp tool for installing new rubber diaphragm.

(The Stabilometer illustrated is complete except for crank handle attachment on displacement pump.)

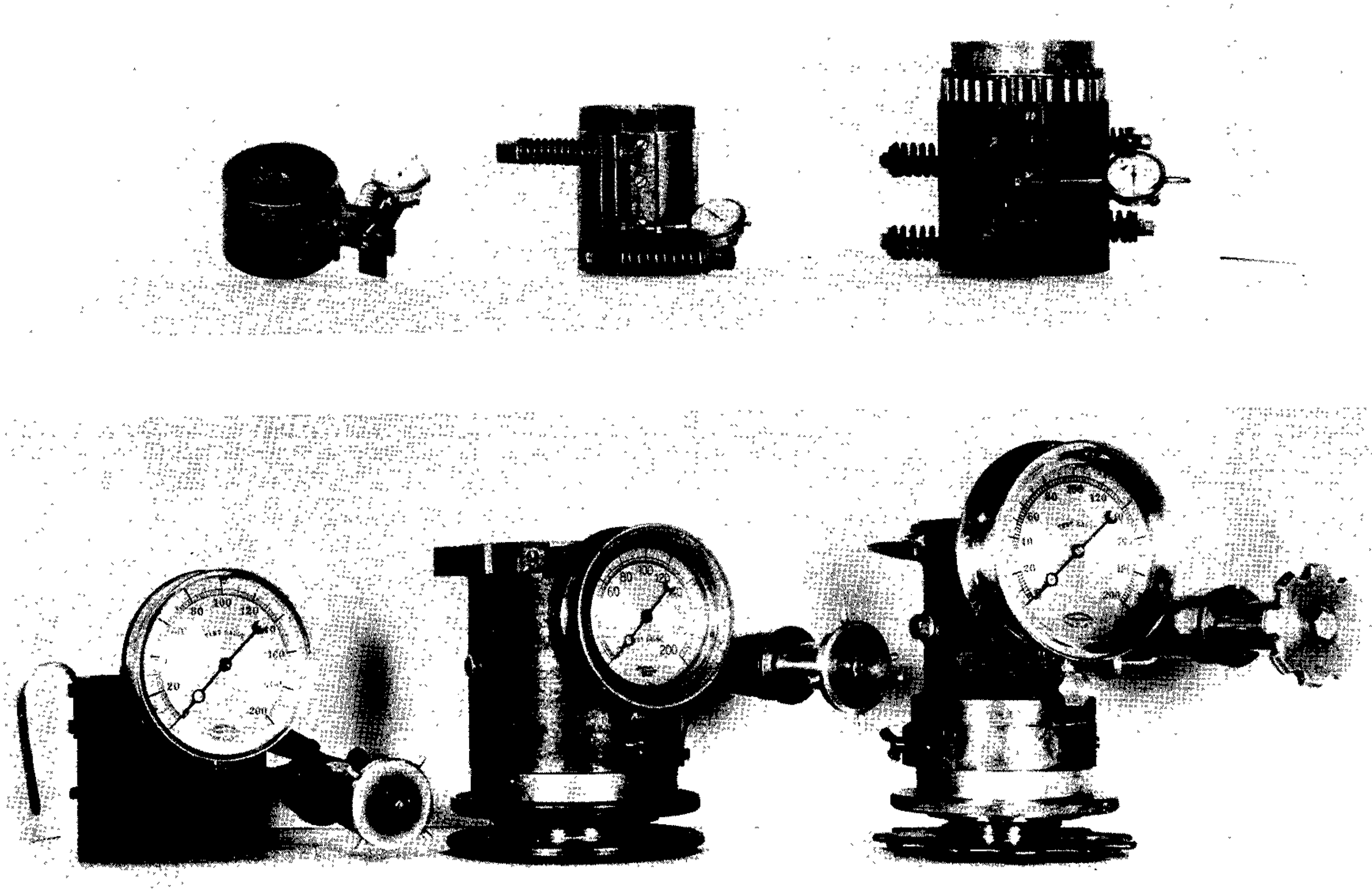
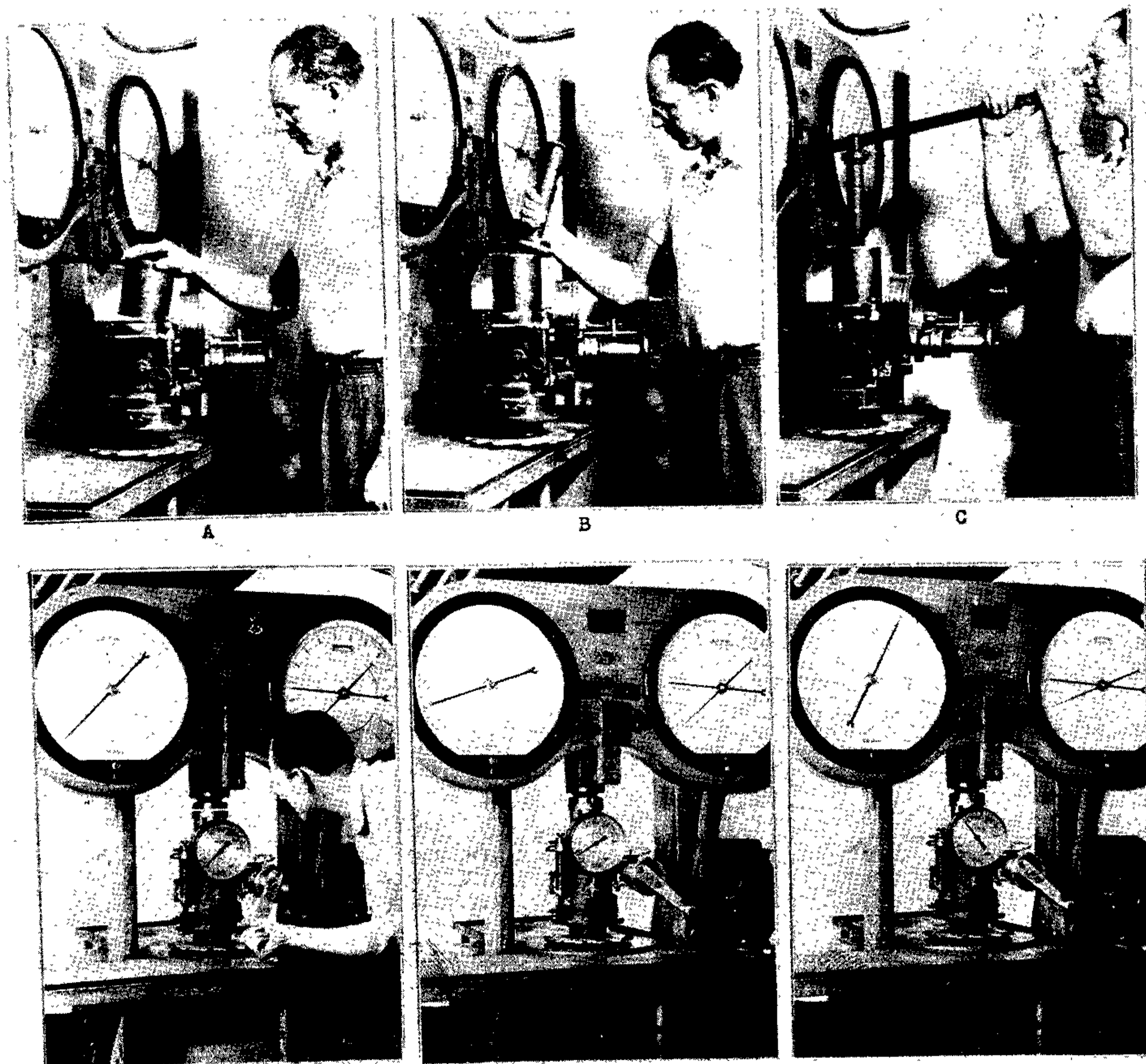


