BEHAVIOUR OF BRICK AGGREGATES
IN
BASE AND SUBBASE COURSES

A Thesis

by

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SYNOPSIS

In Bangladesh roads are usually constructed of flexible pavement in which base and subbase courses serve as key elements in distributing the superimposed loads to the subgrade soil without overstressing. Because of the dearth of stone aggregates in Bangladesh brick aggregates are commonly used in base and subbase courses. Since most researches on pavement design and analysis have been carried out in western countries with stone aggregates, they can not be applied diractly to conditions where brick aggregates are used. In this thesis work attempt is made to investigate and recommend the suitable brick aggregates for base and subbase constructions.

The search for appropriate materials gives gas burnt picked jhema bricks as most suitable type of bricks for base and subbase construction. The wearability and absorption of these bricks are minimum. The CBR value obtained with gas burnt brick eggregates-sand-soil mixtures is as high as ninety seven percent which is much above that required for base courses of high type pavements.

The well graded aggregates and sand-soil mixtures when compacted give maximum CBR values. An optimum amount of fines to be used in the mixtures was obteined at which maximum CBR value is attained. The CBR value with brick aggregate-sand-soil mixture is seen to be more susceptible to compaction than the typical stone aggregates-sand-soil mixtures. For the construction of base and subbase courses in flexible pavements, crushed gas burnt picked jhama brick aggregate-sand-soil mixtures are suggested.

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ABBREVIATIONS

AASHO	-	American Association for State Highway Officials
AASHTO	-	American Association for State Highway and Transportation Officials
ASTM	-	American Society for Testing and Materials
ANSI	-	American National Standard Institute
ACV	-	Aggregate Crushing Value
BRRL	-	Bangladesh Road Research Laboratory
CBR	-	California Bearing Ratio
CDH	-	California Division of Highways
GBPJ	-	Gas Burnt Picked Jhama
LAA	-	Loss Angeles Abrasion
PI	-	Plasticity Index
PCF	-	Pounds Per Cubic Feet
PSI	-	Pounds Per Square Inch
Pen.	-	Penetration
RN	-	Road Note
SW	-	Sand Well Graded
Sp.Gr.	-	Specific Gravity
Spn.	-	Specimen
TRRL	-	Transport and Road Research Laboratory
USA	-	United States of America
U.K	-	United Kingdom
WT.	-	Weight
ZAV	-	Zero Air Void

CHAPTER-1
INTRODUCTION

1.1 General

In Bangladesh construction of flexible road pavements is being preferred because of their low initial cost and adaptibility for stage construction. Flexible pavement may be defined as a structure that maintains intimate contact with and distributes loads to the subgrade and depends on aggregate interlock, particle friction and cohesion for stability. Classical flexible pavements include primarily those pavements that are composed of a series of granular layers topped by a relatively thin high quality bituminous wearing surface. Fig. 1.1 shows a typical flexible pavement

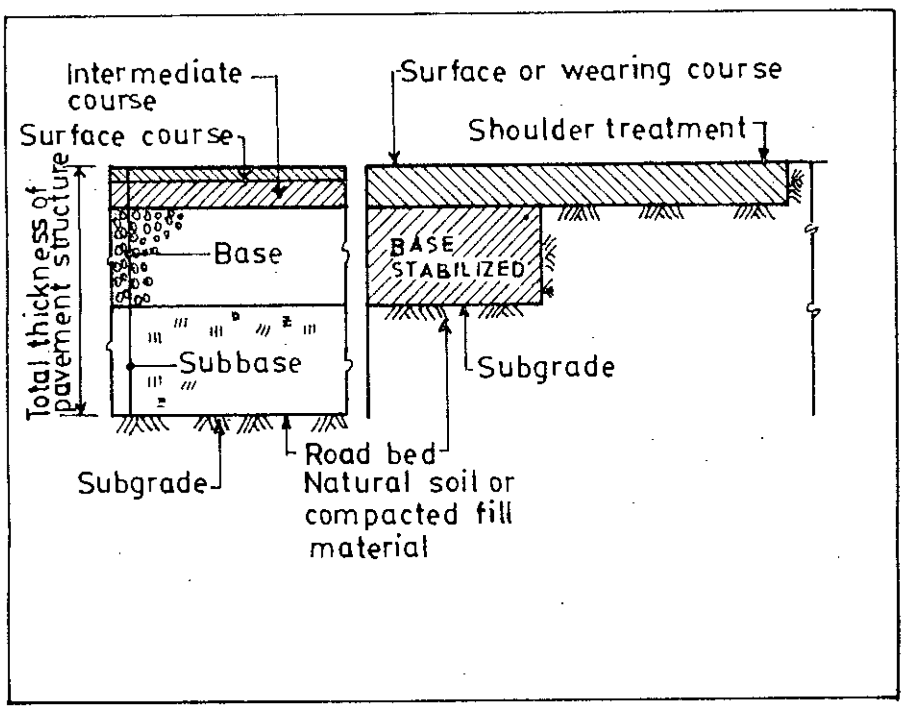

Fig. 1.1 Typical flexible pavement cross-section[1].

cross-section. The principal elements of the infrastructure here are shown to be the pavement that is composed of a 'wearing surface'; 'base'; subbase and 'subgrade'.

The wearing surface and the base often comprise two or more layers that are somewhat different in composition operations. On heavy duty flexible pavements a subbase of select material is generally placed between the base and subgrade. Sometimes the material under a rigid pavement is called a subbase.

1.2 Role of Base and Subbase in Pavement Structure

The function of the base course varies according to the type of the pavement. Base courses are used under rigid pavements for (1) prevention of pumping, (2) protection against frost action, (3) drainage, (4) prevention of volume change of the subgrade, (5) increased structural capacity, and (c) expedition of construction.

The top layer of a flexible pavement is constructed by a relatively thin high quality bituminous wearing surface. The main thickness is built by the base and subbase courses. Let W be the the load on the surface of the pavement having a total thickness of 'd' incnes (Fig. 1.2a). Based upon approximations of stress distribution concepts in homogeneous, one layer (Boussinasq) system, the load is assumed to be distributed through the pavement to the subgrade in the form of a cone. The surface of the cone is at an angle θ with the vertical axis of the cone (the axis being assumed to be at right angles to the surface of the pavement), and the unit pressure of 'q' pounds per square inch on the subgrade is assumed to be uniform. The radius of the base of the cone at the subgrade is d tan θ and the relation of the thickness of the pavement to the load and the unit

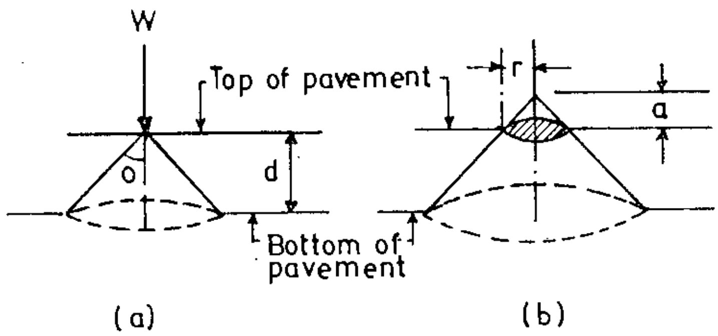

Fig. 1.2 Distribution of wheel loads through flexible pavements to the subgrade.

subgrade pressure is

$$q = \frac{W}{\pi d^2 \tan^2 \theta} \qquad 1.1$$

Equation 1.1 assumes that a wheel load is concentrated at a point, whereas it is actually distributed over an area of contact between the tire and the pavement as shown in Fig. 1.2(b). If this area of contact is circular in shape

$W = q\pi(d+a)^2 \tan^2\theta$ and hence the unit subgrade pressure is $q = W/\pi(d+a)^2 \tan^2\theta$; since a is small in comparison to d. From the above equations it is seen that the subgrade stress due to imposed load is inversely proportional to the square of the depth of the base and subbase course (assuming that the thickness of wearing course is small in comparison of the combined base and subbase courses).

Analyzing the pavement section as a multilayered elastic system Peattie(2) found the vertical stress solutions and presented in graphical forms. The stresses at points vertically below the road surface are dependent on factors influenced by both the thicknesses and the elasticities of the upper layers.

Neilson(3) illustrated the influence of changing the pavement layer thicknesses upon the vertical compressive stress factor for a three-layered pavement system. He showed that for a given load, the subgrade stress is greatly decreased by an increase of the base course thickness.

Hence the principal purpose of base course in a flexible pavement is to distribute or 'spread' the stresses created by wheel loads acting on the wearing surface so that the stresses transmitted to the subgrade will not be sufficiently great to result in excessive deformation or displacement of that foundation layer. The base course also may provide drainage (if so designed) and give added protection against frost action when necessary.

1.3 Factors Influencing the Base and Subbase Characteristics

Modern pavement design procedures are based on multi-layered elastic theory concept. In all rational pavement design procedures, it is emphasized that the stress at any point below the pavement due to a load or loads on the surface is a function of many factors of which the quality of the material is the constant influencing factor. The strains and stresses are functions of Poison's ratio and modulus of elasticity which depend on the material type and quality. The quality reflects the properties like strength, toughness, soundness, durability. Other important factors which influence the base and subbase courses are the particle size distribution, particle shape, relative density, internal friction, cohesion, type of bindar, void ratio, and porosity. The above factors influence the following general characteristics of the mixture used in base and subbase construction:

1) Density and stability,
2) Effect of crushed particles,
3) Effect of plasticity,
4) Effect of skip grading,
5) Soundness, and
6) Permeability.

1.3.1 Density and stability

The stability of any layer is its most important requirement for design. Stability of an aggregate-soil mixture depends upon particle-size distribution, particle shape, relative density, internal friction and cohesion. A granular material designed for maximum stability should posses high internal friction to resist deformation under load. Internal friction and subsequent shearing resistance depend to a large extent upon density, particle shape, and grain size distribution. Of these factors, the size distribution of the aggregates, particularly the proportion of fine to the coarse fraction, is considered to be the most important. For maximum stability the mixture should have fines just sufficient to fill all the voids between aggregates to float in the soil. The density will decrease and the mixture is practically impervious and frost susceptible. Thus the stability of an aggregate soil mixture is dependent upon the grain size distribution of the particles.

The grain size distribution of a material can be represented by the equation $p = 100 \left(\frac{d}{D} \right)^{n}$ * where d represents the sieve in question, p is the percent by weight finer than the sieve, and D is the maximum size of the aggregate. Maximum density generally occurs where the exponent n equals to 0.5. This yields 6.2 percent passing No.200

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* Equation 11.1 given in 'Principles of pavement design' by Yoder and Witczak.

mesh sieve for a material which has a maximum grain size of ½ inch. Comparing density and strength in terms of CBR it is seen that maximum CBR resulted when the quantity of fines was somewhat less than that indicated for maximum density. Density as well as stability increases as the size of the aggregate increases.

1.3.2 Effect of crushed particles

For identical grain size distribution, the California Bearing Ratios of mixtures made up of angular particles are usually somewhat greater than those containing mostly rounded particles. The crushed particles have, in general, more stability than round grained materials, due primarily to added grain interlock. In addition, for a particular gradation the crushed materials also possess high co-efficients of permeability and, hence are more easily drained. Crushed materials show excellent performance in most instances and are normally preferred.

1.3.3 Effect of plasticity

The physical properties of the binder soil have a great effect on stability, especially when grain to grain contact is destroyed. Fig. 1.3 shows the effect of plasticity of the binder on the triaxial strength of a gravel with varying amounts of material passing No. 30 mesh sieve.

It is seen that when the percent passing No. 30 mesh sieve is low, plasticity has vary little effect on the strength, and that as the amount of material passing No.30 sieve is increased plasticity has an increasing effect.

1.3.4 Effect of skip grading

It must be recognized that if the material is not 'well graded' the plasticity requirements, as well as the requirements relating to the amount of fine material, do not necessarily apply as they do for well graded materials. The net effect of having a skip-graded material is that there is a deficiency in intermediate size and, as a result, the void space is increased.

The effect of skip grading on the triaxial strength of a mixture has a complex relationship and depends upon the amount of material passing No. 200 sieve, as well as on the dust ratio. The dust ratio is the ratio of the portion passing No. 30 mesh sieve to the portion passing a No. 200 mesh sieve. For low amounts of material passing No. 200 sieve the dust ratio has little effect and it can be concluded that skip grading would have no harm upon the mix. On the other hand, for higher amounts of material passing No. 200 sieve, an increase in the dust ratio causes a decrease in the strength upon a certain limit of dust ratio and then the strength increases beyond this limit.

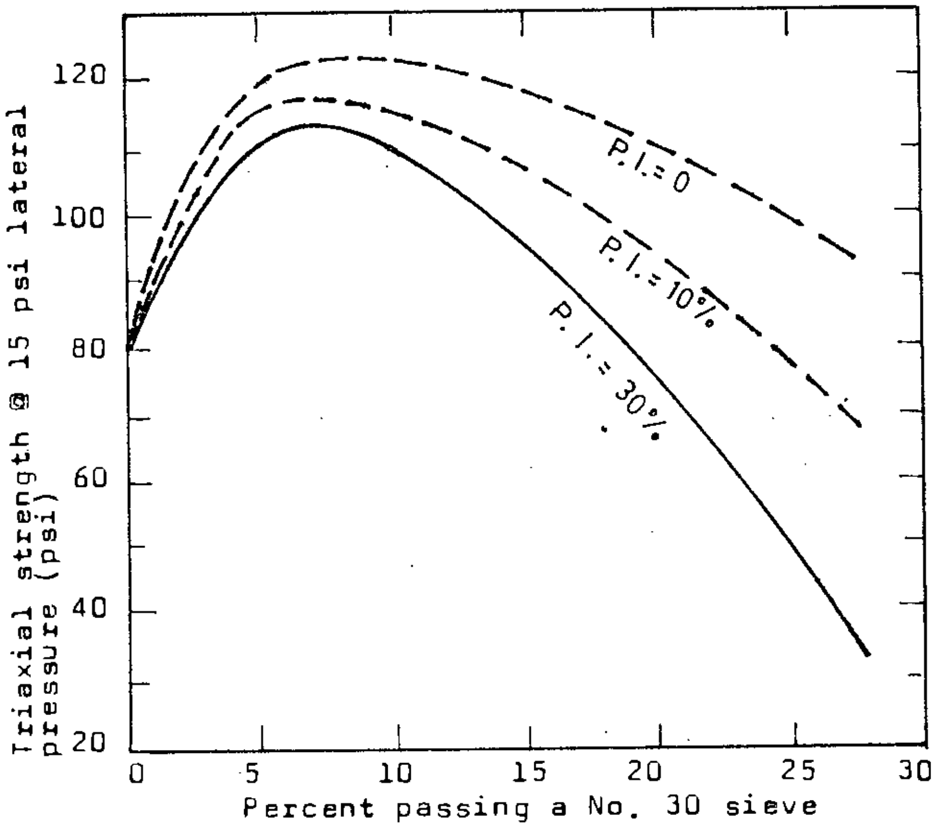

Fig. 1.3 Effect of plasticity on triaxial strength of a gravel. Maximum aggregate size is 1 inch.*

Furthermore plasticity becomes less important when skip grading is used.

1.3.5 Effect of soundness

Soundness as regards base and subbase materials, is defined as the ability of the aggregate to withstand abrasion and/or crushing. This is important from the standpoint of generation of fines under the action of rollers and traffic. Durability of the course depends mainly on the soundness of the aggregates. Unsound aggregates disintegrate badly under the action of weather.

* Fig. 11.5 given in 'Principles of pavement design' by Yoder and Witczak.

1.4 The Problem

In conventional road pavements the aggregates used for surface, base and subbase courses consist of crushed stone, gravel and crushed slag. These dense, low absorptive natural aggregates having high crushing strength are not available in Bangladesh except in small quantities in Northern Sylhet and Dinajpur areas. It is extremely expensive to carry the stone aggregates from their sources to the job site if the haulage length is too high. Again with the increased and continued consumption those naturally occuring aggregate sources are being depleted. On the other hand bricks are available readily or can be manufactured in kilns near the job sites. Crushed brick aggregates are being used and are in use for a long time in the construction of base and subbase courses of pavements. But no research has yet been carried out to investigate their suitability and no report is available about the performances of brick aggregates in such constructions. Therefore search has to be intensified to investigate the suitability of brick aggregates in the base and subbase courses.

1.5 Objectives of the Research

The strength and behaviour of aggregates depend upon a number of variables, such as gradation, porosity, absorption, wearability etc. Review of literatures shows a deficiency of knowledge in regard to the properties of brick aggregates and aggregate sand mixtures. The objectives of the research therefore are as follows:

(i) to determine the physical properties of brick aggregates to be used in base and subbase construction and to compare these properties with stone aggregates;

(ii) to find the effect of gradation, moisture content, percent fines on CBR values for crushed brick-sand-soil mixtures;

(iii) to find the effect of compactive efforts applied during compaction on the CBR values of different aggregate sand-soil mixtures.

CHAPTER-2

LITERATURE REVIEW

2.1 General

Literatures are not available directly on the use of brick aggregates in base and subbase construction. Stone aggregates and stone-sand or stone-soil mixtures have been used for the construction of base, subbase courses for high type pavements and top courses for low type pavements. Leteratures, specifications, recommendations are available regarding the characteristics of natural aggregates and soil-aggregate mixtures in base and subbase courses. Sometimes the aggregates are stabilized by some admixtures to have a firm base or subbase to provide the support for a relatively thin wearing surface. Literatures are also available for such type of construction. The present research work has been taken to determine the characteristics of untreated brick aggregata-soil mixture in base and subbase constructions. Limited litarature available for unstebilized stone aggregate and/or gravel - soil mixtures are discussed in the following articles.

2.2 Laboratory Studies

Load supporting capacity indicated by the stability and density of the aggregate soil mixture is the principal requirement of a base or subbase course. Different organisations carried investigations to find a suitable gradation to have dense and stable mixtures. These work in the form of recommandations are discussed in Article 2.5.

The proportion of the fines (material passing No.200 sieve) to coarse fraction is also an important factor to have a dense and stable mixture. Deklotz's[4] works discussed by Yoder (1975) on "Effect of varying the quantity of fines of highway aggregates on their stability" reveals that there is an optimum amount of fines for a particular aggregate-soil mixture at which the mixture will have its maximum density and stability for a particular compactive effort. According to Mr. Yoder results of laboratory studies on a well graded stone aggregate show that the maximum density occurs when the mixes contain about 8 to 10 percent fines passing a No.200 sieve. In contract, the maximum stability as measured by the CBR test resulted when about 6 to 8 percent of the material passed a No. 200 mesh sieve.

Yoder[5] (1975) also has shown the affect of compactive effort on density and stability of a stone aggregate mixture for a particular gradation. He concluded that the more the compactive effort, the more will be the density and stability. But the response for the increase is more pronounced in the case of stability rather then density.

Laboratory studies also were carried on to compare the density and stability values between round shaped naturally occuring gravel mixtures and crushed stone mixtures.

These tests and field experiences have shown that crushed particles have in general, more stability than round-grained material due primarily to added grain interlock.

Tests to find the effect of the physical properties of binder soil on the stability of the mixture were done by Makdisi-Ilyas, Faiz[6]. They found that the effect of plasticity is detrimental to the strength with higher amount of material passing No. 200 mesh sieve. This happens due to the reason that plasticity is dependent upon the amount of material passing No. 30 sieve is increased. The required amount of material passing No. 30 sieve for maximum density is 15.30 percent and when the binder content exceeds this value, the plasticity becomes important.

Faiz, A[7] worked with the skip graded mixtures. It must be recognized that if the material is not 'well graded' the plasticity requirements as well as requirements relating to the amount of the fine material, do not necessarily apply as they do for well graded materials. The net effect of having a skip graded material is that there is a deficiency in intermediate sizes and, as a result the void space is increased. Results from laboratory studies show that skip grading gives a complex relationship with triaxial strength, which depends on both dust ratio and percent material passing No. 200 sieve. It is also seen that for high values of dust ratio and plasticity, the skip grading becomes beneficial to some extent.

