CORRELATION OF C.B.R. WITH SHEAR STRENGTH OF CEMENT STABILISED SOILS

By

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This is further to certify that he has worked for a period of 5½ months from 20th April to 5th October, 1962 for preparing the thesis for Master of Engineering Degree at the University.

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SYNOPSIS

An attempt has been made to correlate two important factors in the design of soil-cement pavements, namely, California Bearing Ratio and Shear Strength.

Three mixes A, B and C were prepared using locally available Ranipur sand (fine sand) and clay in three proportions. In mixes A, B and C the percentages of clay to sand were 10, 20 and 30 respectively. The samples in the C.B.R. testing mould and for triaxial shear test were prepared using 0, 4, 8 and 12 percent cement for the above three mixes at optimum moisture content.

The samples were cured in moist condition for three days and then soaked for another four days under water. The tests were carried out in C.B.R. testing Machine. In the triaxial shear machine, 10, 20, 30 and 40 psi. confining pressures were used. The strength parameters 'C' and 'Φ' were obtained from these tests.

The C.B.R. values and cohesion for each sample were plotted on a double logarithmic graph and were found to follow a straight line relationship for equal percentages of cement.

The value of 'Φ' for all the three mixes increased slightly with cement percentage, irregularly and was assumed to be practically constant.

1 INTRODUCTION

1. INTRODUCTION.

The most widely used method for the design of flexible pavements is the empirical one known as C.B.R. method. It has wide applicability in the design of highway and airfield flexible pavements and is the standard procedure followed by the U.S. Corps of Engineers and many other Organizations.

The use of soil-cement in airfield pavements is increasing day by day. As soil-cement acts as a semi-rigid pavement, the C.B.R. method cannot be used for its design. The design of soil-cement pavements based on rigid pavements design cannot, also be followed, because its flexural strength is low.

If C.B.R. value is correlated with shear strength then use of high C.B.R. values may be made towards design of pavements and we will also know the corresponding shear strength value, or knowing the shear strength requirements, the corresponding value of C.B.R. for a particular soil depending on cement percentage, may be specified.

Another advantage of correlation, is that, the C.B.R. value is related to one of the fundamental properties of soil-cement, i.e. shear strength, which is not sought so far.

The method of design of flexible pavements based on shear strength was first developed in 1948 by Glossop and

Golder (1)*.

In 1952, an attempt was made by Yoder and Lowrie(8) to develop a triaxial testing method for application to design of flexible pavements. This method takes into consideration the rate of strain, rate of application of load. In 1957, Nascimento and Simões (4) tried to correlate the C.B.R. value with modulus of strength (i.e. product of diameter of loading plate and modulus of subgrade reaction).

In 1961, Wiseman and Zeitlen (7) developed a correlation between the shear strength and C.B.R. values of pavement material. Both tests were performed in-situ.

In 1961, Dutron and Canfyn (6) have developed some curves correlating the compressive strength and C.B.R. values of soil-cement samples. They worked on pure sand and silt with only 4 and 7 % cement and obtained a straight line between C.B.R. and compressive strength.

As the soil-cement pavements are particularly suitable for airfields for jets, as a base for water tower, etc., it would be advantageous to correlate the two values. Particularly in case of jets the impact is high and a high C.B.R. value is needed besides flexibility of the pavement.

In this study an attempt has been made to develop a correlation between C.B.R. value and shear strength of soil-cement samples. Samples were tested with four different

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* ... refer to bibliography on page 56-57

percentages of cement with three types of sand-clay mixtures. To find shear strength triaxial shear machine was used, so that the strength parameters 'C' and 'Φ' are obtained.

2 SOIL-CEMENT

2. SOIL - CEMENT

In the stabilization of soil with cement, 5 to 15 percent cement by weight, is added to the soil to produce a material "Soil-cement", which is considerably stronger and more durable than the untreated soil. Soil-cement was first employed for road construction in U. S.A. in 1935 and since then the material has been in use in most of the countries though its major use has been developed in U.S.A.

Besides the various applications in building construction, Foundations for houses, Canal lining and Plastering, its main use lies in construction of airfield pavements for jets and base course for major and minor roads (depending upon the type of road). One of the major uses is also to construct base for large water storage tanks.

Factors Affecting Soil-Cement Properties :-

The main factors affecting the quality of soil-cement are, soil type, cement content, compaction, method of mixing and age of curing.

a) Soil Type :-

This is considered to be the most important factor and may be divided into two.

1. Particle Size Distribution :-

According to U.S. Highway Research Board the following limits are specified for soils which can be economically stabilized (1).

Maximum size	- 3 inches	
Passing 3/16 inch B.S. Sieve	>	50%
Passing No.36 B.S.Sieve	>	15%
Passing No. 200 B.S. Sieve	<	50%

B.S. Plasticity test Limits :-

Liquid limit	<	40%
Plasticity Index	<	18%

Mitchell and Freitag (2) suggest the following limits :-

Maximum size	- 3 inches	
% finer than 0.002 mm	<	35%
% passing No.4 Sieve (4.76 mm opening)	>	55%
Liquid limit	<	50%
Plasticity Index	<	25%

2. Chemical Composition of the Soil :-

The soil should be low in organic matter though all the organic matteris not harmful. The safe upper limit is specified to be 2%. It has been found by Clare and Sherwood (2) that organic compounds with high molecular weights such as cellulose, starch and lignin are less harmful as compared to those with low molecular weights, e.g. nucleic acid and dextrose which act as hydration retarders.

b) Cement Content and Type of Cement :-

The cement content depends upon the type of soil and the compressive strength to be attained. Soils are successfully stabilized by using 4 to 25 percent cement. In most soils, an increase in the cement content generally increases compressive strength of soil. However, the increase in case of clayey soils is less than that in sandy soils. The effect of presence of coarse aggregates is to give low compressive strength in lean but a relatively higher strength in rich mixes.

Rapid hardening cements, such as "417" in Great Britain (Super-rapid hardening cement) which contains 2% $CaCl_2$, give an ultimate strength similar to Portland cement, but their one day and 7 day strengths are considerably higher.

c) Compaction :-

For optimum compaction it is necessary to bring the materials to the maximum dry density, for a given effort. The moisture content for this is governed by the type of soil and method of compaction.

The work at Road Research Laboratory, London, has shown that for a given dry density, there is increase in strength with moisture content. Unpublished work from South Africa also shows that best results in durability tests are obtained at moisture contents somewhat above the optimum though highest compressive strength is achieved at moisture content slightly below optimum. It has been reported that a decrease of 1 lb./cft. in dry density is the cause for the decrease in compressive strengths between 20 and 40 psi, and a greater proportional loss in durability.

Stanton, Hveem and Beatty (1) state that a 5% decrease in the relative compaction causes greater drop in the compressive strength than a decrease of 10 to 15% in the cement content.

Further work at Road Research Laboratory, London, also shows that moisture content has little effect on the quality of soil-cement except in so far as it affects the compacted dry density. The influence of reduction in compressive strength is less in case of sand-cement mixes rather than in silt-cement mixes as reported by Dutron and Cloes (13). The loss of strength due to inadequate compaction in sand-cement mix is partly counteracted by an increase in cement content with a corresponding reduction in moisture content.

d) Mixing :-

The mixtures made in the laboratory have higher strengths and greater durability than similar mixtures in the field. This factor has been considered in the standards for preliminary tests.

The compressive strength of soil-cement prepared by mix-in-place method with agricultural plant is about 40 to 60 percent of the corresponding laboratory mix whereas mixes made with an efficient rotary tiller have 60 to 80 percent of the strength of laboratory mixes, as reported by Road Research Laboratory, London (1).

e) Age of Curing :-

It has been found that the compressive strength of soil-cement increases with age. The soil type affects the rate of hardening.

The soil-cement is cured, in practice, after compaction. This is necessary in the initial setting period for strength, to prevent the drying of surface. Normally, a damp atmosphere is maintained to prevent the formation of thin hard crust which cracks and flakes off under load.

OTHER FACTORS.

a) Temperature :-

Investigations carried out by Clare and Pollard (2) have revealed the following effects of temperature on strength of soil-cement mixes.

1. Increase in 7-day compressive strength by 2 to 2.5 percent with 1° rise in curing temperature, when it is near 25° C.

2. Considering the compressive strength as sole criterion of soil-cement quality, the amount of cement required in warm weather is less than that in cold weather.

3. If the temperature is above freezing, soil-cement gets hardened in cold weather.

4. During the first three months after construction, soil-cement yields 50 to 100% more strength in warm weather than similar construction in cold weather.

b) Admixtures :-

In general, addition of asphalt decreases the strength in proportion of the quantity, but addition of 5 to 7.5 percent asphalt emulsions with 3 to 5% cement gives a product possessing rigidity and water resistance.

There is an increase upto 30 percent in the strength of soil-cement if 0.5 to 1.5 percent Polyvinyl alcohol by weight of dry soil, is added.

c) Though grain size, density, specific surface, void - cement ratio and compressive strength of the untreated soil contribute to some extent in cement stabilization, yet none has predominant effect.

3 DESIGN OF SOIL-CEMENT PAVEMENTS AND BASES

3. DESIGN OF SOIL-CEMENT PAVEMENTS AND BASES.

United States Practice :-

In this case, soil-cement is considered to display the characteristics of a flexible-type pavement or in some cases a semi-flexible type. Nevertheless design methods have been limited largely to determination of cement content, and thickness has been designed arbitrarily by selection of thickness from within a rather narrow range of thicknesses, the range of thicknesses being dictated in the past more by capacities of the pulverizing and mixing equipment than by the thickness requirements for traffic. Thickness requirements have been satisfied by the use of granular sub-bases and in some instances by adjustments in the type and thickness of bituminous surfacing. The general practice in the mix design has been as follows :-

1. Classify the soil and select several trial cement contents.

2. Prepare the trial soil-cement mixtures and determine the compaction characteristics.

3. Prepare two specimens at optimum moisture content from each trial mix.

4. Subject one specimen from each trial mix to the A.S.T.M. - A.A.S.H.O. wet-dry test and the other to the freeze-thaw test.

5. Select the percentage of cement by comparing the weight losses in the tests with allowable losses.

Individual variations in the foregoing procedure have been largely in the greater use of compressive strength as a criterion for mixe quality in some areas and limiting testing to the wet-dry test in areas of no base freezing.

California Highway Department Method :-

California Highway Department determines the necessary thickness of soil-cement base on the basis of :-

a) Resistance (R) value of subgrade.
b) Traffic Intensity.
c) Anticipated wheel loads.
d) Strength (c) value of pavement material.

This procedure recognizes the soil-cement as a construction material that can be designed in the same manner as other common paving materials. According to this procedure the thickness required is 35 to 50 percent less than that required for a granular base.

British Practice :-

Maclean and Robinson (2) have pointed out that for high wheel loads and tyre pressures the design should be based on :-

a) Stress imposed.

b) Strength of Stabilized soil.

c) Strength of Sub-grade.

For an unconfined compressive strength of soil-cement of the order of 250 psi, the flexural strength is about 50 psi. For a wheel load of 9000 lbs., and a subgrade having subgrade modulus (k) of 100 lbs/sq.in the design based on Westergaard's method of rigid pavements, gives a thickness of 24 inches. However, it has been found in practice that a thickness of 6 inches is adequate. Therefore, flexural failures must have occured to draw the conclusion that soil-cement acts as a flexible material.

Almost all soil-cements show formation of shrinkage hair cracks. It was observed that for a hair-cracked base of soil-cement, the C.B.R. value should exceed 300.

Maclean (2) has further suggested that for much higher strengths than 250 psi., beam action is more pronounced In this case, the flexural failure occurs with cracks occuring at greater spacing leading to less interlocking and wider cracks.

Some additives would be desirable to attain a very high strength material (modulus of rupture 2000 psi) without further addition of cement, so that a considerable saving is achieved.

British military Engineers have applied the shear strength method of design for cohesive subgrades, having a strength essentially independent of the overburden pressure. A thickness of soil cement is selected in such a way that at any depth greater than the base thickness, the induced shear stresses are less than the shear strength of the subgrade.

4 REVIEW OF LITERATURE

4. REVIEW OF LITERATURE.

Previous Correlations Between C.B.R. and Different Soil Properties :-

The most widely used methods of designing flexible pavements is to make use of C.B.R. test. U.S. Corps of Engineers have developed families of curves, for many loadings, between C.B.R. value and thickness of protective layer. The mathematical expressions for C.B.R. values and thickness of pavement have been obtained by Turnbull and Alhvin (5) for C.B.R. values below 12 %.

$$h_t = \sqrt{P\left(\frac{1}{8.1CBR} - \frac{1}{p\pi}\right)}$$

where h_t = Thickness of pavement in inches.

P = Total load in lbs.

p = Tyre pressure in psi.

Nascimento and Simões (4) have correlated C.B.R. and modulus of strength (Product of diameter of loading plate and modulus of subgrade reaction K_s) based on the tests carried out in Lisbon :-

For Soft Materials :-

Modulus of strength = 10 to 20 (CBR)

Modulus of subgrade reaction = 1/8 to 1/4 (CBR)

For Hard Materials :-

Modulus of Strength = 10 to 30 (CBR)

Modulus of subgrade reaction = 1/8 to 1/3 (CBR)

Black (9) has developed a correlation between in-situ CBR values and the bearing capacity of the soils. Thus this co-relation helps to find in-situ CBR values from the knowledge of cohesion, true angle of internal friction and suction of the soil. The in-situ C.B.R. values are corrected for confining pressure of mould to give the laboratory C.B.R. values.

It has been shown by Black ,

$$CBR = \frac{q_u}{10}$$

where,

q_u = Ultimate bearing capacity of soil in psi.

and q_u is given by Meyerhof's equation,

$$q_u = 1.2\ CN_c + \gamma DN_q + 0.6\ R\gamma N_\gamma\ .$$

N_c, N_q and N_γ being bearing capacity factors depending only on ' ϕ ' value of soil and have values as given by Meyerhof.

C = Cohesion of Soil.

D = Depth of footing.

γ = Bulk density of soil.

R = Radius of footing.

To reduce the time required for carrying out in-situ C.B.R. tests particularly, pavements for military airfields, it was advantageous to develop a test which could be used to give results quickly. Vicksburg penetrometer was used for this and a correlation was obtained between C.B.R. values and penetrometer readings by Evans (10) in 1951.

Another test was developed by Robertson (10) which consists of loading a 3" diameter plate to failure and noting the load. In addition to this it was decided to use C.B.R. plunger in the same way, by Robinson (10) who after carrying out tests at several sites developed the following relation,

$$\log_{10}(\text{CBR}) = 0.76837 \log_{10} (\text{Plate load in lbs}) - 1.64420 .$$

It was only recently when Wiseman and Zeitlen (7) made an attempt to correlate the in-situ C.B.R. values with in-situ shear strength of soils. To measure the shear strength of soil, static penetration test was used. In evaluation of shear strength, the rate of penetration played an important part.

Analytically it is shown that for any combination of pavement thickness total wheel load and tyre pressure, the C.B.R. required of the subgrade is 8 times the maximum shear stress induced (kg/cm^2) (7).

For the clays tested, the in-situ C.B.R. value was found to be 4 times the in-situ shear strength, by the above authors (Wiseman, Zeitlen).

Assuming the clayey soil at 0.1" penetration to behave as an elastic mass with a Poisson's ratio of 1/2.

$$CBR = 0.127\ E$$

where, E = Modulus of Elasticity in kg/cm^2.

if, S = Shear strength of subggade.

$$CBR = C_1 S$$

where, $C_1 = 0.127\ E/S$ (sq.cm./kg).

C_1 is assumed to be constant, the ratio of E/S being constant for a range of consistency of clay.

C_1 may be evaluated by calculating CBR/S or E/S. Attention must be paid to the rate of strain.

Casagrande and Shanon (7) have shown that with increase in strain rate, the shear strength increases.

Dutron and Canfyn (6) worked on sand and silt with cement to attempt a correlation between C.B.R. and compressive strength. Only 4 and 7 % cement was used in both. They obtained straight lines between C.B.R. value at 14 days and compressive strength at 7 days.

For sand C.B.R. % $= 125 + 10.2\ R_c$

For silt C.B.R. % $= 150 + 20.0\ R_c$

where, R_c = Compressive strength in kg/cm^2.

All these authors have tried to correlate the C.B.R. value with some soil property. Only attempt towards any such correlation for soil - cement was that of Dutron and Canfyn (6) and they also worked on pure sand and silt.

Hence in this study an attempt is made to find some correlation between C.B.R. value and shear strength for soil-cement.

Possibility of Correlation :-

Recently triaxial testing method has been applied to the design of flexible pavements by Yoder and Lowrie (8). It can be used to determine the fundamental strength characteristics of the materials used in the construction of flexible pavements. It provides an opportunity to utilize these materials on basis of resistance to strain and shear, comparable to other structural materials such as steel, concrete and timber.

The thickness of pavement was found theoretically and also on the basis of triaxial tests and two showed a close agreement. In our case also, to determine the strength parameters, triaxial testing method is used. The C.B.R. value is the resistance to penetration, which is also a kind of expressing the strength. With the attempts made by different authors to correlate the laboratory or in-situ C.B.R. value with various parameters, it seems possible to have one between C.B.R. and shear strength of soil-cement.

The choice of soil-cement has been made due to its wide applicability as a material in construction of pavements, particularly for airfields. The modern problem consists of designing a pavement for jets so as to withstand high impact loads and temperature of gases and also flexible enough to allow elastic deformation, so that the base of the pavement is not cracked.

With the stabilization of sandy soil with cement, it may be possible to develop such one because of its high C.B.R. values and shear strength. Moreover, once we know the required shear strength of a soil, depending upon the stresses produced due to wheel loads, tyre pressures and other causes, we can directly specify the amount of cement to be used for that soil and the probable value of C.B.R. or vice versa.

5 LABORATORY INVESTIGATIONS

5. LABORATORY INVESTIGATIONS.

Choice of Soil and Cement Percentages :-

Before conducting the tests, it was necessary to choose types of soil and percentages of cement to be mixed with them to stabilize. Three types of mixes were prepared by mixing clay with sand. The sand used was a local fine sand known as Ranipur sand. (minus No.40 U.S. Sieve) The particle size distribution for the same is shown in Fig.No.1 The clay used was also available locally and its properties are shown at table No.1.

The mixes were prepared by using 10 %, 20% and 30% clay by weight of sand. The mixing was done manually.

The percentages of cement chosen were such to bracket the amounts of cement required for different types of soil, e.g., usually 6 to 8 % cement is sufficient for sandy soils, for sandy clays 9 to 10 % and for clays 10 to 12 % cement is required (1). The percentages used in our study were 4, 8 and 12 % by weight of dry soil.

