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Introduction

This is a summary report of research directed at improvement of the R-value test (Test Method No. Calif. 301) by evaluation of factors which may affect its reproducibility. The R-value test is performed in the Laboratory to determine the strength of soil samples which are compacted through a range of moistures. The test results are used to design pavement structures, evaluate and qualify materials for specification compliance, as well as in research.

The work conducted under this authorization was performed between mid-1965 and 1971. It includes a number of individual studies of variables in the soil preparation, compaction and testing phases of the test. The research included the evaluation of newly developed semi-automatic R-value equipment, which was expected to further reduce testing error. Also, a preliminary estimate of single and multiple operator variance was made.

This report is presented on the assumption that the reader has a technical familiarity with the R-value test, therefore a discussion of its details (which are complex) has been excluded. Perspective on the history and development of the R-value test may be gained by reference to the list of uncited references, which is appended.

Particular emphasis is given to those findings for which implementation is indicated, but has not yet been accomplished. There are also included recommendations for further work, which appear warranted either from this research, or the observed characteristics of the R-value test.

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A Summary Report By: Robert E. Smith

Under Supervision of: George B. Sherman

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INTRODUCTION

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The work conducted under this authorization was performed between mid-1965 and 1971. It includes a number of individual studies of variables in the soil preparation, compaction and testing phases of the test. The research included the evaluation of newly developed semi-automatic R-value equipment, which was expected to further reduce testing error. Also, a preliminary estimate of single and multiple operator variance was made.

This report is presented on the assumption that the reader has a technical familiarity with the R-value test, therefore a discussion of its details (which are complex) has been excluded. Perspective on the history and development of the R-value test may be gained by reference to the list of uncited references, which is appended.

Particular emphasis is given to those findings for which implementation is indicated, but has not yet been accomplished. There are also included recommendations for further work, which appear warranted either from this research, or the observed characteristics of the R-value test.

The work performed in the individual studies are briefly described in this report with a summary of results, conclusions or implementation, which resulted from the work. For brevity, supporting data and detailed analyses are not submitted. This information is available in the project file, referenced in accordance with this report index.

RECOMMENDATIONS

1. Amend test method to require oven drying (only) of soils and aggregates at 140°F.

2. Modify test method references to permit use of the newer electro-hydraulic compactors, in addition to the "mechanical kneading compactor", now described.

3. Require that at least one specimen in a set be compacted at the standard 350 psi foot pressure. Also specify a minimum foot pressure, to limit permissible reduction in compactive effort.

4. Review that portion of the test method dealing with correction of R-values according to height of specimen. (It is probable that this should be qualified according to R-value range of soil.) Acceptance or control tests should be within the specified 2.45" to 2.55".

5. Revise "mold roughness" criteria to specify a roughness between 25 and 100 micro-inches/inch, similar to a rough machine finish.

6. Maintain present arbitrary criteria for fixed machine-head with load control of press during the exudation phase of the R-value test, and spherically-seated head with strain control during the stabilometer phase.

7. Continue to evaluate, stock, and supply stabilometer diaphragm material.

8. Revise the present test method to clearly permit use of newer electro-hydraulic testing presses. (At present, the test method describes mechanical features of the older manual hydraulic testing presses.)

9. The exudation phase of the test, presently used to select the design or "control" R-value from the basic data, should be replaced. It is suggested that study of the expected field conditions, as compared with the laboratory data (strength vs. moisture, density, expansion, etc.), will provide a more consistent or rational criteria for this critical decision.

10. Develop and/or maintain a continuing program of operator training and correlation testing between operators.

DISCUSSION

Soil Preparation Phase

Preliminary Drying Methods:

The R-value test requires that test specimens be batched from laboratory processed samples which have been separated by sieve sizes, all coating of fine material removed from the coarse aggregate, and all clay lumps broken down till the material will pass a No. 4 sieve. In many cases drying is required in order to accomplish this preliminary breakdown and separation. The method of sample preparation described in Test Method No. Calif. 201, "Method of Soil and Aggregate Sample Preparation", allows for drying by any means which does not heat the material above 140F. Oven drying at 140F and air drying at room temperature are the two most common methods used. An experiment was carried out to determine whether these methods of drying had any significant effect on the R-value results.

