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16. ABSTRACT

The Stabilometer is one of the principal testing instruments upon which the California design method is based. Development of this triaxial compression device began in the early 1930's, while studies were being undertaken concerning the plastic deformation characteristics, or so-called "stability", of asphaltic mixtures.

The first device consisted of a cylindrical split steel band equipped with a restraining coil spring and an "Ames" dial spanning the opening to measure the expansion during the test. A test specimen was confined in the sleeve and as an axial compression load was applied, the lateral movement or expansion of the metal sleeve was measured with the dial gage. Through a process of evolution over the years, a hydraulic device was subsequently developed and refined into the "modern" Stabilometer as we know it today. This transition is illustrated in Figure 1 where the various stages in development of the steel band models are shown from left to right in the upper row and likewise for the hydraulic models in the lower row.

Briefly, the present Stabilometer consists of a cylindrical, magnesium shell which has a portion of the inside walls hallowed out and a neoprene rubber sleeve or diaphragm fixed in position over the depression. The cell, or annulus formed behind the diaphragm, is filled with a hydraulic fluid and is connected to a pressure gage mounted on the outside of the shell. A screw type pump is also provided for the purpose of adjusting the volume of fluid in the cell. The schematic diagram shown in Figure 2 illustrates the placement of the 2-1/2" high x 4" dia. test specimen in the Stabilometer and the application of vertical loading with a testing press. That portion of the vertical load which is transmitted by the specimen to the liquid annulus in the Stabilometer, is registered on the pressure gage.

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THE HVEEM STABILOMETER AND ITS APPLICATION TO SOILS IN THE STRUCTURAL DESIGN OF PAVEMENT SECTIONS

By

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Soils Engineering Associate

Presented at

Twelfth Annual Road Builders Clinic
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Daniel R. Howe*

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While the Stabilometer was originally devised for the testing of bituminous mixtures, its application was extended to the field of soil mechanics in the early 1940's and reported in a Highway Research Board paper by Hveem and Carmany in 1948*. The studies have demonstrated that the principal property by which granular materials resist deformation under a load, is the contact friction between adjacent solid particles or as it is more commonly called "interparticle friction". The resistance offered by a soil, as derived from the Stabilometer, is expressed as the ratio between the lateral transmitted pressure and a vertical pressure of 160 psi applied with a testing press. This ratio provides an index indicating the resistance to plastic flow, arranged on a linear scale of 0 to 100, which is called "The Resistance" or R-value. The general equation for R-value is:

$$R = (1 - {}^{Ph}/_{Pv})\ 100$$

Where Ph & Pv are horizontal and vertical pressures respectively.

*F. N. Hveem and R. M. Carmany "The Factors Underlying the Rational Design of Pavements". Proceedings Highway Research Board, 1948.

This relationship may be summarized by stating that the lateral pressure will vary inversely with the internal resistance of the mass. For example, an R-value of 100, indicates a material which exhibits no deformation, under the load imposed by the test, and consequently no lateral pressure transmittal. Conversely, a zero R-value indicates the absence of shear resistance and the lateral pressure would equal the applied load as in the case of a liquid. In general soils used in highway construction range from less than 5 to about 85 R-value.

The Stabilometer has proved to be an extremely effective instrument for realistically anticipating the physical behavior of soil layers which are acted upon in a roadbed by relatively local and often intense wheel loads. In the usual academic approach to soil mechanics, two principal internal strength properties are recognized. These are: (1) friction and (2) cohesion. As previously stated friction is derived from contact between two or more solid particles and is dependent upon roughness and contact pressure. The term cohesion as used in soil mechanics means that part of the strength or resistance that is independent of the pressure. On the other hand, the dictionary definition, and as used in our analysis, cohesion means the tensile strength exhibited by the material and in untreated soils this is largely dependent upon the presence of water and clay. Our experience has demonstrated that while cohesion is an important strength factor in the upper layers of the structural section, it is of little consequence in the underlying soils and the primary source of "stability" is inter-particle friction. As a matter of fact, since roadbeds will normally contain moisture in varying amounts (i.e. from capillarity, evaporation-condensation phenomena or infiltration of surface water) the clay element, from which cohesion is largely derived, will actually be detrimental to the stability of the soil. The combination of clay and water forms an effective lubricant and will reduce or destroy interparticle friction which, on the basis of overall resistance to plastic deformation, can more than nullify any slight benefit obtained from soil cohesion. Evidence that the Stabilometer primarily reflects the internal friction factor and the effect of clay lubricity is shown in Figure 3. In this chart, R-value test determinations are displayed for a clean gravel which has had increasing percentages of several different clay minerals added. It is noted from the left hand curve that the R-value drops immediately and dramatically when as little as 5% bentonite (montmorillonite) is added.

Along this same line, it has long been known that the various types of clay minerals will differ widely in so-called "plastic" behavior. Kaolinite is considerably less active than montmorillonite and illitic clays will vary somewhere between these two. The right hand curve in Figure 3 where kaolinite was added to the gravel, demonstrates by comparison with the "bentonite" curve, how the Stabilometer discriminates between the clay types. The kaolinite being less active and therefore having less lubricity, requires in excess of 14% clay before the R-value of the mixture begins to drop seriously. Actually, in nature the clay component of soil is rarely in pure mineralogical form, and the middle curve, labeled "gravel and local clay", probably represents a mixture of two or more clay types.

Integration of the Stabilometer into a structural design method began with correlation studies on our own test track, located just east of Sacramento in Brighton (1940-43) and at the Army Corps of Engineers Airport test facility in Stockton (1942). The resulting design method was adopted by California in 1951. While subsequent experience on our highways has required some alterations in certain design assumptions, the basic relationship of the variables affecting the structural integrity of the roadbed remains in accordance with the original concept.

On the basis of the test track findings, three primary variables are currently evaluated in determining the thickness and character of structural elements which will be capable of supporting traffic loads. One of the variables concerns the active or motivating factor and refers to the destructive effect of traffic. This is the combined affect of weight and number of wheel loads to produce plastic deformation which we express in numerical values as the traffic index. The other two variables are resistive in nature and embody the strength factors of the materials employed in the structural section. First, there is the structural quality of the soils which make up the roadbed. This is the ability of the soil to resist plastic deformation and is, of course, measured in terms of R-value. Secondly, there is the slab value of the pavement and supporting layers. This varies in relation to the tensile strength of the layers and is expressed as a cohesiometer value, which will be explained later. From the relationships established in the test track studies, these three variables are arranged in an empirical equation which is given as follows:

$$T = .095 \frac{(\text{Traffic Index})(90-R)}{\sqrt[5]{\text{Cohesion}}} = \text{Inches of cover.}$$

This equation is the basis for our present structural design method and for ease of calculation it is conveniently arranged in the form of a nomograph as illustrated in Figure 4.