Laboratory Tests :-

Two main types of test were required to be conducted. 1) The C.B.R. test and 2) Triaxial shear test. The other types of tests performed were a) standard Proctor Compaction test b) Particle size distribution c) Atterberg

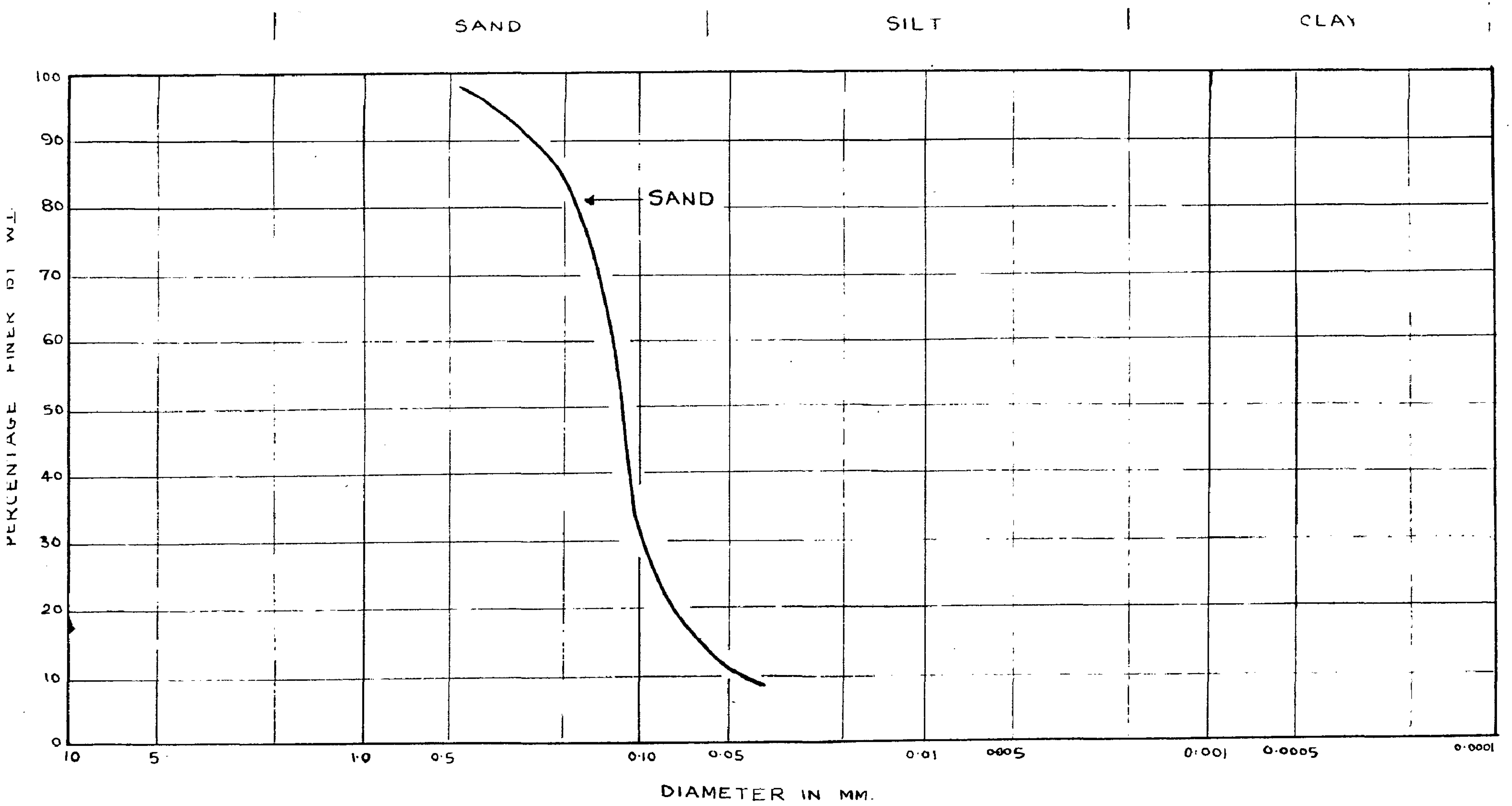


FIG. No. 1 GRAIN SIZE DISTRIBUTION FOR SAND USED

TABLE - 1.

PROPERTIES OF CLAY USED.

Liquid Limit	=	41.5 %
Plastic limit	=	26.6 %
Plasticity Index	=	14.9 %
Specific Gravity	=	2.64
Sensitivity	=	4.0
Unit weight	=	1.63
Group according to unified soil classification system	=	CL - ML

limits.

a) All the three types of soil were mixed with 0, 4, 8 and 12% cement. In the first instance the sand and clay were mixed thoroughly and then required percentage of cement by weight was added. This mixture was again ensured for thorough mixing. When uniformity in colour was obtained, calculated amount of water was sprayed, in parts, and mixed for a certain period of time. This was fixed in this case as 6 minutes, on the basis of minimum time required for thorough mixing. It was also considered that no setting of cement occurs in that time.

The optimum moisture content was determined by compacting the mix in standard Proctor mould in three layers with 25 blows/layer of 5½ lbs. hammer with 12" fall.

The typical dry density - moisture content relationships are shown at Figs. 2, 3 and 4.

b) For particle size distribution, the soil was sieved through a set of B.S.Sieves (Nos. 4, 8, 14, 25, 50, 70, 100 and 200). For soil passing through No.200 sieve , hydrometer analysis was carried out. The results are as shown in Fig.1

c) Liquid limit and plastic limit tests were carried out for clay to ascertain plasticity of clay.

d) The C.B.R. and Tri-axial tests are dealt with in details separately.

Preparation of Samples :-

a) C.B.R. TEST :-

The sand and clay were mixed to prepare following three mixes :-

10% clay - Soil 'A'

20% clay - Soil 'B'

30% clay - Soil 'C'

The required percentage of cement by weight of dry mix was then added and the three mixed thoroughly. Calculated amount of water (to obtain OMC) was added by spraying it with a sprayer. The mixing was done for 6 minutes.

The compaction of soil in the C.B.R. mould was according to A.A.S.H.O. compaction test specifications. i.e. the mix was compacted in the mould, at the bottom of which a filter paper was placed, in five equal layers. Each layer was compacted by a rammer of 10 lbs. weight with a fall of 18" giving 55 blows. The blows were uniformly distributed over the surface. Before putting another layer the top of previous layer was scarified by a knife to ensure proper bond between two layers. To ease the removal of sample from mould, grease was applied to the inside of the mould.

The preparation of one sample (i.e. compaction) required about 7 to 8 minutes and no appreciable drying

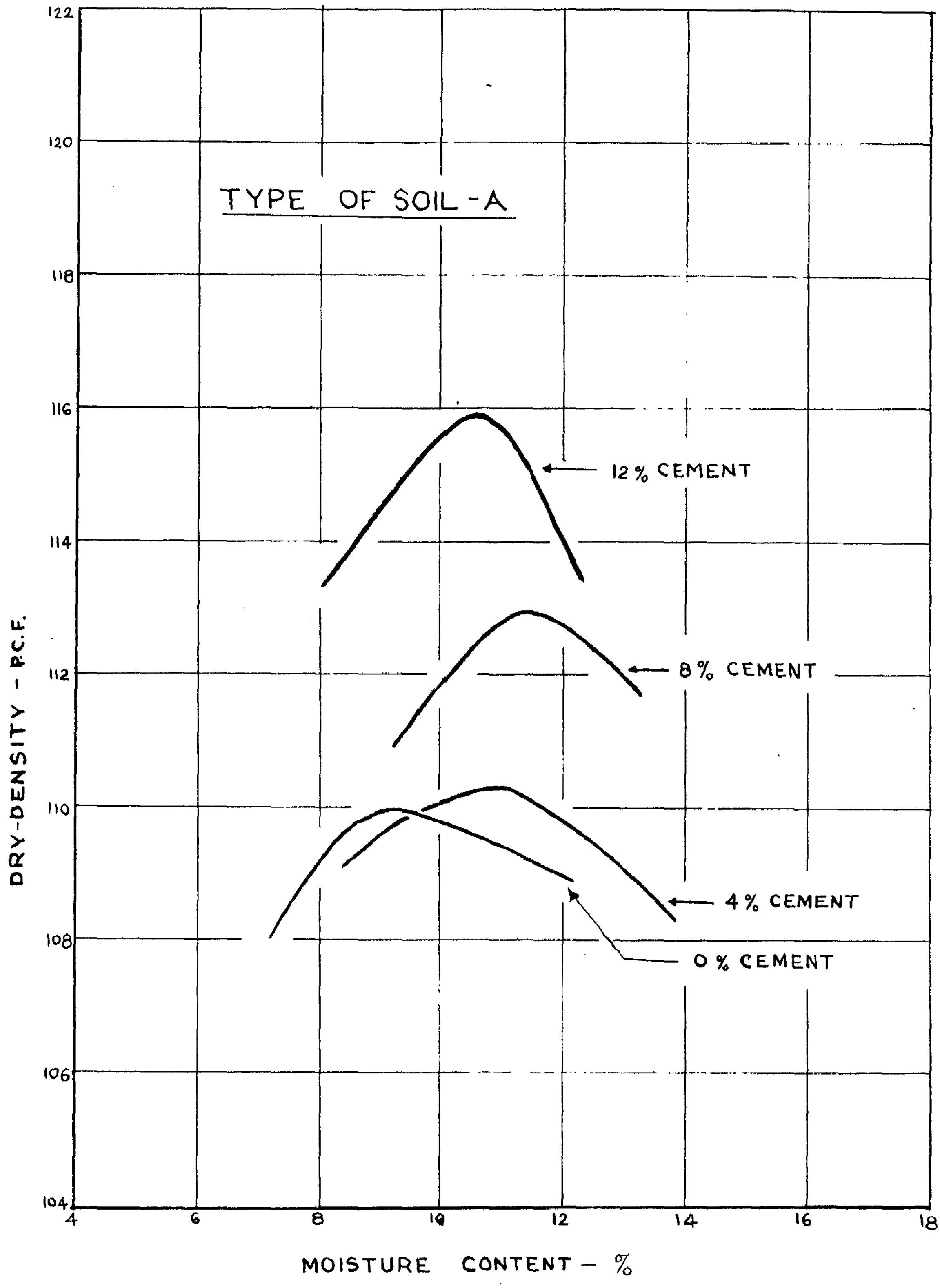


FIG. No. 2 DRY DENSITY - MOISTURE CONTENT RELATIONSHIP FOR SOIL A

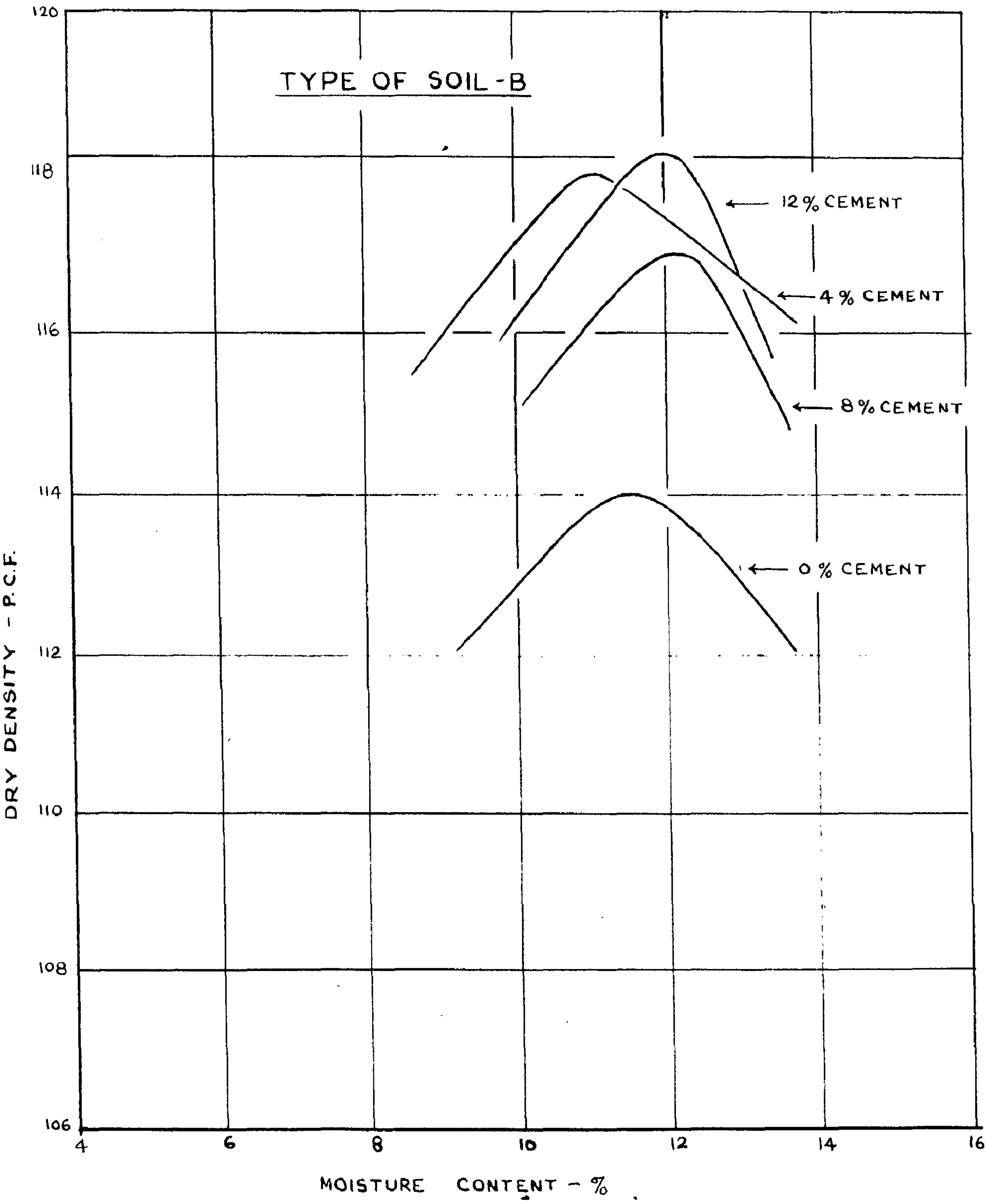


FIG. No. 3 DRY DENSITY - MOISTURE CONTENT RELATIONSHIP FOR SOIL-B.

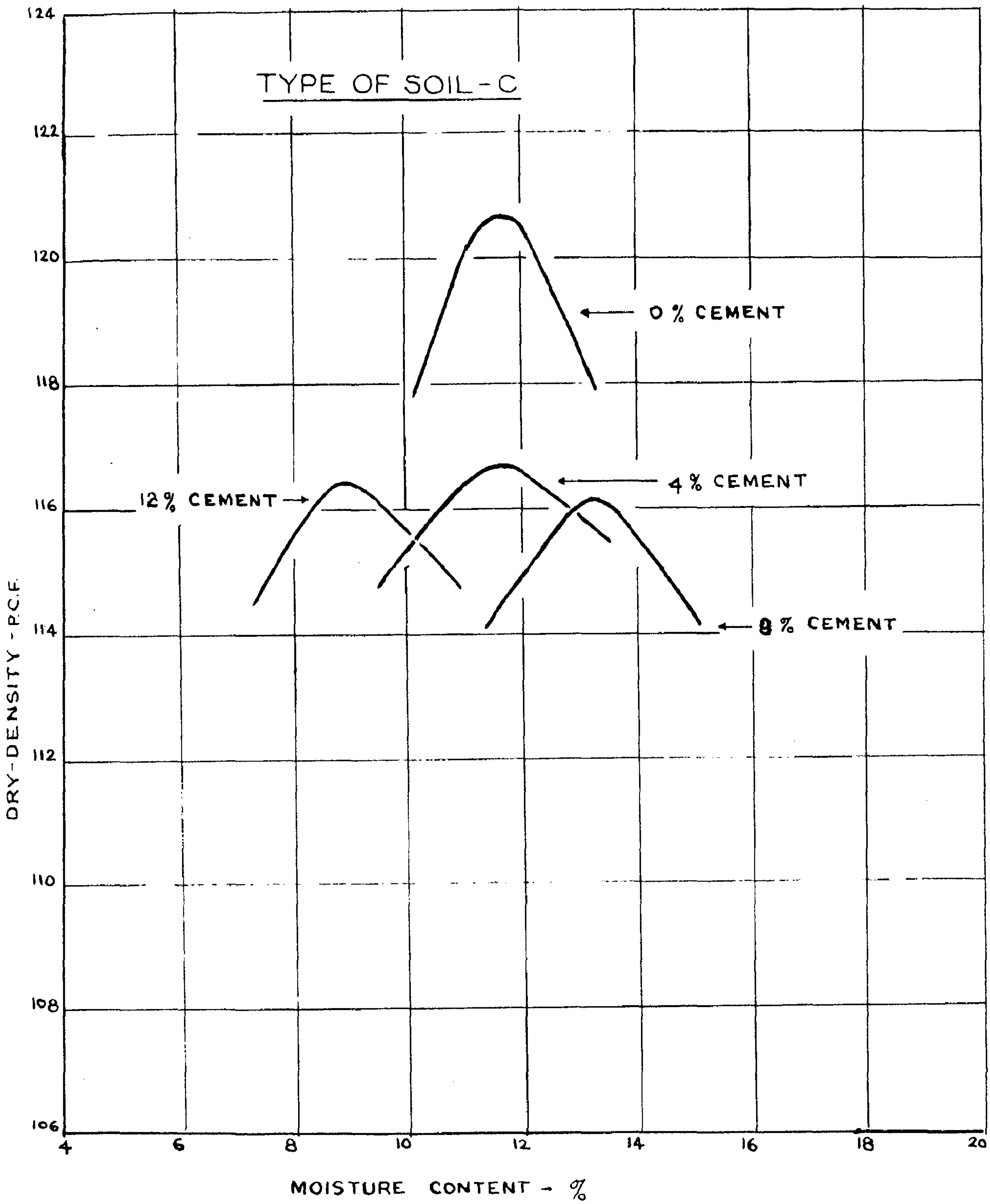


FIG. NO. 4 DRY DENSITY - MOISTURE CONTENT RELATIONSHIP FOR SOIL C of the remaining mix was noticed.

After compacting the final layer, the collar was detached, the extra soil was removed with a knife edge and surface made level to give a uniform height of 5". The mould with compacted soil was weighed (without collar) and calculations were made to check the dry density of the mix. Again the collar was attached and three annular weights each of 5 lbs., were placed on the sample and the mould kept for curing.

The curing was done in metal container having a perforated plate about 3" above the base on which the moulds could be placed. The gap between the base of the container and the perforated plate was filled with water. Care was taken to see that water did not touch the bottom of the mould. The container was then covered with a lid and sealed with wax.

After curing for three days, the samples were soaked for four days under water. The water head above the top of samples was ½" to 1" . After completion of soaking, the samples were drained for 15 minutes, before testing.

Three samples of each cement content were prepared.

b) Triaxial Test :

As the maximum size of sand used was passing No.40 U.S. Sieve the diameter of sample was kept 1½" and length 3". For correlation of results, it was necessary to have same dry density for triaxial samples.

To obtain the same dry density, samples were extruded from compacted C.B.R. sample with the help of a cutter having internal dia., 1½". 3½" long samples were extruded with it and then finished to a length of 3". The cutter was pushed into the compacted soil and slighly hammered if necessary.

With this procedure there was slight change in dry-density. However, it was ensured that the change was not so much as to cause significant difference in dry - density and strength. Five samples could be extruded from one C.B.R. mould. There was no significant change in dry density when the last sample was taken out i.e. when maximum disturbance had occured.

According to usual procedures, the samples should have been coated with wax to ensure curing at moisture content at which they are compacted (12). To simulate the same conditions in C.B.R. test and triaxial test, it was necessary to soak the samples after curing. The coating of samples with wax would prevent penetration of water during soaking. To avoid this, the samples were put in the membrane itself during curing and the membrane removed while soaking. The soaking was done for four days.

Before testing the samples, they were drained of excess water around them i.e. all the water was removed from the top and bottom of the sample. Before testing, membrane was put on again.

Curing :-

As the fundamental object was to investigate if any correlation exists, the curing period was kept 3 days followed by 4 days soaking. The samples were placed in metal containers containing water for curing, and sealed.

Testing Procedure :-

1. C.B.R. Test.

C.B.R. tests on the three soils A, B and C with 0, 4, 8 and 12% cement were performed in the conventional manner with a rate of penetration of 0.05" /minute. For higher percentage of cement, it was not possible to control the rate of penetration with hand operated machine. For this purpose, the samples were tested in a 200-ton compression testing machine with hydraulic control of rate of penetration. The load was applied on the top of plunger, which seated on the sample.

The observations are shown in Tables 2 and 3. Load-penetration curve is plotted for each case, taking into

TABLE - 2.

TYPICAL RESULTS OF C.B.R. TEST.

Type of soil - B-3. Rate of Strain - 0.05"/min.