Mainfort and Lawton (1952)[8] carried investigations on the laboratory compaction tests of coarse graded paving materials. They reported the result of a laboratory study for the applicability of the Proctor type of compaction of coarse graded materials. The tests indicated that the standard Proctor method using a standard 4 inch mold is suitable for determining the maximum density and optimum moisture content of coarse materials and mixtures. From their field observations it was found that the densities obtained in the laboratory by the Proctor type of compaction test appear to agree with densities obtainable with either vibratory or roller types of field equipment.

2.3 Field Studies

Since the end of the second world war there has been a vast increase in highway traffic and many test roads were constructed to observe the performances of the roads and to develop design methods. In 1949 a research project was set up by Highway Research Board in Maryland, USA, to determine the relative effects of various axle loads and configurations on distress of pavements. This test was intended for observation of the behaviour of concrete pavement constructed on a imporved granular subbase material and no findings regarding base course was obtained.

The WASHO road test was done prior to AASHTO road test near Malad, Idaho, USA. For flexible pavement the test recommends a total thickness of pavement and base for different axle loads.

The most intensive and extensive research on road was a co-operative project sponsored by AASHO at Ottowa, Illinois, USA. In the principal flexible pavement test sections the base course was constructed by a well-graded crushed lime stone and the subbase by a uniformly graded sand-gravel mixture. Other test sections were constructed with bases by a well graded uncrushed gravel, a bituminous plant mixture, and a cement treated aggregate. On the basis of the performance records of the various test sections a new concept to evaluate the pavement infrastructure was introduced which is PSI - Pavement Service-ability Index. The important conclusion made by them about bases is - "the performance of the treated gravel base is definitely superior to that of the untreated crushed stone base".

The first of the British full scale field experiment began in 1949 on a section of the A1 trunk road in Yorkshire U.K. They used three types of base material - tar macadam base; dry bound stone base; hand pitched base. From observations over a period of ten years they found that the open textured tar macadam bases performed much better than either the dry bound stone bases or the hand pitched bases.

In addition the hand-pitched base showed increased surface deformation and found worse than dry bound stone base and is no longer recommended.

A further experiment, also on the A1 road at Alconbary Hill in Huntingdonshire, U.K was initiated in 1957 to compare the performances of five different base materials laid to various thicknesses. The base materials were cement stabilized sand, wet mix slag, lean concrete, tar macadam, and hot rolled asphalt. Experimental sections, each 2000 ft long, were constructed on a sand subbase of varying thicknesses. Results after six years show that the sactions with rolled asphalt bases have performed the best whilst those with sand-cemant base are clearly the worst. All these field tests for base courses were comparative studies between different types of bases, treated or untreated but no test was done with one specific base by varying its components, materiels etc.

Field experiments were done by Mr. Drake[9] of Kentucky Department of Highways on the performances of flexible base courses designed primarily to improve the riding qualities of high type bituminous pavements. Four inch dense graded lime stone base was constructed with 1 inch downgraded; 5 to 15 percent passing No. 200 sieve, wall graded material over a 4 inch of waterbound macadam subbase course. Observations and measurements showed that the combination of the two courses could be built satisfactorily, the dense graded aggregate produced a high base density and the possibilities for finishing to uniform section were much better with the dense graded aggregate than with the macadam.

Cadergren[10], made field CBR tests on granular subbase and bases. He criticised the general idea that the CBR values on large macadam type construction will be higher than with smaller aggregates. In testing coarse grained materials he found almost invariably that CBR values are not too high but too low.

2.4 Method of Evaluation of Base and Subbase Courses

The base and subbase courses are evaluated in the field and/or in the laboratory by the following methods.

(i) Plate Bearing Test - F*

(ii) Triaxial Compression Test - L**

(iii) Stabilometer Test - L

(iv) California Bearing Ratio Test (F and L)

(i) Plate Bearing Test

The Plate Bearing test developed by Mr. N.W. McLeod of Canada Transportation Department expanded the results

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* F indicates field test.

** L indicates laboratory test.

of his extensive field study relating to it to pavement design methods based on the theory of elasticity. The test can be used to measure the strength at any elevation in an asphalt pavement structure: surface of the subgrades, top of subbase, top of the base course, or surface of the finished pavement.

Deflection of circular rigid plates are measured by deflection dials under vertical loads applied at some standard rate. The modulus of the layer on which the plates are placed is calculated by means of the following equations,

$$K = \frac{P}{\Delta}$$

where P is the unit load on the plate (psi) and Δ is the deflection of the plate (inches). Tests are generally made directly on the unconfined base course and the field value is adjusted to the most unfavourable base condition that can be expected. This can be accomplished by the additional data obtained by loading the samples in confined conditions.

(ii) Triaxial Compression Test

The triaxial compression test was developed to determine the shear stress of a soil sample under lateral pressure. The test is suitable for only fine grained soil or sand where specimens are loaded vertically under constant lateral pressure to have a shear failure. The stability of the soil is determined by the equation,

$$S = C + \sigma \tan \phi$$

where S = shearing resistance developed

C = cohesion

σ = vertical stress applied

ϕ = angle of internal friction.

Values of cohesion and internal friction can be determined from the plots of the test results.

Based on the principles of triaxial test, McDowel developed Texas triaxial cell to evaluate base course materials. The apparatus is suitable for performing a large number of tests economically. Shear stress is measured at different normal stresses and the results are plotted to classify different types of materials.

(iii) Stabilometer Test

California Division of Highways developed a semitheoritical method of flexible pavement design based on two properties of materials cohesion and friction. These properties of treated or untreated base, subbase or subgrade materials are determined by tests in the Hveem stabilometer developed by F.N Hveem and R.M. Coumany of California Division of Highways (CDH) which measures the horizontal pressure developed in a short cylindrical sample loaded vertically on its ends. This device was concieved to measure the stability of both field and laboratory samples of bituminous pavement and treated base courses. Loads are applied vertically; the resulting horizontally developed stresses are measured, and the vertical and horizontally developed stresses are measured. The vertical and horizontal pressures are utilized in the following equation for calculating stabilometer resistance values.

$$R = 100 - \frac{100}{(2.5/D_2)(P_v/P_h - 1) + 1}$$

where R = resistance value

P_v = applied vertical pressure (160 psi)

P_h = transmitted horizontal pressure at P_v = 160 psi

D_2 = displacement of stabilometer fluid necessary to increase horizontal pressure from 5 to 100 psi, measured in revolutions of a calibrated pump handle.

Cohesion is measured by means of the cohesiometer, an apparatus capable of breaking small beams of base course materials. The base course materials are then ranked on the basis of stabilometer resistance values and cohesometer values.

(iv) California Bearing Ratio Test

The California Bearing Ratio test abbreviated as CBR is the most widely used method of evaluation of subgrade, subbase and base course materials. The method was first developed by California Division of Highways and then adopted and modified by U.S Corps of Engineers, in 1961. The American Association of State Highway Officials, AASHO accepted this test in 1963 with Designation T 193-63 for determining the bearing values of subgrade soils and some sub-base and base course materials containing only a small amount of material retained on the $\frac{3}{4}$" sieve.

CBR test is a penetration test wherein, a standardized piston, having an end area of 3 sq. in. is caused to penetrate the sample at a standard rate of 0.05 inch per minute. The unit load required to penetrate the sample at 0.1 inch penetration is then compared with a value of 1000 lb per sq. inch required to effect the same penetration in standard crushed rock. The test is to be carried on sample of subbase or base material compacted to the moisture and density condition which site investigation and considerations of the construction methods and plant to be used, indicate to be appropriate. For design purpose the CBR value of the base or subbase course at worst condition is required which can be obtained by testing the sample, after being saturated. Due to swelling of the specimen, the top surface may be loose to some extent. Therefore the stress-strain curve (Fig. 4.11) obtained from the penetration test some times will be concave upward which requires correction by moving it to the right. By CBR value it means corrected value when this correction has been applied to the curve.

Laboratory CBR values obtained on samples compacted in confining steel molds are obviously to be checked in the field after construction. This can be done by comparing the densities in the laboratory and in the field or directly penetrating the course in the field. Field CBR test is basically the same as the laboratory test but a correlation is to be established to correct the field values for saturation. The laboratory CBR values are expected to be slightly higher than those obtained in the field because of the confining action of the mold in the laboratory. Precautions must be taken during field tests to ensure intimate contact of the piston with an undisturbed surface of the material tested.

2.5 Practices and Recommendations for Base and Subbase Courses

For a high type pavement generally both base, between surface course and subbase, and subbase, between base and subgrade are constructed. For low and intermediete type of pavement subbase course may be omitted. In some cases the base for a low type pavement can be used as subbase for a high type pavement. Whether it is base or subbase the objective of the present research is about the behaviour of the materials used in such construction. Mainly there are 3 types of constructions for base and subbase courses on the basis of materials used. These are:

1. Soil-aggregate and gravel bases
2. Macadam bases
3. Treated bases.

In some types of macadam bases and in treated bases a binder material is used to create bond between grains. This treatment is usually costly and suggested for high type pavements and where other type of construction is not economical. Soil-aggregate and gravel bases often termed as untreated bases are constructed without admixture. The stability, and density are developed in the course by using proper gradation, appropriate amount of fine material - silt and clay, moisture content and of course by proper compaction. When aggregates are available near road side, soil from the road bed can be mixed with them and compacted. In most cases, this type of construction is economical. The research work has been concerned with the evaluation of this type of mixtures. Almost in all developing countries and also in some developed countries this type of construction is in use for rural roads. In the following articles the recommendations and practices regarding this untreated base course constructions are briefly discussed.

2.5.1 Practices in USA and AASHTO Recommendations

In some states of USA low type roads are constructed with soil aggregate mixtures as the surface course. In intermediate type of roads and in some high type rural roads untreated soil aggregate mixtures are used for base and subbase constructions. The American Association of State Highway and Transportation Officials has first come to specify materials for this type of constructions. The materials for aggregate and soil aggregate subbase, base and surface courses are specified by AASHTO(11) under designation M 147-57(67) (71). AASHTO specified 'Materials for Aggregate and Soil-Aggregate subbase, base, and surface courses'. The requirements are as follows:

General Requirement

(a) Coarse aggregate retained on No.10 sieve shall consist of hard, durable particles or fragments of stone, gravel or slag.

(b) Coarse aggregate shall have a percentage of wear by Los Angeles test, of not more than 50.

(c) Fine aggregate passing No.10 sieve shall consist of natural or crushed sand, and fine mineral particles passing No.200 sieve.

(d) The fraction passing No. 200 sieve shall not be greater than two thirds of the fraction passing No. 40 sieve.

The fraction passing No. 40 sieve shall have a liquid limit not greater than 25 and a plasticity index not greater than 6.

(e) All material shall be free from vegetable matter and lumps or balls of clay.

Subbase Material

Materials for subbase shall conform to the general requirements for gradings A,B,C,D,E or F (Table 2.1).

Base Course Material

Materials for base course shall conform to the general requirements for grading A,B,C,D,E or F.

The United States Agency for International Development(12) in the Guidelines for Highways and Bridges specified Grading B (Table 2.1) for class-1 aggregate base course. The requirements are same as specified by AASHTO M 147.

2.5.2 California Division of Highways Recommendations

Since its establishment the California Division of Highways (CDH) has been making vital contribution to the development of pavement technology. Engineers, researchers of this division from time to time brought new techniques for the construction of road pavements. In the 'standard

Table 2.1 Grading Requirement for Soil Aggregate Materials for Subbase and Base Constructions (From AASHTO)

Sieve designation	Percentage by wt. passing square mesh sieve					
	Grading A	Grading B	Grading C	Grading D	Grading E	Grading F
2 inch	100	100	-	-	-	-
1 inch	-	75-95	100	100	100	100
$\frac{3}{8}$ inch	30-65	40-75	50-85	60-100	-	-
No. 4	25-55	30-60	35-65	50-85	55-100	70-100
No. 10	15-40	20-45	25-50	40-70	40-100	55-100
No. 200	2-8	5-20	5-15	5-20	6-20	8-25

specification'[13] of this division, aggregate subbase and base courses are specified under section 25 and 26 respectively.

CDH classified both subbase and base courses into three classes viz class-1, class-2 and class-3. Requirements for class-1 aggregate base are as follows:

(a) The aggregates shall consist of a crushed product of stone or gravel. It shall be free from vegetable matter and other deleterious substences, and shall be of such nature that it can be compacted readily under watering and rolling to form a firm, stable base.

(b) The amount of crushing shall be regulated so that at least 80 percent by weight of $1\frac{1}{2}$ inch maximum size material retained on the No. 4 sieve and 90 percent by weight of the $\frac{3}{4}$ inch maximum size material retained on No. 4 sieve.

(c) The percentage composition by weight of aggregate bese shall conform to one of the grading given in Table 2.2.

Table 2.2 Percentage Composition by Weight for Aggregate Base (from CDH)

Sieve size	Percentage passing	
	$1\frac{1}{2}$" maximum size	$\frac{3}{4}$" maximum size
2"	100	-
$1\frac{1}{2}$"	90-100	100
$\frac{3}{4}$"	50-85	90-100
No. 4	30-45	35-55
No. 30	10-25	10-30
No.200	2-9	2-9

(d) The aggregate base shall conform to the following requirements:

Tests	Requirements
Loss in Wetshot Rattler	55% max.
Loss in Loss-Angeles Rattler	50% max.
Resistance (R-value)	80 min.
Sand equivalent	50 min.

2.5.3 U.K. Practice and Transport and Road Research Laboratory, U.K. Recommendations

The road subbase and base courses are constructed conforming to the requirements given in Road Note No.29 (14) of Transport and Road Research Laboratory, U.K and Ministry of Transport specification(15) suggests a granular subbase material to conform to the gradings specified in Table 2.3. Type-1 aggregates comprise crushed rock, crushed concrete, crushed slag or well burnt nonplastic shale. These materials will remain stable over a much wider range of moisture contents than type 2 aggregates which include well graded natural sands, gravels, and rock or slag fines, and are therefore to be preferred in Bangladesh, where site conditions are likely to be wet during construction. The Road Note No.29 requires a minimum CBR of 30 percent on aggregate subbase.

Table 2.3 Grading Requirements for Granular Subbase Materials (From Road Note No. 29)

B.S. sieve size	Percent by wt. passing	
	Type-1 Aggregate	Type-2 Aggregate
3 inch	100	100
1½ inch	85-100	85-100
3/8 inch	-	25-85
3/16 inch	25-45	25-85
No. 25	8-22	8-45
No.200	0-2	0-10

For base course the minimum CBR requirement is 80 percent and suitable materials for base include crushed stone or blast furnance slag, dry lean concrete, cement bound granular material and bituminous bound materials.

The Transport and Road Research Laboratory, U.K prepared Road Note No. 31[16] in 1962, edited third time in 1977 to give a guide line for the structural design of bitumen-surfaced roads in tropical and subtropical countries. The techniques given in this report are suitable for and followed by many developing countries. They recommended in the note the two types of untreated base materials such as

i) mechanically-stable natural gravel or crushed gravel and

ii) crushed rock.

The requirements of these base courses are given as follows:

a) The natural gravel or crushed gravel must have a grading that is mechanically stable and must contain sufficient fines to provide a dense material. Table 2.4 gives typical grading limits of suitable materials.

b) The material passing BS 425 um sieve (No. 40 ASTM) should be such that Plasticity Index is less than 6; liquid limit is less than 25 and linear strinkage does not exceed 4.0 percent.

c) The gravel should be compacted to a field density equal to or greater than the maximum density achieved in the British Standard compaction test (100 percent maximum standard AASHO density) and for this density in the laboratory the minimum CBR after four days immersion in water, should be 80 percent.

Table 2.4 Typical Limits of Particle Size Distributions for Mechanically Stable Natural Gravel for Use as Base Course (From Road Note No. 31)

B.S. sieve size	Percentage passing			
	Nominal maximum size			
	37.5 mm(1½")	20 mm(¾ in)	10 mm(⅜ in)	5 mm(3/16 in)
37.5 mm(1½ in)	100	-	-	-
20 mm(¾ in)	80-100	100	-	-
10 mm(⅜ in)	55-80	80-100	100	-
5 mm(3/16 in)	40-60	50-75	80-100	100
2.36 mm(No.7)	30-50	35-60	50-80	80-100
1.18 mm(No.14)	-	-	40-65	50-80
600 um(No.25)	15-30	15-35	-	30-60
300 u mm (No.52)	-	-	20-40	20-45
75 um (No. 200)	4.5-15	5-15	10-25	10-25

2.5.4 Practice and Recommendation by Bangladesh Road Research Laboratory

W.G. HODGKINSON(17) under assignment to the Ministry of Overseas Development, U.K. prepared a guide in co-operation with the Bangladesh Road Research Laboratory for the structural design of bitumen surfaced roads in Bangladesh. The guide recommends the requirements of brick aggregates to be used for base course construction. But no field test or laboratory tests were made to evaluate the construction with crushed brick aggregates. The design charts call for the base to have a minimum CBR of 80 percent. Only gas burnt picked picked jhama bricks with the following properties are suggested to be used.

Table 2.5 Strength Limits of Stone and Brick for Base Course (BRRL)

Aggregate Crushing Value (ACV)	- not greater than 30 percent
Los Angeles Abrasion(LAA)	- not greater than 34 percent
Average Crushing Strength (bricks only)	- not less than 5000 psi
Water Absorption	- not greater than 9 percent
Plasticity Index of Fines	- not greater than 6 percent

A typical grading envelope for all in crushed brick aggregate is shown in Table 2.6 which employes a continuous graded brick (or stone) material of maximum size 37.5-50 mm ($1\frac{1}{2}$ - 2").

Table 2.6 Grading Limits for all in Crushed Aggregate Base Material (From BRRL Guide)

Sieve size	Percent passing by weight
50 mm	100
37.5 mm ($1\frac{1}{2}$")	90-100
20 mm ($\frac{3}{4}$")	60-80
10 mm ($\frac{3}{8}$")	40-60
5 mm (No. 4)	30-45
2.3 mm (No.8)	20-35
600 um (No. 30)	12-25
76 um (No. 200)	5-15

CHAPTER-3

MATERIALS

3.1 General

The design of a pavement is valid only if the materials of construction meet the specification. For highway constructions various alternate materials are available but the pavement should be constructed with the materials having properties to give sufficient stability and durability. In flexible pavement, base course is the main structural component to distribute the superimposed load to the subgrade. If there is some failure in the base course due to the weaknesses in the material, deterioration after being progressive, chuckholes may be formed. This type of distress gradually leads to the eventual failure of the road. The properties of these materials individually or the mixture as a whole are of such critical importance to pavement life that examples of pavement failure traceable to improper material selection and use are numerious. Therefore, special emphasis must be given for the selction of materials for construction of base and subbase courses. The materials dealt with are those consisting of artificially prepared bricks and natural sand and soil. The one of the objectives of this thesis is to search for appropriate material for the construction of base and subbase courses for flexible pavement. Following articles are viewed to classify and investigate the appropriate soil-aggregate materials for such constructions.

3.2 Materials Used for the Research

The materials used in the mixture to be used in base or subbase construction consists of crushed brick, coarse to medium sand and silt and clay fractions of soil. These three components of the mixture were selected to meet the desired gradation. Informations regarding the availability of the materials is contained in Appendix-A. For comparison four types of bricks with different crushing strength and absorption were used. These bricks are locally named as 'Picked Jhama'; 'First Class' and 'Third Class' (Description of bricks are contained in Appendix-A). In addition a comparative study was made using stone aggregates. Main portions of the coarse and fine aggregates in the mixture were obtained by crushing these bricks or stones. Very small amount of materials between No. 8 mesh sieve to No. 200 mesh sieve are obtained during crusning of bricks. To meet the grading requirement between No. 8 mesh sieve to No. 200 mesh sieve some coarse to medium sand was blended. Informations regarding the typical hand crushing of bricks and stones are contained in Appendix-B.

Properties of the different types of bricks used in the study are tabulated in Table 3.1.

Boulders used to get the stone aggregates have average crushing strength of 15,500 psi and absorption of 1.65 percent.

Table 3.1 Properties of Bricks

Properties	Gas burnt picked jhama	Coal burnt picked jhama	First class	Third class
Colour and Burning condition	Blackish red/over burnt	Blackish red/over burnt	Red/ well burnt	Pale red/ under burnt
Average* weight of a brick, lbs	7.55	6.38	6.15	5.86
Average crushing strength, psi.	5050	3575	3130	1375
Average absorption, percent	11.0	11.03	12.25	23.49

* Average values are taken from at least ten samples selected at random.