Past test track studies have also indicated a fourth important variable, which at the present time is not evaluated directly in any design formula. This factor concerns the "springy" or resilient behavior of the structural section which is evidenced on the road by the deflection (i.e. momentary depression and rebound) of pavements under moving wheel loads. Experience has demonstrated that the continual flexing of bituminous pavements, where relatively high deflections occur, can result in failure of the surfacing by fatigue and form "map" or "alligator" type cracks. Since pavement deflection is normally associated with the resilient properties of underlying soils layers, we have been directing intensive research studies towards developing a test for predicting potential resilience of these underlying soils and integrating this information as a variable into the design method. A reliable testing device, called the Resiliometer, has been developed and correlation with field performance is now well under way but the work is not yet complete.

In an effort to amplify the physical significance of the present California design equation it is appropriate, at this point, to discuss some of the fundamental concepts behind the relationship and the manner in which numerical values are developed for the variables.

The destructive effect of traffic involves two primary factors which are (1) load magnitude and (2) repetitions of the load. From our test track data it was possible to establish a proportionality between these two variables and cover thickness (T) which is given as follows:

$$T \propto \text{load}^{0.57} \times \text{repetitions}^{0.113}$$

In applying this relationship to highway traffic, it is immediately apparent that the cost and difficulty of weighing even a sample of all truck traffic for each design situation, would be prohibitive. It has, therefore, been found expedient to evaluate traffic in terms of a common unit of 5000 lb. equivalent wheel load repetitions or as we call it EWL. This is accomplished through the use of constants which were developed from statistical analysis of a statewide loadometer survey and the application of the above proportionality. These constants are established for various axle groupings as shown in Table I. The annual EWL for any given section of highway may then be computed from average daily traffic tabulations by multiplying the respective constant by the number of vehicles in the different axle groups and taking the summation of all group EWL's. For design purposes this EWL is totaled for 10 years with adjustment for a future increase in truck traffic. The Traffic Index, which gives numerical values ranging roughly on a scale from 2 to 13, is calculated from the following equation:

$$T.\ I. = 1.35\ (EWL)^{0.11}$$

TABLE I

EWL Constants

Axle Group	Average Daily Traffic Multiplier
2 axle	330
3 axle	1070
4 axle	2460
5 axle	4620
6 axle	3040

The two "resistive" variables in our design equation, R-value and cohesion, both work to restrain plastic deformation. This can be demonstrated by referring to the schematic diagram in Figure 5(b). If we consider that a heavy block load is impressed upon a surface, then the soil particles in the lower reaches will tend to move laterally away from the load into zones of lesser pressure. The principal deterrent to this movement will be the R-value of the soil. However, if there is sufficient lateral deformation in spite of the shear strength of the soil, then by displacement, a wave will form in the surface outside of but adjacent to the load. From this it can be visualized that the pavement and base are subject to tensile stresses and that the higher the tensile strength displayed by these layers, the greater will be the resistance to deformation. In addition, the stiffness of the surface materials immediately under the load tends to reduce stresses which promote plastic flow in the underlying soils. Since cohesion serves as a measure of a material's ability to resist tensile stresses, it is logical that this function be included in the design evaluation.

The cohesion values used in the design equation are based upon our own cohesiometer test. Briefly, this test consists of confining a 4 inch diameter specimen with two clamps which are connected at the bottom legs only by a hinge as shown in Figure 6. A steadily increasing load is added to the beam until the specimen fractures at the hinge from the tensile stress acting along the entire vertical plane. The cohesiometer value is expressed as the breaking load in grams per inch of width for 3 inches of height. It may be compared to the Modulus of Rupture Value for concrete for example.

For design purposes, cohesiometer values have been established for various common road building materials as shown in Table II.

TABLE II

Design Cohesiometer Values

Material	Cohesiometer Value
Asphaltic Concrete	400
Cement Treated Base, Class A	1500
Cement Treated Base, Class B	750
Road Mixed Surfacing	150
Soils, Aggregate Bases and Class C CTB	100

Where multilayer systems are involved (e.g., AC over CTB) it is necessary to determine a single equivalent value for the combination of layers. This is calculated on the basis of a proportional relationship between the respective cohesiometer values and assumed layer thicknesses. For convenience equivalent cohesiometer values are given in a table in our Materials Manual for various combinations of materials and layer thicknesses.

In the process of determining an R-value for application to the design equation, it is important that the material be tested in the most unfavorable condition that may be expected to develop in the roadbed during the life of the project. Application of this criteria requires that the sample should first be compacted to the anticipated "worst structural condition" and then tested in the Stabilometer in a moisture state as near to full saturation as possible. Full saturation with moisture presumes the worst possible stability condition a soil might be expected to experience during its service life in the roadbed.

In the test procedure, 4 in. diameter by 2-1/2 in. high test specimens are fabricated with a special mechanical compacting apparatus (See Figure 7) which consolidates the material through a kneading like action. The machine alternately applies and releases a pressure of 350 psi to small sectors, successively around the specimen face, while the balance of the surface is unrestrained. This type of compaction develops a working of the soil which simulates the action given to the road by normal compaction equipment.

Saturation is approached after mechanical compaction, by the unique expedient of loading the material, confined in a steel mold, with a testing press until moisture is just squeezed from the specimen. In effect, this process closes down the pore spaces in the specimen until they become filled with contained water as indicated by the exuding moisture. The pressure exerted by the press at the point where moisture begins to squeeze out of the specimen is called the Exudation Pressure.

Except where highly expansive materials are encountered, the design R-value is based upon the test R-values interpolated to a theoretical specimen which would exude water at 300 psi exudation pressure. This is assumed to represent the worst condition likely to be reached by the soils in place a number of years after construction. Based on test data and considering overall soil types, climate, drainage and current construction practices in California, the 300 psi level provides a reasonable correlation with actual soil conditions.

In the conduct of the test procedure, three or four specimens are normally fabricated at different moisture contents to give exudation pressures ranging between 100 and 800 psi. After completion of the exudation pressure phase, the specimens are subjected to an overnight expansion pressure test and then tested for R-value in the Stabilometer the next day. The R-value of each specimen is plotted against the respective exudation pressures and connected with a smooth curve as shown in the left hand chart of Figure 8. With this curve, it is then a simple matter to determine the R-value at 300 exudation pressure, which is the R-value used in the design equation if the material is non-expansive.