Fig. 2



A B C

D E F

Fig. 3

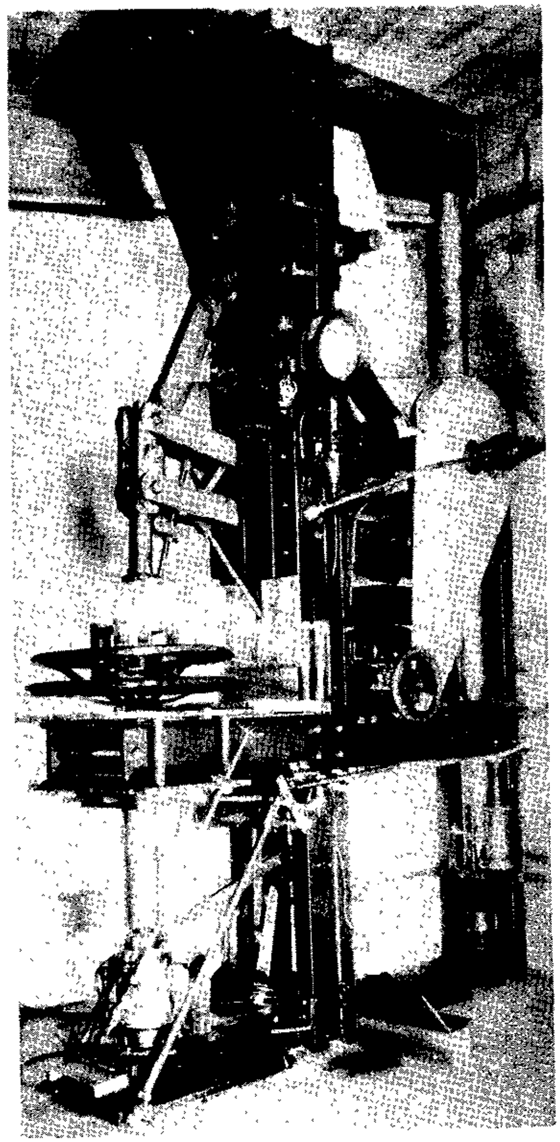


Fig. 4
Semi-Automatic
Mechanical Compactor
Constructed by California
Division of Highways in 1935

Fig. 5

CHART SHOWING STABILOMETER READING (P_h) UNDER DIFFERENT VERTICAL LOADS (P_v)