R-value tests were performed on replicate samples of three soil types to compare air-dried samples with oven-dried samples. The oven-dried samples were dried in a circulating air oven at 140F for 18 hours, whereas the air-dried samples were dried at room temperature (approximately 75F) on a splitting canvas for 18 hours. There were no differences in results for the high R-value range and low R-value range materials between air-dried and oven-dried samples.

There was, however, a significant effect on the mid-range R-value soil. The air-dried material had an average R-value of 56 as compared with 43 for the oven-dried. Since these mid-range materials are those which are critical in testing (and design), it is recommended that all soils be oven-dried at 140F in the preliminary preparation phase of the R-value test. Appropriate modification to test methods 201 and 301 should be made in forthcoming revisions.

Pre-Moistening of Soil:

After drying of the soil, it is batched by weight into individual containers. The procedure then provides for a pre-conditioning or "soak" period. It is required that one half to two-thirds of the total moisture required be added at least 16 hours prior for compaction of the test specimens.

Since the amount of soak water is a matter of judgment, there is opportunity for considerable variation, not only between operators, but by the same operator when retesting a given material at another time.

The effect of the "soak" phase on the R-value test was researched by testing three soils (low and high R-value) with: a) no pre-conditioning, b) approximately 2/3 total moisture. The results indicated that the soils with no pre-moistening had consistently higher R-values than the soils which were pre-conditioned.

This means that a certain amount of time is required to get the water into the soil, and rapid testing without pre-moistening could give erroneously high results. The effect was greatest for the low strength soil (about 12% for a 15 R-value), which decreased to around 2 to 4% for the 70 R-value soils.

It was concluded that the same degree of pre-moistening of soils is necessary, but that the practice of permitting the experienced operator to estimate the required amount of water is satisfactory. The resulting variation in amount of moisture added should not significantly affect the results.

Compactor Phase

Comparison of Automatic Compactor (Cox) with Older Compactor (Hveem):

A newly developed electro-hydraulic compactor (Photos 1, 2, Appendix) was compared with the old type mechanical-pneumatic developed in the 1930's[1]. After initial adjustment of the new compactor, no significant difference was found in the R-values of soils compacted in the two machines.

It is concluded that the electro-hydraulic compactor is satisfactory for use in the R-value test. It is recommended that the references to "mechanical kneading compactor" in the present test method be modified to define compactive effort in terms of pressure profile (rise time, dwell, and maximum pressure).

Compactor Foot Penetration:

The R-value test procedure requires that the test specimens be compacted with a compactor foot pressure of 350 psi, except that this pressure is to be reduced as necessary to prevent the compactor foot from penetrating the surface of the specimen more than 1/4 inch. A pressure reduction is commonly required

[1]Specifications, drawings, and other descriptive materials concerning these compactors are available from the Pavement Section, Transportation Laboratory.

for low R-value materials, such as soft clays fabricated at high moisture contents. The depth of penetration, however, is entirely dependent on operator judgment. The object of this phase of the study was to determine how critical this 1/4-inch maximum penetration is to the reproducibility of the test.

Replicate samples of two soils were compacted at compactor foot pressures which would allow penetrations of 1/4-inch and 1/2-inch. A total of twelve test specimens were prepared from each soil. The same moisture content was used in each specimen. Six specimens of each group were compacted allowing a foot penetration of 1/4-inch, while the remaining six specimens were compacted allowing a foot penetration of 1/2-inch.

No consistent difference was found when testing the specimens compacted by the two depths of penetration. It is concluded that, for saturated soil specimens, the variation in compactive effort (foot pressure) to limit foot penetration should not affect test results. Therefore, foot penetration variations within the limits, permitted in the present test method, should be satisfactory.

It is, however, recommended that the test method be modified so that at least one specimen within a set be fabricated at a moisture content which permits use of the standard 350 psi compactor test pressure. It is further recommended that a minimum foot pressure be stipulated, to limit permissible reduction in effort. Specimens which cannot be compacted at the minimum pressure should be discarded. A minimum of three satisfactory specimens would be required.

Compactor Foot Pressures:

A limited study was made of the effect of compactor foot pressure on R-value, in conjunction with varying soak water and specimen height. The experiment indicated no significant difference for a material with an R-value of 70, when compactor pressure was lowered from the 350 psi specified, to 300 psi. However, those are not critical soils, as compared to those of low and mid-range strengths. These results are therefore considered inconclusive, and present standards for compactor foot pressure should be maintained subject to the recommendations made in the previous section "Compactor Foot Penetration".