If the soil contains appreciable amounts of clay material which will swell on exposure to free water, then further analysis must be undertaken. The problem with expansive soils under bituminous pavements concerns the lowering of stability that is associated with the moisture takeup and disruption of particle arrangement which normally occurs during the act of swelling. Since the restraining weight (or pressure) of cover is the principal force opposing expansion, it is logical that the amount of dead load needed, be evaluated in terms of expansion pressure which the soil is capable of developing.

The expansion pressure test is performed utilizing a device which confines the compacted soil specimen under a perforated disk equipped with a stem which impinges on a previously calibrated spring steel bar as shown in Figure 9. The perforated disk is covered with water and any specimen expansion will deflect the bar. After 24 hours the deflection is measured with a dial gage and knowing the stress-strain relationship of the bar, the expansion pressure exerted by the specimen can be calculated. This pressure is in turn converted to inches of cover necessary to provide a balancing weight, by assuming a unit weight for the cover (e.g., 130 p.c.f.).

Referring again to Figure 8, the expansion pressures for the individual specimens, expressed in inches of cover, are plotted against moisture at compaction. Likewise, the thickness of cover is calculated from the Stabilometer R-values, by means of the design equation, and plotted on the same chart. The intersection of the two curves is the point where the thickness of cover required to support traffic from the standpoint of stability is also sufficient in weight to restrain further expansion of the soil. The R-value represented by the thickness at the intersection of the curves, is used for design if it is numerically <u>less</u> than the R-value determined at 300 exudation pressure.

In this presentation, I have attempted to summarize the role played by the Stabilometer in our approach to pavement design. In no sense do we claim to have an overall panacea for difficulties encountered in road structures. The task of engineering modern highways to carry the ever increasing traffic loads is complex and there are innumerable interacting factors which still must be resolved. However, we firmly believe that any ultimate satisfactory solution to the problems will only be reached through actual measurements and experiments which are realistically undertaken.