Sand used as fine aggregate has a fineness modulus of 2.70 and a specific gravity of 2.59.

Soil used as fines passing No. 200 sieve has a specific gravity 2.72 and unit weight of 113.5 lb/cft (dense condition).

These materials were used to have 'coarse aggregate', 'fine aggregate' and 'finas' in the mixture.

3.2.1 Coarse Aggregate for the Study

Coarse aggregate has been defined as that portion of the mixture which is retained on No. 10 sieve. The coarse aggregates contribute to the stability of the mixture by interlocking and frictional resistance of adjacent aggregate particles to displacement.

Coarse aggregates were obtained by crushing the bricks or boulders (for stone aggregate). The crushing was done manually and brought to the sizes of one inch or less. The aggregates were then sieved using U.S. standard sieves and separated out in different fractions. They were then washed and dried and combined in appropriate proportions of designed gradations.

3.2.2 Fine Aggregate for the Study

Fine aggregate is that portion of the aggregate material in the mixture which passes No. 10 sieve and is retained on a No. 200 sieve. Fine aggregate contributes to the stability of the mixture through interlocking and internal friction and also by filling the voids in coarse aggregate. After crushing bricks or boulders it is seen that all of the fine aggregates required for a well graded mixture are not obtained. Therefore some sand is to be blended with the crushed aggregate to meet the grading specification. For the gradations considered in this work coarse to medium sand having fineness modulus between 2.5 to 3.0 is required to be mixed. The fine aggregate in the mixture is therefore a mixture of crushed brick or stone and sand.

3.2.3 Fines Used for the Study

Fines are that portion of the mixture which passes No.200 sieve. They largely are visualized as void filler material in the mixture. Fines are used in a well graded dense mixture in amounts ranging from 5 to 15 percent by weight. From crushing of overburnt picked jhama brick a negligible amount of fines are obtained. The major portion of the fines is obtained by mixing dry powdered soil which is the cheapest among the available materials. In most cases the subgrade soil or soil from adjacent site can be mixed with aggregate blend to have the desired percentage of fines in the mixture.

3.3 Test Procedures for Determining Physical Properties of Aggregates

Coarse Aggregate: Tests required to determine the physical properties of coarse aggregates are loose and dense unit weight, specific gravity, water absorption, percent wear by Los Angeles Abrasion. All these tests were performed according to ASTM standard 1979 and AASHO standard 1971. In Table 3.2 the test results of coarse aggregates obtained from different types of bricks and boulders are summarized.

According to AASHTO specification M195-65, the maximum dry loose unit weight of light weight aggregate for structural concrete is 55.0 lb/cft. Table 3.2 shows that the unit weight of all types of bricks particularly gas burnt picked jhama brick is much above 55.0 lb/ft^3. Hence bricks used cannot be treated as light weight aggregate. But these unit weight values indicate that they are lighter compared to the conventional natural aggregates.

From the specific gravity records it is seen that the differences between the apparent and bulk specific gravities for brick aggregates are much higher than the

Table 3.2 Physical Properties of Coarse Aggregates

Name of the test	Type of coarse aggregate				
	ASTM/AASHO designation	Gas burnt picked jhama	Coal burnt picked jhama	First class brick	Crushed stone
Unit weight, lb/cft	C29-78	75.72	72.68	68.98	101.75
Bulk specific gravity	C127-77	2.06	1.98	1.76	2.59
Apparent specific gravity	C127-77	2.49	2.37	2.31	2.68
Absorption, percent	C127-77	7.29	7.99	10.32	0.86
Percent wear in LAA	C131-76	32.00	35.00	40.00	29.50

same for stone aggregates. This is due to high absorption of brick aggregates.

The percent wear in Los Angeles abrasion for gas burnt picked jhama brick is lower than those for other types of bricks. This is because of the high crushing strength of gas burnt picked jhama brick (see Table 3.1).

The absorption of brick aggregates are about 10 times that of stone aggregates indicating that the bricks contain much more water permeable pores compared to boulders or stones.

<u>Fine Aggregate</u>: Tests were performed on fine aggregates to determine the loose and dense unit weight, specific gravity and water absorption. The fine aggregates were mixtures of finer portion crushed brick or stone and sand. The results obtained for different fine aggregates are listed in Table 3.3. Three types of fine aggregates, mixing sand with fine portions of gas burnt brick, first class brick and crushed stone were considered. Eighty to ninety percent sand were used in the mixture.

Table 3.3 Physical Properties of Fine Aggregates

Name of Test	ASTM/ Designa-tion	Type of fine aggregates		
		Sand plus gas burnt pick jhama brick	Sand plus first class brick	Sand plus crushed stone
Unit weight, lb/cft	C29-78	83.65	82.34	103.75
Spacific gravity (apparent)	C127-77	2.62	2.61	2.68
Absorption percent	C127-77	4.23	5.15	1.31

About ten to twenty five percent of the total fine aggregates required in the mixture can be obtained during the hand crushing of bricks or stones. The lower value is for materials having higher crushing strength. The rest of the fine aggregates may be used by mixing appropriate sand. Table 3.3 snows that the unit weight and specific gravity decrease when crushed bricks are mixed with sand and these values with stone chips remain more or less same as that of sand. The absorption of the brick aggregate-sand mixture is much higher than that for stone screenings-sand mixture.

Fines: The specific gravity of the natural fines was determined according to ASTM standard C128-68 and the value is 2.72. The unit weight of fines was determined according to ASTM standard C29-71 and the values are 61.3 lb/cft at loose state and 73.2 lb/cft at dense state. These values are tabulated in Table 3.4. A hydrometer analysis of fines to determine the grain size distribution was also done and the results are tabulated in Appendix-C.

Table 3.4 Physical Properties of Fines

Name of the test	ASTM Designation	Test Results
Specific Gravity	C128-68	2.72
Unit weight (loose) lb/cft	C29-71	61.30
Unit weight (dense) lb/cft	C29-71	73.2U

CHAPTER-4

LABORATORY INVESTIGATION AND TEST RESULTS

The properties of the materials as discussed in Chapter 3 reveal that aggregates obtained from the gas burnt bricks are suitable for base and subbase constructions from the consideration of strength and toughness. With these brick aggregates-sand-soil mixture first a suitable gradation was found out after performing CBR tests for different gradations described in Article 4.1. With the gradation giving maximum CBR value then a search was made by varying amount of fines to find the optimum percent fines and finally a gradation with optimum fines is suggested.

After the gradation of the mixture was found, comparative studies were made between different types of brick and stone aggregates. If excess amount of clay material is present in the mixture, when mixed with water, the mixture becomes plastic. This type of material is not suitable for base course construction. The plasticity of the mixture depends on the portion of the mixture passing No. 40 sieve. An investigation is therefore carried to find the plasticity characteristics of the portion of the mixture passing No.40 sieve.

A relation between the compactive efforts and CBR values were also established. The laboratory works done for the research and the test results are discussed in the following articles.

4.1 Density-Gradation Relationship

Initially five aggregate gradations were selected from available literature. These gradations are listed in Table 4.1. The grain size distribution bands are shown in Figs. 4.1 to 4.5. The gradations are designated as X_1, X_2, X_3, X_4 and X_5. Gradation X_1 was taken from the recommendations of Bangladesh Road Research Laboratory for aggregate crusher run base (shown in Table 2.5). Gradation X_2 and X_3 are chosen from the AASHO standard M147 grade A and B (Table 2.1). X_4 is the gradation in Road Note No.31 of TRRL, U.K. for untreated crushed aggregate base (Table 2.3 - 1½ inch maximum size). From specifications of California Division of Highways gradation X_5 was selected (1½ inch maximum size of Table 2.2). From the combined plot of all the gradations (Fig. 4.6) an arbitrary gradation was selected from the analysis of the results of all the above gradations in view to have the best results. That final gradation is gradation Z (Fig. 4.7). Table 4.1 shows gradation Z with other gradations for comparison.

Coarse aggregates, fine aggregates, sand and soil were mixed together in proportions as specified in these gradations and optimum moisture content and maximum dry density were found for these mixtures according to the standard AASHO compaction method under ASTM designation D698-78. The results of these compaction tests are shown in a concised form in Table 4.2. The moisture content- density graphs are plotted in Figs. 4.8 to 4.10. The line of Zero Air Void (ZAV) also is plotted with the help of average apparent specific gravity of tb combined mixture. CBR tests were performed for the mixtures of gradation X_1, X_2, X_3, X_4, X_5 and Z compacting the samples at respective optimum moisture contents.

Table 4.1 Aggregate Gradation Requirements of Different Organisations and the Selected Gradation Z.

Sieve size	Percent Finer for Gradations					
	X_1	X_2	X_3	X_4	X_5	Z
2 inch	100	100	100	-	100	-
1½ inch	90-100	-	-	100	90-100	95-100
1 inch	-	-	75-95	-	-	-
¾ inch	60-80	-	-	80-100	50-85	70-90
⅜ inch	40-60	30-65	40-75	55-80	-	50-68
No.4 (3/16")	30-45	25-55	30-60	40-60	30-45	38-50
No.8	20-35	-	-	30-50	-	28-40
No.10	-	15-40	20-45	-	-	-
No.30	12-25	-	-	15-30	10-25	15-22
No. 40	-	8-20	15-30	-	-	-
No. 200	5-15	2-8	5-25	5-15	2-9	8-12

4.2 Effect of Gradation on CBR Value

Picked jhama Brick chips with sand and soil at different gradations were compacted in the laboratory to find the CBR

AGGREGATE GRADATION CHART

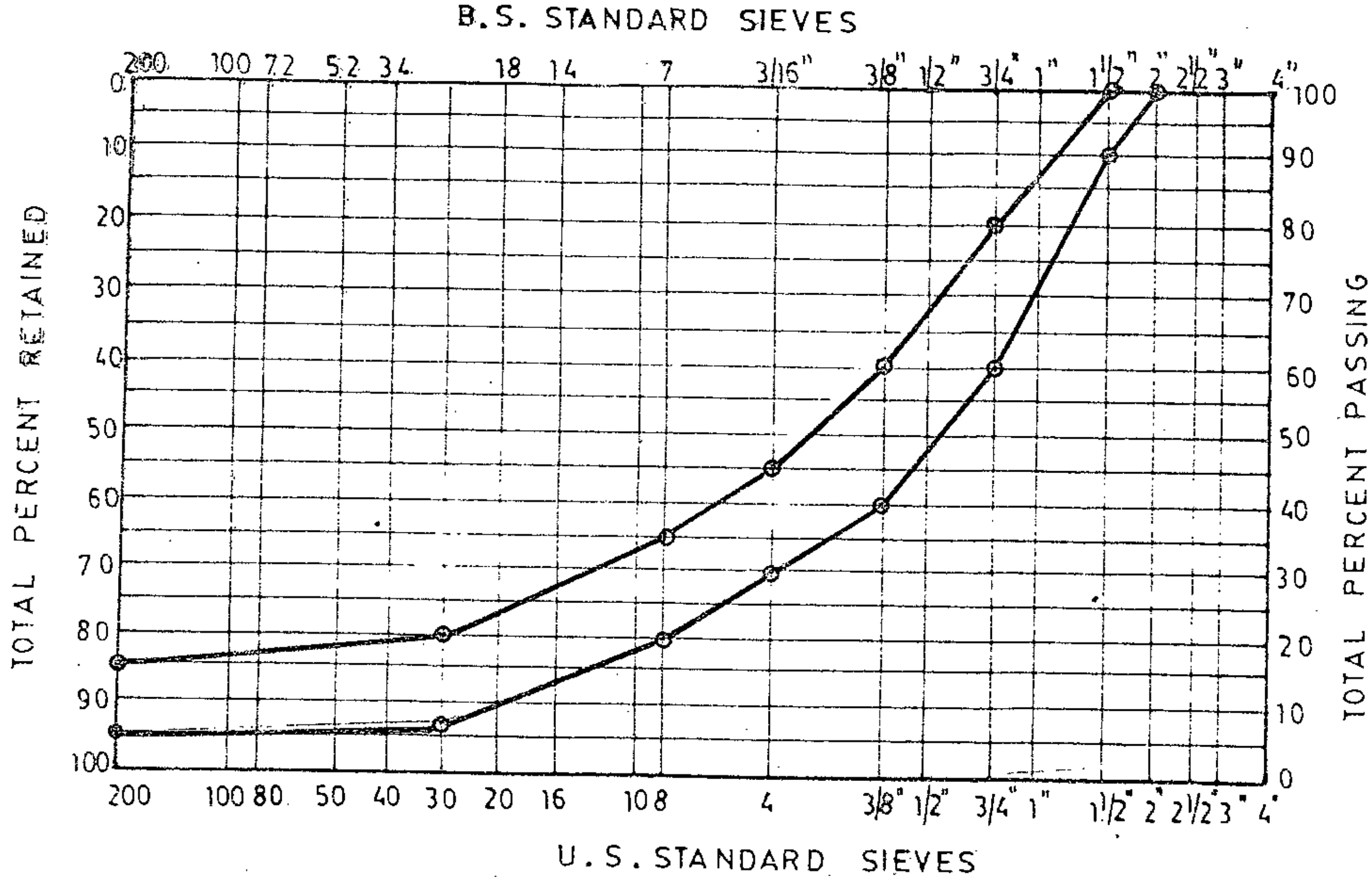


FIG. 4.1 GRADATION X_1 (BRRL)

AGGREGATE GRADATION CHART

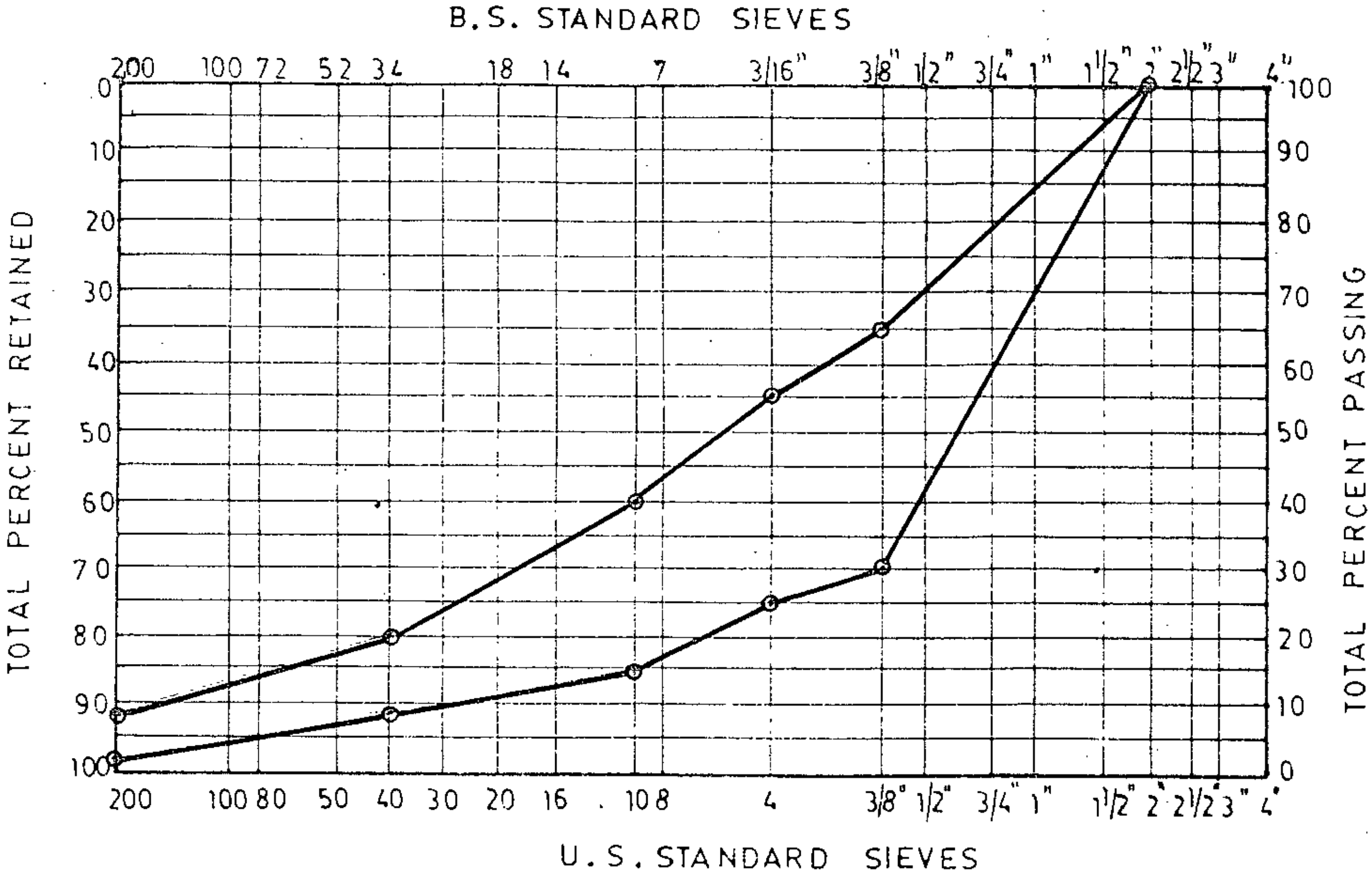


FIG. 4.2 GRADATION X_2 (AASHO)

AGGREGATE GRADATION CHART

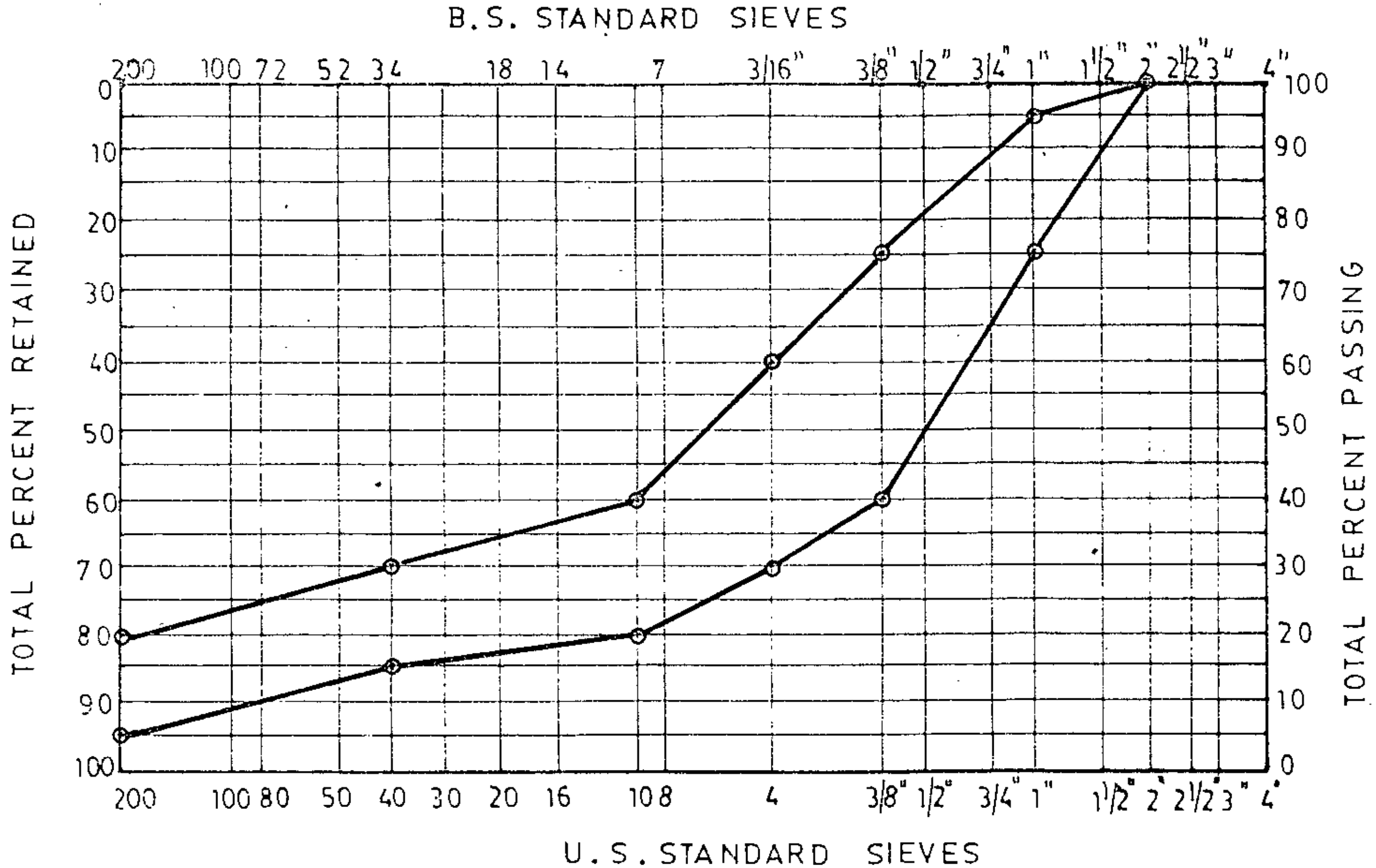


FIG. 4.3 GRADATION X_3 (AASHO)