Specimen Height:

A set of briquettes for a typical R-value test consists of 4 specimens. The first briquette is a "pilot" specimen which is used as a guide to estimate material quality (soil and water) required to fabricate the remaining three briquettes. The test method specifies as an objective, soil specimens measuring 2.50 inches in height, when measured immediately following the exudation phase. In practice specimen heights may vary considerably. It is known that height variations can affect compactive effort, and substantially change specimens densities and specimen R-values. The lower height specimens get more compactive effort and consequently greater densities and R-values. To correct R-values of specimens that are not exactly 2.50 inches high, a chart (Figure XIV) is available in Test Method No. Calif. 301-G. This chart was developed from data collected from many R-value tests with various specimens heights. No correction is necessary for specimen heights between 2.45 and 2.55 inches. Outside these height limits, corrected R-values are determined by means of the correction chart.

For this research, the effect on R-value of varying specimen height from the specified 2.50 to 3.0 inches was investigated, using two soils. The experiment was conducted with high R-value soils, and the results were inconclusive. There was no great difference in test results between the two specimen heights, and the trends reversed between the two soils.

It does appear that if an attempt had been made to adjust the R-value of the over-height specimen using the correction chart, a substantial error would occur. It is probable that the corrections should vary with quality, being greater for poorer soils and decreasing to a minimum for high-strength granular materials. Therefore, it is recommended that this portion of the test method be reviewed, and the chart verified or otherwise qualified as appropriate.

Mold Roughness:

Soil specimens for R-value testing are contained by steel molds (4 inches inside diameter by 5 inches high) during the compaction, exudation, and expansion phases of the test procedure. A degree of roughness is provided on the inner face of the mold in order to keep samples from slipping out of the mold.

Prior to this research project, studies were made with the objective of determining whether mold roughness had a significant effect on R-value test results. In 1963, 37 soil types with R-values ranging from 16 to 80 were tested using both smooth and rough molds (actual mold roughness unknown). Results did not indicate that mold roughness was a significant factor for most soils. However, there was some indication that higher R-values would be obtained with poor soils (particularly silty clays) if smooth polished molds were used. As a result, the test was revised in 1964 to require a mold surface roughness of 250 micro-inches per inch (in accordance with the General Electric surface roughness scale). This requirement remains in the present test procedure.

Repeated usage of molds causes them to become smoother, particularly in their central portions. The resulting surface roughness may be lowered to less than 25 micro-inches per inch, although most molds retain an average roughness of approximately 100 micro-inches per inch. Since it is quite expensive to re-texture, or replace molds, it was decided to investigate the effect of varying mold roughness.

For this study, two mold roughnesses were selected. Rough molds were 250 micro-inches per inch or greater in roughness, whereas smooth molds were considered as 100 micro-inches per inch or less. Three soils representing the normal range of R-values, were tested. There appeared to be a slight tendency for the mid-range and high R-value soils to attain higher values when compacted in smooth molds.

Since these were not the soils which appeared to be affected in the 1963 study, that data were reviewed. It consisted of paired tests on materials with R-values from 18 to 80. The data were subjected to regression analysis. Results indicated no significant difference (95%) between those molds classified as "smooth", and those as "rough".

It was concluded that molds with a reasonable degree of roughness (say a rough machine finish) of between 25 and 100 micro-inches/ inch, be specified for new molds. This provides some texture which aids in retaining specimens, and is representative of the roughness found in molds after a period of normal service. The variance in roughness of molds in ordinary service should not be enough to significantly affect test results.

The test method is being revised to include this new criteria.

<u>Testing Phase</u>

Evaluation of the Cox Semi-automatic Testing Press with Automatic Exudation Device:

A new automatic testing press was purchased by the Transportation Laboratory in April 1968. Controlled by a solid state electronics system this 40,000 pound capacity machine (Photo 3, 4) is programmed to automatically perform R-value test operations during the exudation and stabilometer phases. When used for the exudation test, the press is electronically connected to an automatic exudation plate and exudation pressures are presented digitally. This feature eliminates operator judgment, and results in substantial labor savings.