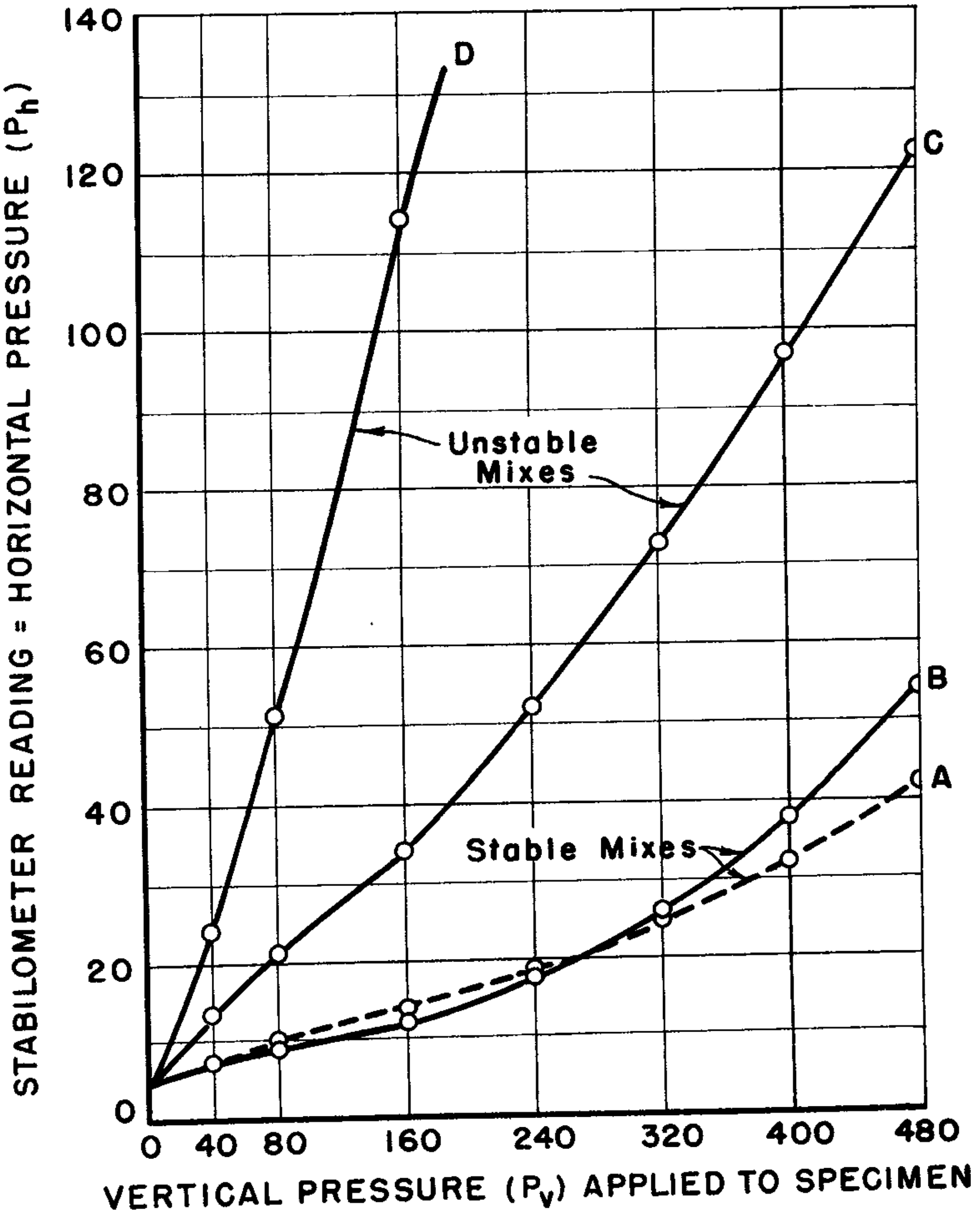
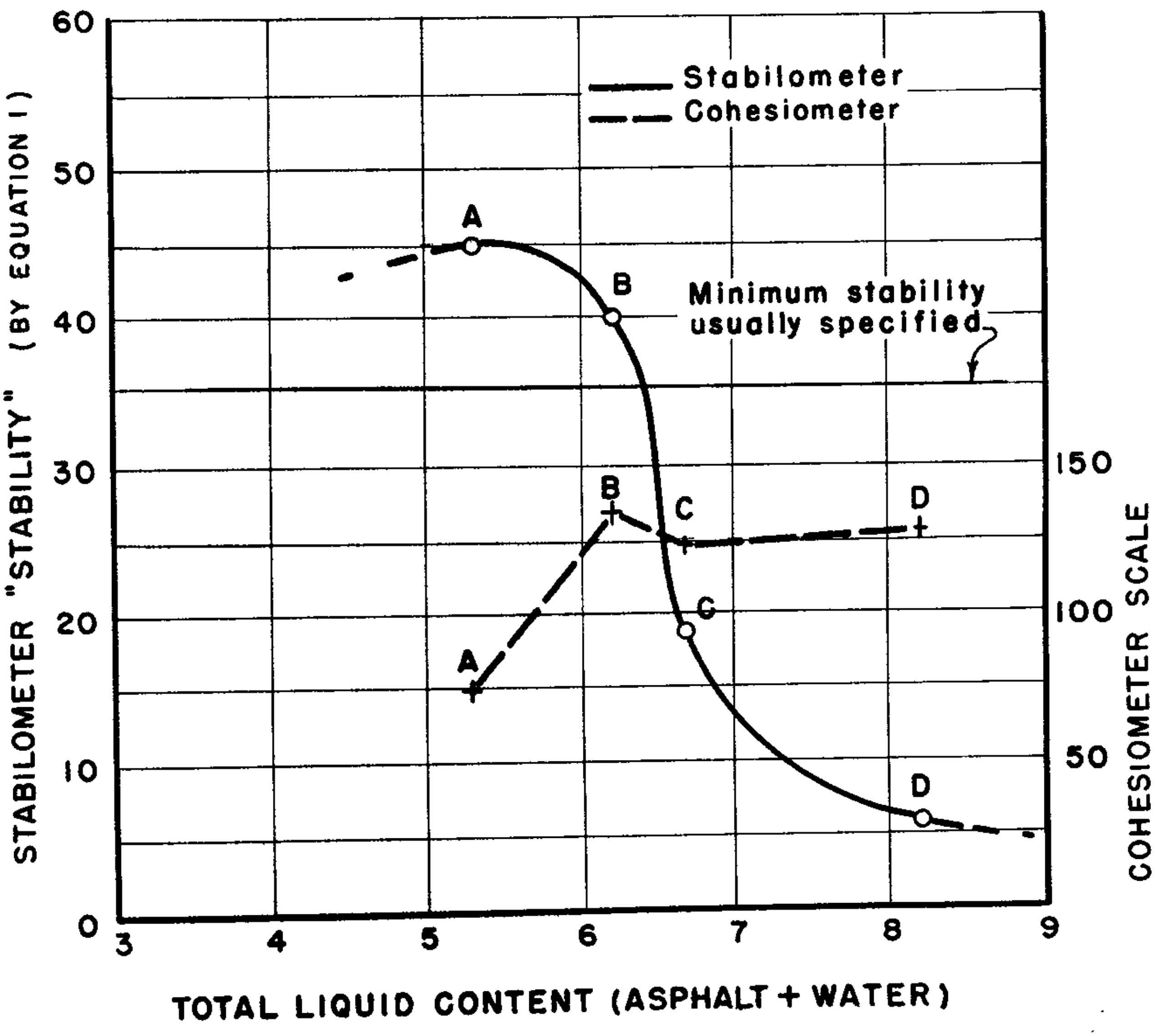