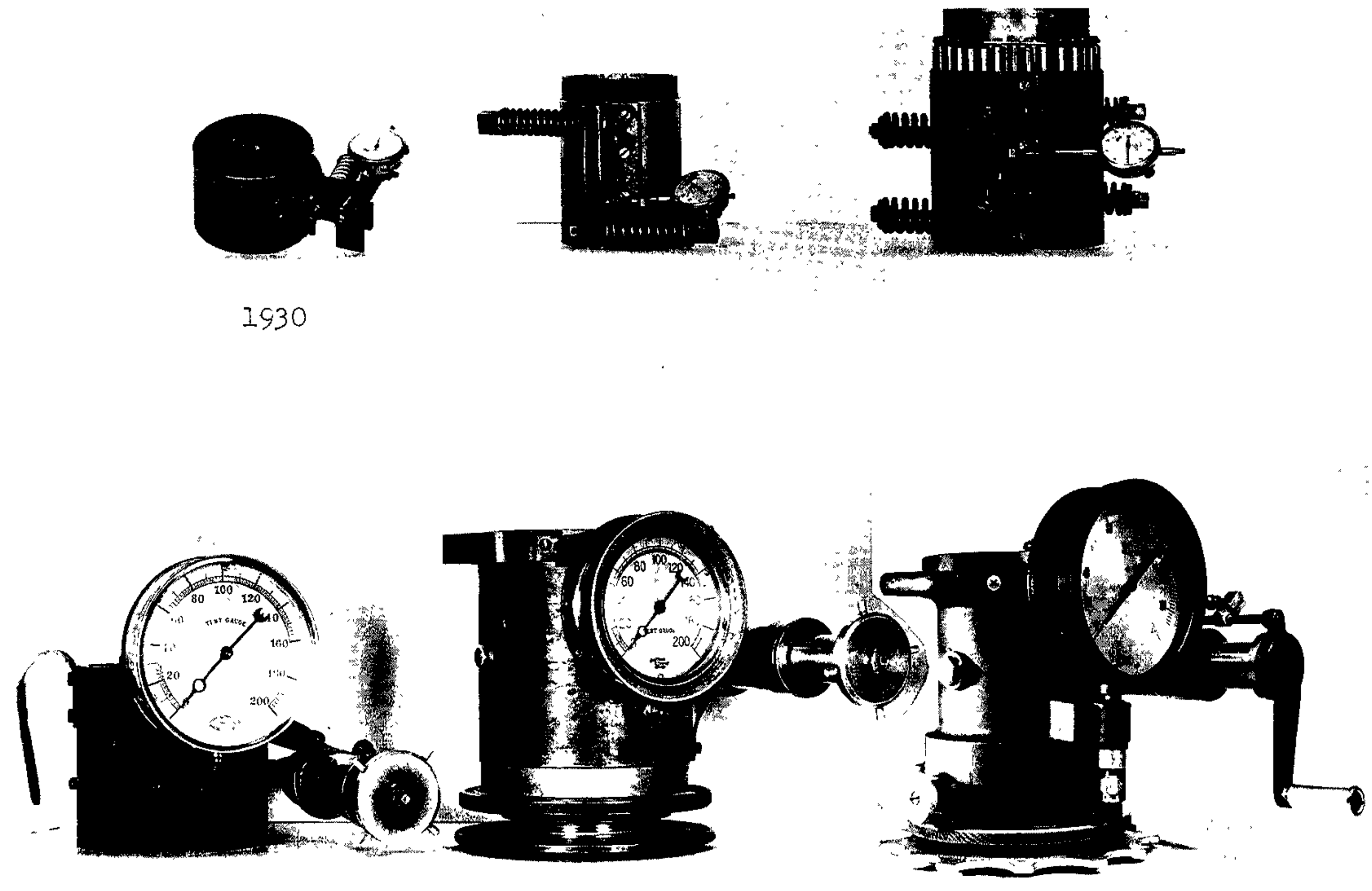

FIGURE 1

The Evolution of the Stabilometer

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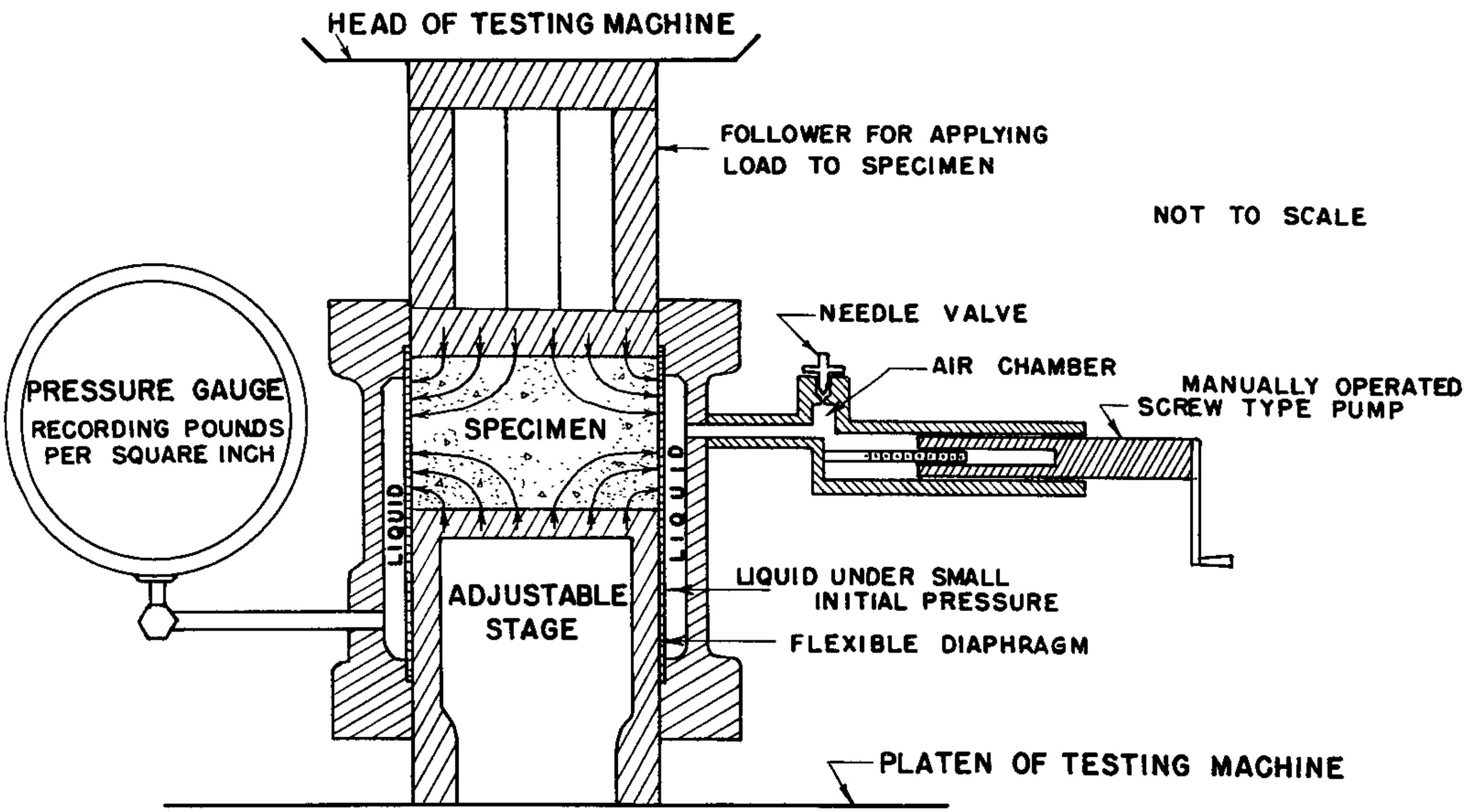
Materials and Research Department

DIAGRAMATIC SKETCH OF THE HVEEM STABILOMETER



NOTE: SPECIMEN GIVEN LATERAL SUPPORT BY FLEXIBLE SIDE WALL WHICH TRANSMITS HORIZONTAL PRESSURE TO LIQUID, MAGNITUDE OF PRESSURE MAY BE READ ON GAUGE.