S. No.	Penetration of plunger inches.	Load on Plunger. Load in Tons	Load on Plunger. Load in lbs.	C.B.R. %	Remarks
1	0.025	0.75 0.75 0.75	1680 1680 1680.		No Zero-correction
2	0.050	1.500 1.375 1.500	3360 3080 3360		
3	0.075	2.000 1.875 2.125	4480 4200 4760		
4	0.100	2.500 2.250 2.625	5600 5040 5890		
5	0.200	4.000 3.875 4.125	8960 8680 9240	202	From Graph
6	0.300	5.250 5.000 5.250	11750 11200 11750		
7	0.400	6.250 6.125 6.125	14000 13720 13720		
8	0.500	7.000 7.250 7.250	15680 16240 16240		

TABLE - 7.

TYPICAL RESULTS OF C.B.R. TEST.

Type of Soil - C-1. Rate of Strain - 0.05"/min.

S. No.	Penetration of plunger inches.	Load on Plunger. Reading dial gauge.	Corresponding load in lbs.	Corrected load lbs.	CBR %	Remarks
		0.25	17.85	29.50		Zero-
1	0.025	0.25	17.85	29.50		correction
		0.25	17.85	29.50		of 0.015"
		0.50	35.70	48.00		
2	0.050	0.50	35.70	48.00		
		0.50	35.70	48.00		
		0.75	53.50			
3	0.075	0.75	53.50	64.50		
		0.75	53.50	64.50		
				64.50		
		1.00	71.40	86.50		
4	0.100	1.00	71.40	86.50		
		1.00	71.40	86.50		
		2.50	178.70	190.70		From
5	0.200	2.00	142.80	154.80	4.09	graph
		2.25	160.50	172.50		
		3.50	243.70	262.70		
6	0.300	3.25	232.00	245.00		
		3.50	249.70	262.70		
		4.50	321.10	333.10		
7	0.400	4.25	303.40	315.40		
		4.50	321.10	333.10		
		6.00	428.40	440.40		
8	0.500	5.25	374.80	386.80		
		5.50	392.50	404.50		

consideration all the three soils tested for each percentage of cement content. The C.B.R. value is calculated from the graph for 0.1" and 0.2" penetrations and the higher value adopted.

Calculations.

a) For type B-3 Soil, Fig. No. 5.16

Load for 0.1" penetration = 5,500 lbs.

C.B.R. Value $= \dfrac{5,500 \times 100}{3000}$

$= 183$ %

Load for 0.2" penetration = 9,100 lbs.

C.B.R. value $= \dfrac{9,100 \times 100}{4500}$

$= 202$ %

Hence C.B.R. value = 202 %.

b) For type C-1, Soil, Fig. No. 5.18

Correction = 0.015"

Load for 0.1" penetration = 86 lbs.

∴ C.B.R. value $= \dfrac{86 \times 100}{3000}$

$= 2.87$ %

Load for 0.2" penetration = 184 lbs.

C.B.R. value $= \dfrac{184 \times 100}{4500}$

$= 4.09$ %

Hence C.B.R. value = 4.09 %

2. Triaxial Shear Test.

To test the samples in triaxial shear testing machine, quick test was performed, due to negligible amount of pore pressure development in cement stabilised soils. Metallic plates were placed at top and bottom of soil sample. The rate of strain was kept at 0.1" /minute. The confining pressure was applied through air and five samples were tested, one at each 10, 20 and 40 psi, confining pressure and two samples at 30 psi., chamber pressure.

The observations are shown in Table 4. For each test performed, Mohr's envelope was drawn (See Fig. 5.22 to 5.27)

Calculations.

From Table 4 we have,

Maximum load dial reading $= 499.0$

Load in lbs. $= 499 \times 0.51$

$= 254.5$ lbs.

Load/sq.in. of sample area $= \dfrac{254.5}{1.77}$

$= 143.75$ psi

Hence normal pressure which the sample can take at a chamber pressureof 30 psi is 143.75 psi.

Strain at maximum Load :-

Dial Reading $= 110.0$

Deformation in inches $= 110 \times 0.0001 = 0.011$

% Strain $= 0.37$ %

TABLE - 4.

TRIAXIAL TEST.

Type of soil - A.2 | Chamber pressure - 30 psi.

Least count of load dial-0.51 lbs | Dia. of sample - 1.5"

Least count of strain dial - 0.0001" | Length of sample - 3.0"

Rate of strain - 0.1"/min. | Area of sample - 1.77 sq.in.

S. No.	Time elapsed min.	Load dial	Load .bs.	Load psi.	Strain dial.	Deformation inches.	Remarks
1	0'30"	97.0	49.4	27.92	6.0	0.0006	
2	1'0"	183.0	93.3	52.70	15.0	0.0015	
3	1'30"	266.0	135.5	76.60	24.0	0.0024	
4	2'0"	335.0	170.9	96.50	35.0	0.0035	
5	2'30"	387.0	197.4	111.50	52.0	0.0052	
6	3'0"	431.0	220.0	124.20	70.0	0.0070	
7	3'30"	475.0	242.5	137.00	89.0	0.0089	
8	4'0"	499.0	254.5	143.75	110.0	0.0110	Sample failed
9	4'30"	494.0	252.0	142.40	135.0	0.0135	
10	5'0"	482.0	246.0	138.0	163.0	0.0163.	

6 DISCUSSION OF RESULTS

6. DISCUSSION OF RESULTS.

Results :-

The maximum normal pressure at different confining pressures were calculated for different soils samples and Mohr's circles plotted. Tangents to these were drawn and the strength envelopes obtained.

The corresponding values of cohesion and angle of shearing resistance are shown on the respective figures (Fig. Nos. 5.22 to 5.27).

Curves are plotted showing the relation between load on plunger (vertical axis) and penetration of plunger (horizontal axis) shown at Figs. 5.10 to 5.21). Wherever the curve did not pass through the origin, it was extended back and correction applied to each reading. The C.B.R. value was calculated for 0.1" penetration and for 0.2" penetration . The higher value was adopted as C.B.R. for that type of soil.

The corresponding C.B.R. values are indicated on the curves :-

Tables No. 5 shows cohesion, angle of shearing resistance and C.B.R. value for each type of mix with different percentages of cement.

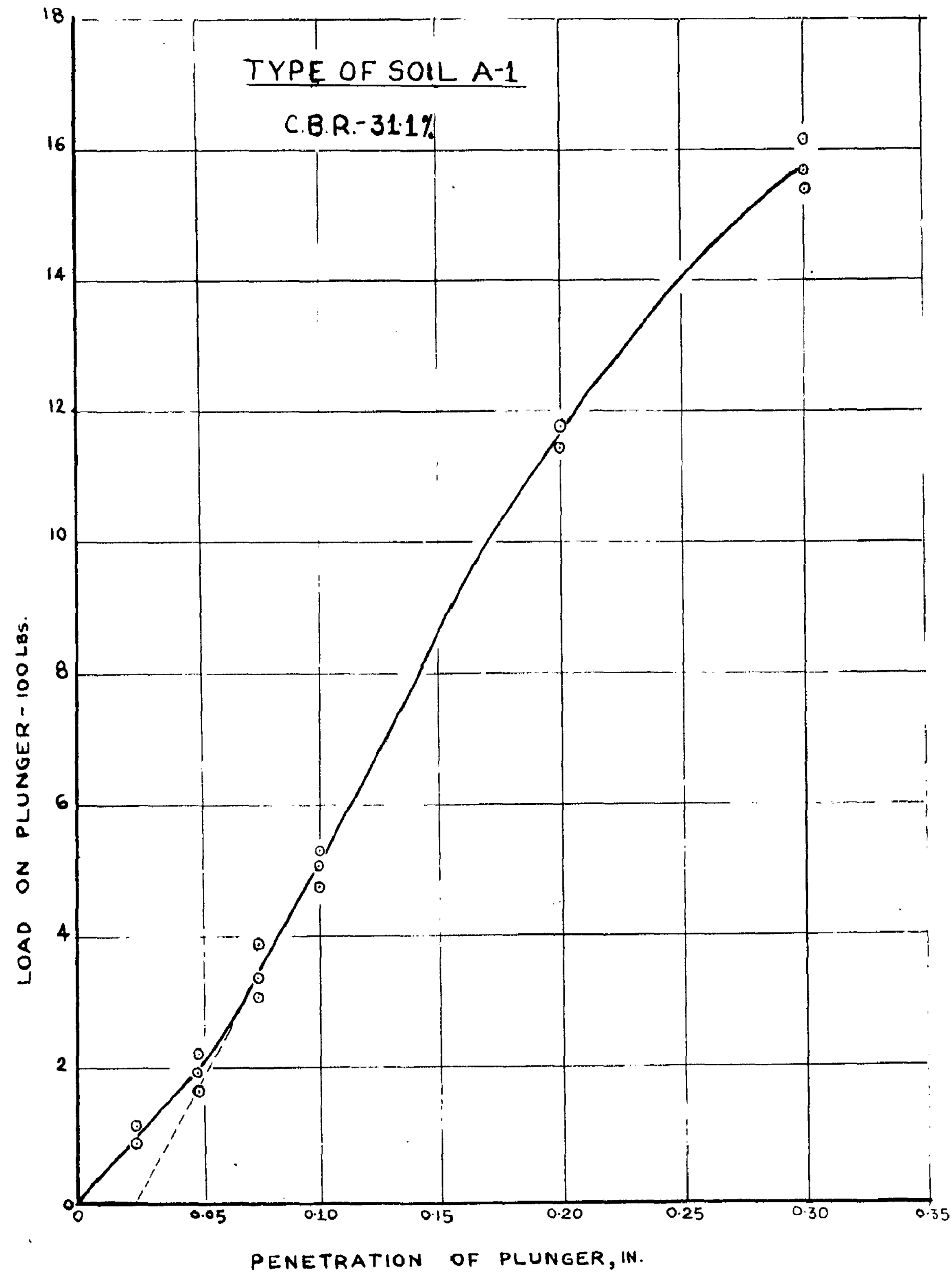


FIG. No. 5.10 LOAD-PENETRATION CURVE FOR SOIL A-1 OF C.B.R. TEST.

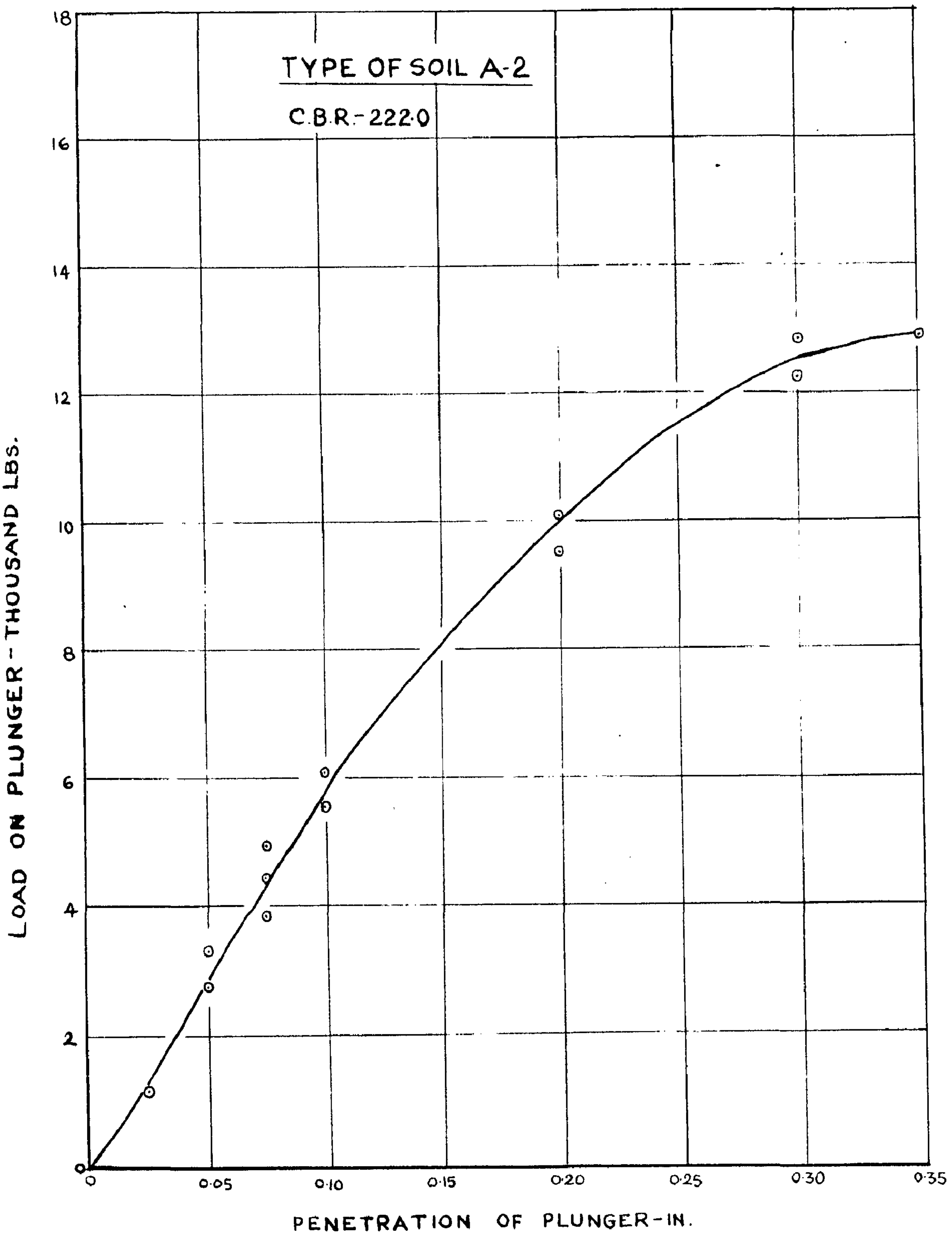


FIG. No. 5.11 LOAD-PENETRATION CURVE OF C.B.R. TEST FOR SOIL A-2.

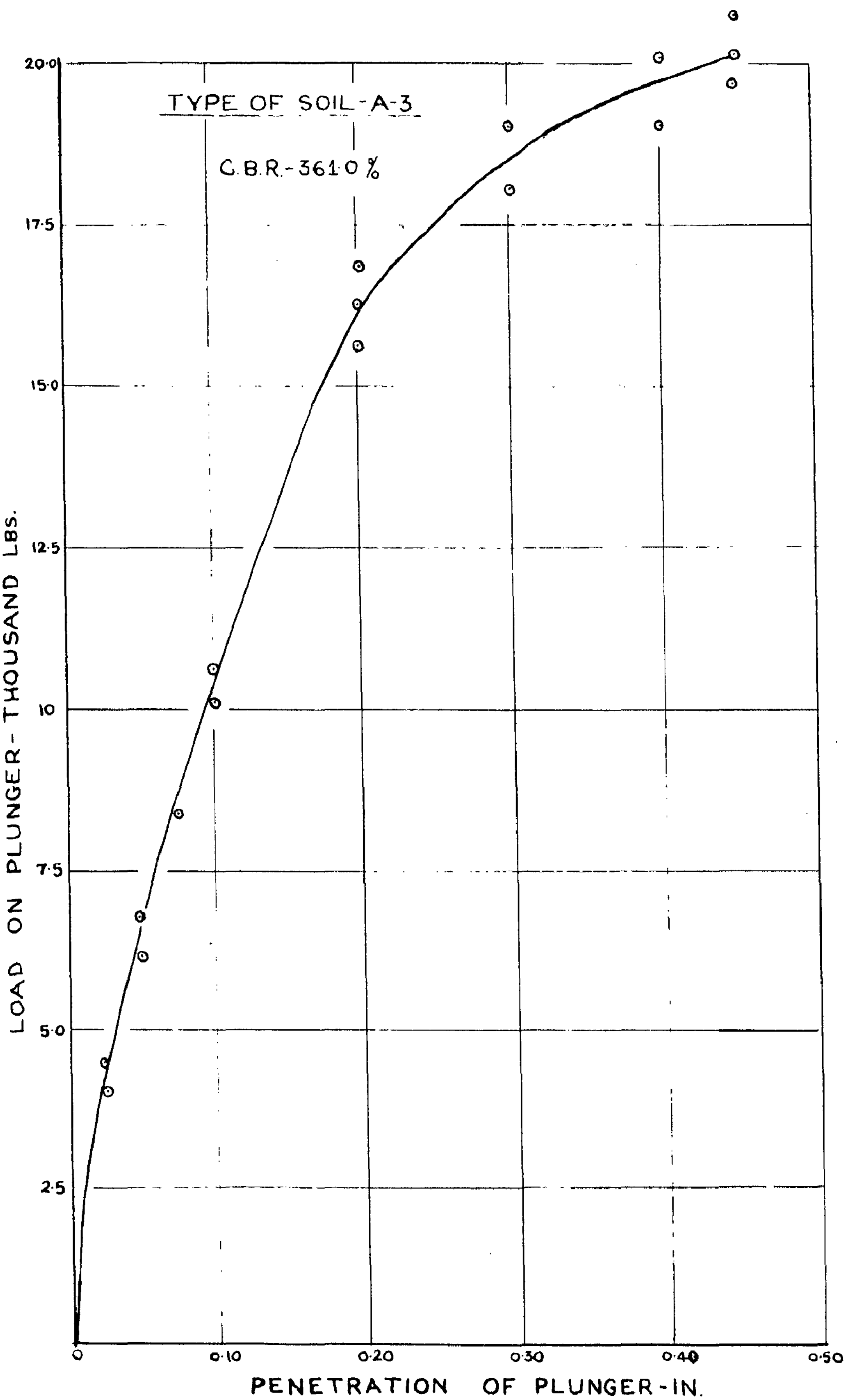


FIG. No. 5.12 LOAD-PENETRATION CURVE OF C.B.R. TEST FOR SOIL A-3.