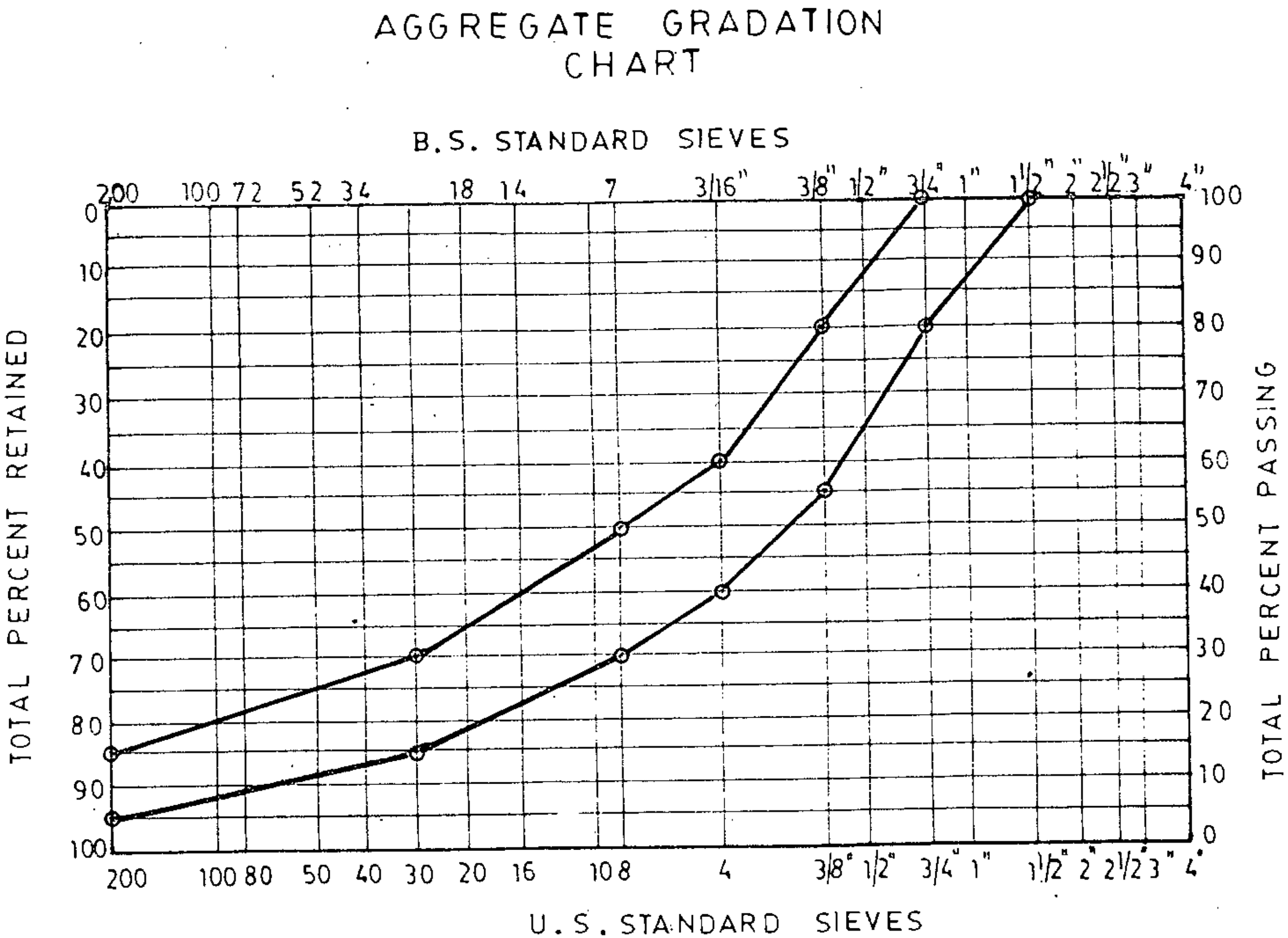


FIG. 4.4 GRADATION X_4 (RN 31, TRRL)

AGGREGATE GRADATION
CHART

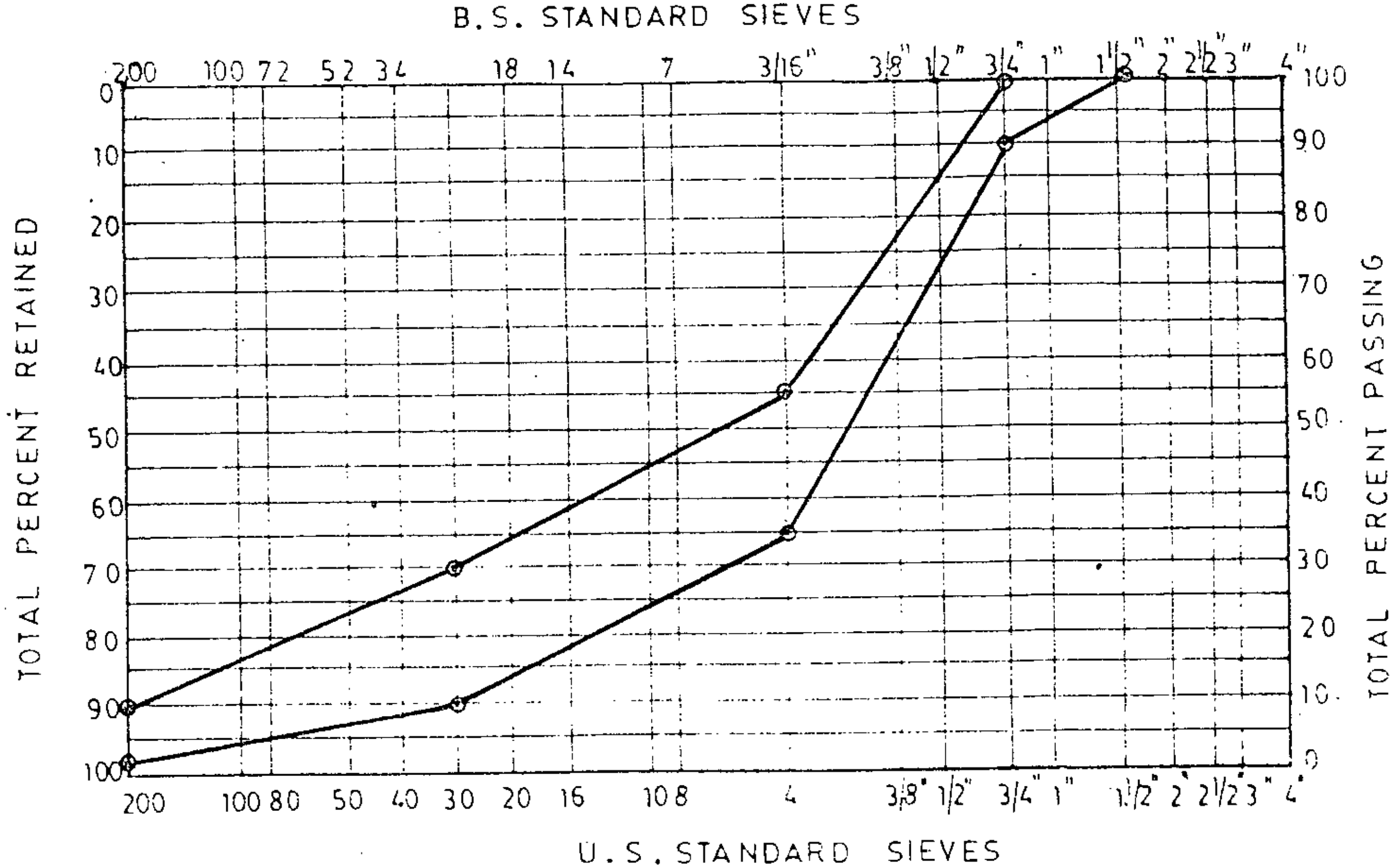


FIG. 4.5 GRADATION X_5 (CDH)

AGGREGATE GRADATION CHART

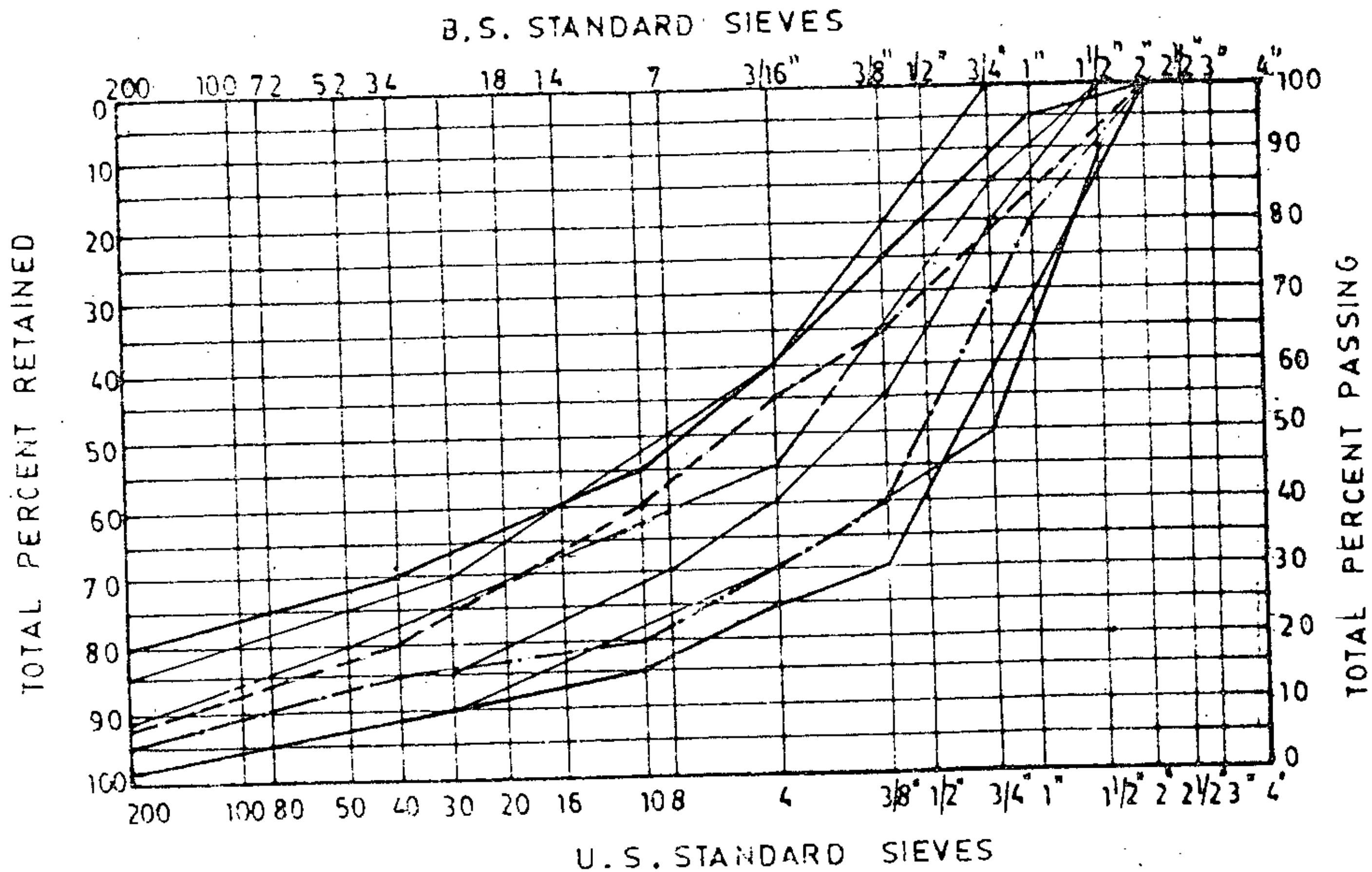


FIG. 4-6 GRADATIONS SUPERIMPOSED

AGGREGATE GRADATION
CHART

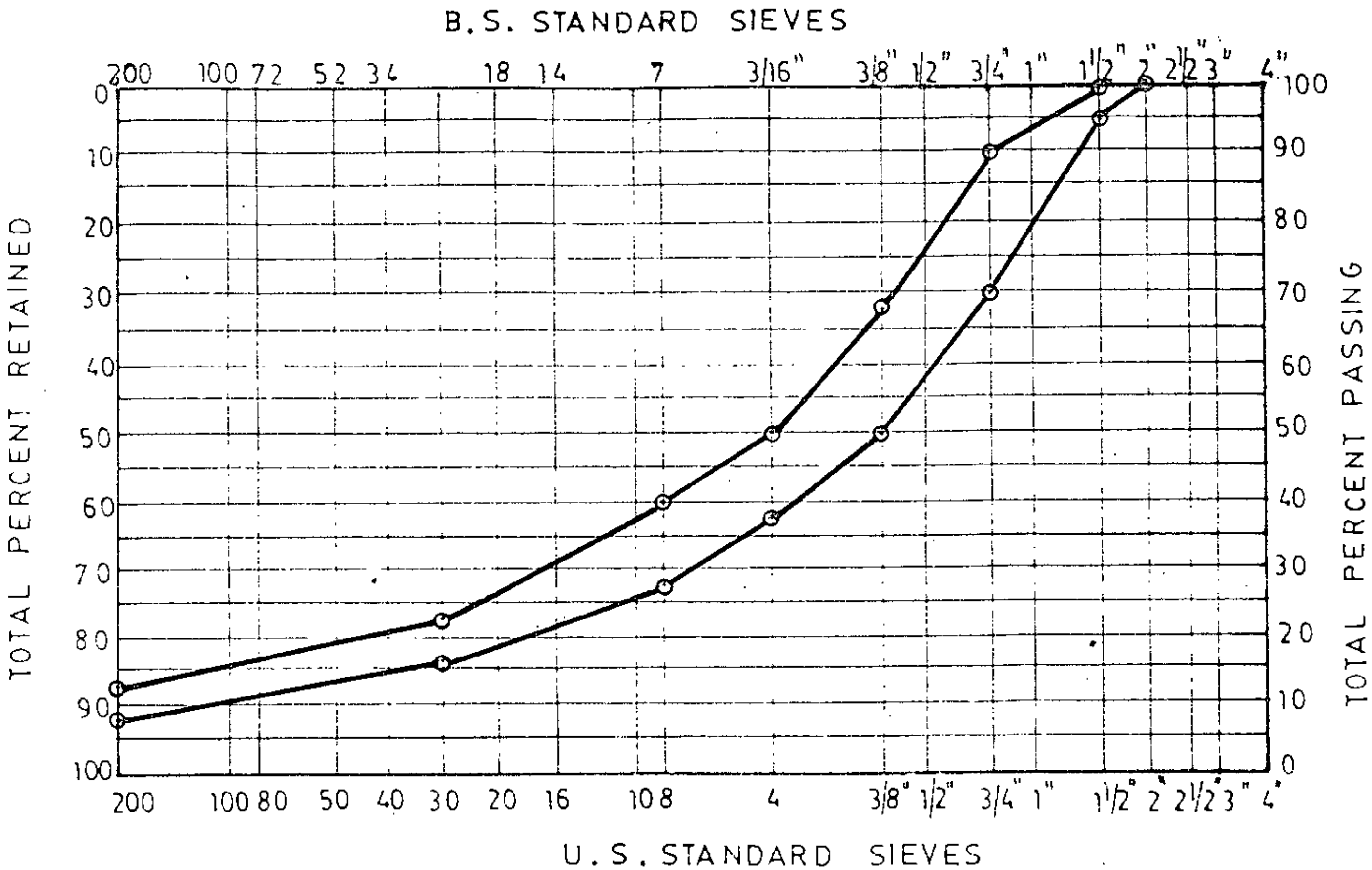


FIG.4.7 GRADATION Z
(SELECTED GRADATION)

Table 4.2 Moisture Density-Gradation Data

Gradation	Moisture content (%)	Wet. density lbs/cft	Dry-density lbs/cft	Optimum moisture content(%)	Maximum dry-density lbs/cft
	5.0	115.08	109.60		
	7.5	120.50	112.10		
X_1	10.0	126.17	114.70	13.0	117.9
	12.3	132.17	117.70		
	14.5	133.39	116.50		
	16.0	133.05	114.70		
	5.0	114.34	108.90		
	7.3	120.33	112.15		
X_2	10.0	125.95	114.50	12.5	117.0
	12.5	131.62	117.00		
	15.0	133.70	116.30		
	17.0	131.27	112.20		
	5.0	115.17	110.20		
	9.0	124.26	114.00		
X_3	12.5	132.30	117.60	13.5	118.0
	15.0	134.55	117.00		
	17.4	135.12	115.10		

Table 4.2 (Contd.....)