FIGURE 2

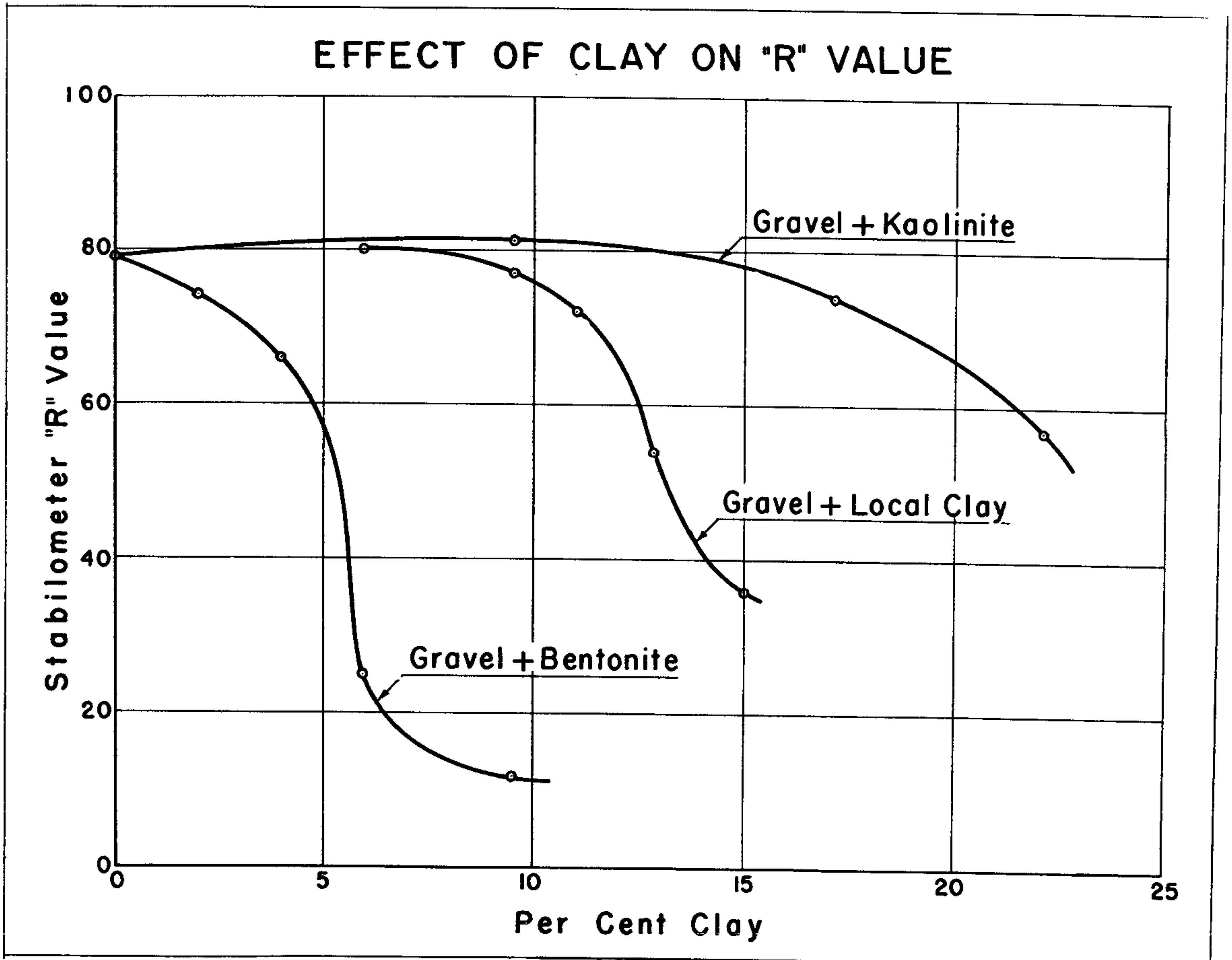

EFFECT OF CLAY ON "R" VALUE
Stabilometer "R" Value
100
80
60
40
20
0
0
5
10
15
20
25
Per Cent Clay
Gravel + Kaolinite
Gravel + Local Clay
Gravel + Bentonite

FIGURE 3

STATE OF CALIFORNIA
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MATERIALS & RESEARCH DEPT.