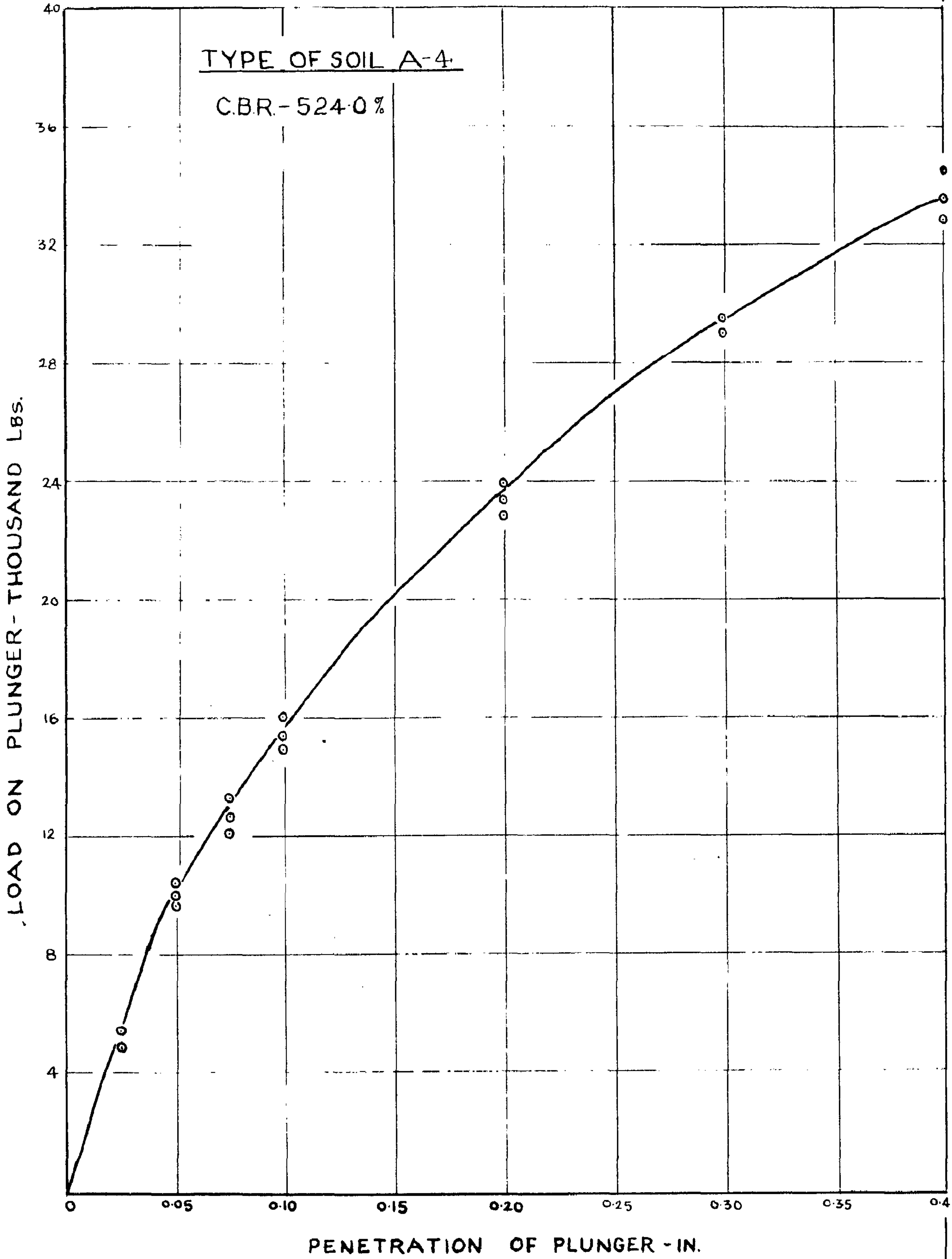


FIG.No. 5.13 LOAD-PENETRATION CURVE OF C.B.R. TEST FOR SOIL A-4

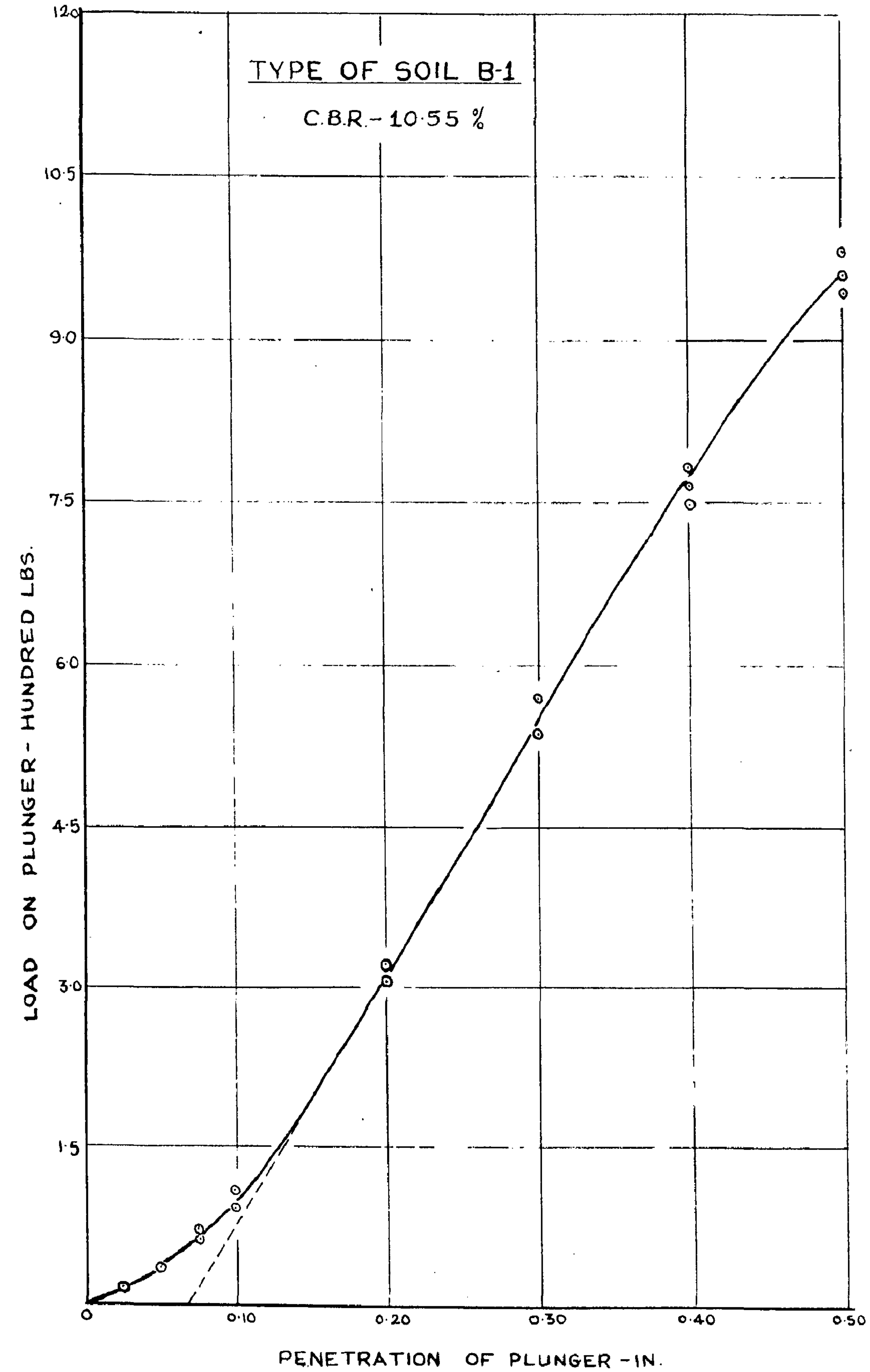


FIG. No. 5·14 LOAD-PENETRATION CURVE OF C.B.R. TEST FOR SOIL B-1.