Gradation	Moisture content (%)	Wet. density lbs/cft	Dry-density lbs/cft	Optimum moisture content(%)	Maximum dry-density lbs/cft
	5.0	117.28	111.7		
	7.5	123.41	114.8		
X_4	10.0	129.25	117.5	12.5	120.5
	12.0	134.40	120.0		
	13.5	135.85	119.7		
	15.5	133.90	116.0		
	5.0	116.13	110.6		
	8.75	124.08	114.1		
X_5	11.75	129.85	116.2	13.0	116.5
	14.0	132.58	116.0		
	17.0	133.38	114.0		
	5.0	115.50	110.0		
	7.5	121.48	113.0		
Z	9.75	124.42	116.1	13.0	119.0
	13.0	134.47	119.0		
	15.0	134.20	116.7		

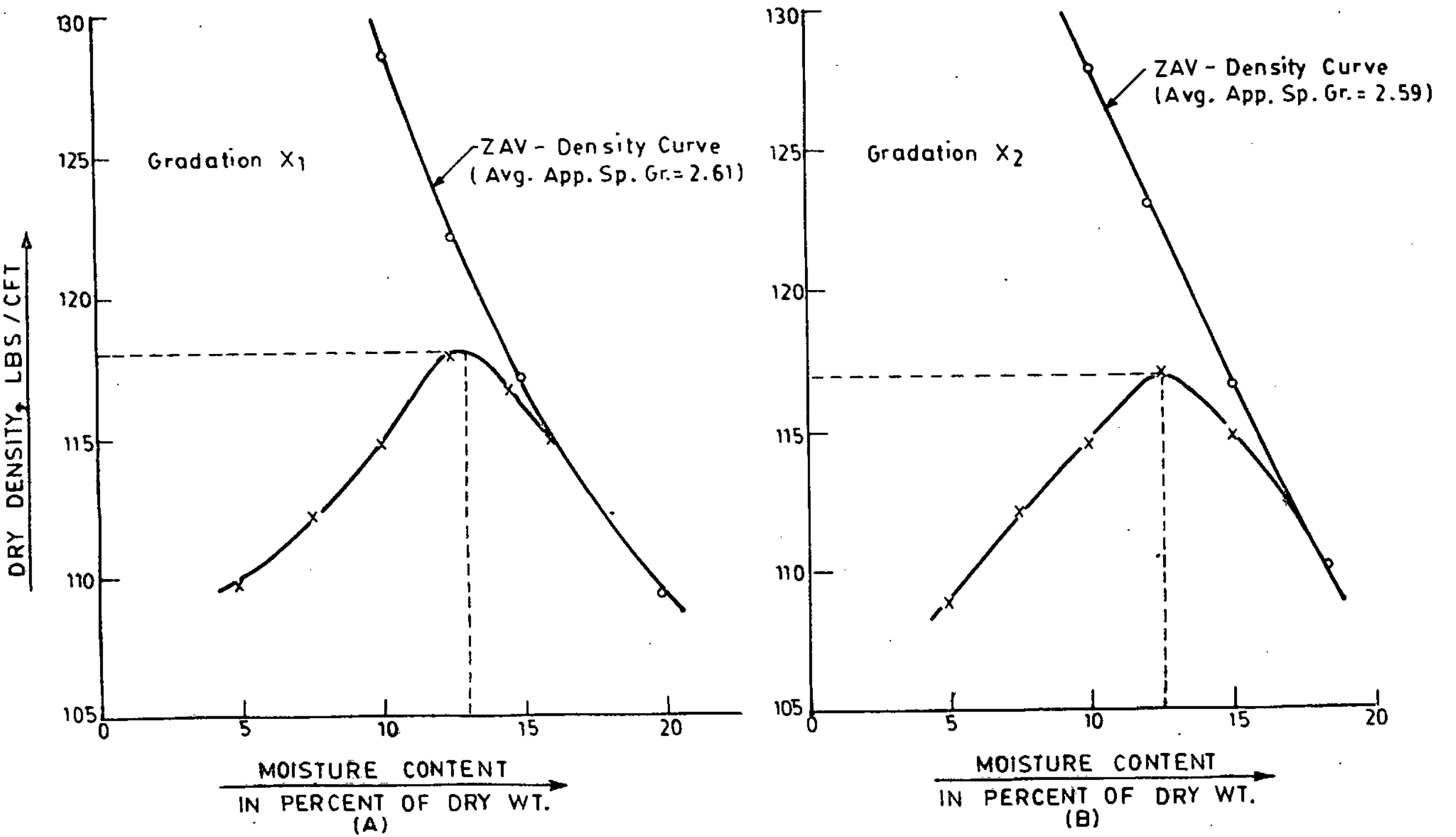


FIG. 4.8 MOISTURE-DENSITY RELATIONSHIP: (A) FOR GRADATION X_1 (B) FOR GRADATION X_2

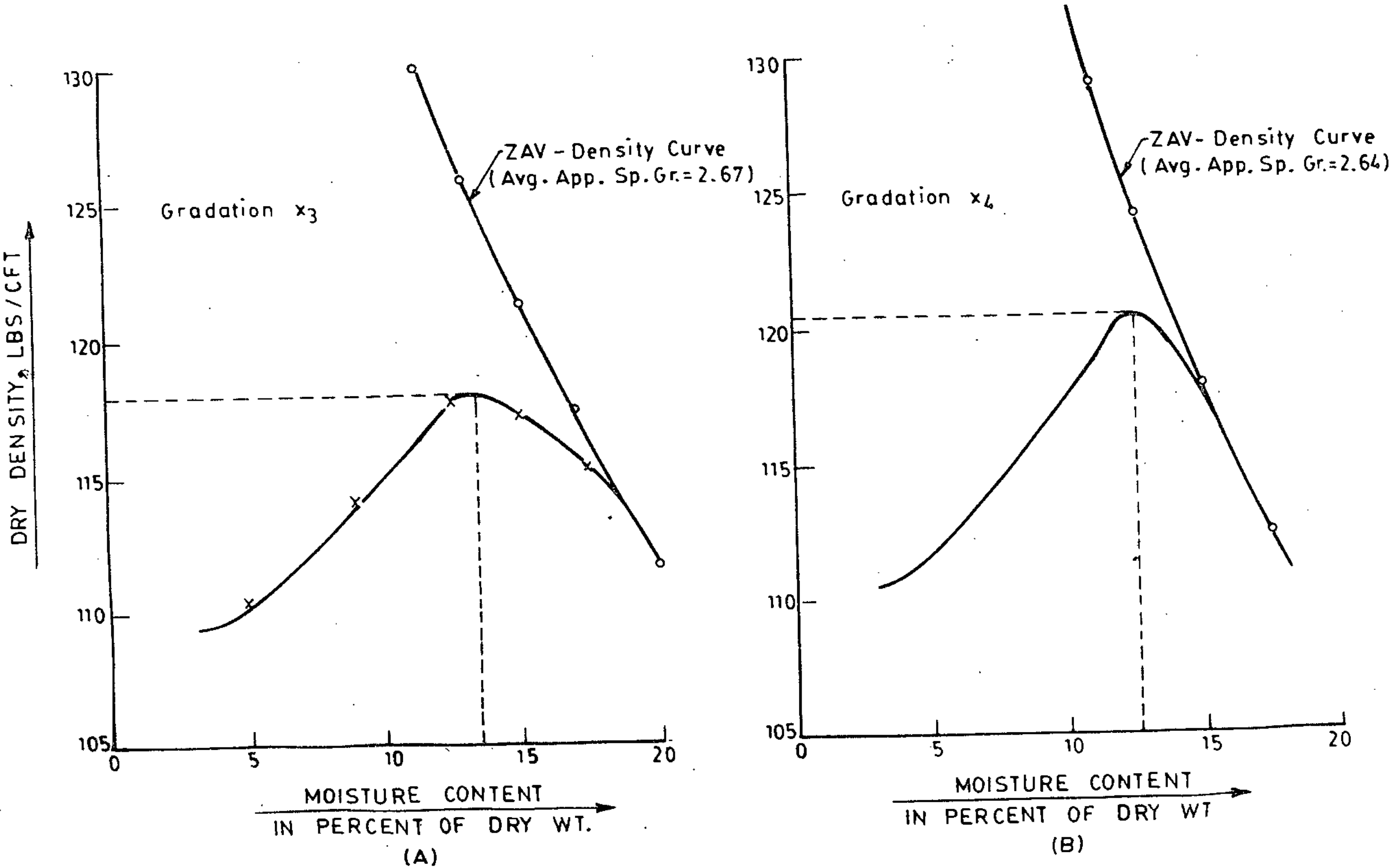


FIG. 4.9 MOISTURE DENSITY RELATIONSHIP: (A) FOR GRADATION X_3 (B) FOR GRADATION X_4

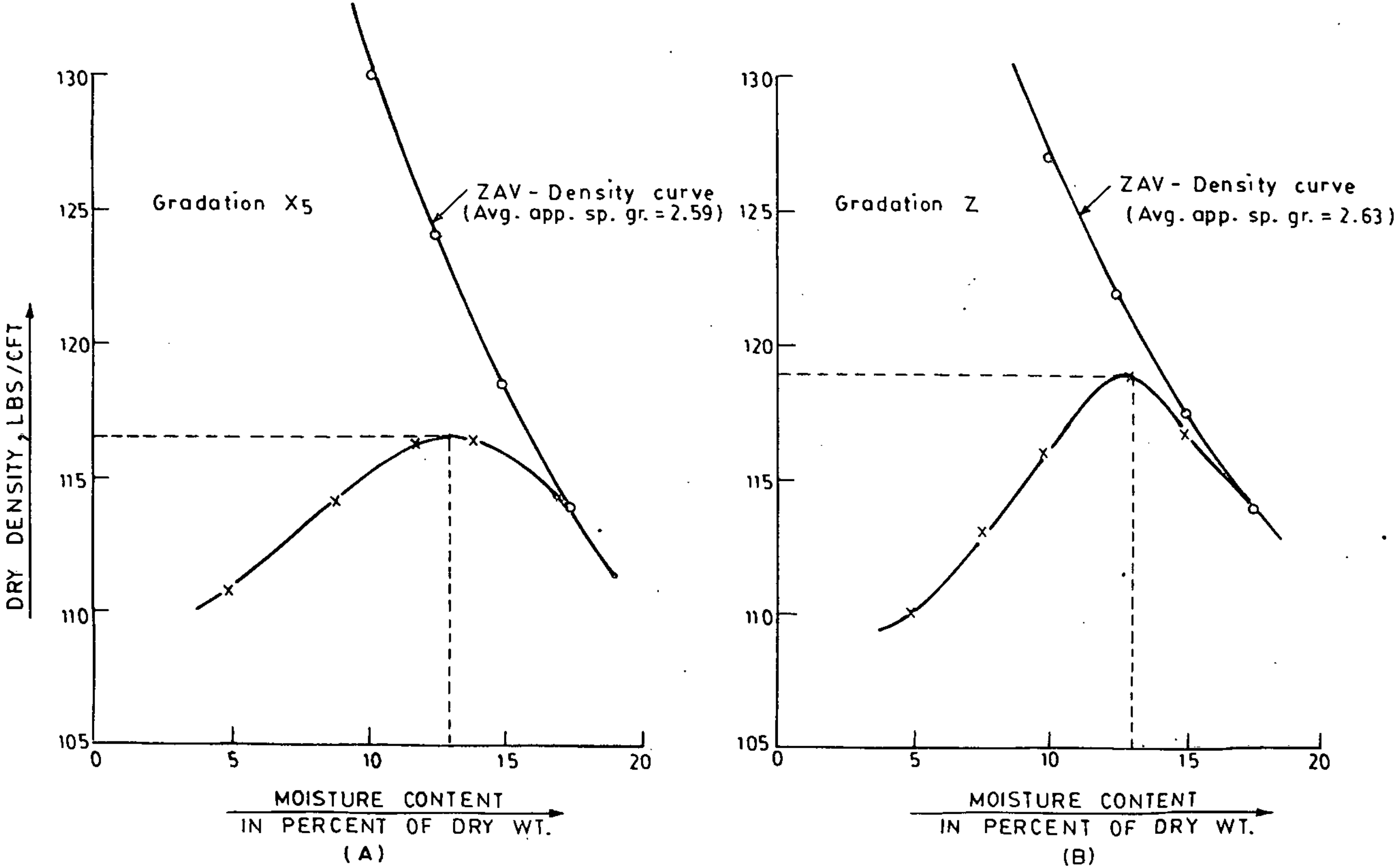


FIG.4.10 MOISTURE-DENSITY RELATIONSHIP: (A) FOR GRADATION X_5 (B) FOR GRADATION Z

value of the compacted mixture. The test was performed following the procedure in ASTM D1883-73 and AASHO T-193-63. The moisture content during compaction was maintained to be optimum. Six samples were prepared at a particular compactive effort. The dry densities of the compacted specimens were measured. The compacted specimens were subjected to four days soaking period applying 10 lbs surcharge and providing swell measuring arrangements. Swell measured after the soaking period was very negligible. Soaked specimens after 15 minutes of free drainage were tested in the testing machines (Figure C-1 to C-6 in Appendix-C). After plotting the data in Figs.4.11 - 4.16 corrected soaked CBR values were obtained. For all the samples CBR values at 0.1 inch penetration are higher than the values at 0.2 inch penetration. With different compactive efforts, dry density and CBR values are plotted in Figs. 4.17 to 4.19. The CBR values for 100 percent standard AASHO maximum densities were obtained from CBR-density plots and compared for different gradations in Table 4.3.

4.3 Effect of Fines on CBR Values

By varying the percent fines from zero to twenty in gradation Z, CBR values were determined with gas burnt picked jhama bricks. The results of this investigation are tabulated in Table 4.4 and plotted in Figs. 4.20a - 4.20c. The percent fines versus CBR and dry density are plotted in Fig. 4.21.

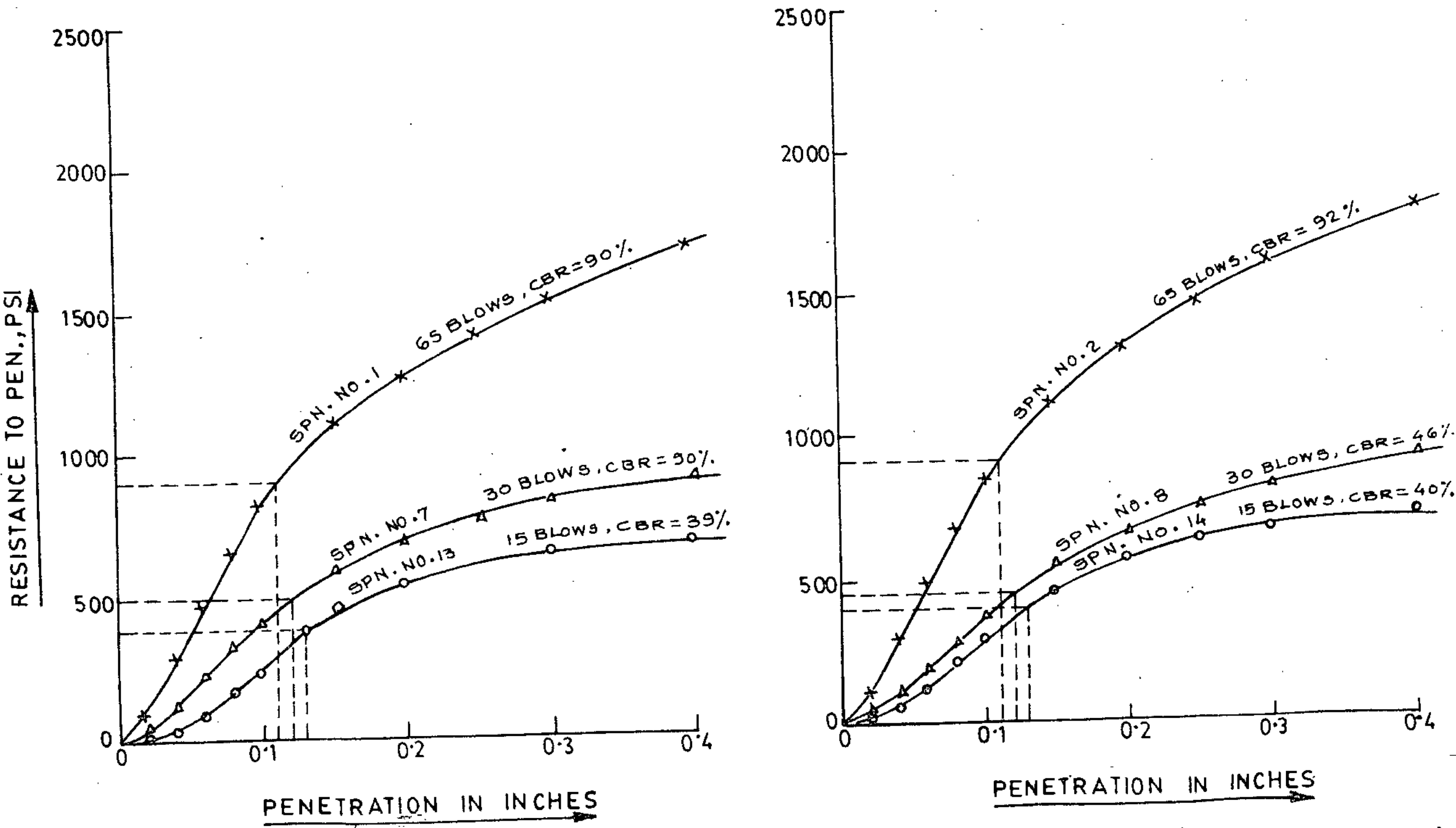


FIG. 4.11a CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION X_1)

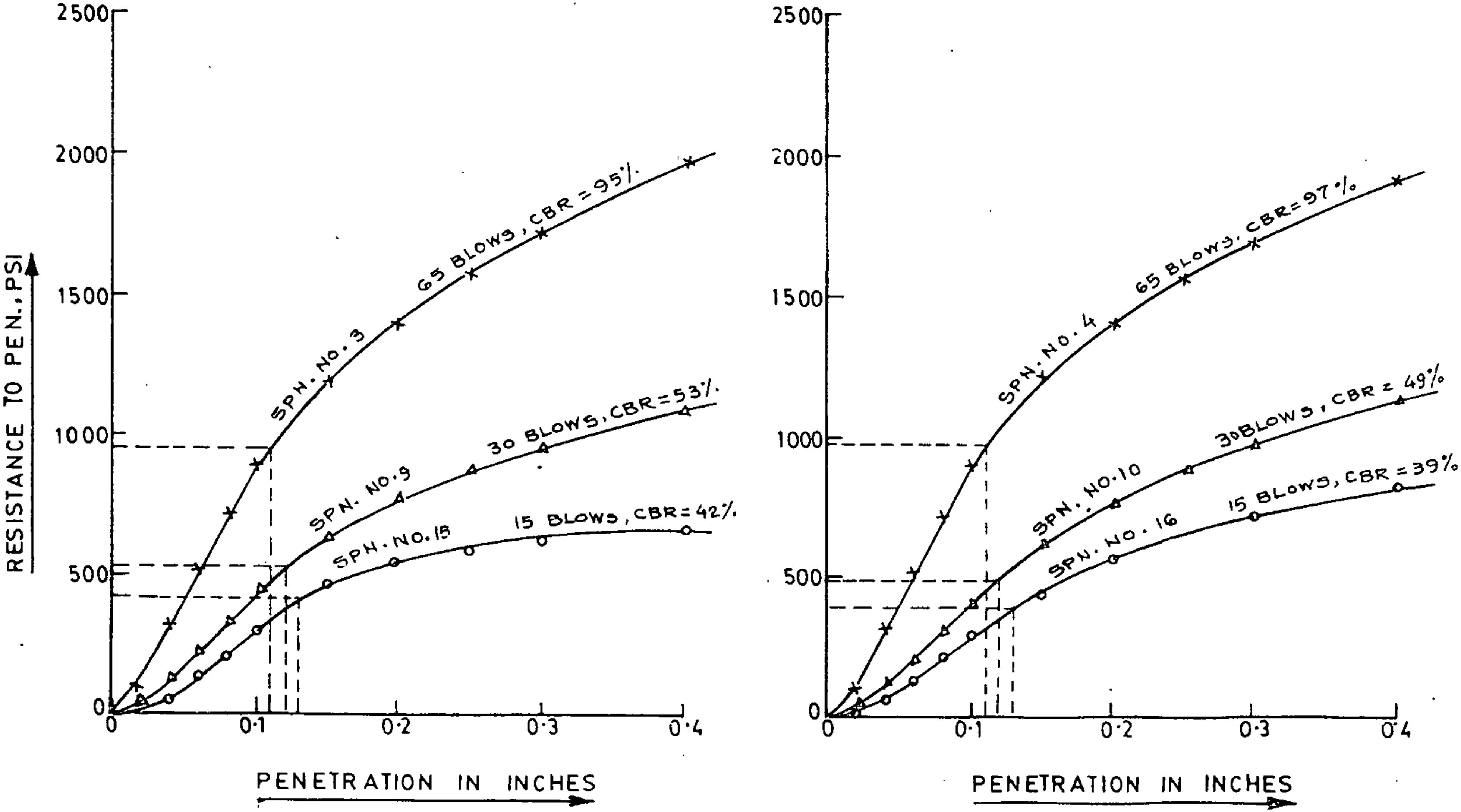


FIG. 4.11b CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION X_1)