DESIGN CHART FOR THICKNESS OF INCREMENTS OF PAVEMENT STRUCTURE

PROCEDURE FOR USE OF CHART

The chart solves the following formula:

$$T = \frac{0.095\,(T.I.)(90-R)}{\sqrt[5]{C}}$$

With a straightedge intersect Scale E at the R-value (R) of the soil tested and Scale F at the design Traffic Index (T.I.). Scale G is a turning point on the nomograph and indicates the thicknesses of gravel cover needed to sustain the design T.I. providing the cohesion of the surface layers is neglected. From the point on Scale G intersect Scale H at the cohesiometer value (C) of the layers above the material in question. The intersection with Scale I determines the required thickness (T) (corrected for the cohesion of the surface and/or base) of cover material needed to prevent plastic deformation of the soil tested.

EXAMPLE

Given

R-value of a soil = 21
EWL = 19,200,000 (T.I. = 8.7)
Cohesiometer value (c) = 620*

* See Calif. Materials Manual Test Method 301-B for method of calculation for layered system.

Answer

Thickness of cover (T) = 16"

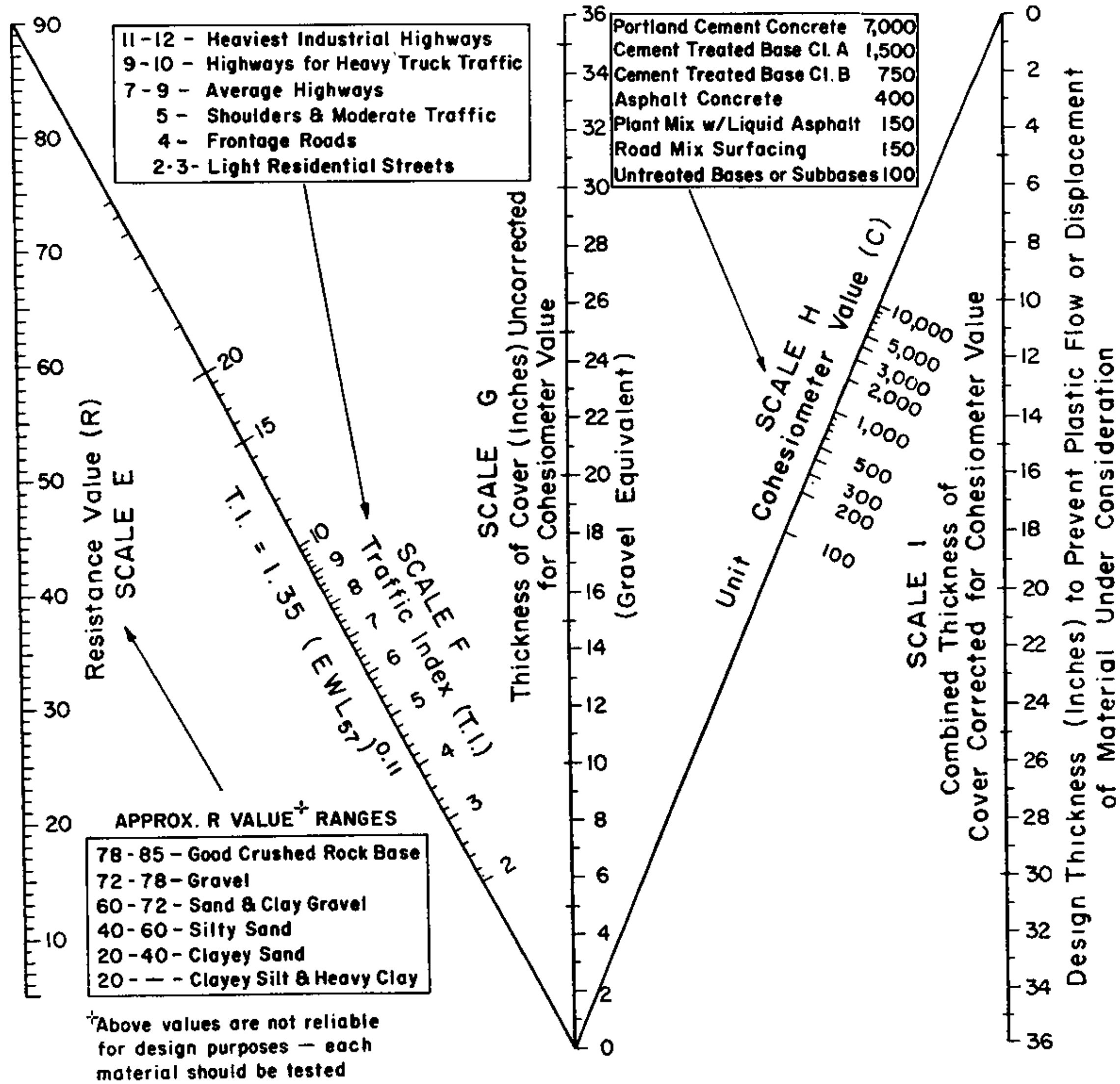


FIGURE 4

SCHEMATIC REPRESENTATIONS OF PRESSURE AND PLASTIC FLOW PHENOMENA

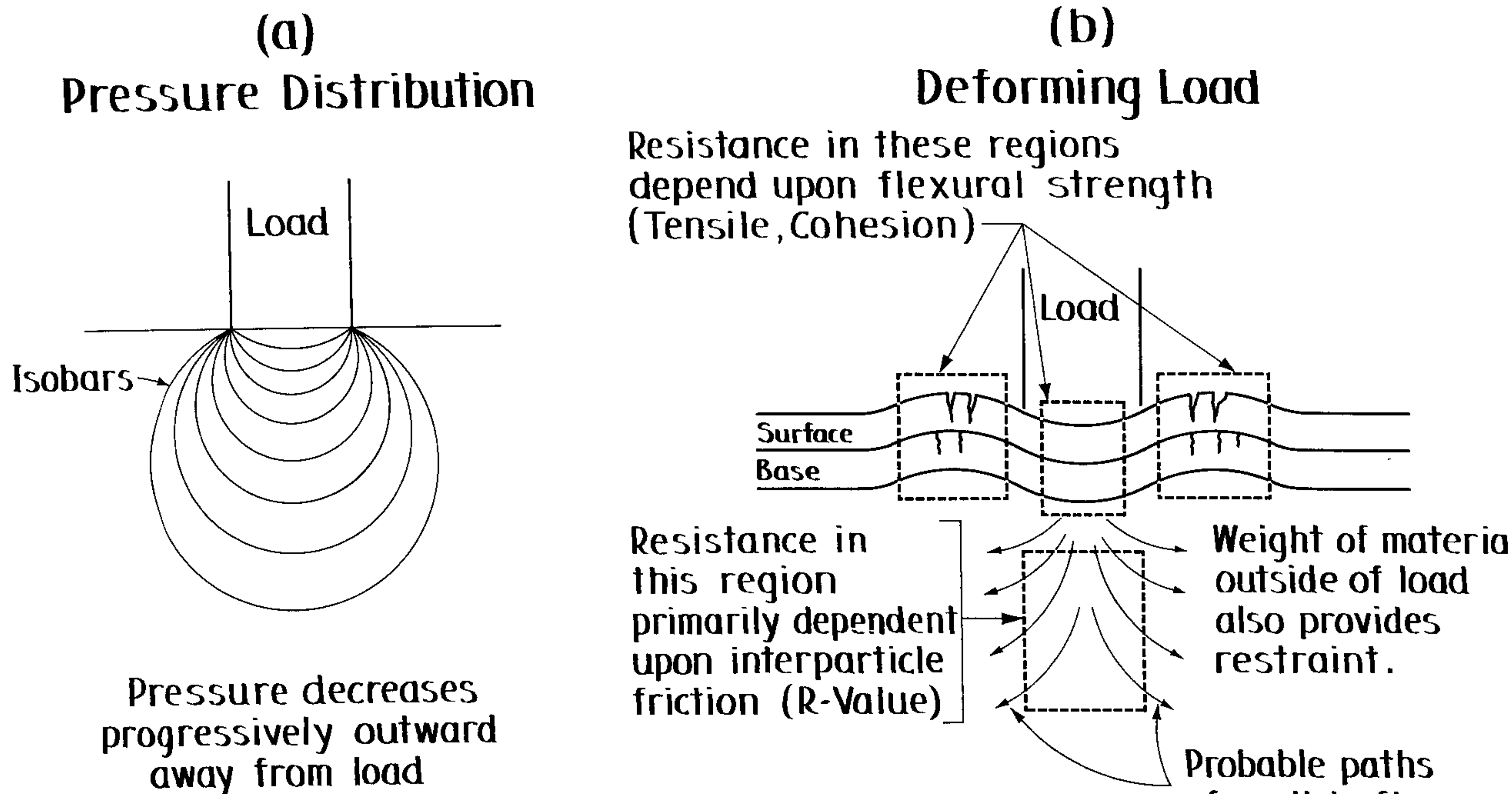
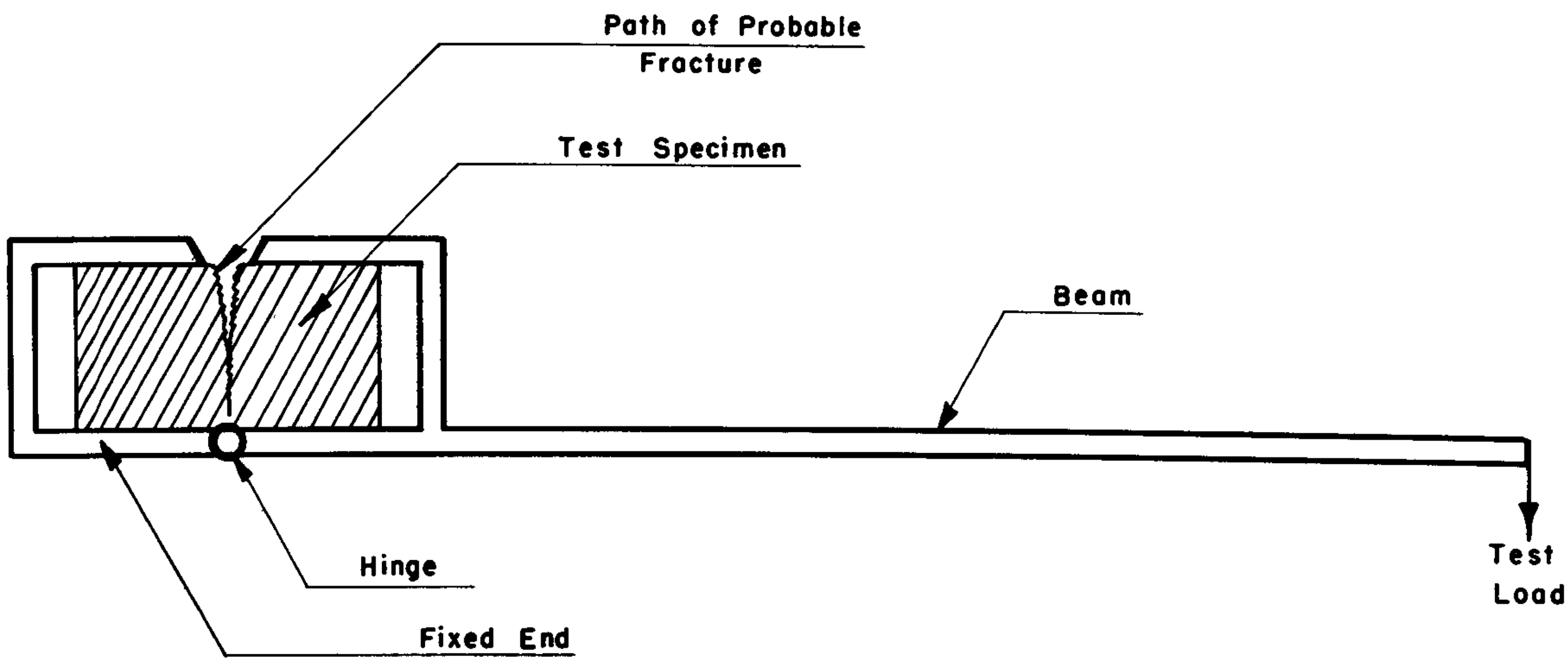