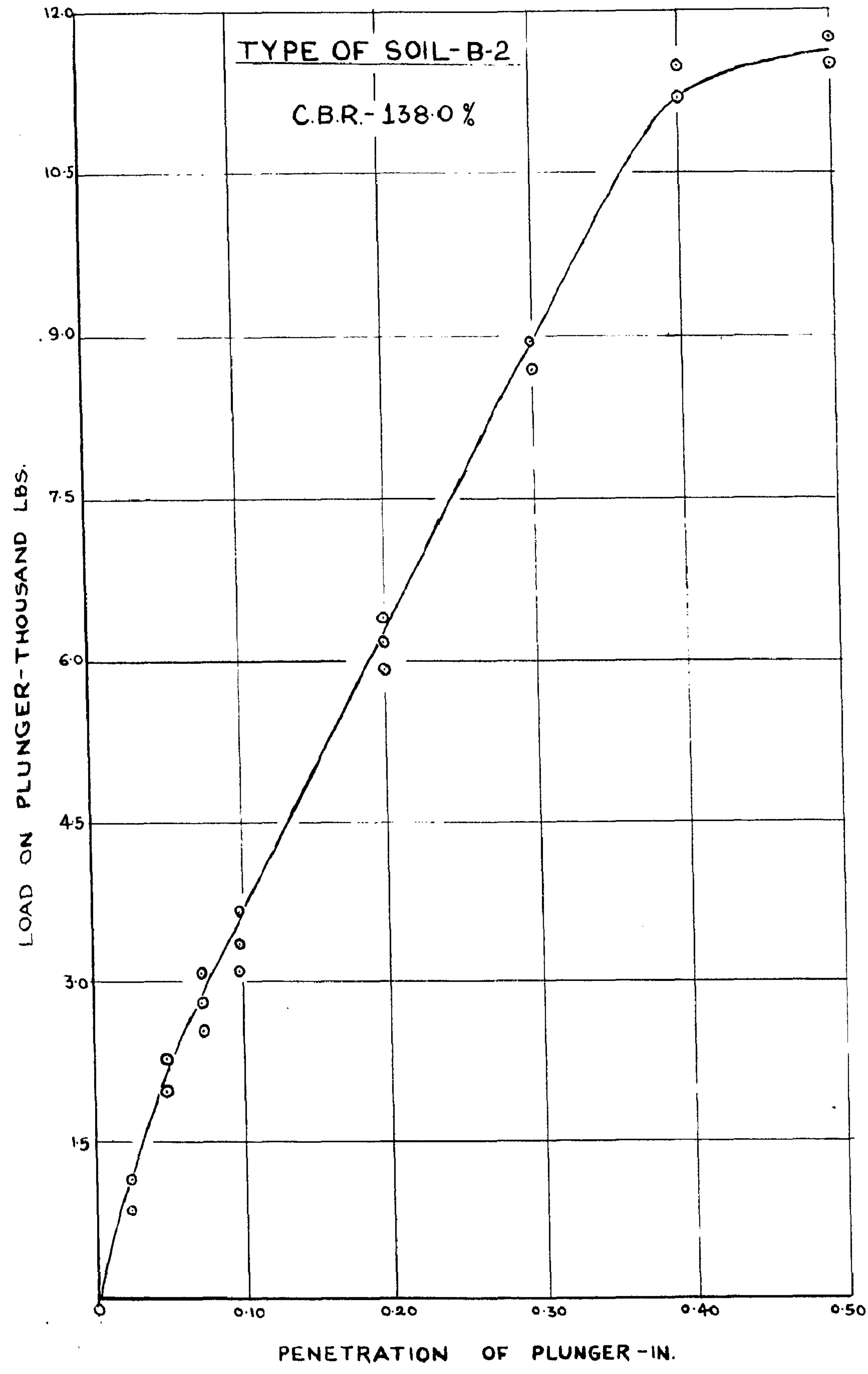


FIG.No. 5.15 LOAD-PENETRATION CURVE OF C.B.R. TEST FOR SOIL B-2

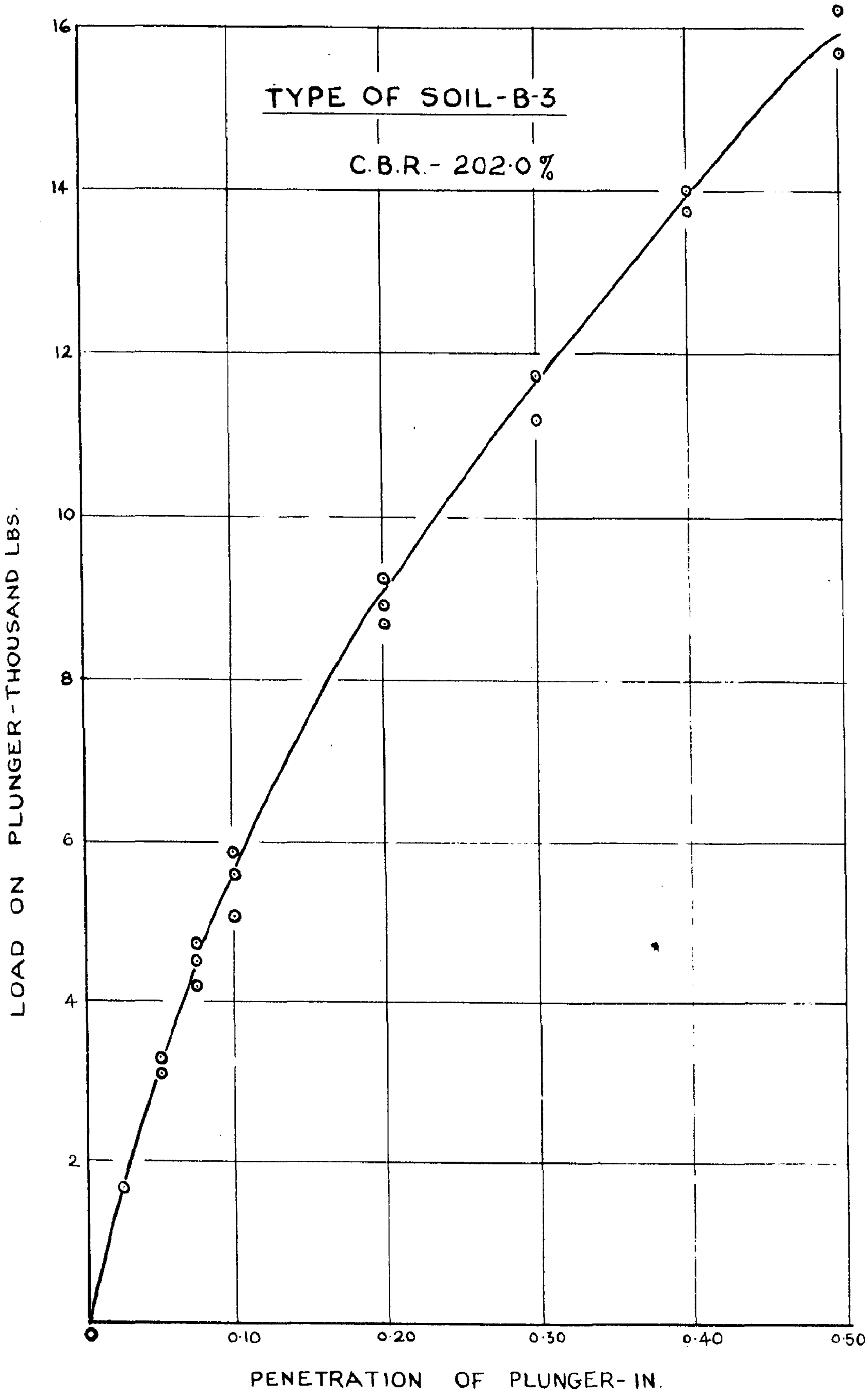


FIG. No. 5·16 LOAD-PENETRATION CURVE OF C.B.R. TEST FOR SOIL B-3

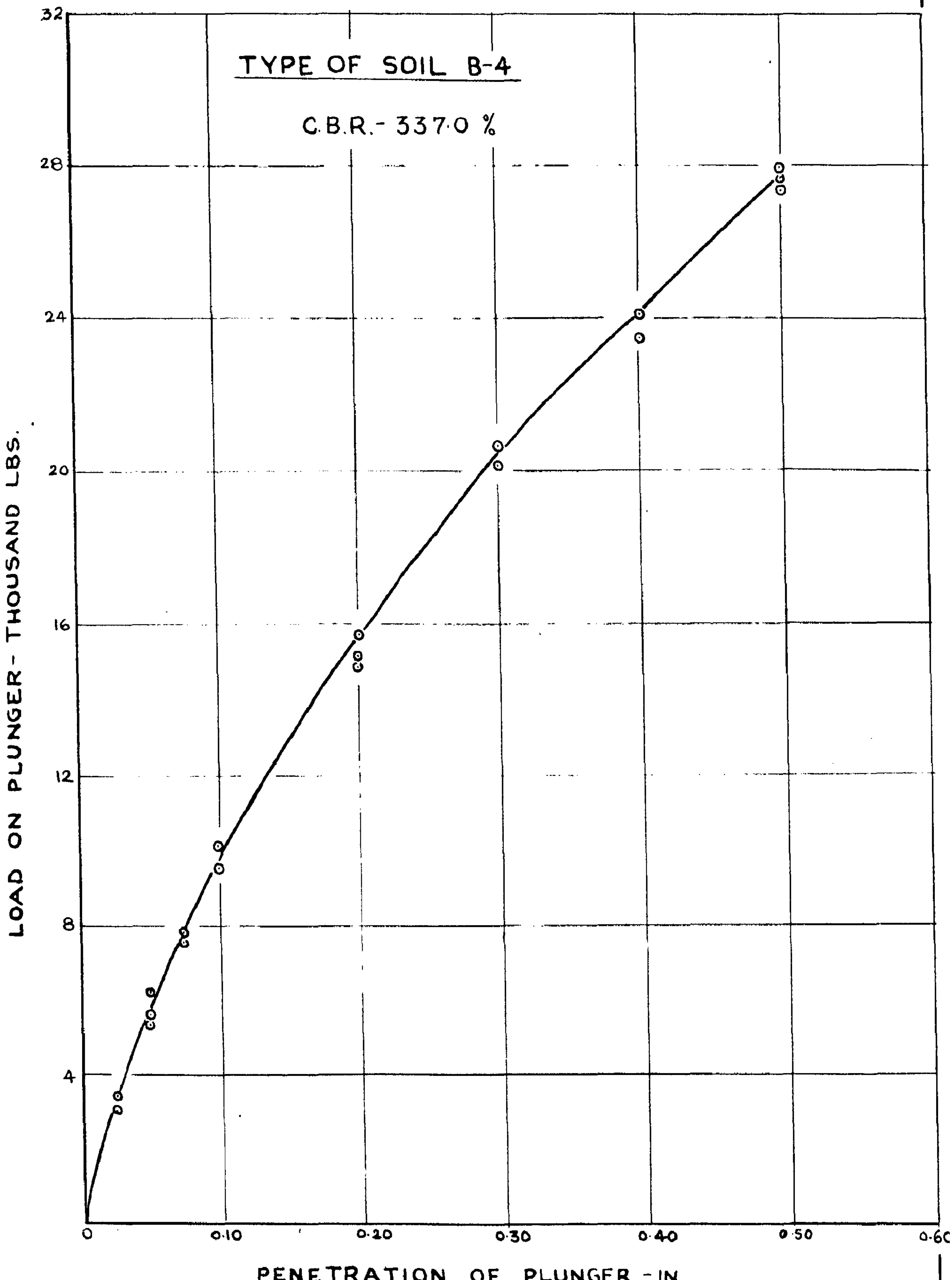


FIG. No. 5.17 LOAD-PENETRATION CURVE OF C.B.R. TEST FOR SOIL B-4

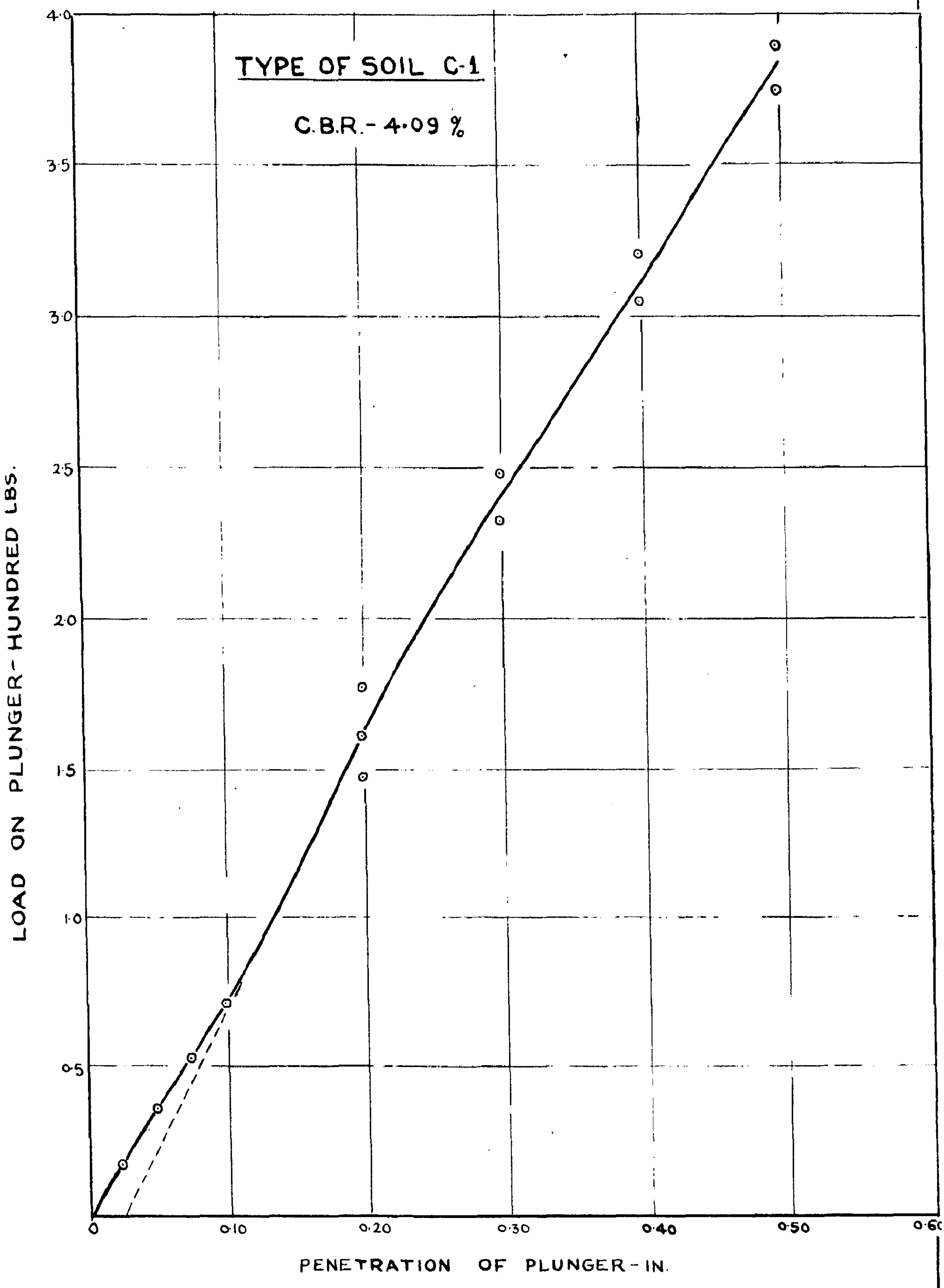


FIG. No. 5.18 LOAD-PENETRATION CURVE OF C.B.R. TEST FOR SOIL C-1

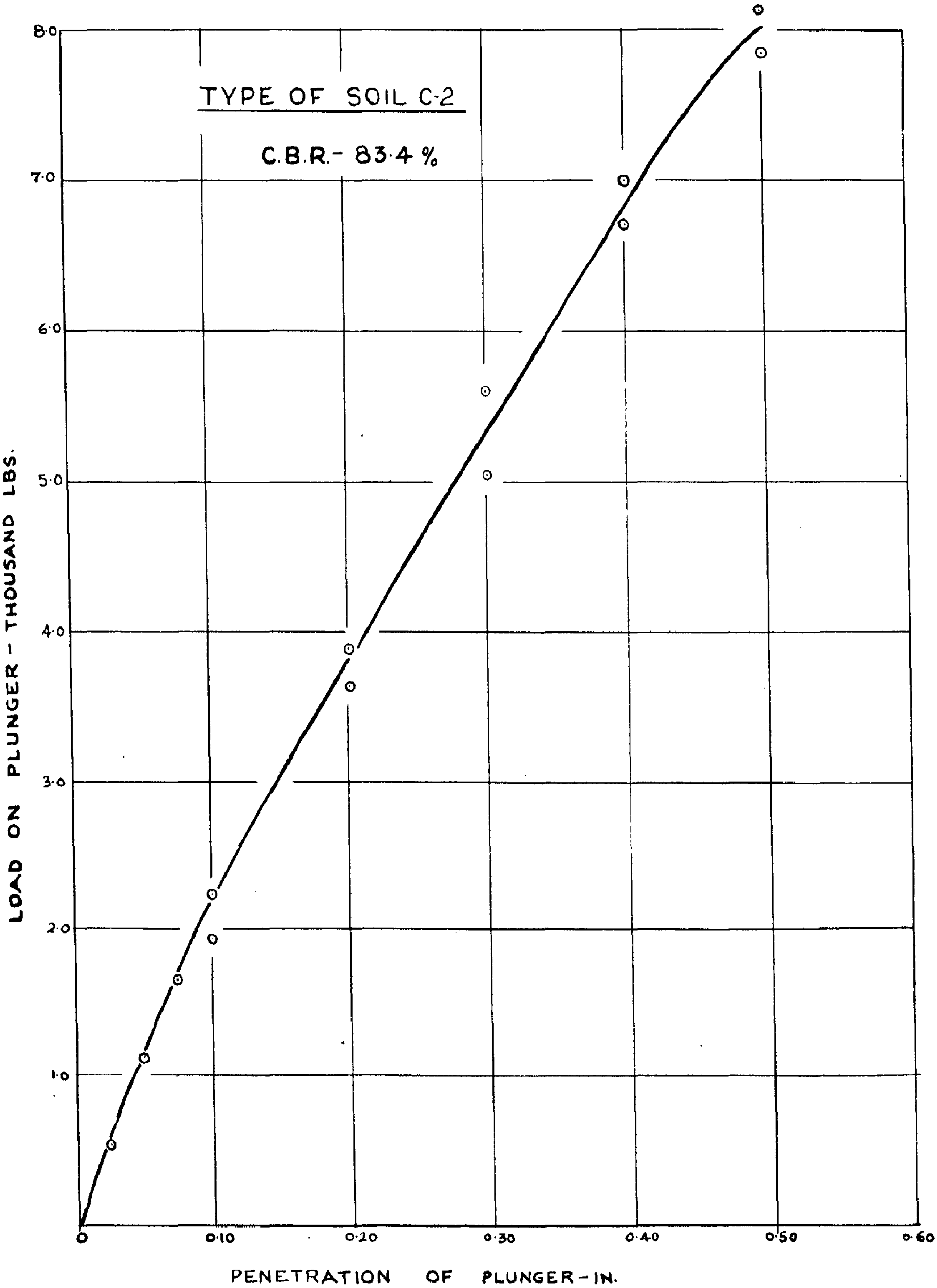


FIG. No. 5·19 LOAD-PENETRATION CURVE OF C.B.R. TEST FOR SOIL C-2

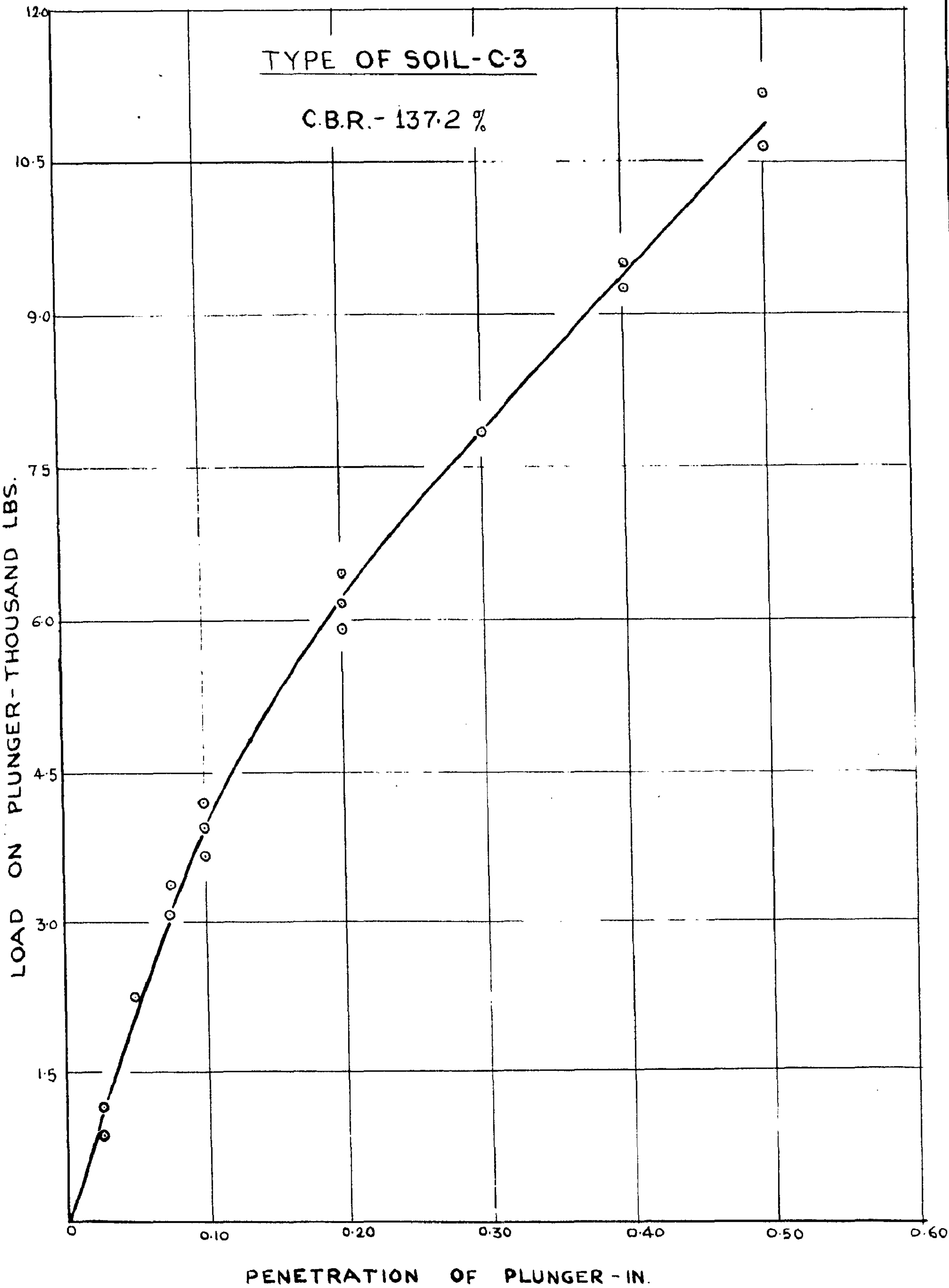


FIG. No. 5.20 LOAD-PENETRATION CURVE OF C.B.R. TEST FOR SOIL C-3

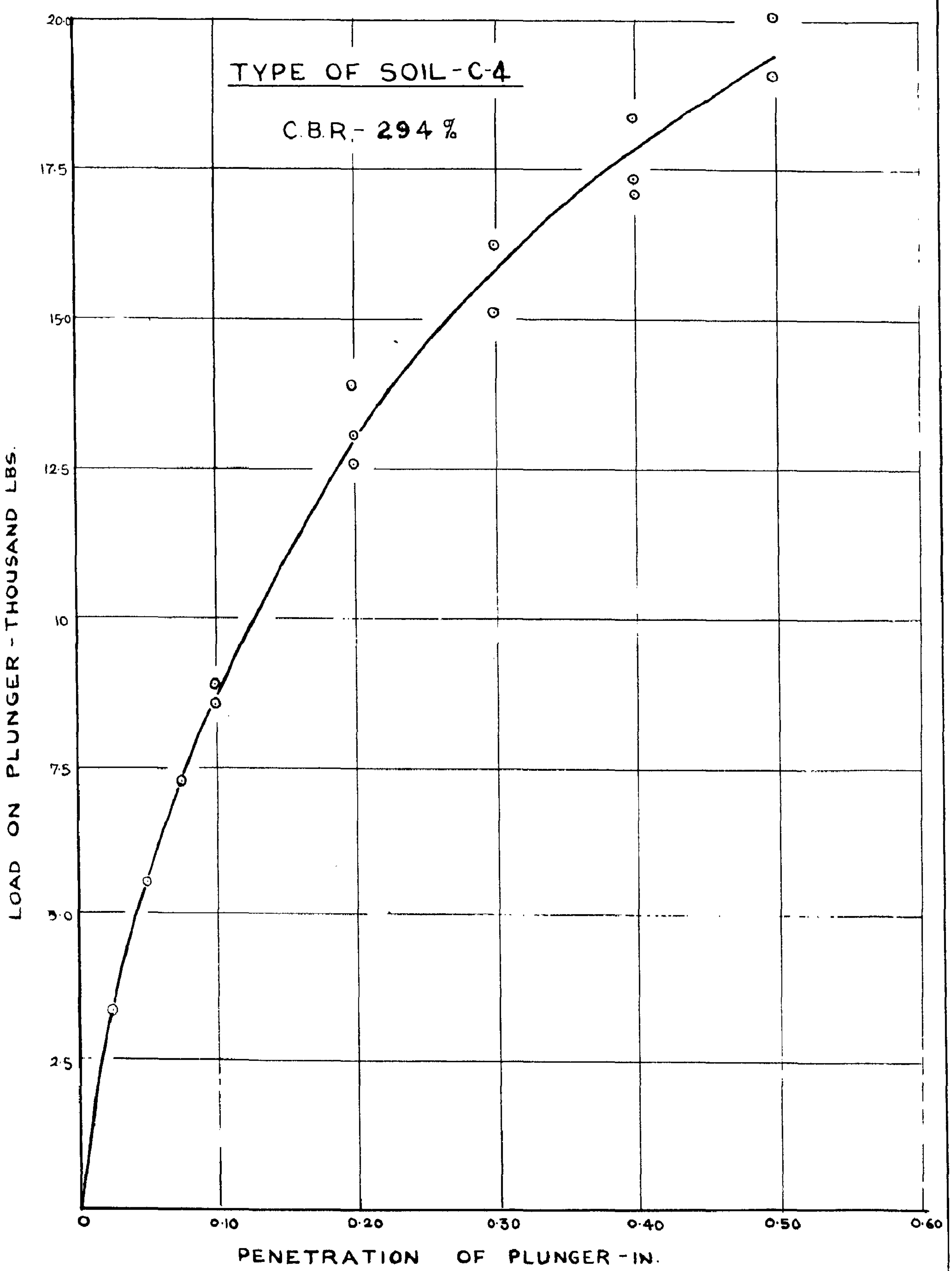
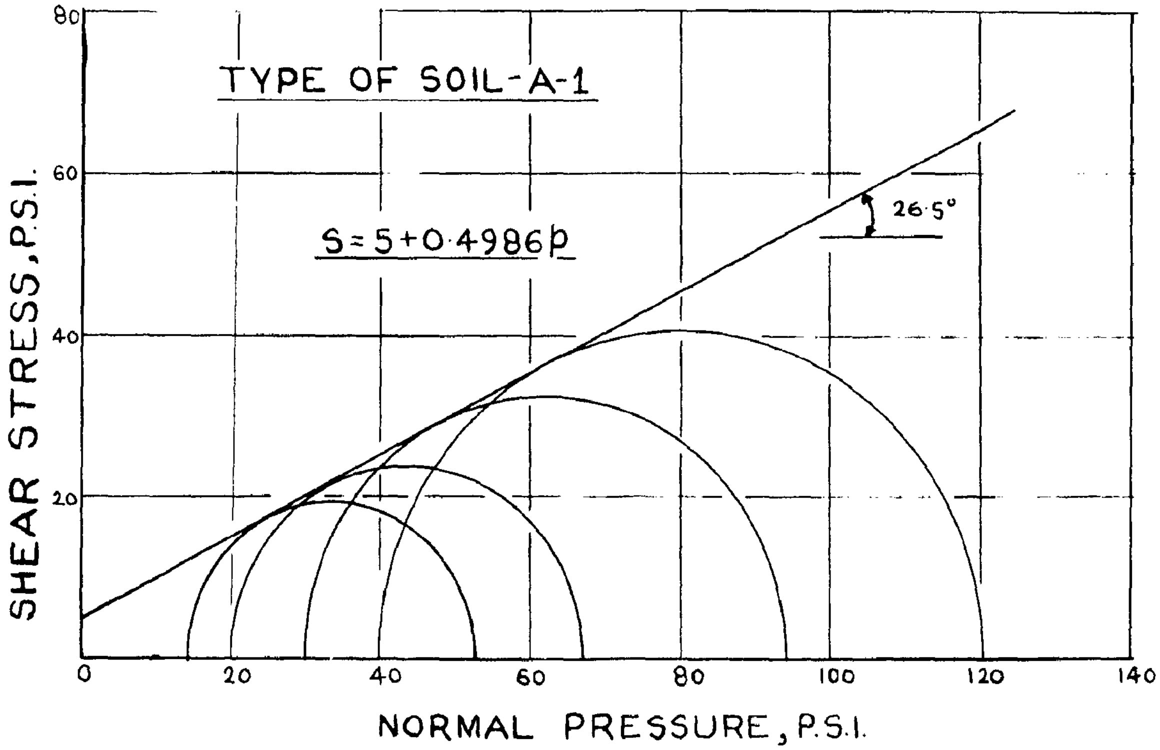


FIG. No. 5.21 LOAD-PENETRATION CURVE OF C.B.R. TEST FOR SOIL C-4



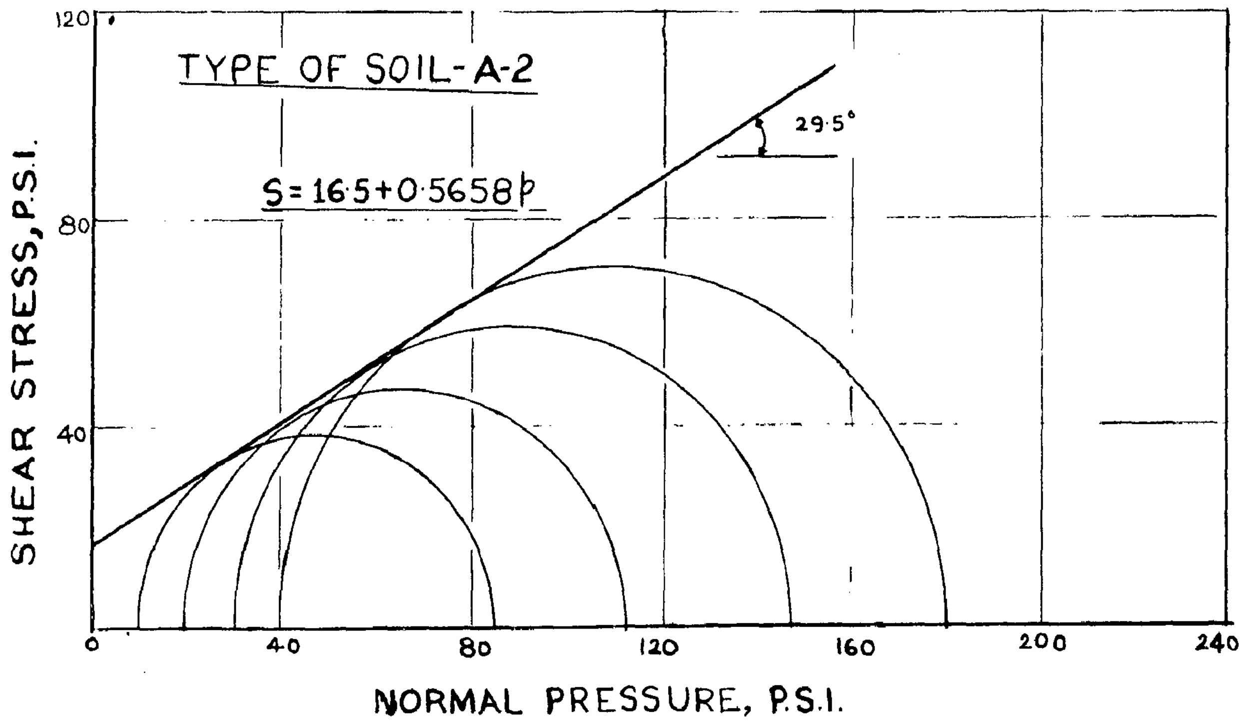
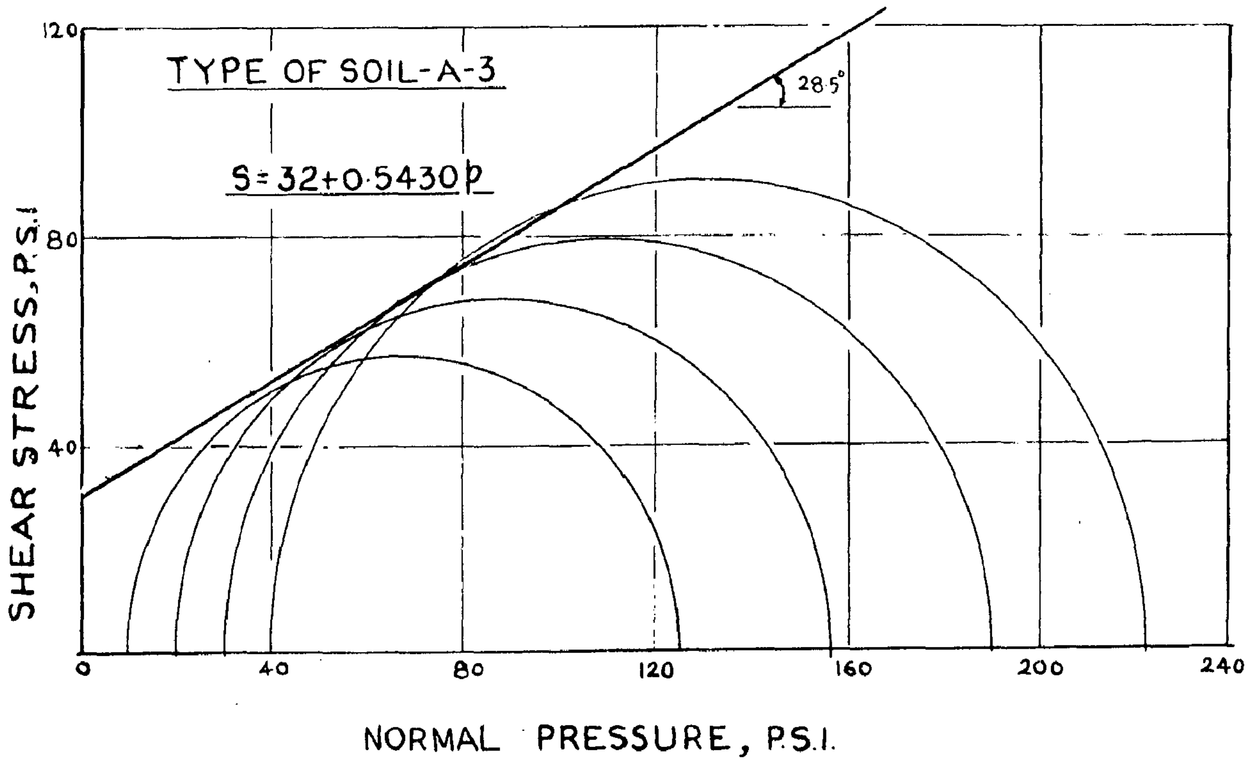


FIG. No. 5·22 MOHR'S RUPTURE DIAGRAM FOR SOILS A-1 & A-2 FROM TRIAXIAL TESTS.