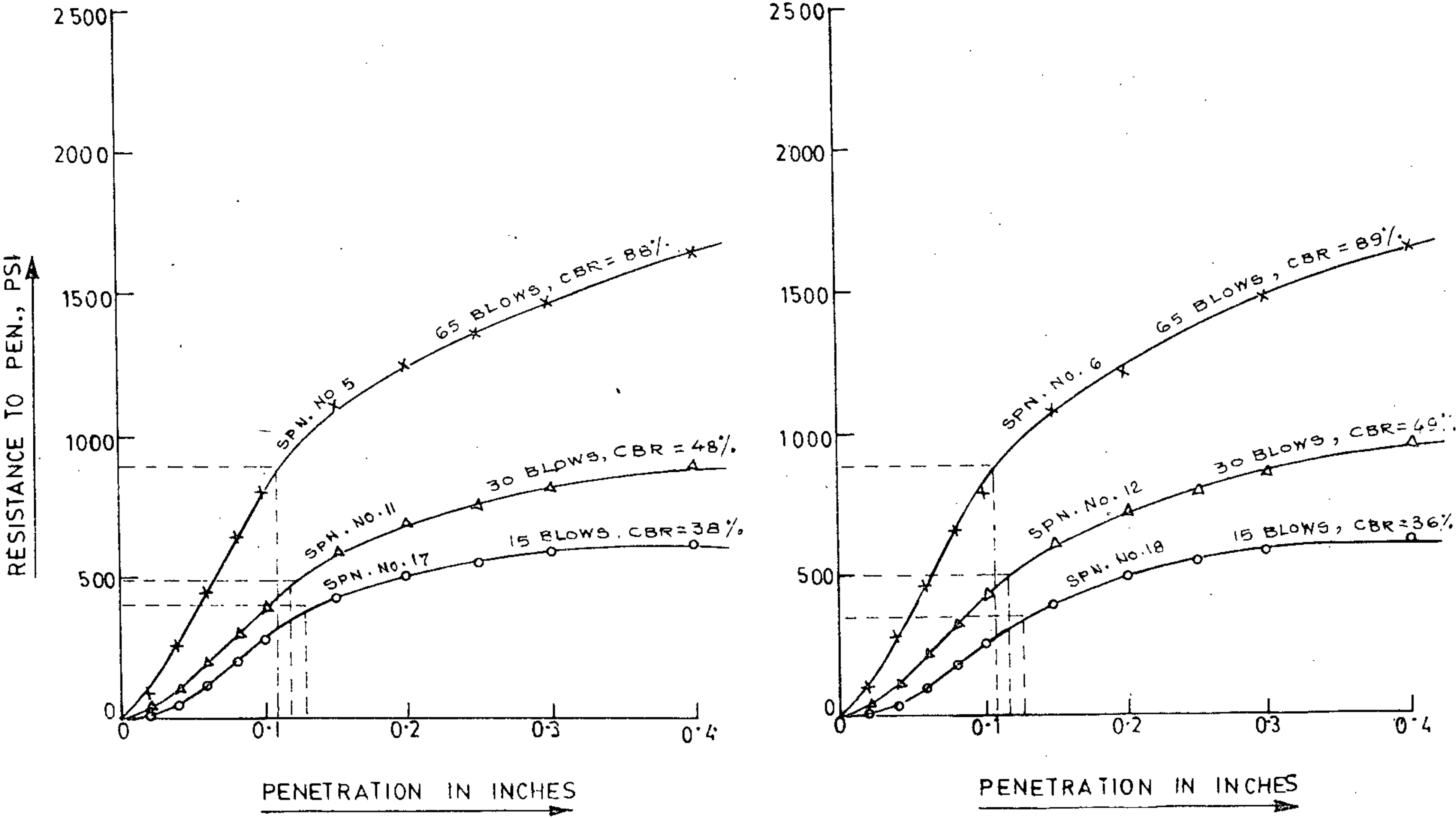


FIG. 4.11c CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION X_1)

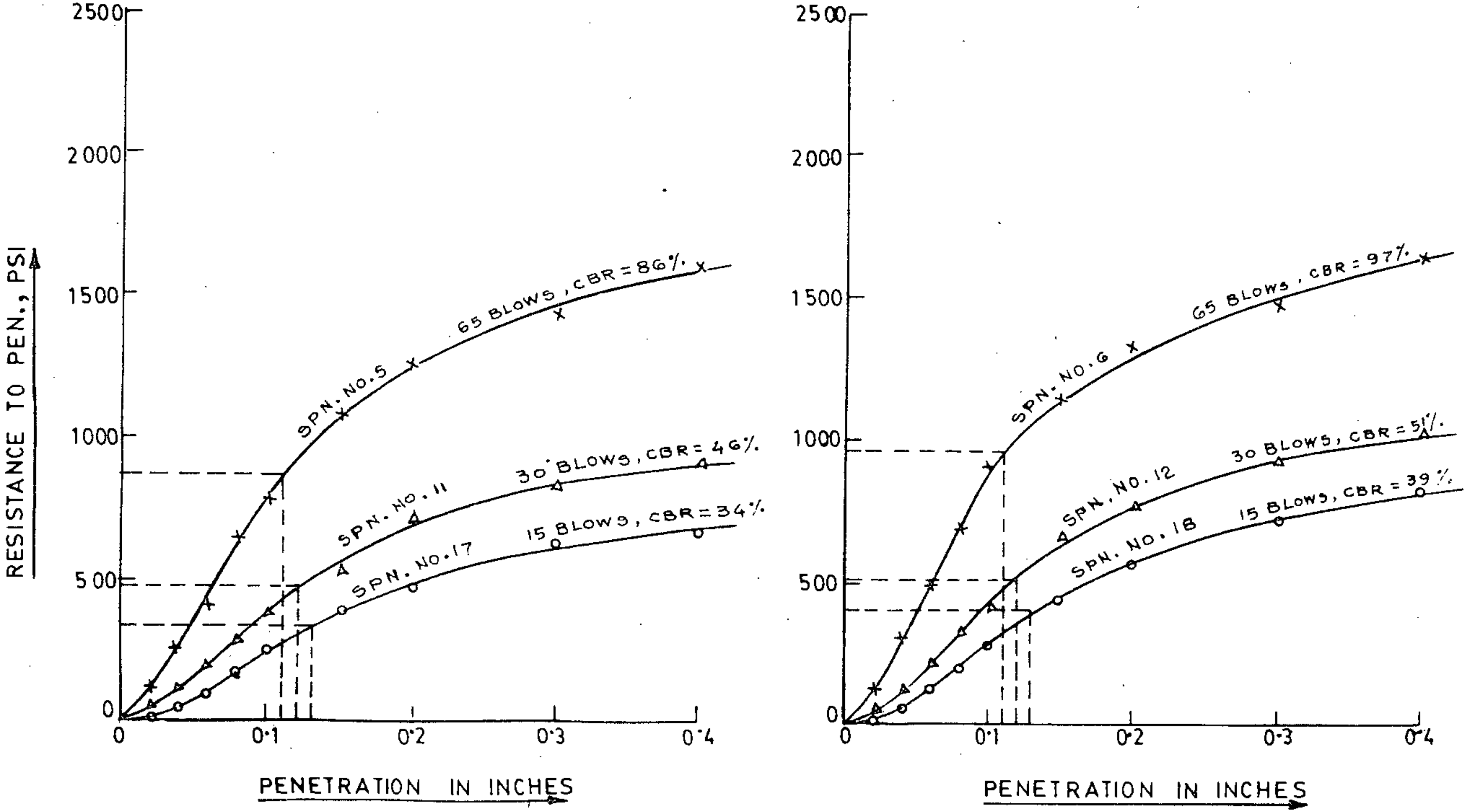


FIG-4.12a CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION X2.)

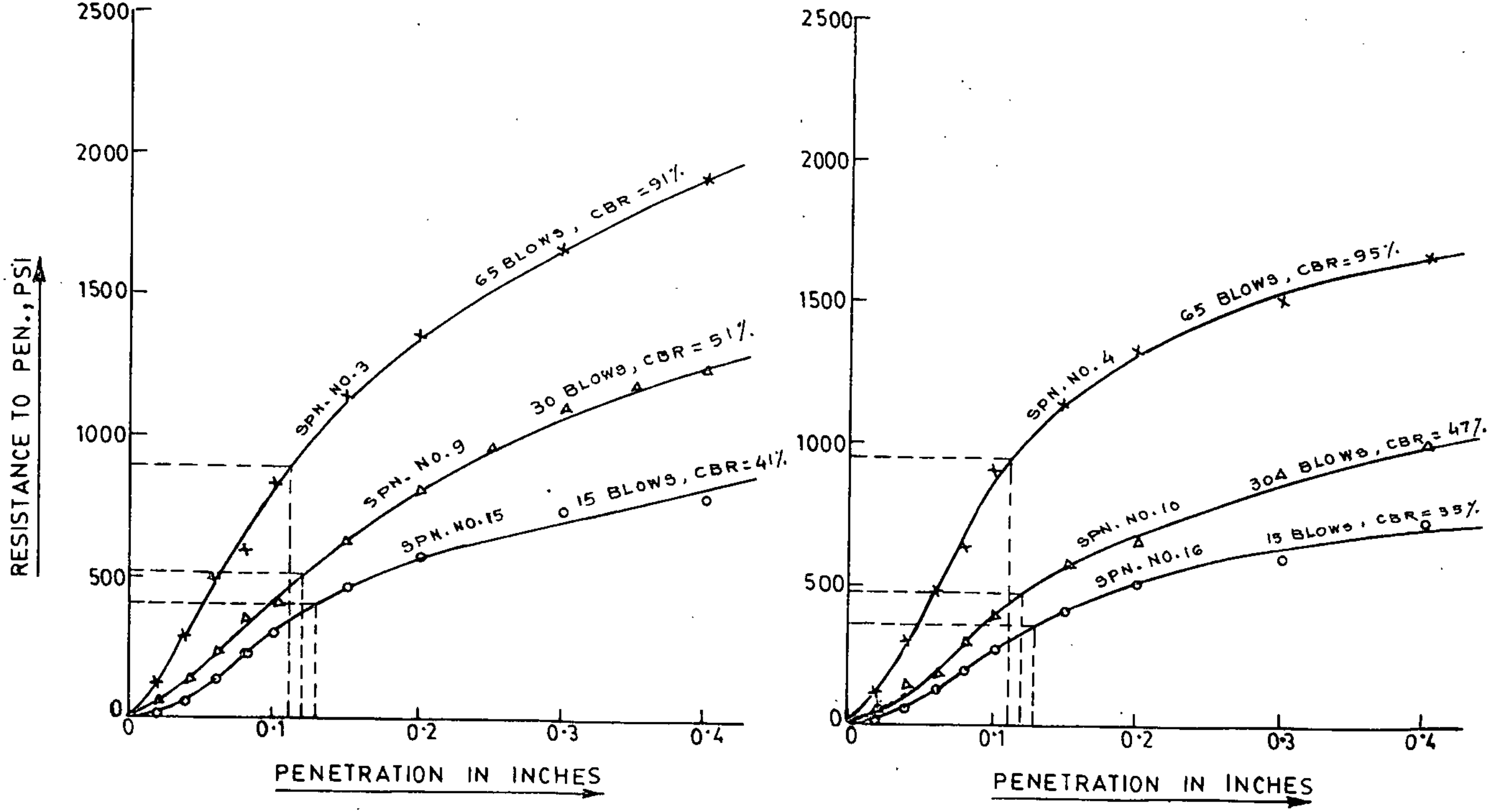
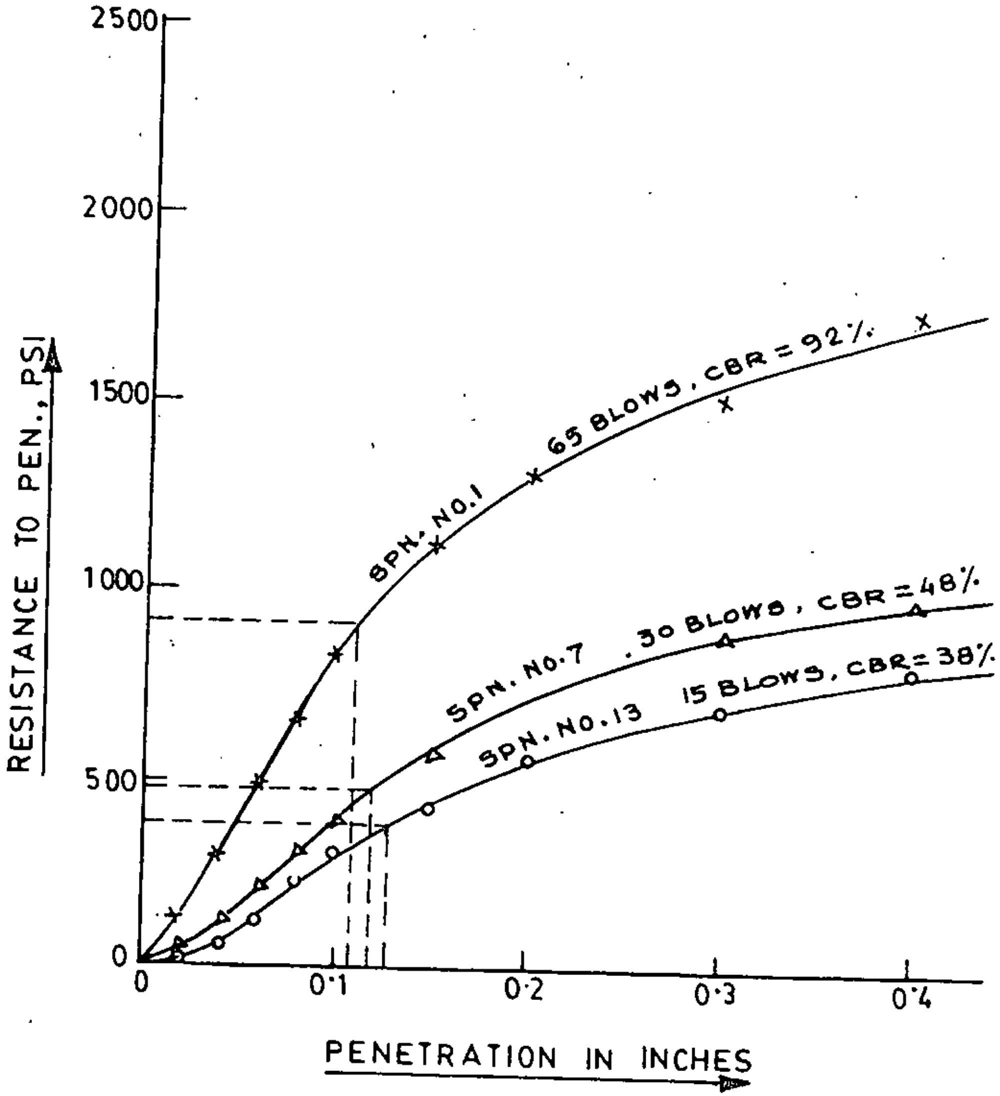


FIG. 4.12 b CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION X2)



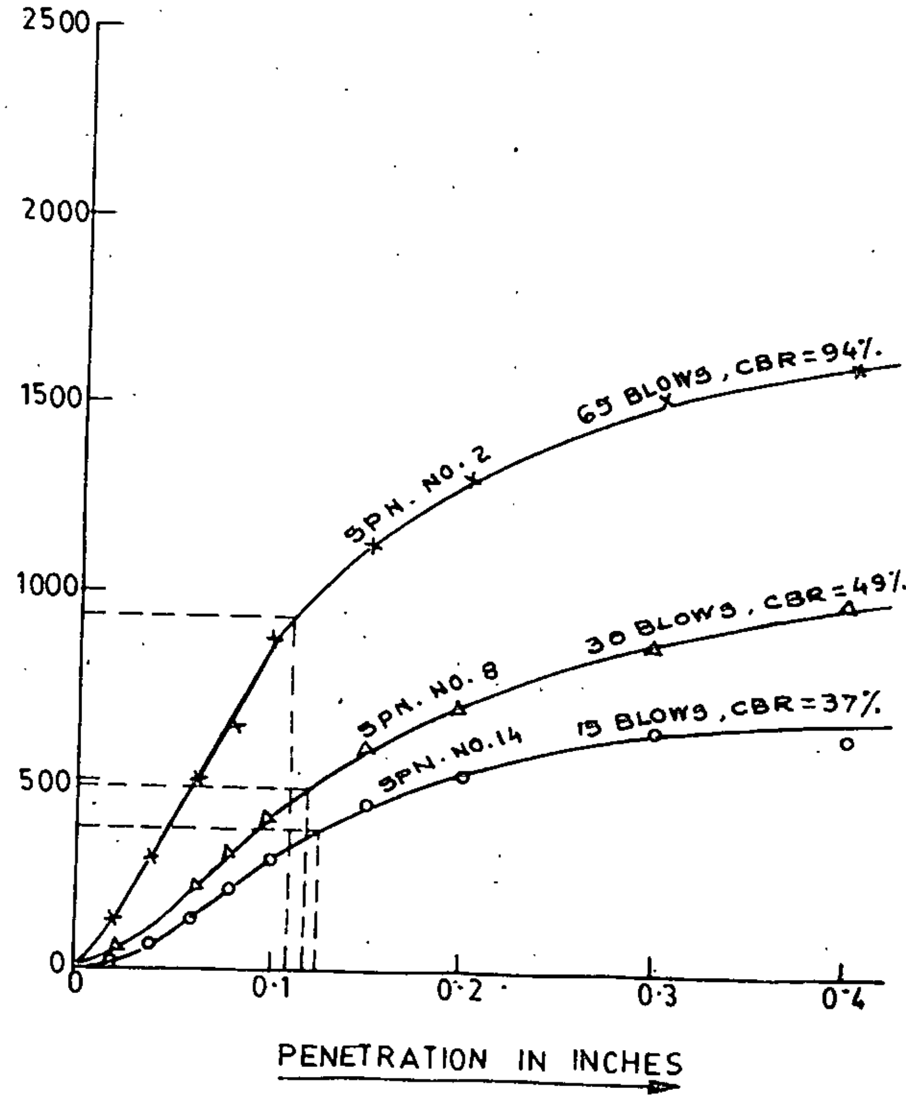


FIG. 4.12c CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION X_2)

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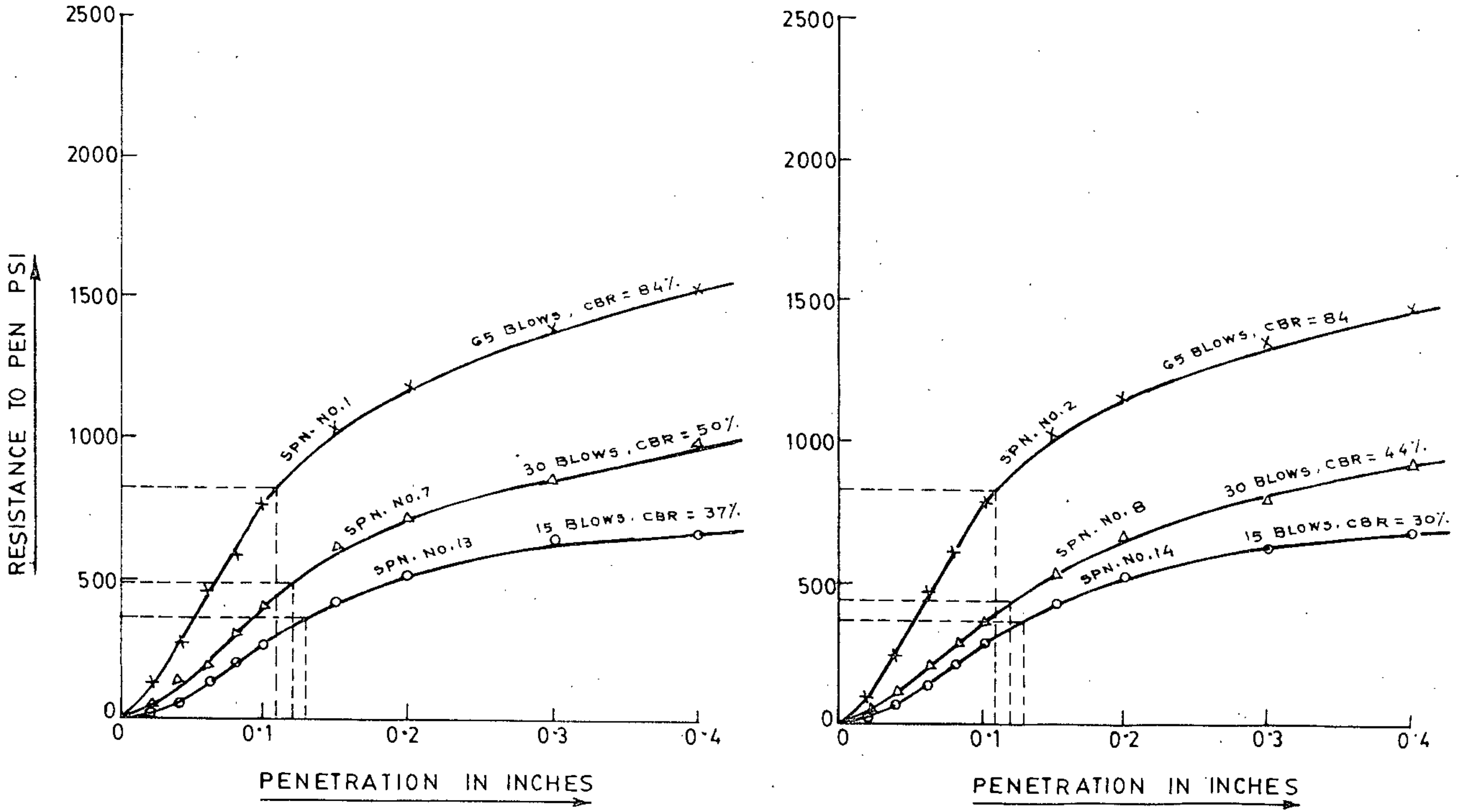
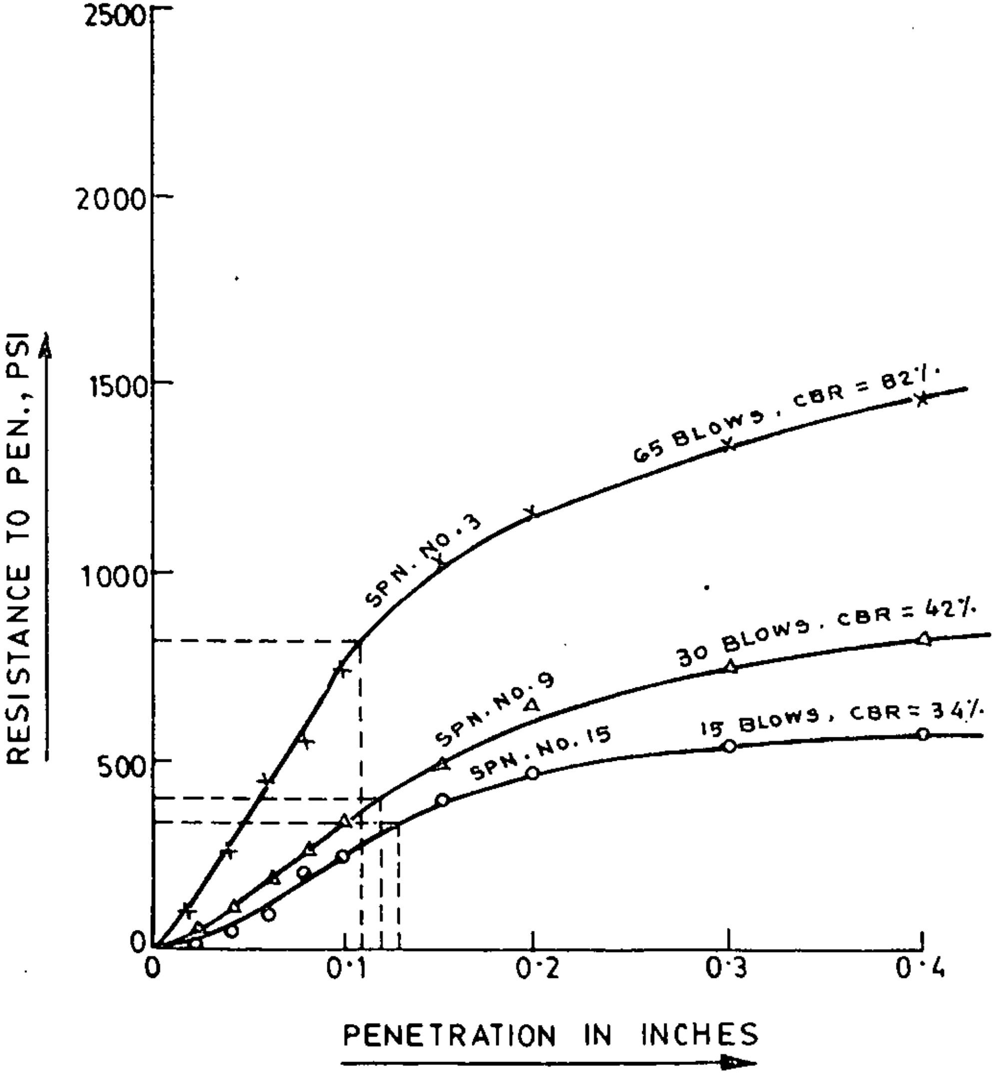