FIGURE 5



SCHEMATIC ARRANGEMENT OF THE APPARATUS USED IN THE COHESIOMETER TEST

FIGURE 6

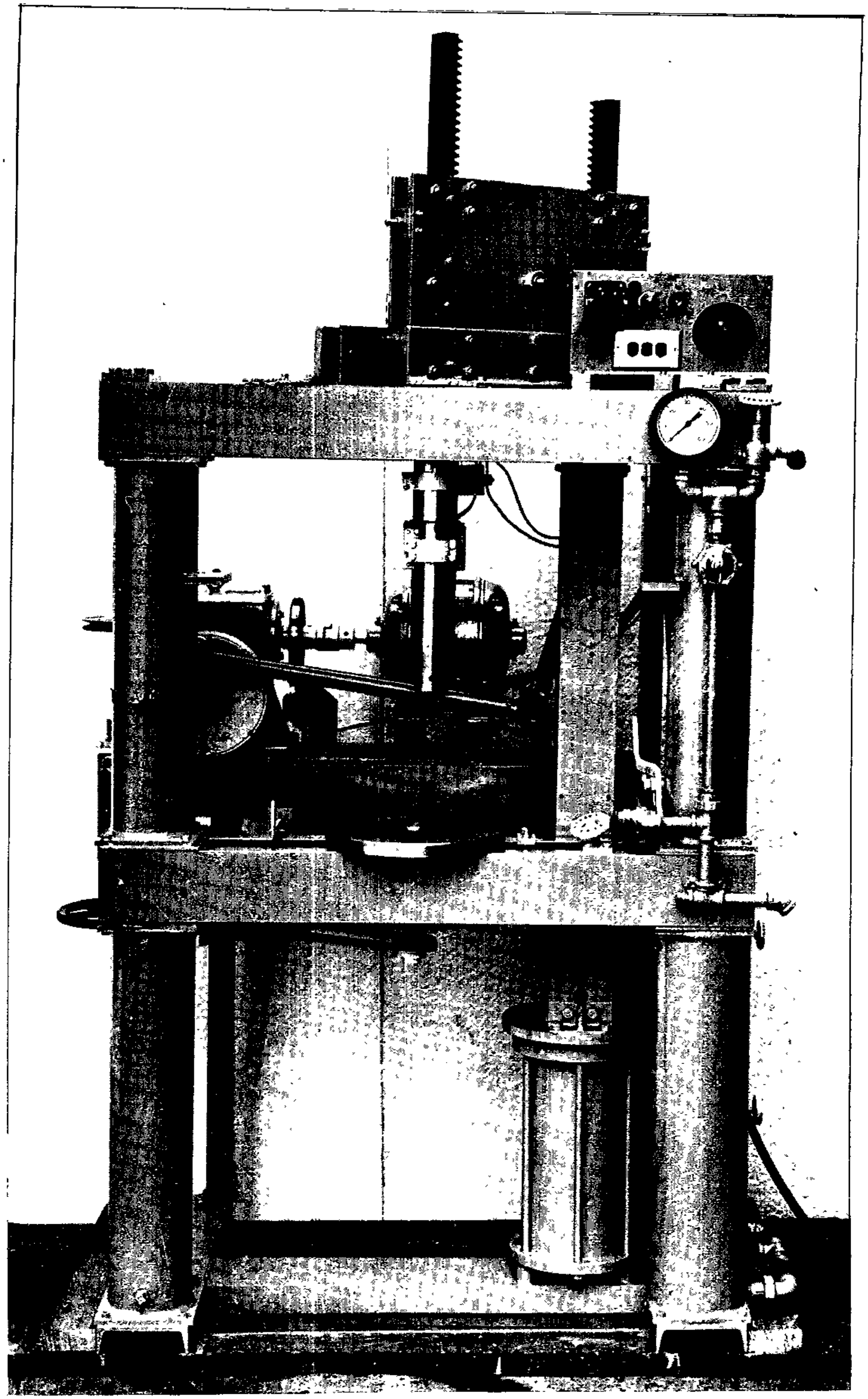
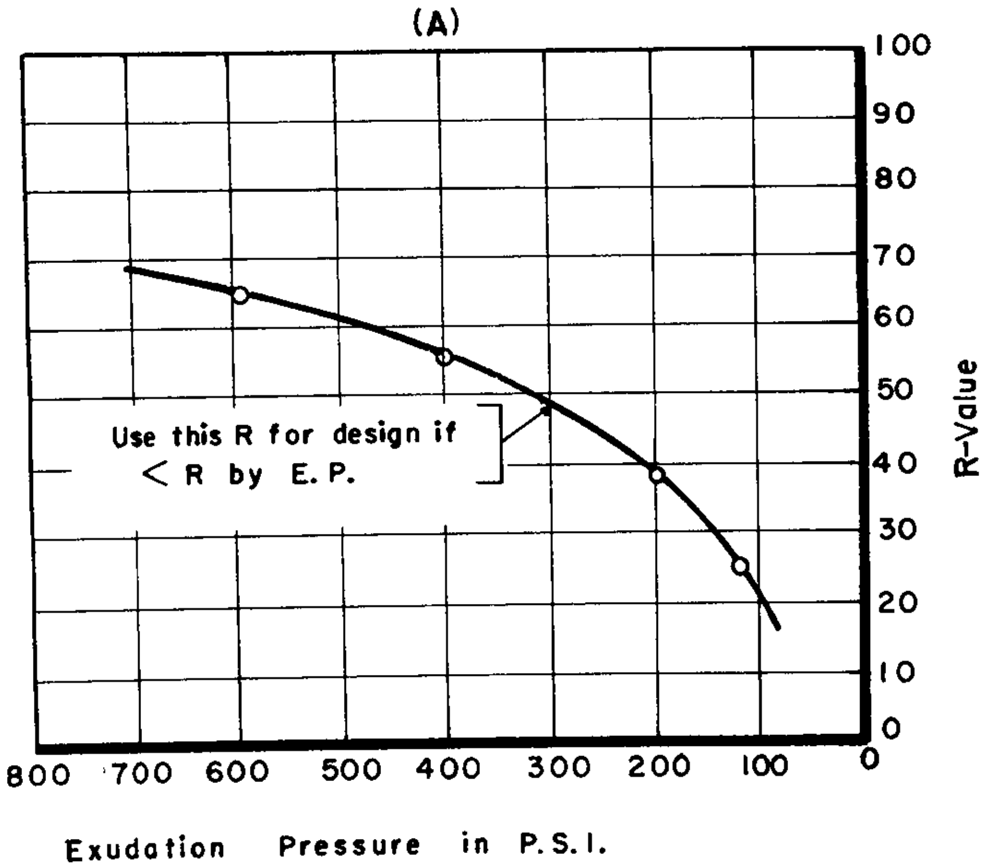
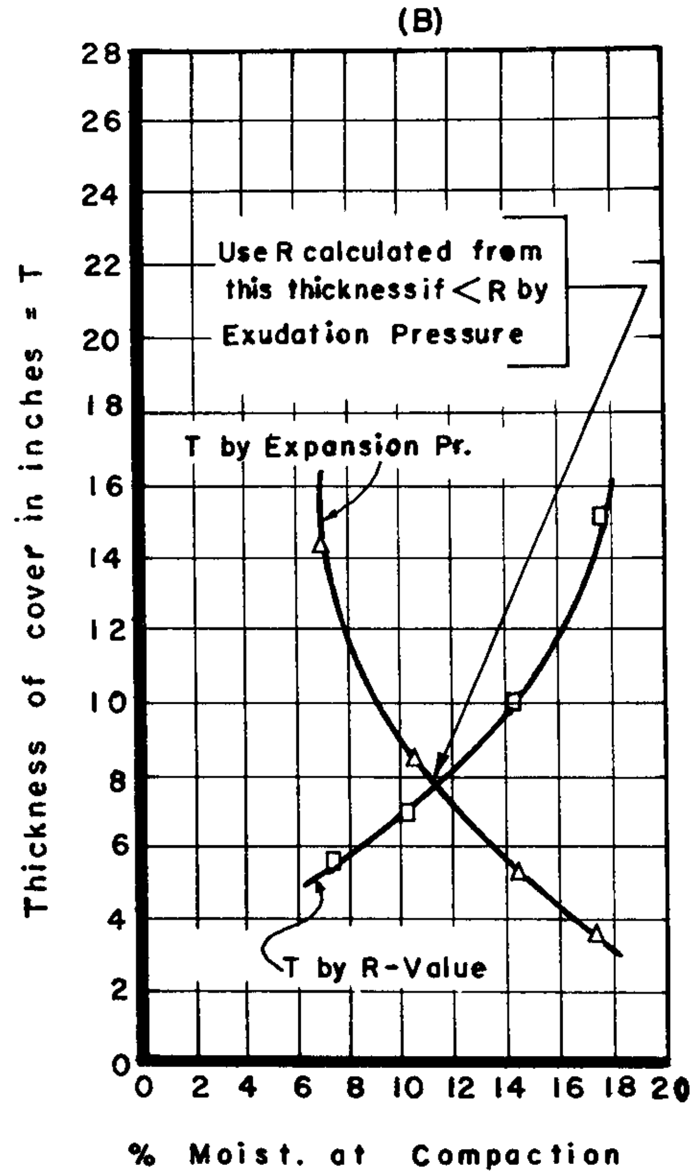