To determine whether this apparatus improves testing reproducibility, comparative tests were performed using both the new automated equipment and the conventional equipment. Representative soils were tested (low, mid-range, high) and no difference was found for the mid and high range soils. The Cox press with automatic exudation control appeared to give slightly lower results for the low R-value (13-18) soils, than the conventional press. Since these soils are usually tested for purposes of design, and the results are conservative, it is concluded that the Cox automatic press is satisfactory for use in R-value testing. The test method will be revised to clearly permit use of the new type testing press for routine and control testing of materials.

Loading Rate During Exudation Phase:

The present test method indicates that a loading rate of 2,000 lbs per minute be applied to the specimen during the exudation phase of the test. An experiment was conducted at three loading rates (2,000, 2,500, 3,000 lb/min) with three representative soils. The results were inconclusive, indicating that normal control of loading at the specified rate should prevent this from being a large source of error in itself.

Strain Control vs. Load Control During Stabilometer Phase:

The present test method stipulates a strain rate of 0.05 in/min during the stabilometer phase of the test. An experiment was conducted with soils at 0.02, 0.05, and 0.10 in/min. It was found that there is possibly a significant difference, with these extreme strain rates. However, nominal or ordinary deviations in this variable should not seriously affect the test results.

Another experiment was conducted comparing load control (2,000 lb/min) with the specified strain control (0.05 in/min) during the stabilometer phase. It was found that both methods gave similar results. However, it is recommended that the test method continue to arbitrarily specify one type control (either strain or stress).

Fixed vs. Spherically Seated Testing-Press Head:

The present test method specifies a fixed testing machine head during the exudation phase, and a spherically seated head during the stabilometer phase. This is something of a bother, and it was found that some operators were neglecting to "fix" the head for the exudation testing. To evaluate the effect of this practice, 32 duplicate sets of 4 specimens each were batched. The materials used ranged from 5 to 70 R-value. One series was compressed under a spherically seated head during the exudation phase, whereas the other was compressed with locked head.

The results indicated the sets that were compressed under a spherically seated testing machine head during the exudation phase generally had lower R-values at equilibrium, than the sets that were compressed under a fixed testing machine during the exudation phase. This appeared particularly true for soils in the 50 to 70 R-value range.

It is concluded that this is an important factor, since acceptance test criteria for subbase and base materials are in this range. It is recommended the established procedure be adhered to.

Experimental Exudation Discs:

In the course of evaluating the automatic exudation device, research was conducted on the effect of increasing the number of perforations in the exudation disc. The standard and experimental discs tried are shown in Figure 1. Use of the experimental discs resulted in increased variance with the low and mid-range soils tested, as well as affecting the mean R-value of the critical mid-range soils.

It is concluded that the present exudation disc hole configuration should be maintained.

Stabilometer Diaphragms:

It has been thought that variation in the tension of the rubber diaphragm in the stabilometer could affect R-value test results. A device to test the tension was built, consisting of a hollow aluminum cylinder with a hole in the side. This cylinder is placed in the stabilometer and the diaphragm deflected into the hole (by turning the pump which controls horizontal pressure) until it engages a microswitch which turns on a battery powered light. The pressure required is determined at 4 equidistant locations around the diaphragm.

During routine calibration visits to the District Laboratories between 1966 and 1970, both diaphragm tension and R-values on standard rubber specimens were determined on District stabilometers. Those were plotted, and a very slight tendency for indicated R-value to increase with increasing diaphragm stiffness may have been detected. It is concluded this should not be a significant factor in variance of the R-value test.

It is recommended that the Laboratory continue to evaluate any stock diaphragm material. This practice should insure a supply of satisfactory diaphragm rubber.

Experimental Stabilometer Evaluation:

An experimental stabilometer (Photo 5) was evaluated which has provisions for automatically setting the initial horizontal or diaphragm pressure (0.5 psi), as well as the intermediate pressure of 100 psi which determines "turns displacement". It was expected that these features should reduce R-value testing variance.

Low, mid-range, and high R-value soils were tested randomly using both a conventional stabilometer as well as the experimental model. No significant difference was found. It is concluded that the "automatic" stabilometer does not offer sufficient advantages in its present form for field implementation.