FIG.4.13a CBR FOR DIFFERENT SRECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION X3)



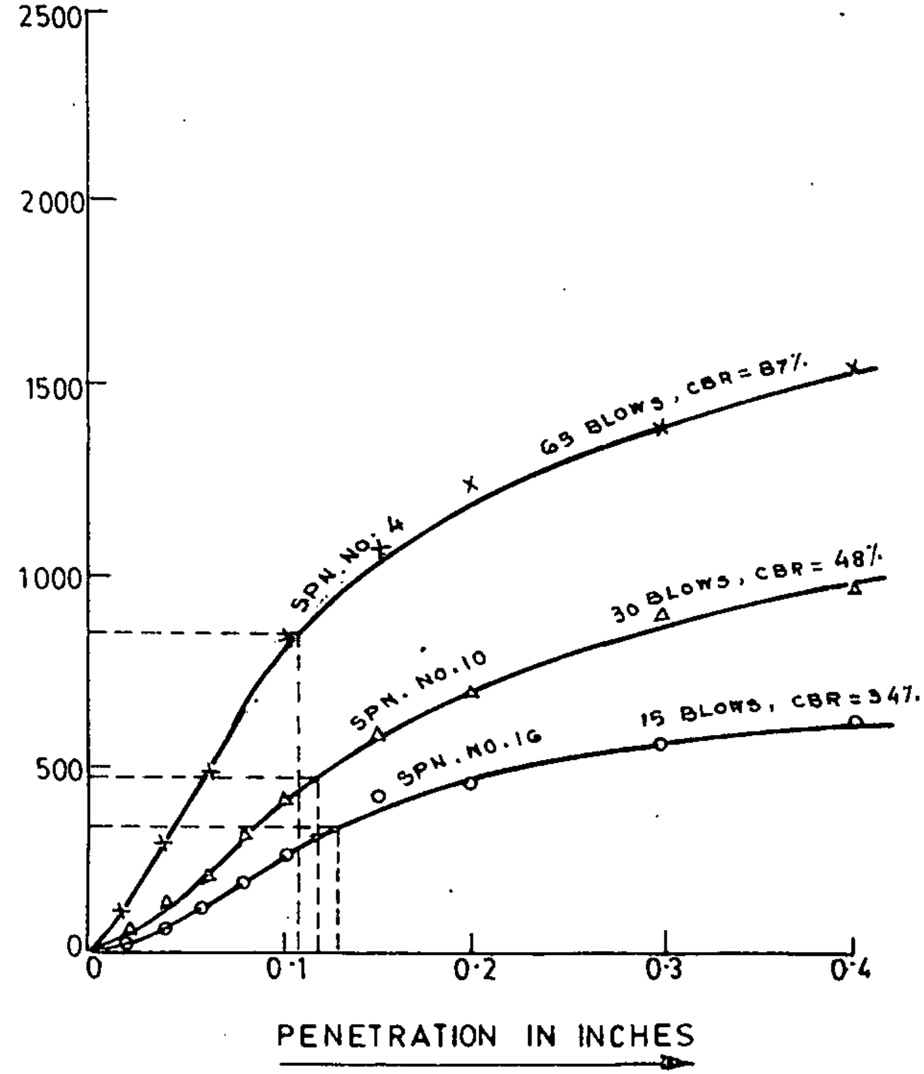


FIG. 4.13b CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION X_3)

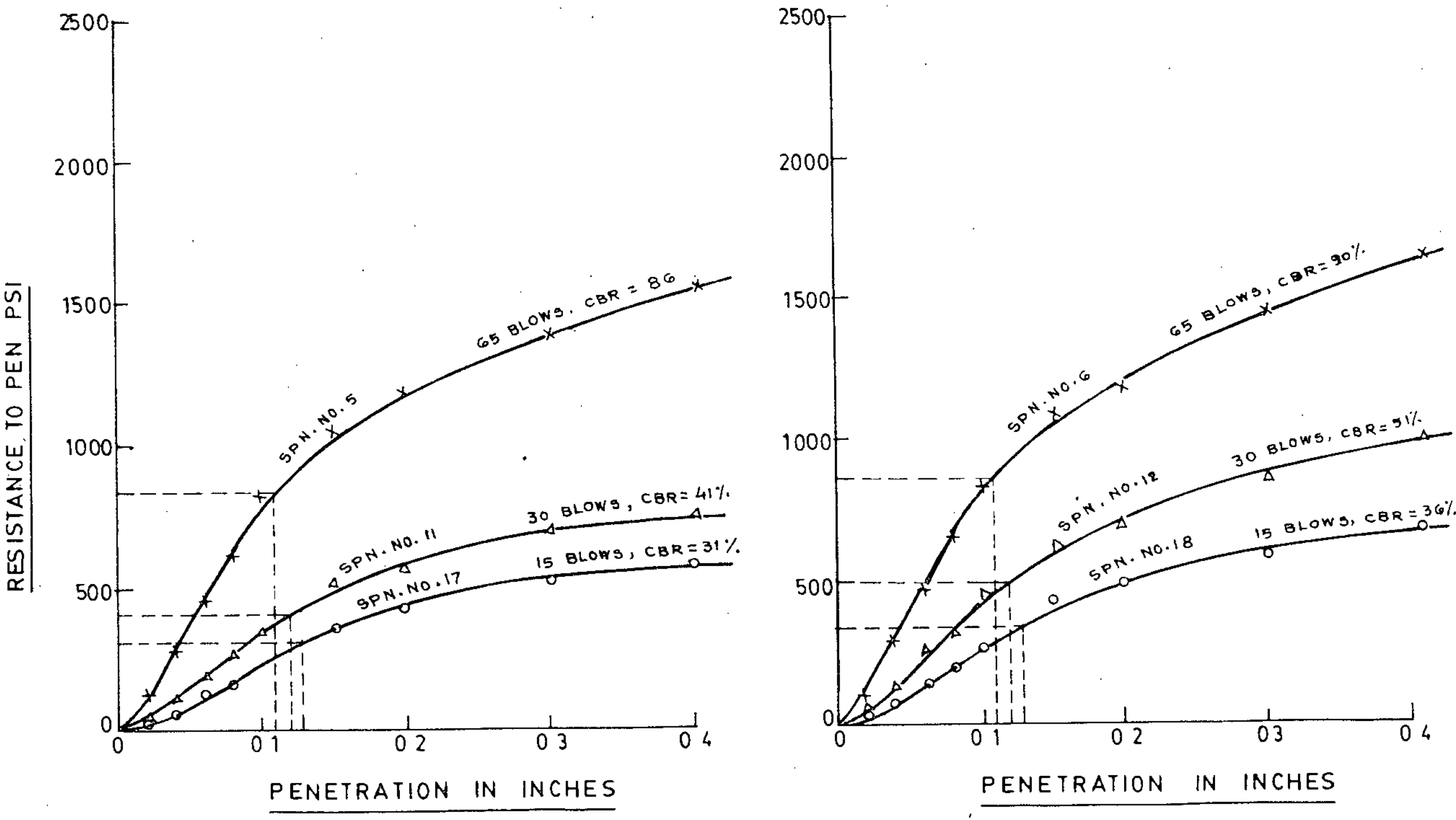


FIG.4.13c CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION X_3)

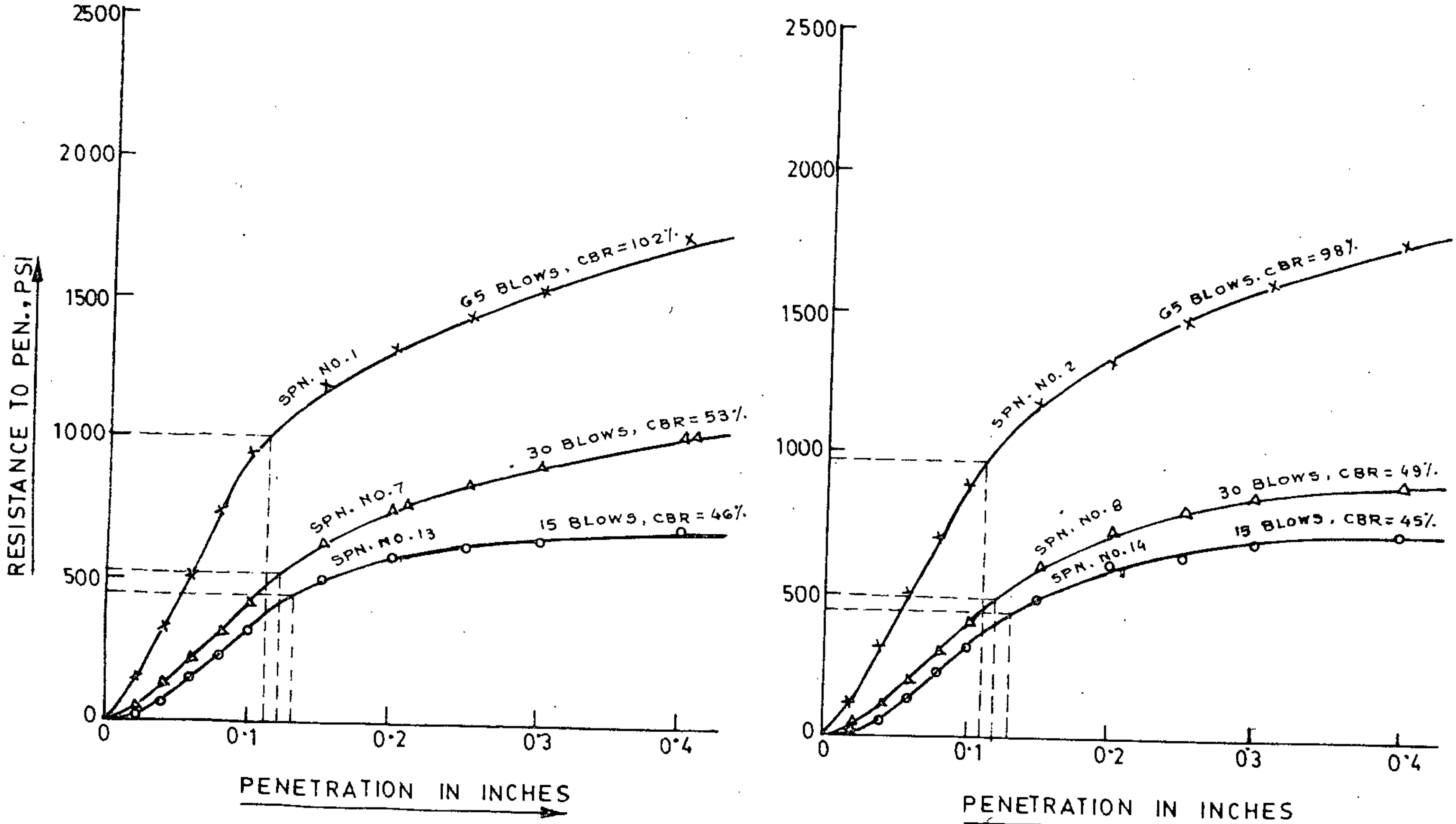


FIG. 4.14a CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION X4)

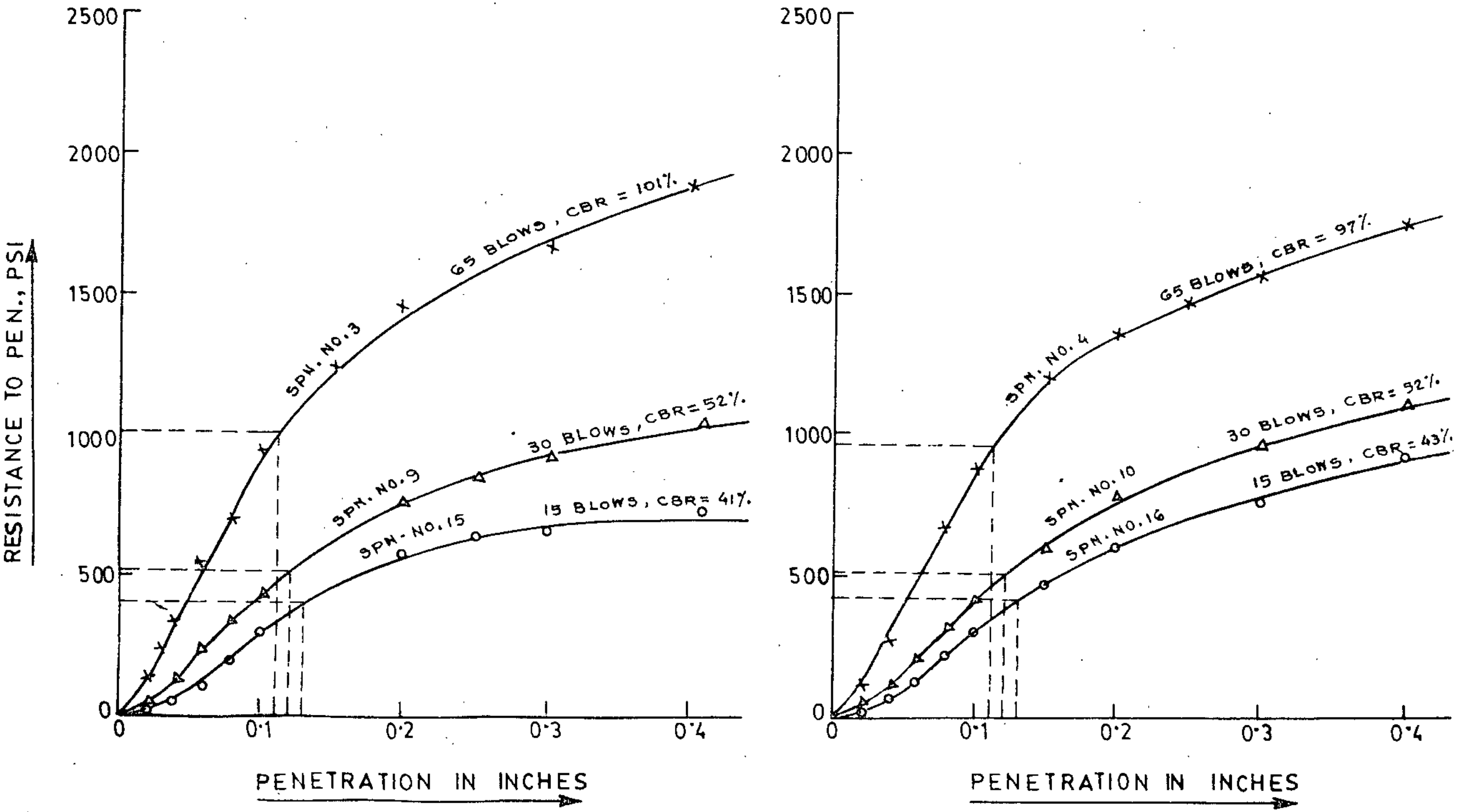


FIG. 4.14 b CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION X4)

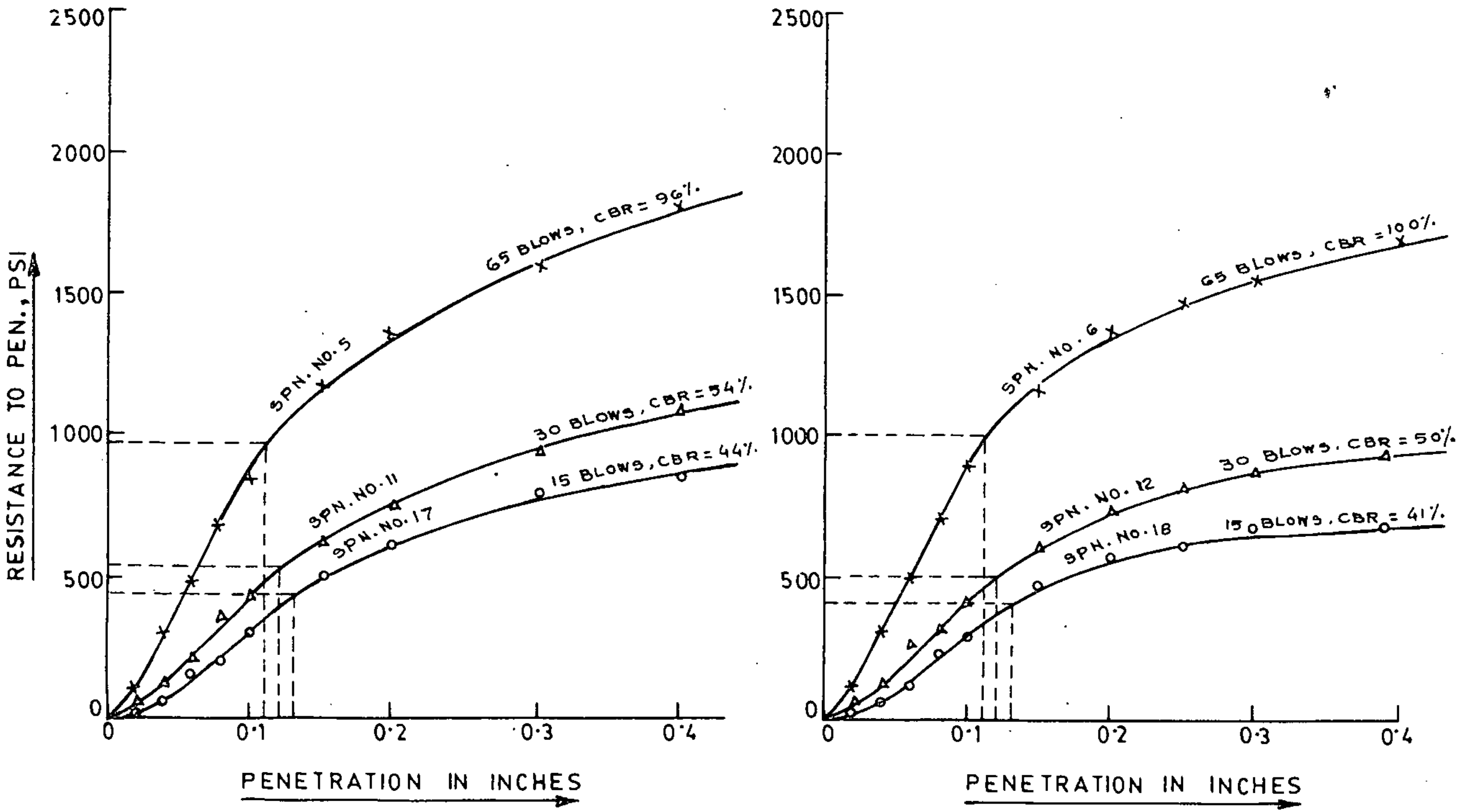


FIG. 4.14c CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION X_4)