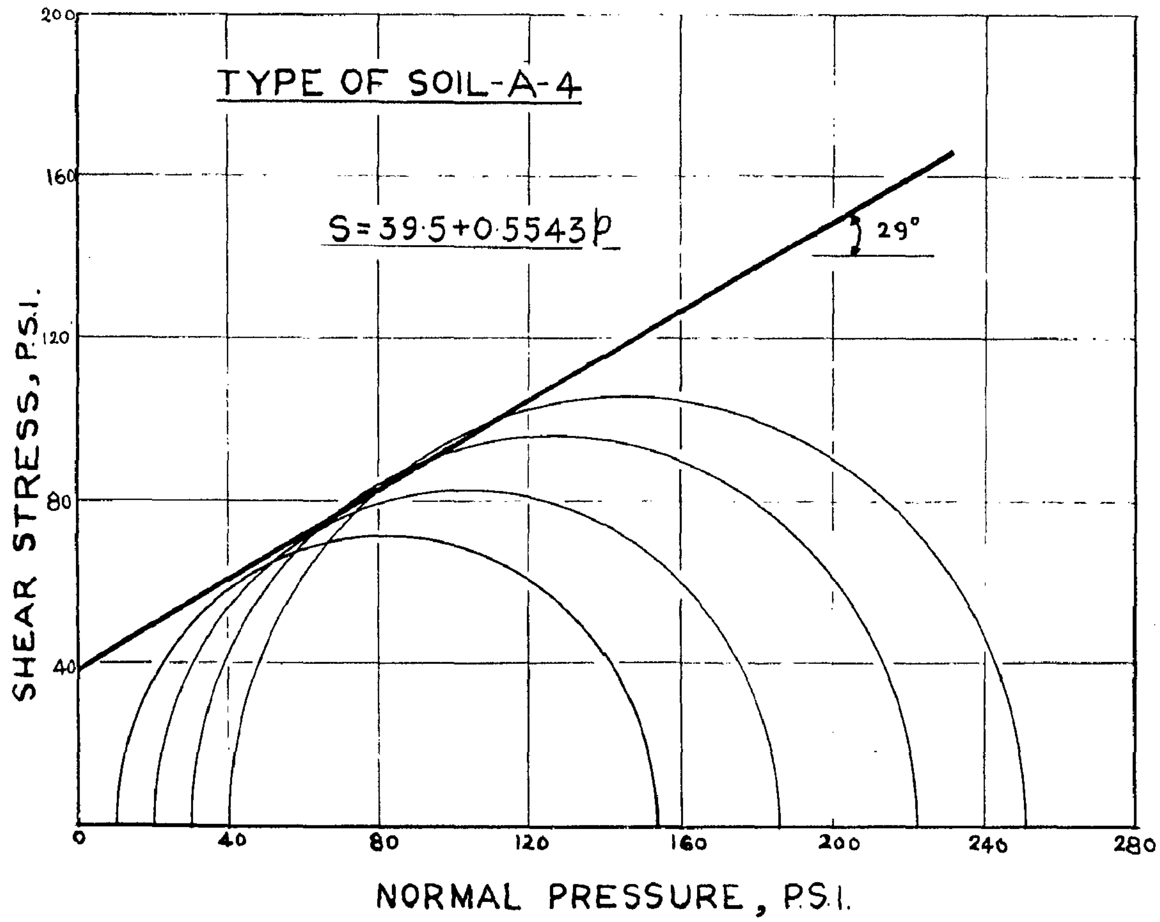
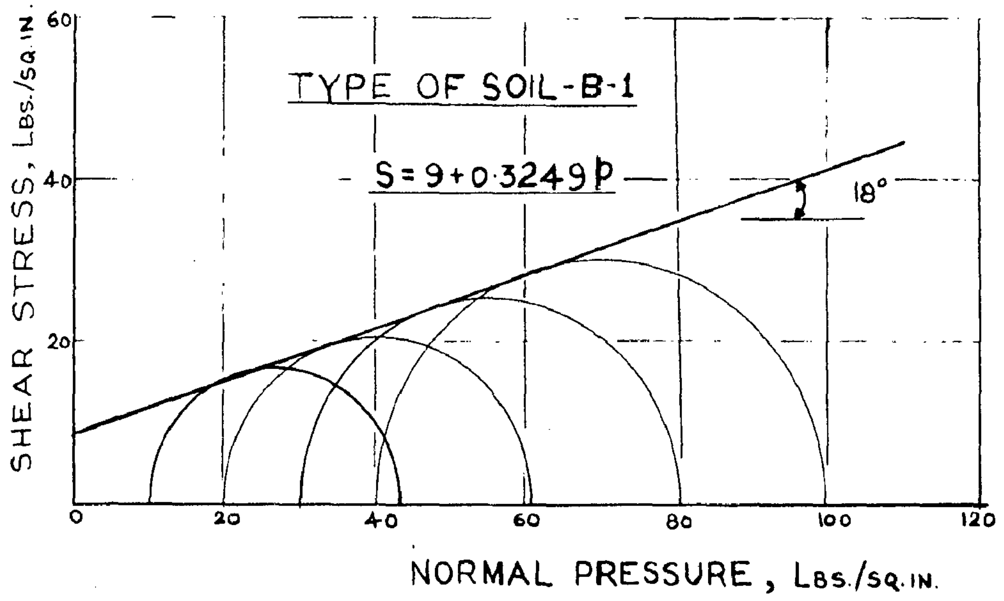


FIG. No. 5.23 MOHR'S RUPTURE DIAGRAM FOR SOILS A-3 & A-4 FROM TRIAXIAL TESTS.



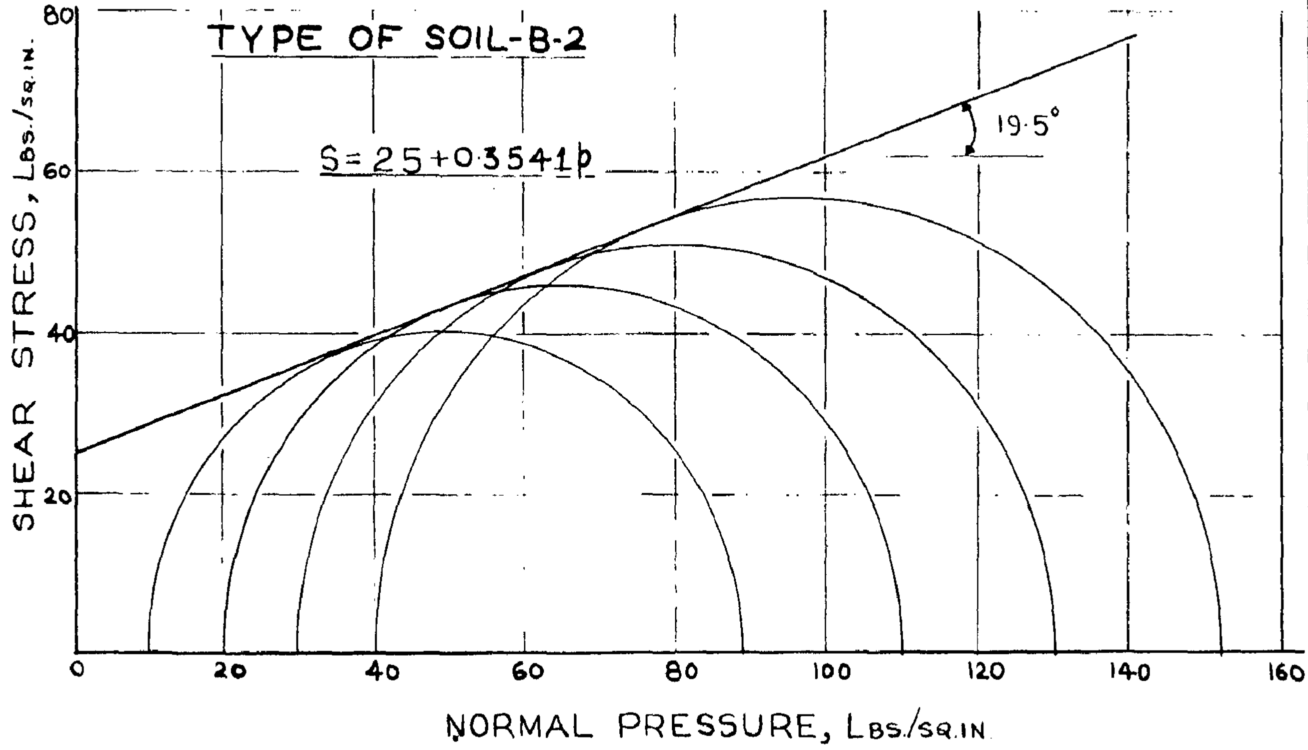
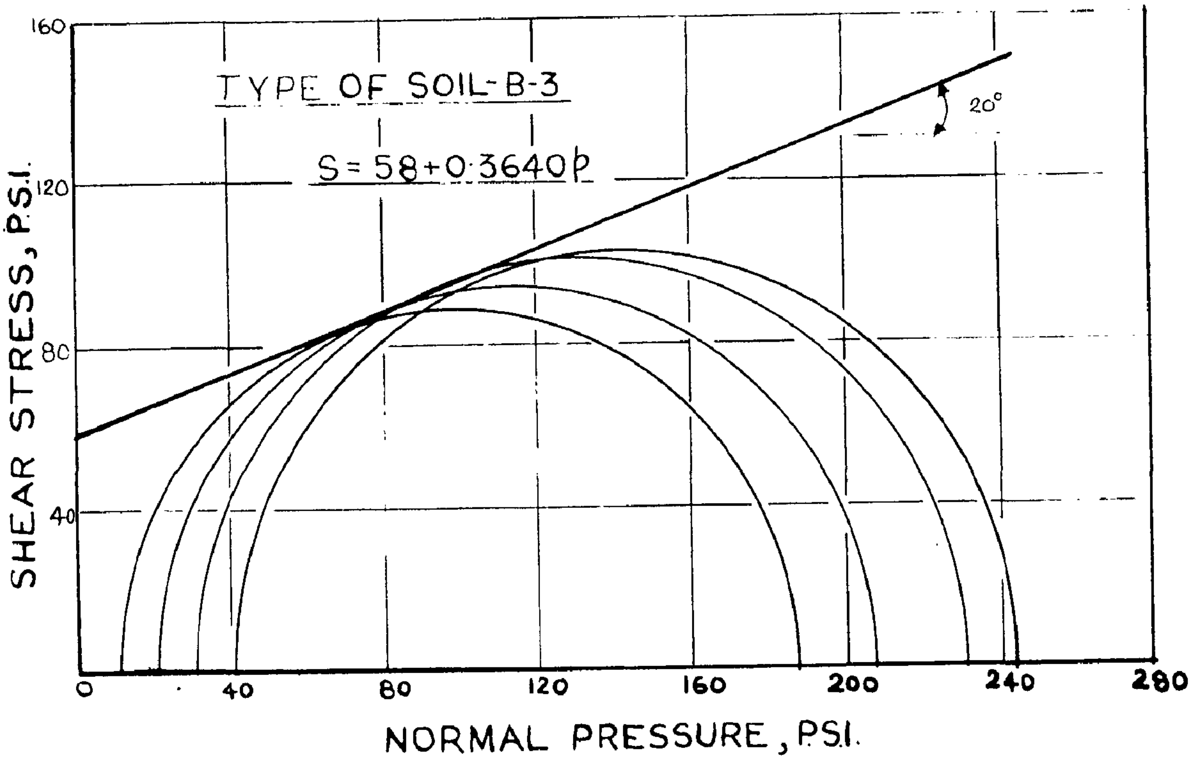


FIG. No. 5·24 MOHR'S RUPTURE DIAGRAM FOR SOILS B-1 & B-2 FROM TRIAXIAL TESTS.



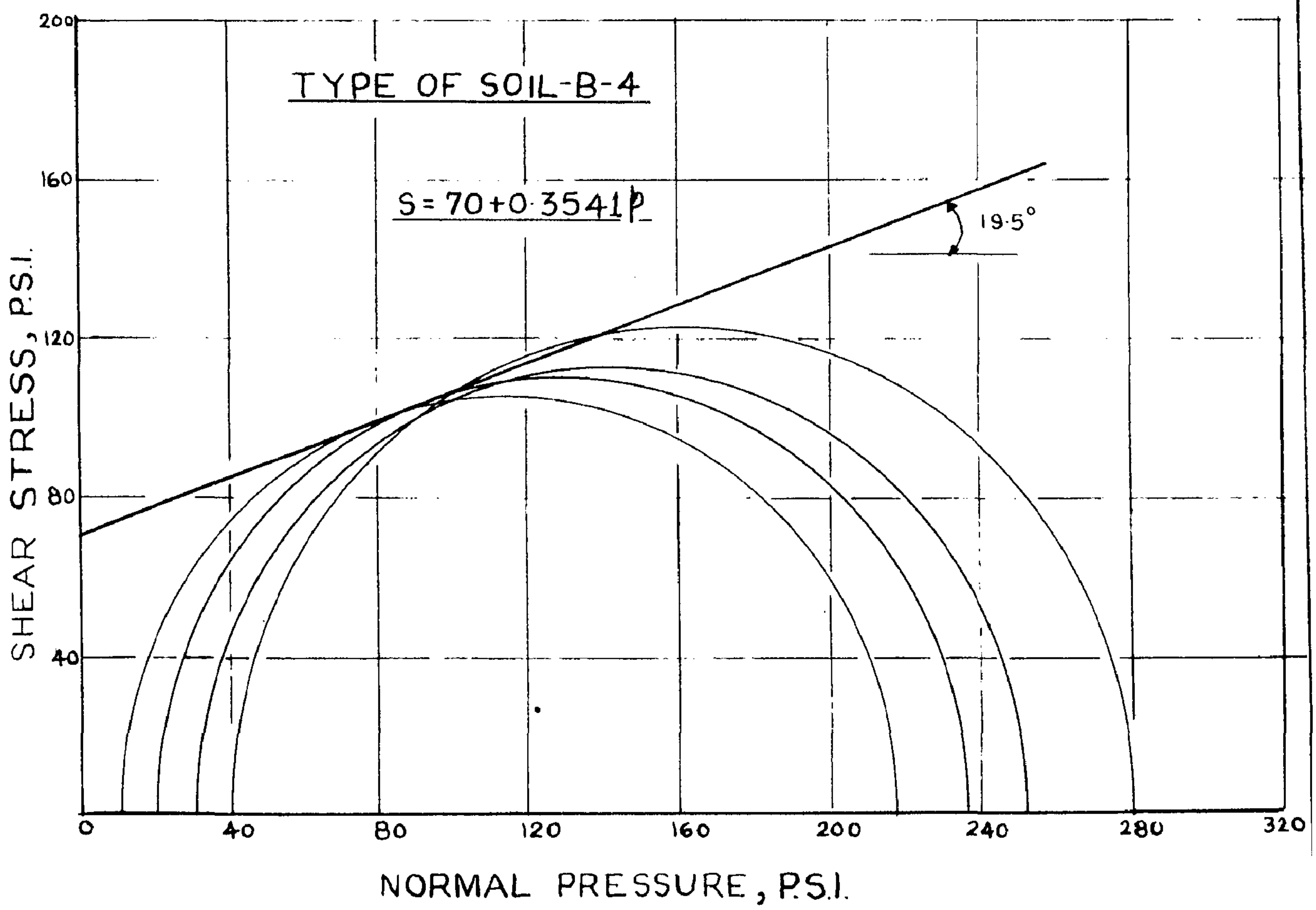


FIG. No. 5·25 MOHR'S RUPTURE DIAGRAM FOR SOILS B-3 & B-4 FROM TRIAXIAL TESTS.