Operator Variance

The contribution of the operator (or operators) to R-value reproducibility was estimated by testing soils in the critical 30-60 R-value range. Ninety sets of specimens were prepared. One half of these were tested by a single technician, and the rest were tested by a group of six operators. This group performed the testing, as a team, and their assignments (compaction, exudation, etc.), would vary from day to day. The mean and standard deviation of the R-values from the two groups of tests were:

R-VALUE

Operator(s)	Replications	Mean $\bar{X}$	Std. Dev.
One	45	61.6	1.6
Six	45	58.8	4.6

This seems to indicate that different operators make a significant contribution to test variance.

A further review of the data from this experiment indicated that, for some of the materials, there was more variance in the exudation phase than in the stabilometer phase. It should be remembered that the basic test procedure considers both of those as parametric functions of moisture, and uses an arbitrary exudation effort (300 psi) as a convenient "black box" means of selecting the design or "control" R-value.

It is true that there is a general agreement between the exudation moisture and field saturation. However, the exudation test itself is redundant to the basic density-moisture-strength relationships established by the test. It appears then that the fundamental problem lies in this attempt to select one unique "R-value" from the basic R-value function. In other words, it was found that the R-value vs. moisture curves themselves were more comparable than the single values arbitrarily selected from these curves by use of the exudation data.

It is recommended that the use of the exudation phase (to select the design or control R-value) be replaced by a more rational appraisal of the expected field moisture/density condition, based on study of the soil's compaction - expansion-shrinkage characteristics, as established by the R-value test.

This recommendation is made with the full acknowledgement that selection of "the" value for use in pavement design will continue to be a most difficult engineering decision, whether the test in question is R-value, or CBR, or triaxial. However, a "black box" procedure for making the selection does not remove the essential uncertainty.

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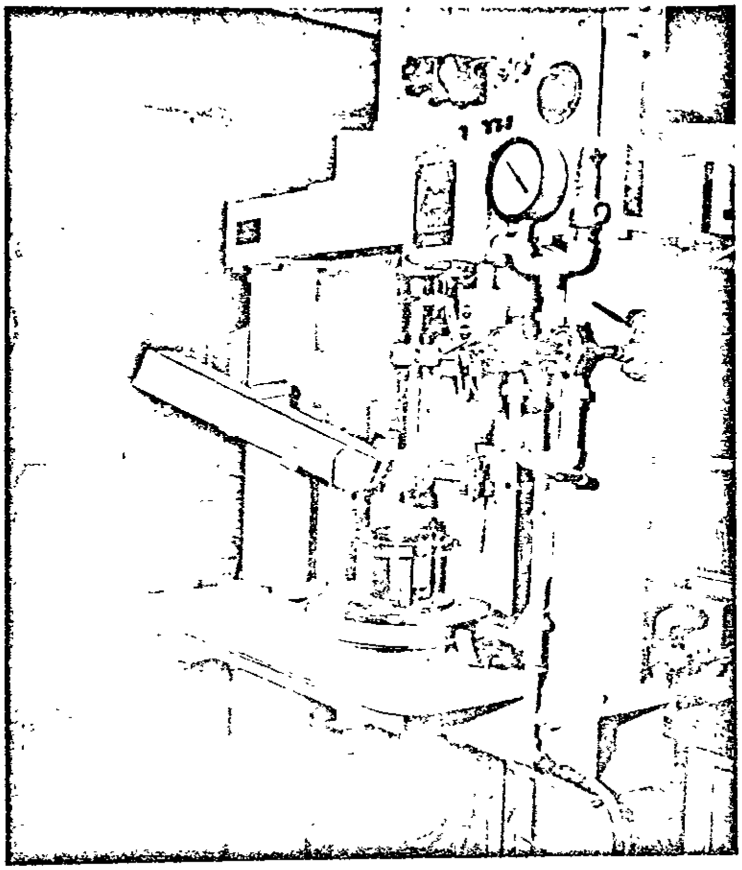
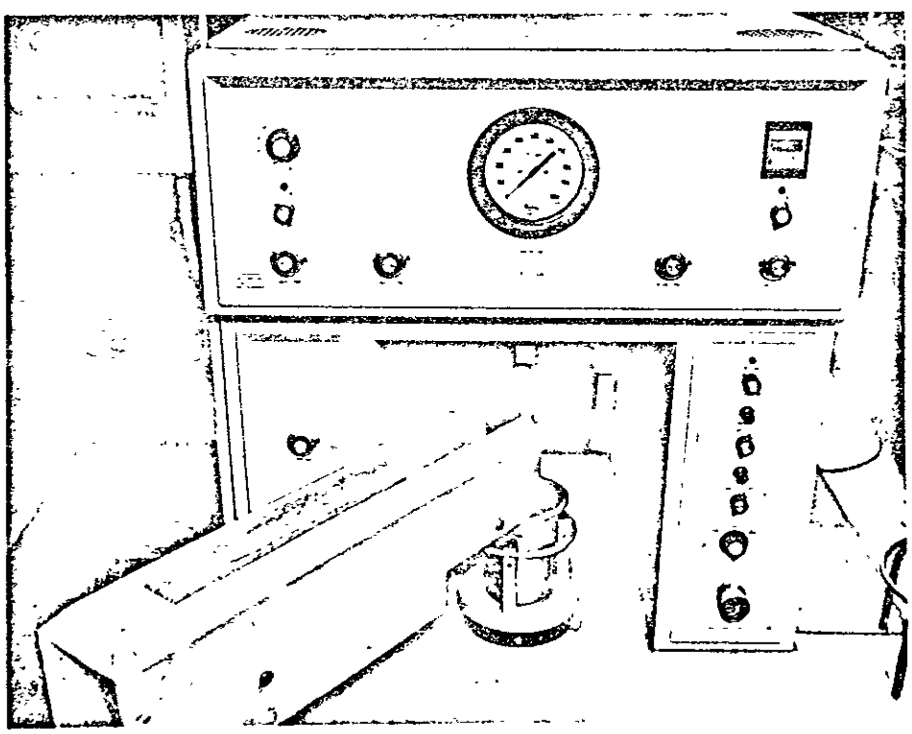