Fig. 6

STABILOMETER AND COHESIOMETER VALUES ON FOUR SPECIMENS WITH DIFFERENT LIQUID CONTENT



DESCRIPTION OF OPERATIONS ILLUSTRATED BY FIGURE 3

A - Steel mold 4 in. in diameter containing compacted test specimen is placed in position on top of Stabilometer. Mold fits into recessed seat providing correct alignment.

B - Steel follower or ram with 4 in. diameter face is placed on surface of test specimen inside of steel cylinder.

C - The specimen is forced into position in Stabilometer by means of a hand lever engaging a fulcrum on testing press.

D - Steel mold is removed, loading follower is put in place and Stabilometer is placed on the platen of the testing press. The operator is shown adjusting the initial lateral pressure to 5 p.s.i. by means of the displacement pump.

E - Test under way. The left-hand dial of the testing press indicates 1000 pounds total load which corresponds to approximately 80 p.s.i. (P_v) on a specimen having an end area of approximately 12.5 square inches. On the specimen shown, the Stabilometer dial indicates about twelve pounds lateral pressure (P_h) at this point.

F - The testing press is operated at a speed of .05 in. per minute and loading is continued at this rate until a total of 6000 pounds is reached (480 p.s.i.), (at which point the specimen shown registers a lateral pressure of approximately 87 p.s.i.). For bituminous surfaces, "stability" is calculated from the Stabilometer readings taken when the vertical load is equal to 400 p.s.i.