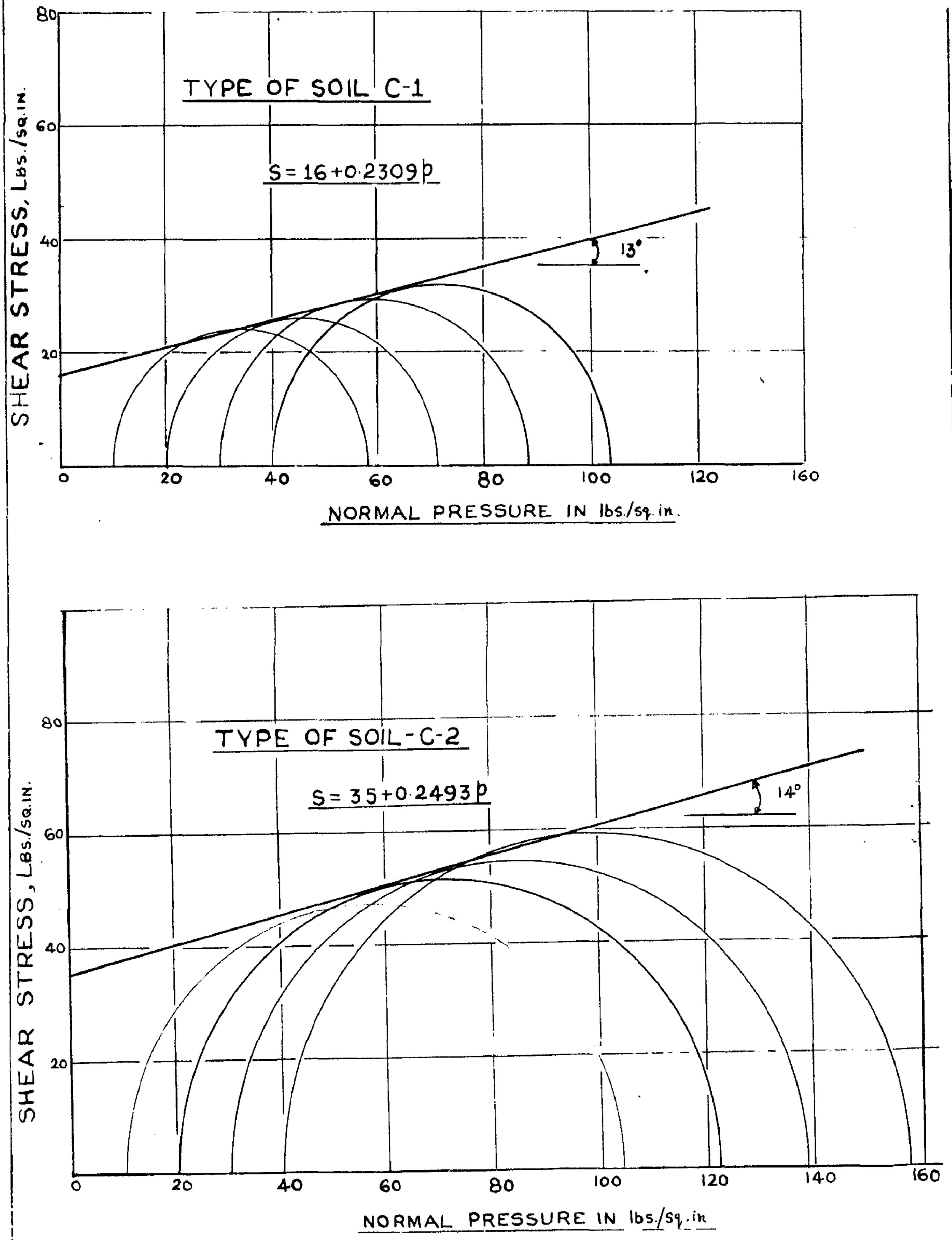
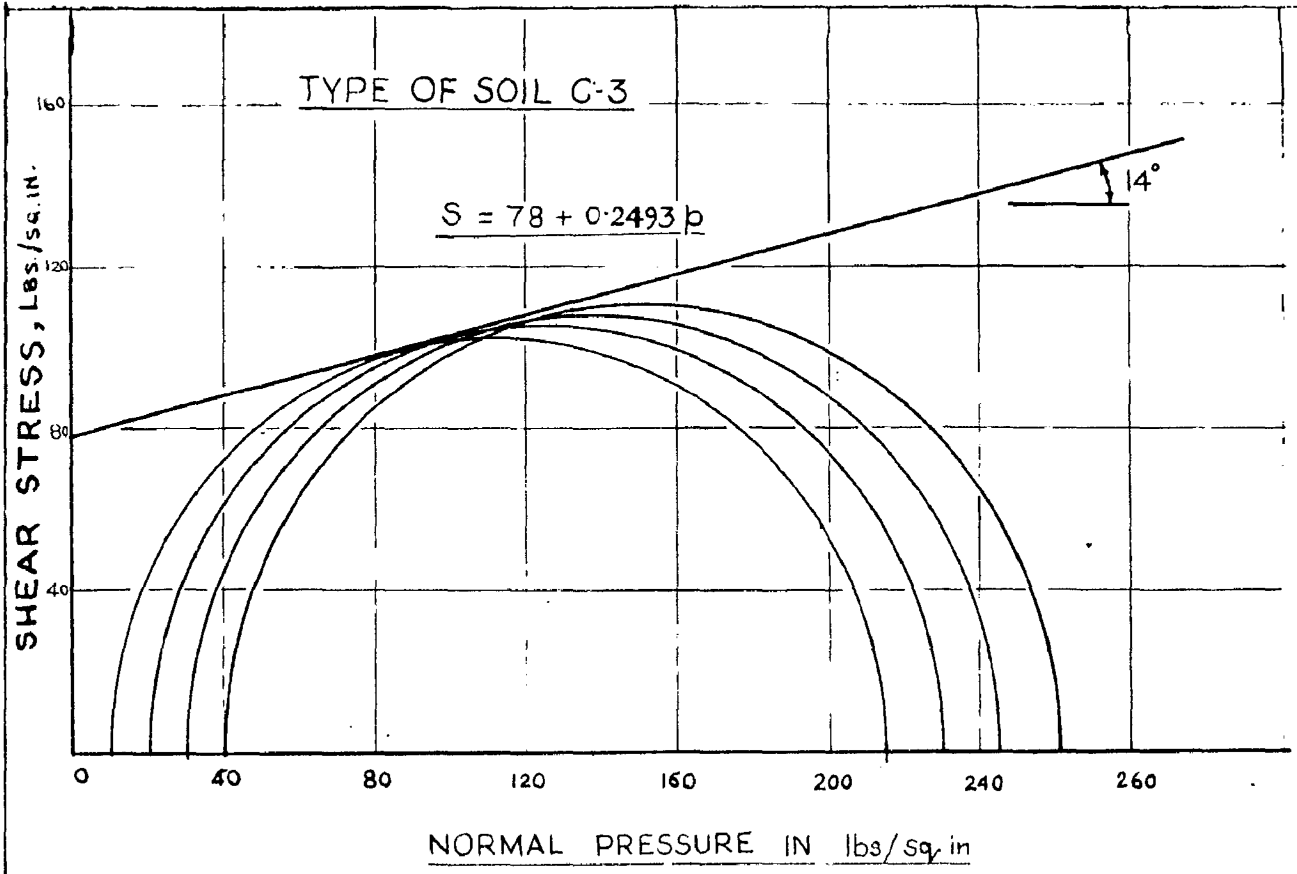


FIG. No. 5.26 MOHR'S RUPTURE DIAGRAM FOR SOILS C-1 & C-2 FROM TRIAXIAL TESTS.



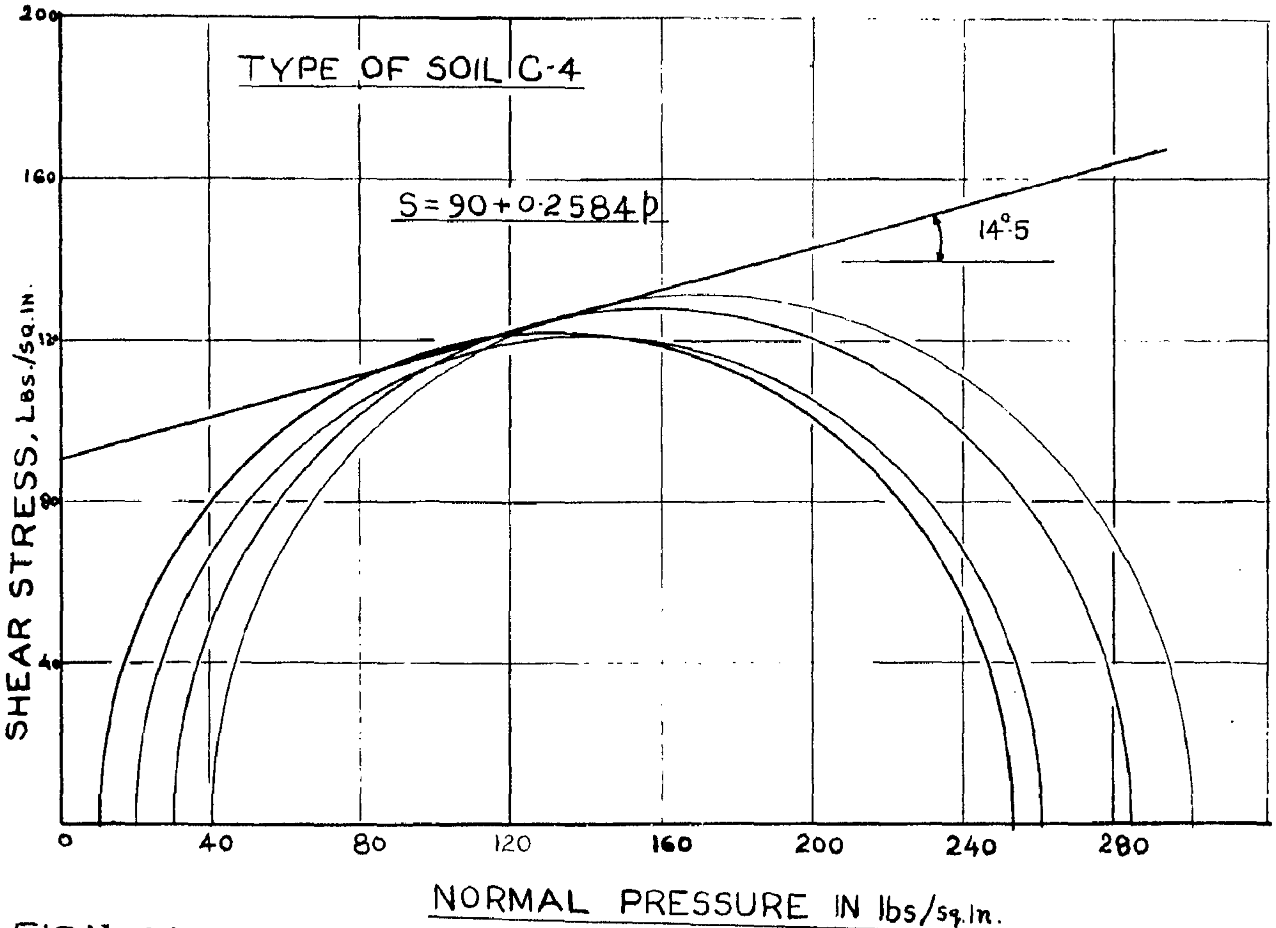


FIG.No.5·27 MOHR'S RUPTURE DIAGRAM FOR SOILS C-3 & C-4

TABLE - 5.

Table showing CBR values, cohesion, and angle of shearing resistance for different soils.

S. No.	Type of soil.	Cohesion (c) psi	Angle of shearing resistance.	C.B.R.	Remarks
1	A-1	5.0	26.5°	23.75	
2	A-2	16.5	29.5°	222.0	
3	A-3	32.0	28.5°	361.0	
4	A-4	39.5	29.0°	524.0	
5	B-1	9.0	18.0°	9.22	
6	B-2	25.0	19.5°	137.75	
7	B-3	58.0	20.0°	202.0	
8	B-4	70.0	19.5°	337.0	
9	C-1	16.0	13.0°	3.88	
10	C-2	35.0	14.0°	83.4	
11	C-3	78.0	14.0°	137.2	
12	C-4	90.0	14.5°	294.0	

Discussion of Results :-

From Mohr's envelopes it is seen, in the case of all soils, that with increase in cement content there is a considerable increase in the cohesion value, whereas there is little increase in the angle of shearing resistance. An increase of 1.5^{0} to 3.0^{0} is noted for types 'C' and 'A' soil. It may, therefore, be said that governing criterion in shear strength is the cohesion of the soil.

There is considerable increase in the angle of shearing resistance and cohesion, in case of Chert gravel treated with cement (14). The maximum cohesion in this case was reached at 6% cement and between 6 and 8% cement there was sudden increase in the angle of shearing resistance. No such phenomena was observed in our study. This may be due to presence of clay and difference in type of soil.

Also P.C.A. studies (14) on sandy and silty mixtures under triaxial loading showed that angle of shearing resistance was relatively constant regardless of cement percentage and age of curing. The cohesion value ranged from about 35 psi to 530 psi upto 28 days of curing, and was dependent on the type of soil and cement content. The cohesion value also increased with age. Soaking of specimens decreased the cohesive value.

The increase in the cohesion should be expected since when the cement is added to a soil and mixed thoroughly, the soil particles cling to the particles of cement and get bound. (just the reverse of what happens in concrete) In concrete, it is the cement particles which coat the aggregates whereas in cement soil mixture, the cement particles get coated by soil particles.

As the cement content is increased, more cement particles are coated by soil particles and the cohesion is increased due to the bond. The maximum cohesion is attained when all the soil particles are used up in coating all the particles of cement. If more cement is added, there are no soil particles to coat it and the additional cement gets dispersed, as it is, into the soil without any appreciable increase in cohesion.

Since there is no increase in size of particles due to addition of cement and the molecular structure also remains the same, the angle of shearing resistance does not increase substantially.

To correlate C.B.R. value with shear strength, curves are plotted between cohesion on horizontal axis and C.B.R. value on vertical axis Fig. 6. The shape of the curves is concave upwards. The curvature increases from type 'A' soil to type 'C' soil. This shows that the increase in the C.B.R. value is less for type 'C' soil than that of type 'B' soil which is less than that of type 'A' soil, for the same increase in cohesion. The increase in C.B.R. value is greatest

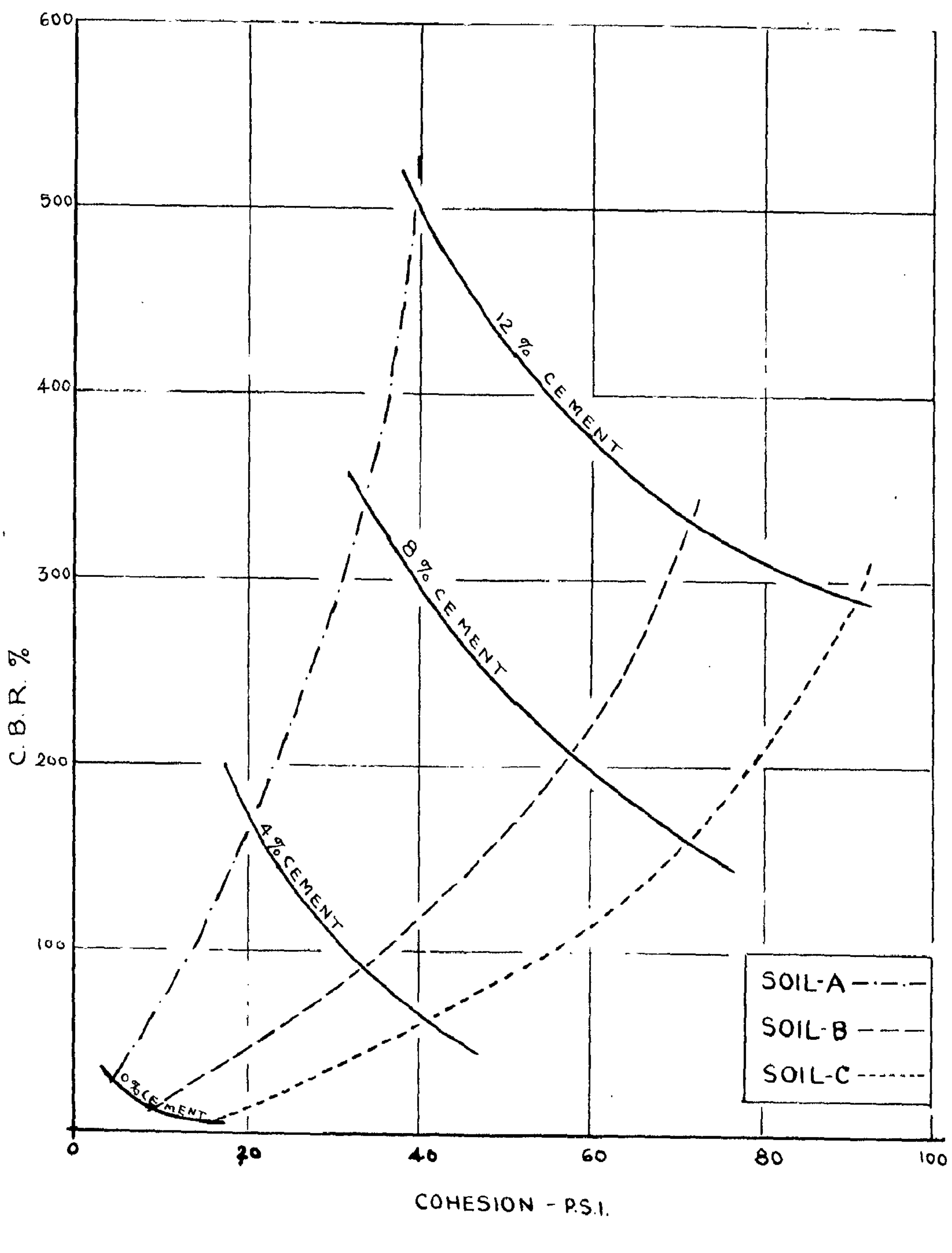


FIG. No. 6 RELATIONSHIP BETWEEN COHESION & C.B.R. FOR DIFFERENT SOILS.

for type 'A' Soil.

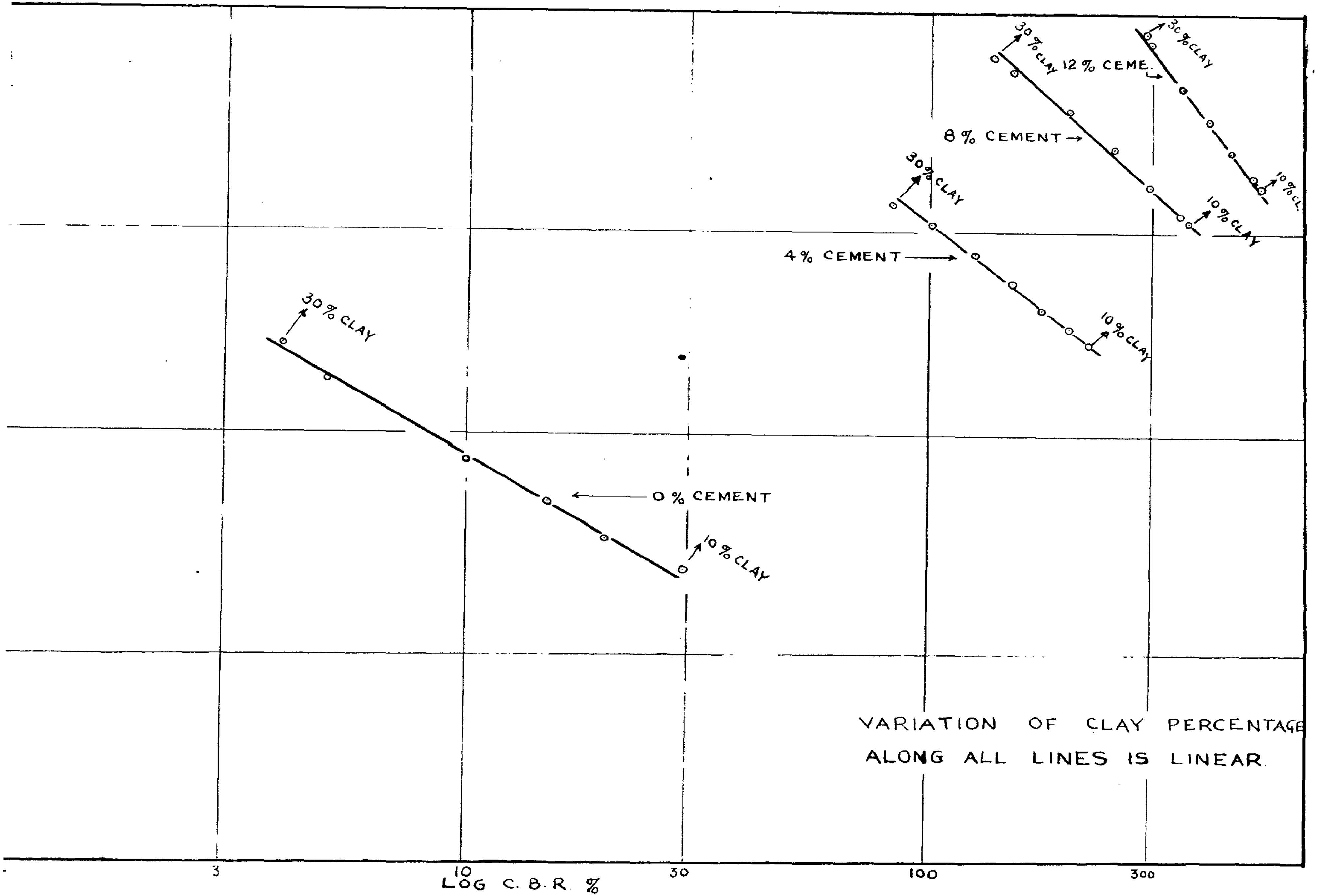
In more cohesive soil, with the addition of cement, there is an increase in cohesion, whereas in case of less cohesive soil, there is relatively greater increase in C.B.R. value.