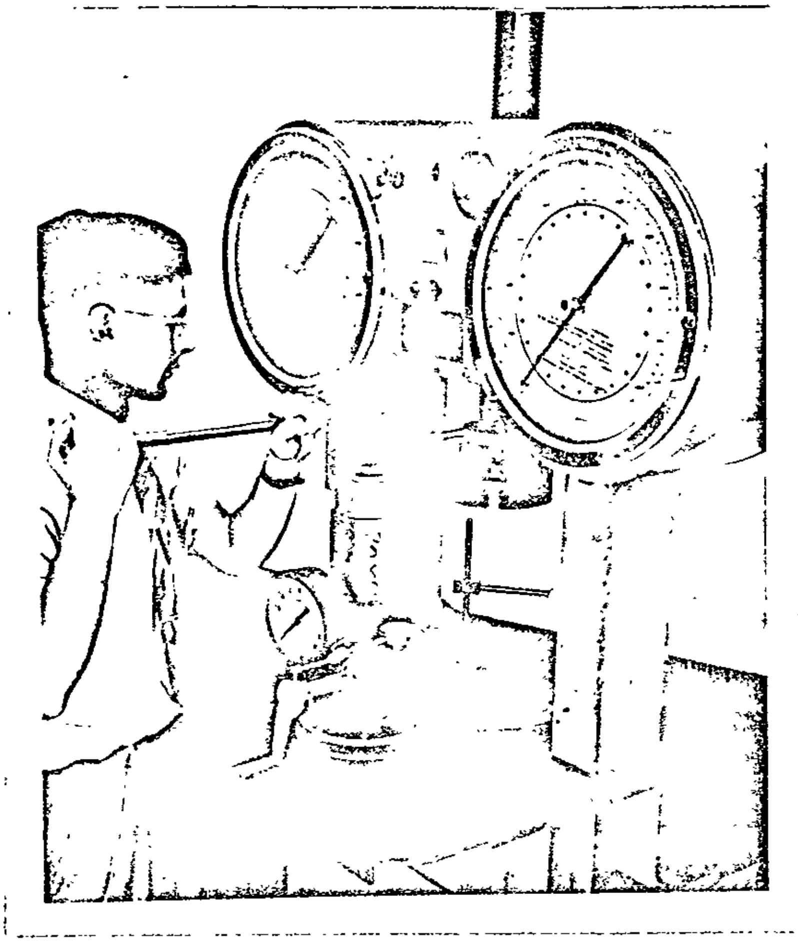
Mechanical-Pneumatic Compactor

Photo 1



Electro-Hydraulic Compactor

Photo 2

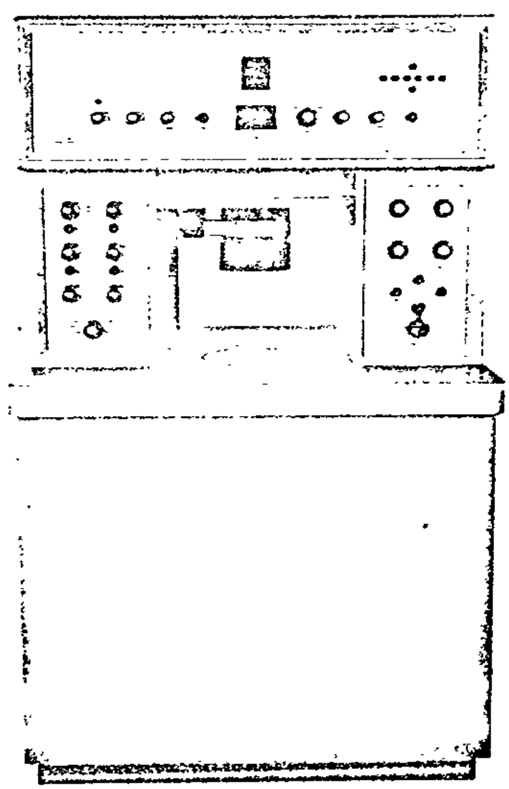


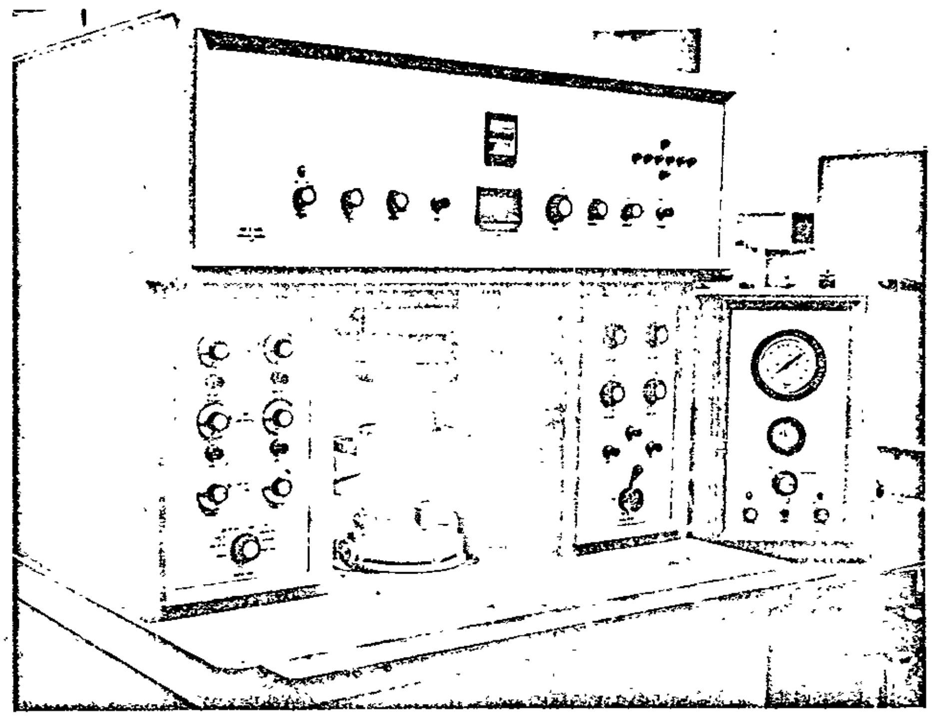
Manual-Hydraulic
Testing Press

Photo 3