Fig 8

RESISTANCE VALUE CALCULATED TO INCLUDE BOTH STABILOMETER AND COHESIOMETER VALUES

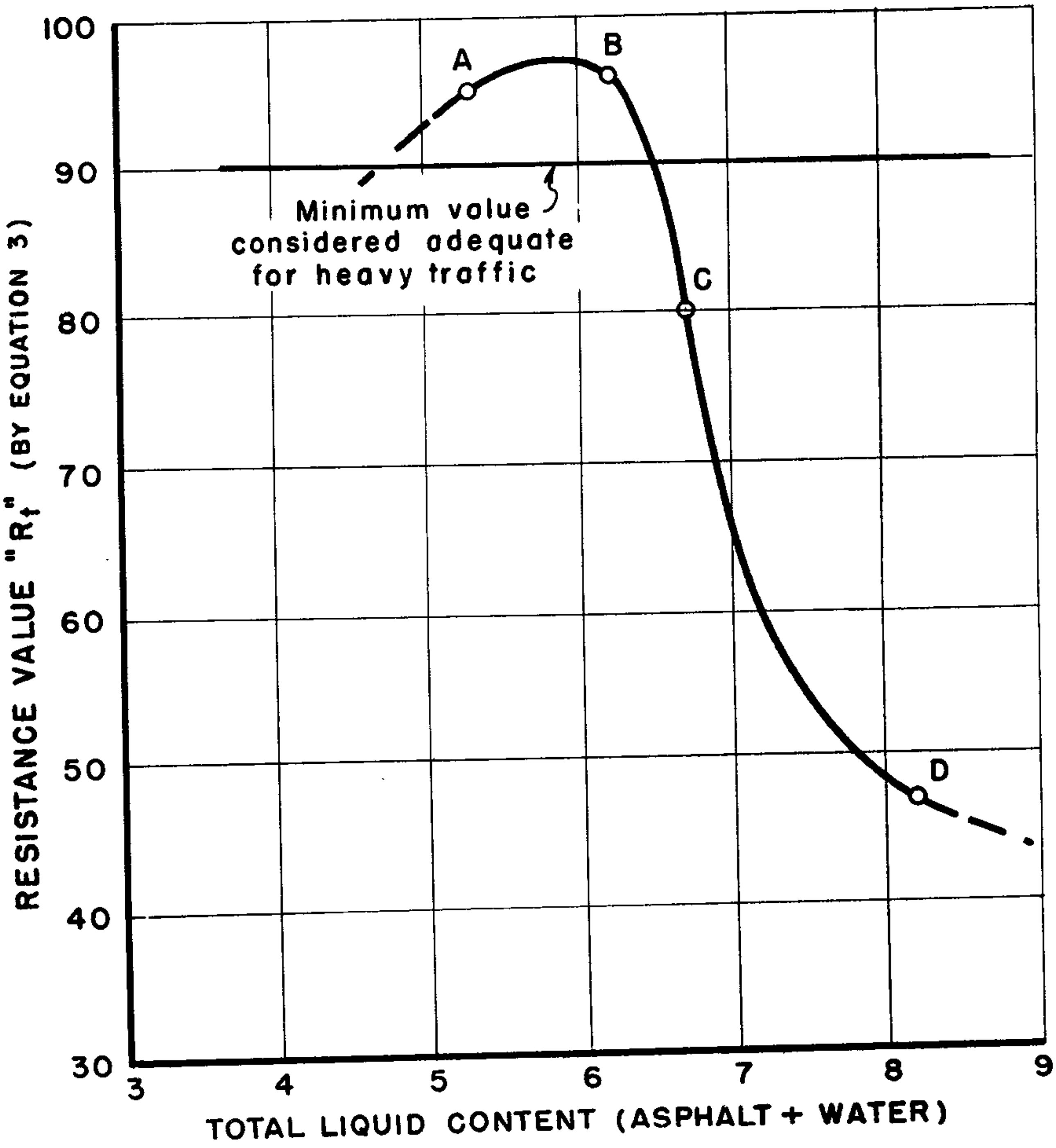


Fig. 7

RESISTANCE VALUE CALCULATED FROM STABILOMETER RESULTS ALONE