For the same percentage of cement added to all the three types of soils, greatest value of C.B.R. is attained in type 'A' soil.

To know the effect of cement content on different types of soils, through the points of equal percentage of cement for three soils, curves are drawn (Fig. 6). The shape of curves resembles that of generalised Boyle's law, $PV^{\gamma} = \text{Const.}$ The concavity of these curves is towards origin. This property of curves shows the possibility of some mathematical expressions of the type $CB^{\alpha} = K$, where C = Cohesion, B = C.B.R. %, α = const., and K = some other constant.

This means that with the increase in cohesion, there is decrease in C.B.R. value and vice verse.

To verify the nature of these curves, different values on the curves were chosen, for C.B.R. and corresponding values of cohesion were read off. These two were plotted on a double-log graph paper to give straight lines (Fig.7) verifying the possibility of the above mentioned mathematical



RELATIONSHIP BETWEEN COHESION & C.B.R. FOR DIFFERENT CEMENT CONTE relations.

The slope of 12% cement line is minimum and it gradually increases with the decrease in cement percentage and is maximum for zero percent cement line. Though the maximum C.B.R. value is reached with 12% cement, the ratio of increase in C.B.R. value is more with less addition of cement. i.e., the rate of increase in C.B.R. value is maximum between zero and 4 % cement and goes on reducing to a minimum value between 8 and 12%, cement. This may be due to the fact that initially, with addition of cement, there is immediate rise in resistance to penetration due to sudden binding of particles. The same rate cannot be maintained with further addition of cement since a good percentage of resistance has already developed.

In this study, results similar to P.C.A. studies (14) have been obtained. The cohesion value may be less due to soaking of specimens prior to testing, for four days. The increase in cohesion was dependent on cement content and type of soil, as well as on age of curing.

Application to Design :-

The common procedure for design of soil-cement bases is California practice (14). This is mainly based on the cohesive resistance of cement treated bases determined by Hweem cohesiometer.

In British Practice, the soil-cement is considered to behave as a flexible pavement because of its low bending strength. British Military Engineers have investigated the applicability of the shear strength method of design for cohesive subgrades, having a strength essentially independent of over burden pressure. A thickness of soil-cement is selected such that any depth greater than the base thickness, the induced shear stresses are less than the shear strength of the subgrade. They have also correlated C.B.R. and compressive strength and indicate the possibility of the use of that method provided appropriate adjustments are made in the application of the method.

Knowing the relation between C.B.R. value and the cohesion of soil-cement we can know either of the two knowing the other, for a given soil. So use can be made of the California practice, which takes into account the cohesive resistance. Also knowing the corresponding C.B.R. value the pavement can be designed based on C.B.R. requirements. From these two criterion the suitable thickness required, for the pavement can be calculated.

CONCLUSIONS

From the laboratory investigations carried out, the following conclusions may be drawn :-

1. There is considerable increase in the value of cohesion due to addition of cement.
2. The rate of increase of C.B.R. value decreases with the increase in cohesion for the same increase in percentage of cement.
3. The rate of increase in C.B.R. value is more at lower percentage of cement than at higher percentage of the same increase in cohesion.
4. The C.B.R. value is maximum for 12% cement in Soil 'A'.
5. With higher value of C.B.R., there is relatively very small increase in cohesion.
6. The curves between C.B.R. and cohesion, for equal percentage of cement in different soils, resemble that of $PV^{\gamma} =$ const. and a mathematical expression for each curve may be developed.

LIMITATIONS.

1. The work was carried out only on three types of mixes and four percentages of cement. Further tests are necessary to verify the conclusions.
2. The curing period was kept at 3 days due to shortage of time, instead of usual 7 days curing.
3. As the angle of shearing resistance did not vary much, the cohesion was considered to be the main contributor to shear strength.

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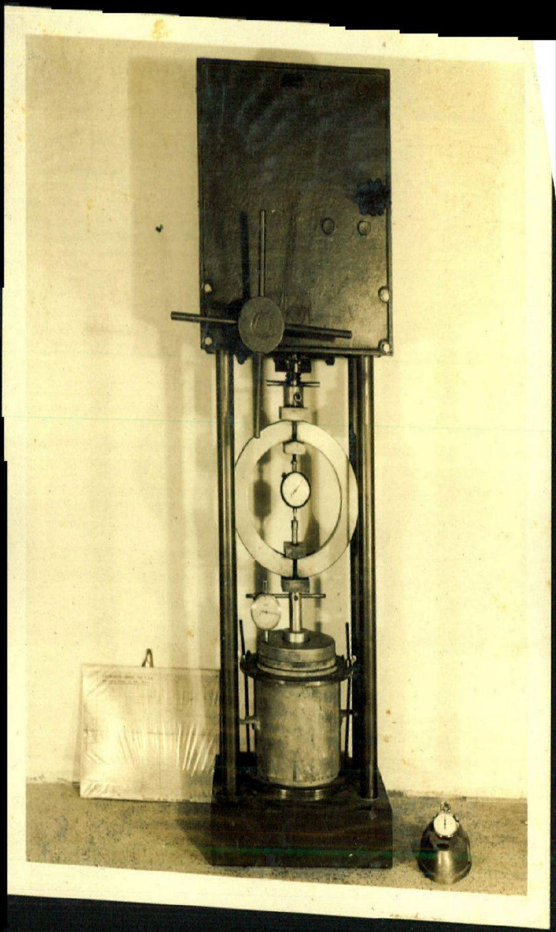
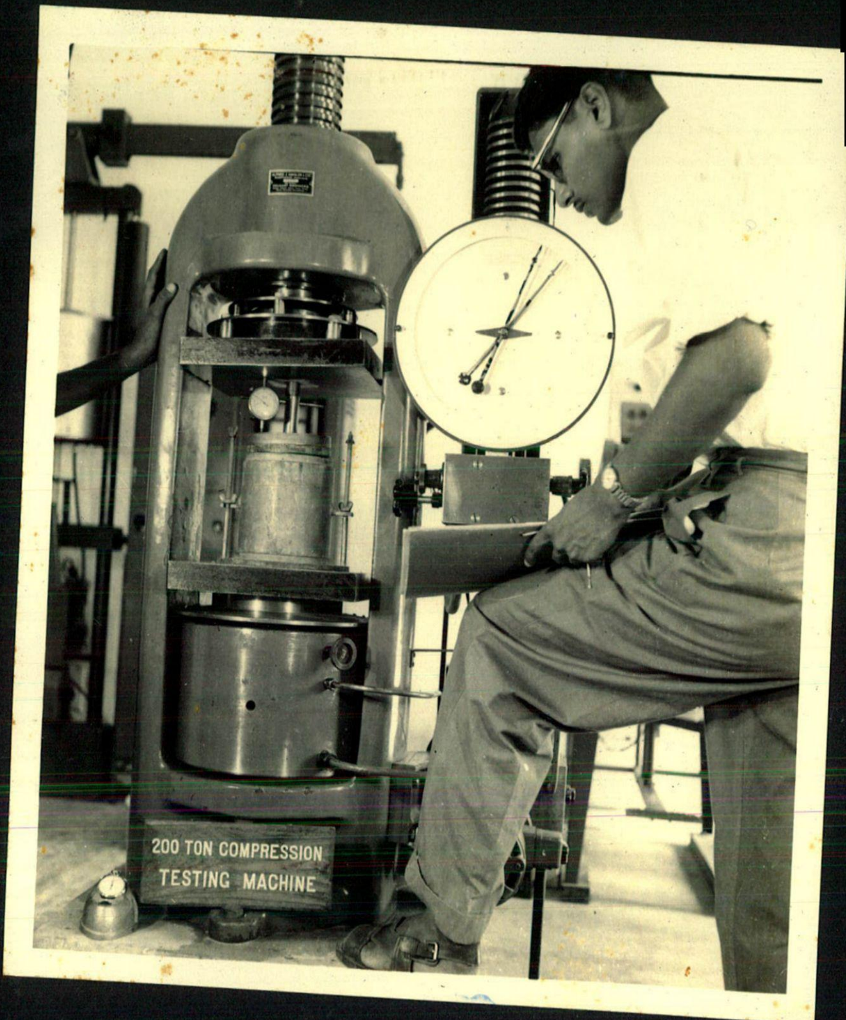
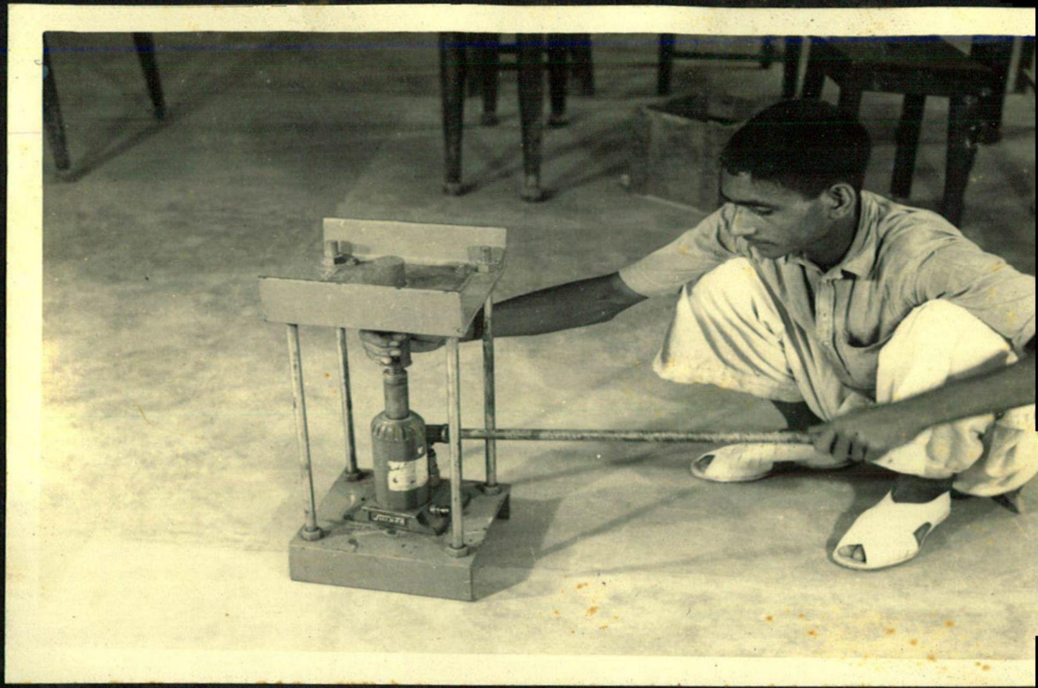
APPENDIX 'A'
ILLUSTRATIONS



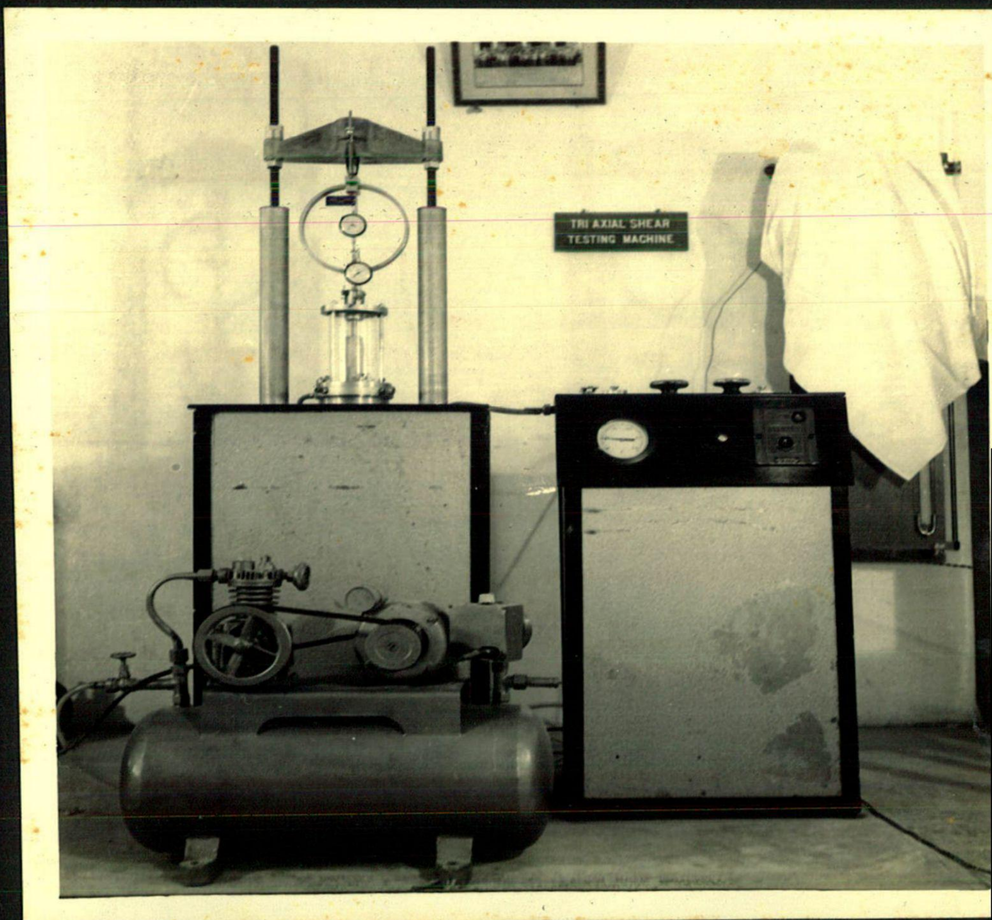
1. C.B.R. TESTING MACHINE



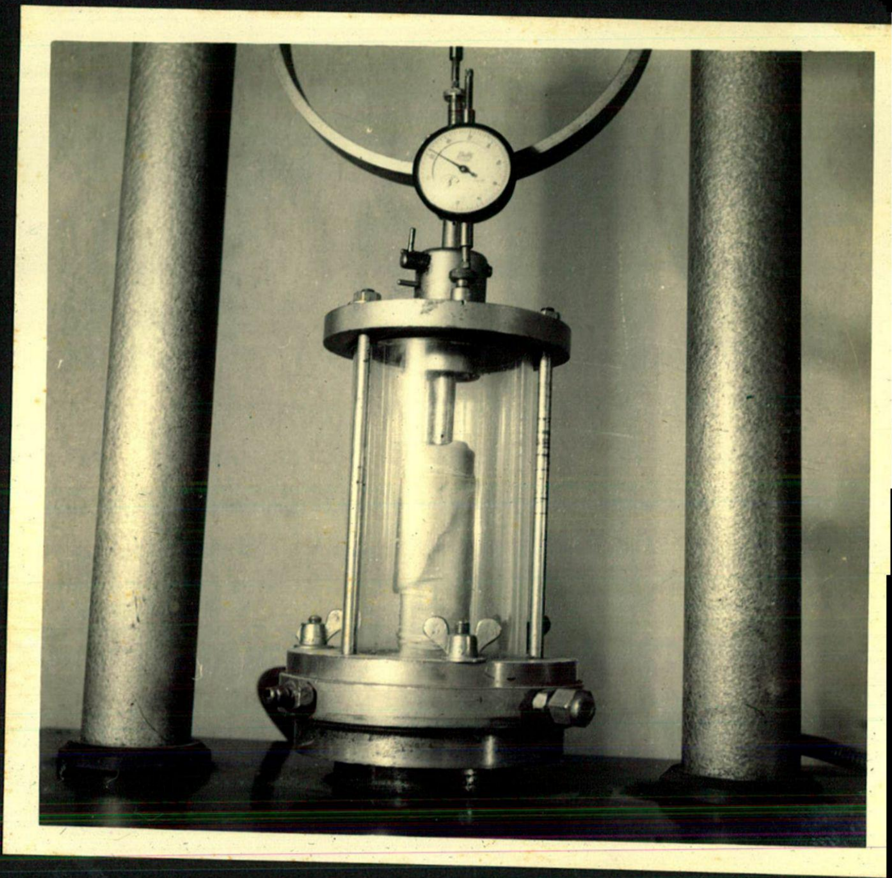
4. TESTING C.B.R. SAMPLE



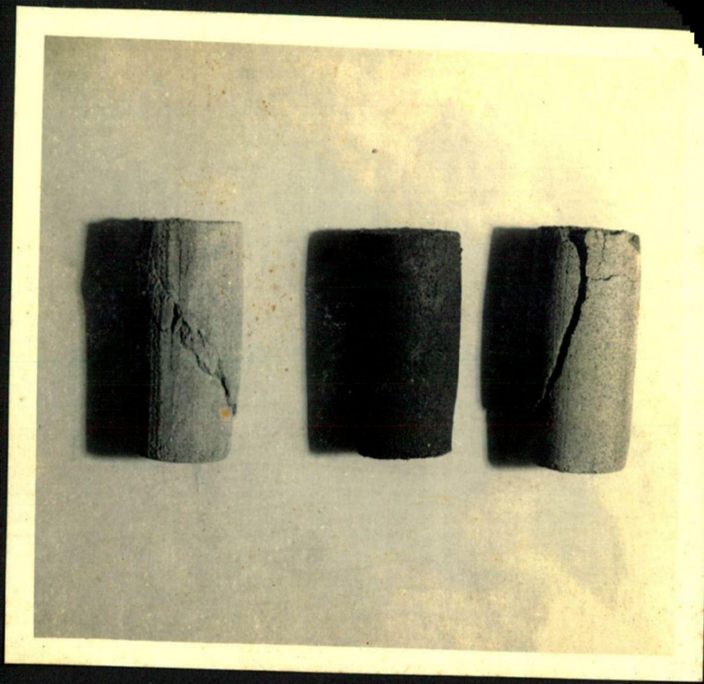
5. EXTRUDING TRIAXIAL SAMPLE FROM CUTTER



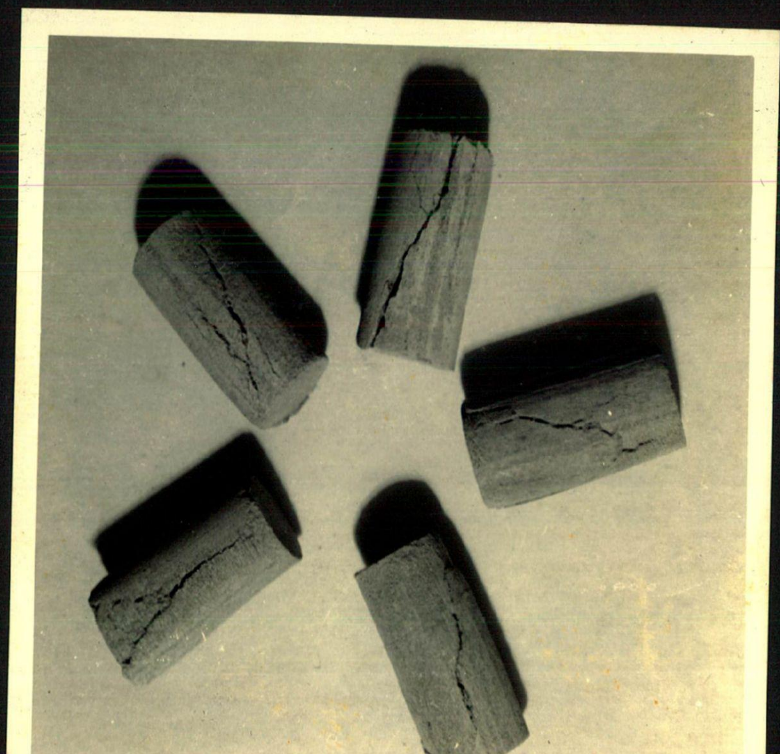
6. TRIAXIAL TESTING MACHINE



7. TYPICAL FAILURE OF SAMP



8. TYPICAL MODES OF FAILURE



9. OTHER FAILURE PATTERNS