Electro-Hydraulic Testing
Press with Programming
Capabilities

Photo 4



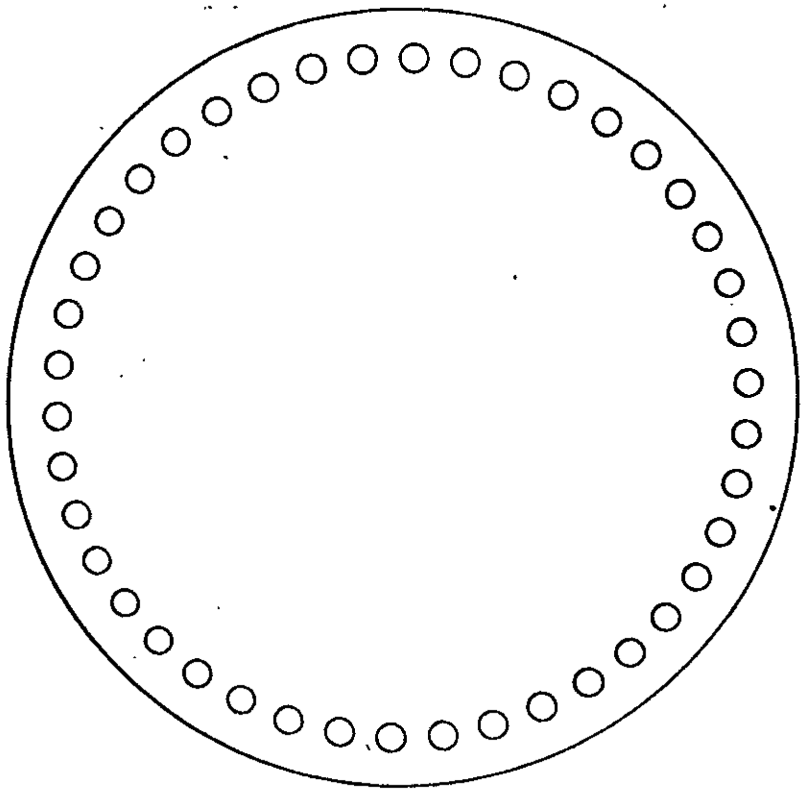


Experimental Stabilometer

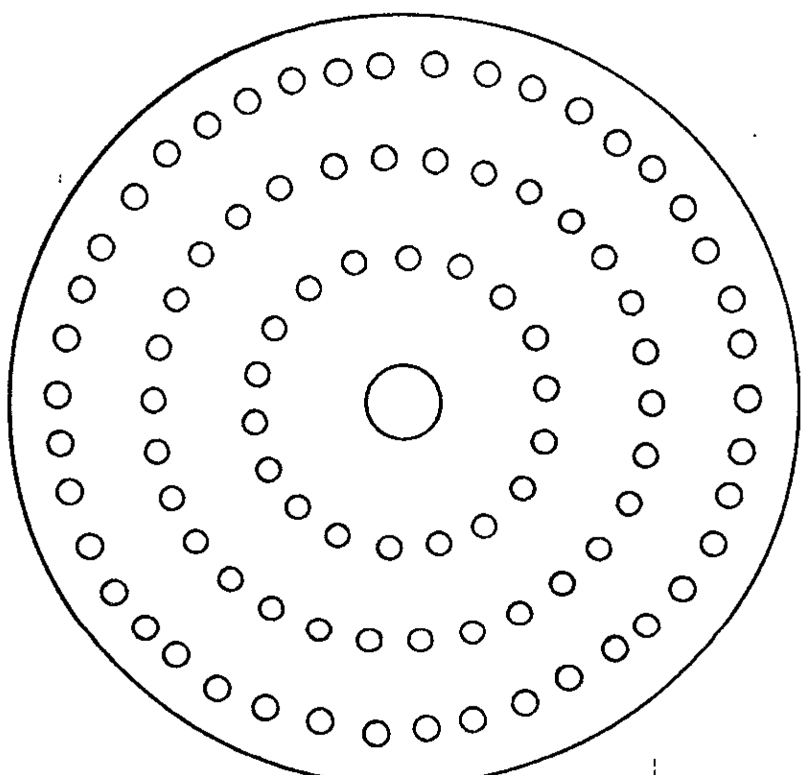
Photo 5

Figure 1

(Discs not to scale)



A 3-31/32 inch diameter disc of phosphor bronze, 28 gage, with one row of 5/32 inch diameter holes (total of 42 holes) located 1-1/3 inches from center of disc to center of holes (Standard for Test Method No. Calif. 301).



Experimental disc with additional holes.