FIGURE 7

The California Mechanical Kneading Compactor





Design Determinations by The R-Value & Expansion Pressure Tests

FIGURE 8

SCHEMATIC DIAGRAM OF EXPANSION PRESSURE DEVICE

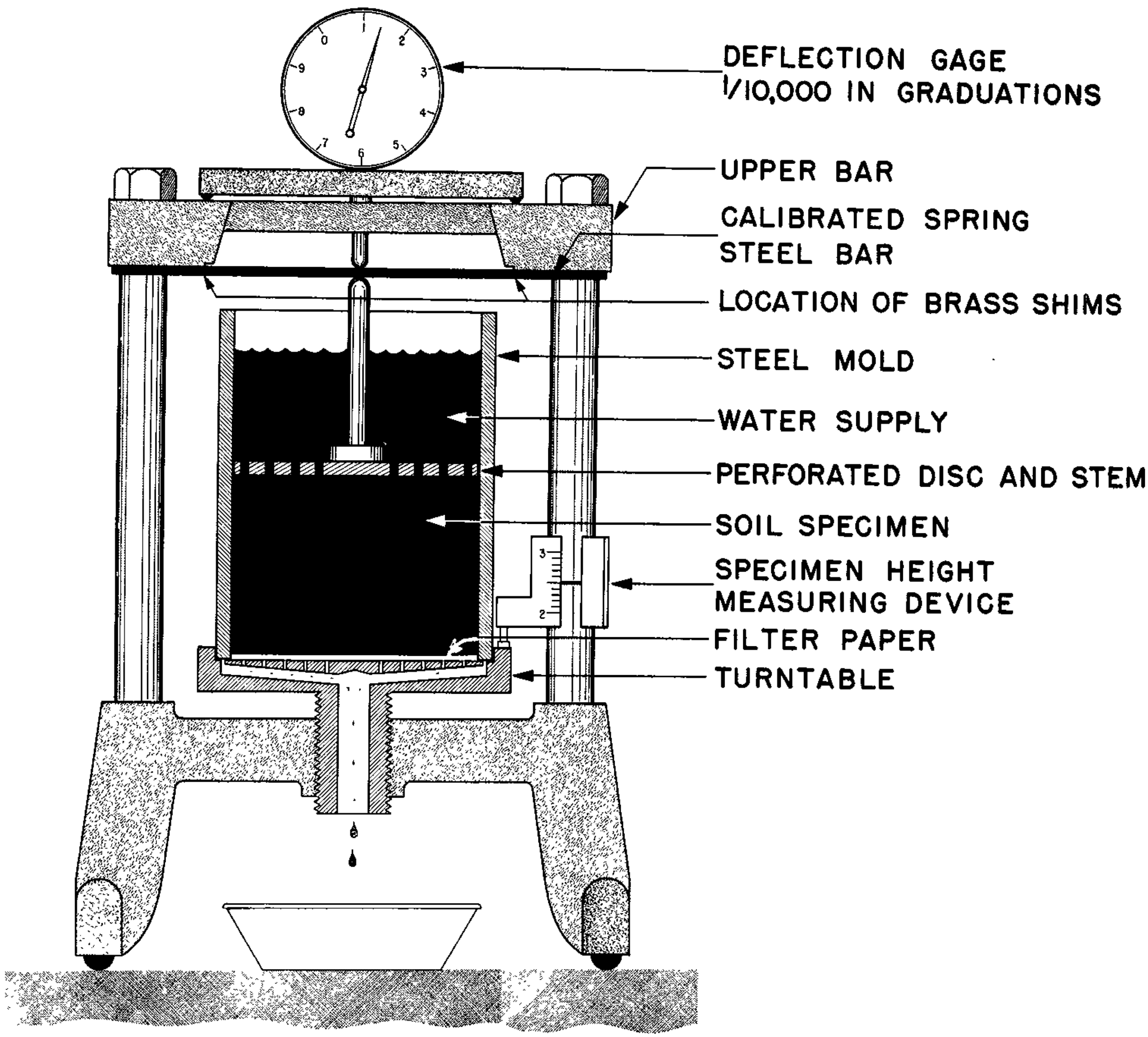


FIGURE 9