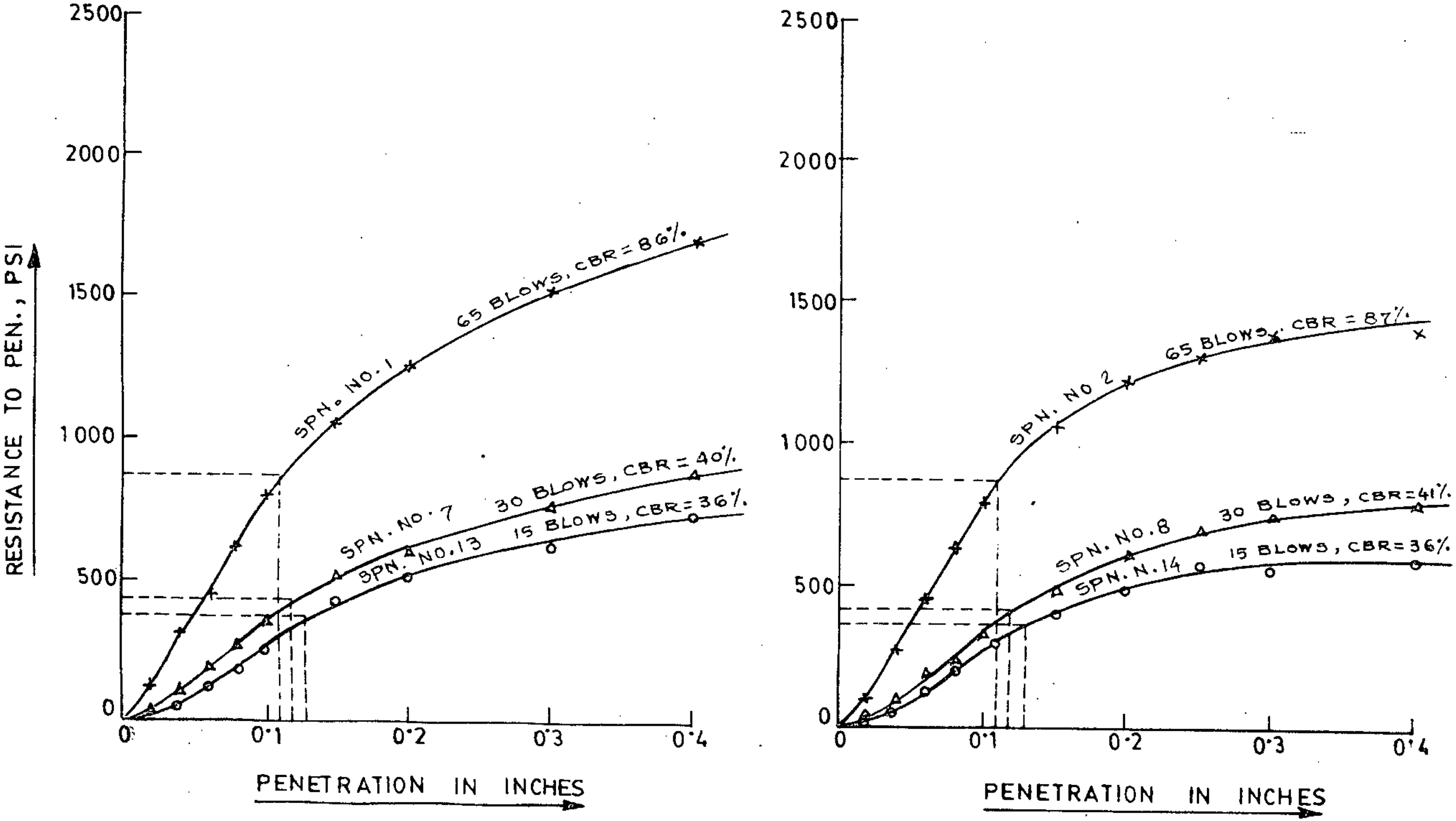
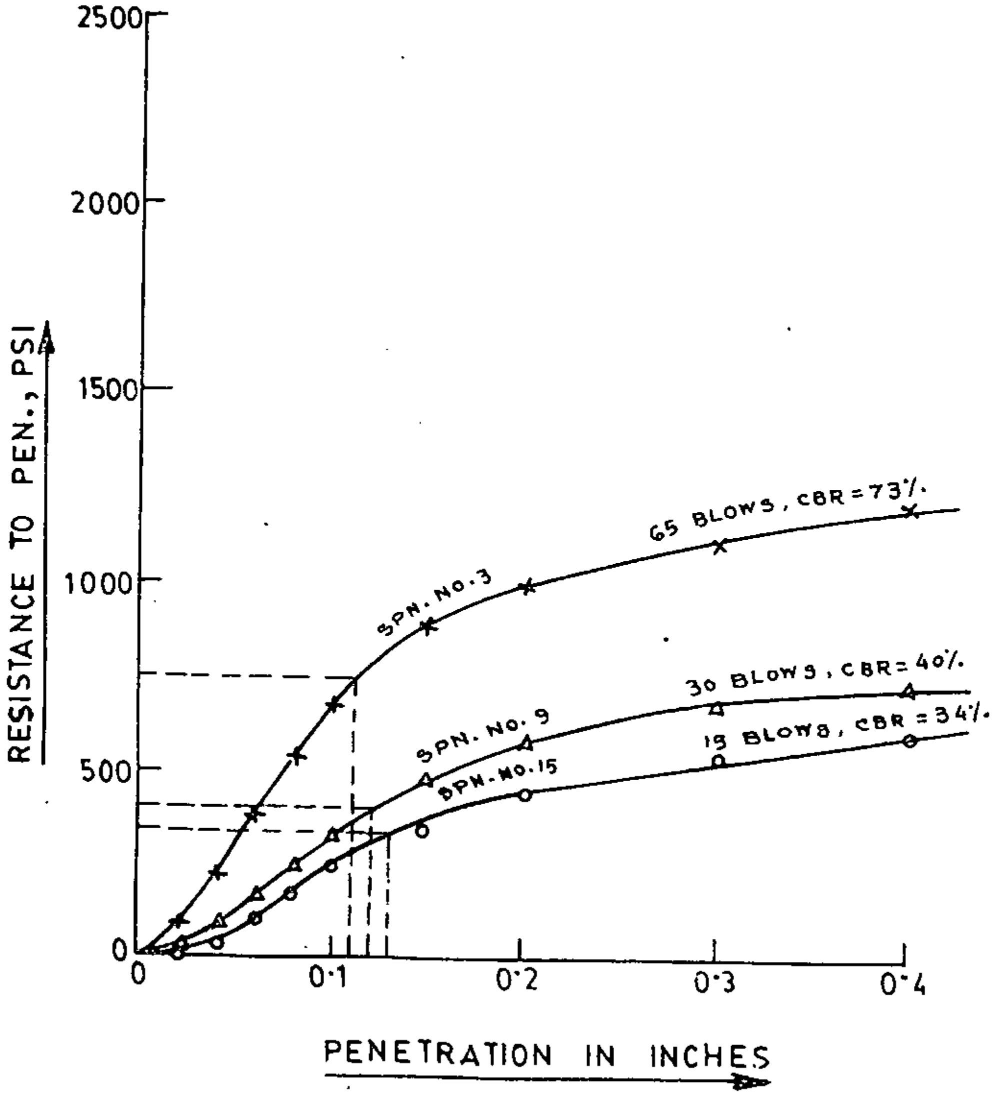


FIG. 4.15a CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION X_5)



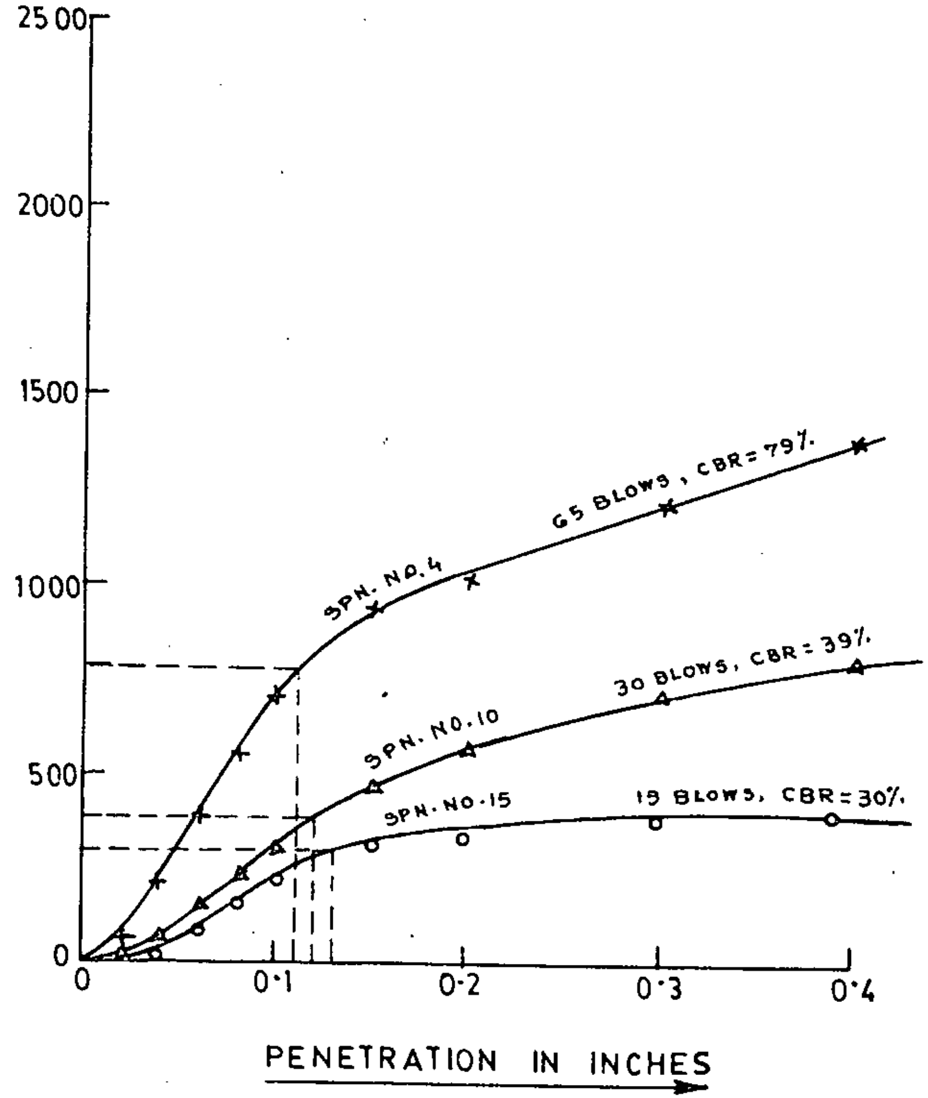


FIG. 4.15b CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION Xs)

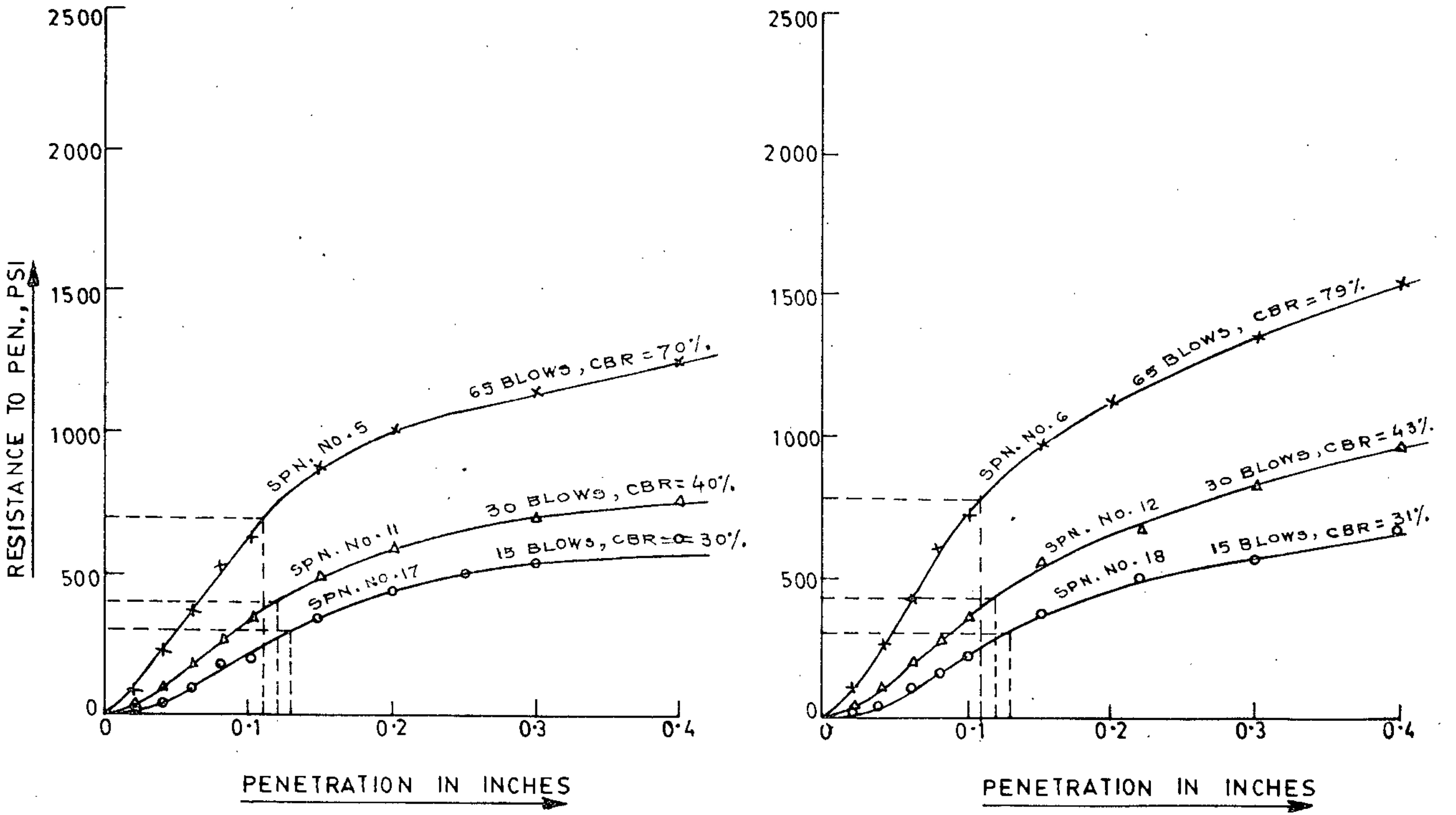


FIG.4.15c CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION X_3)

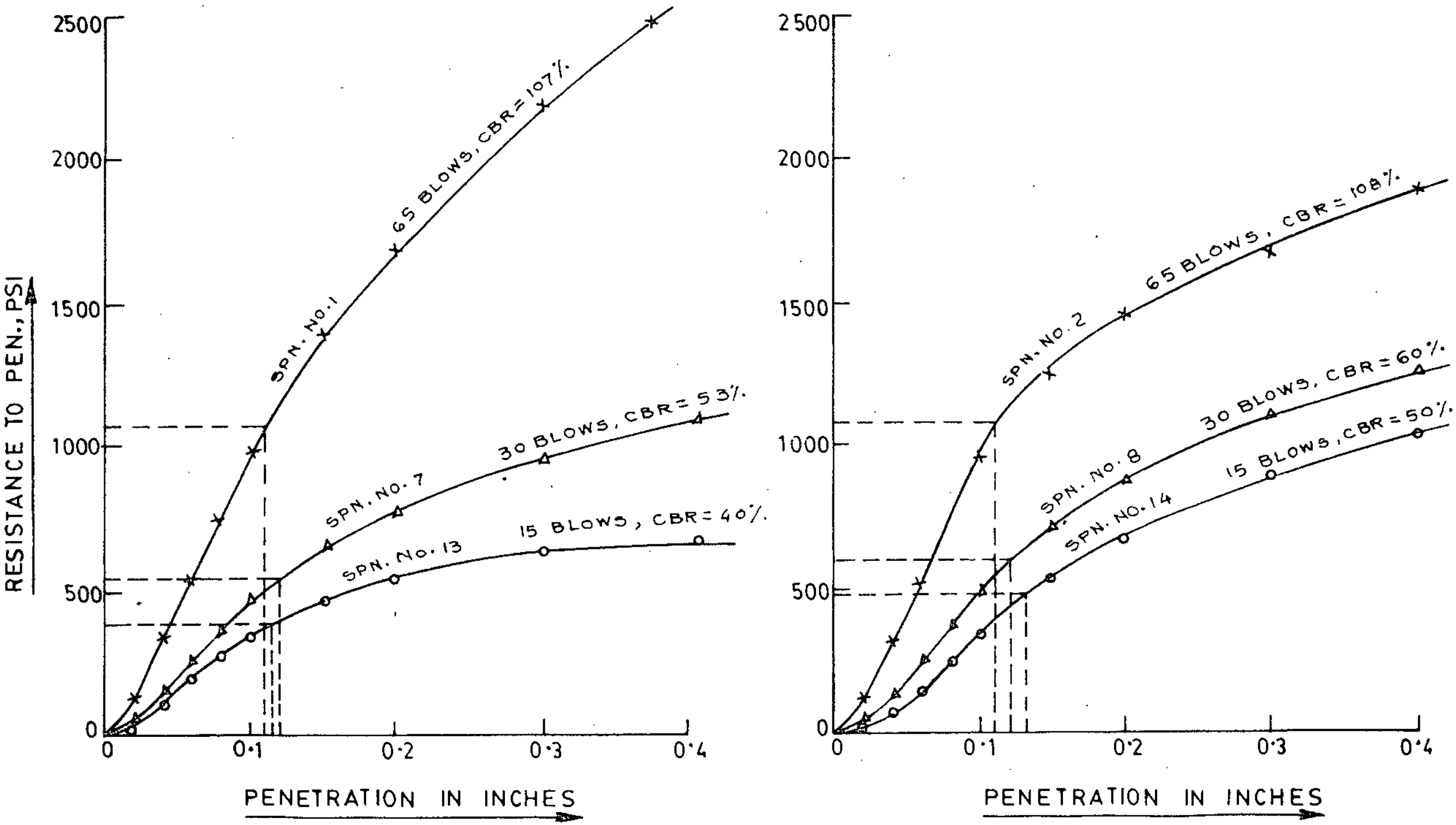


FIG. 4.16a CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION Z)

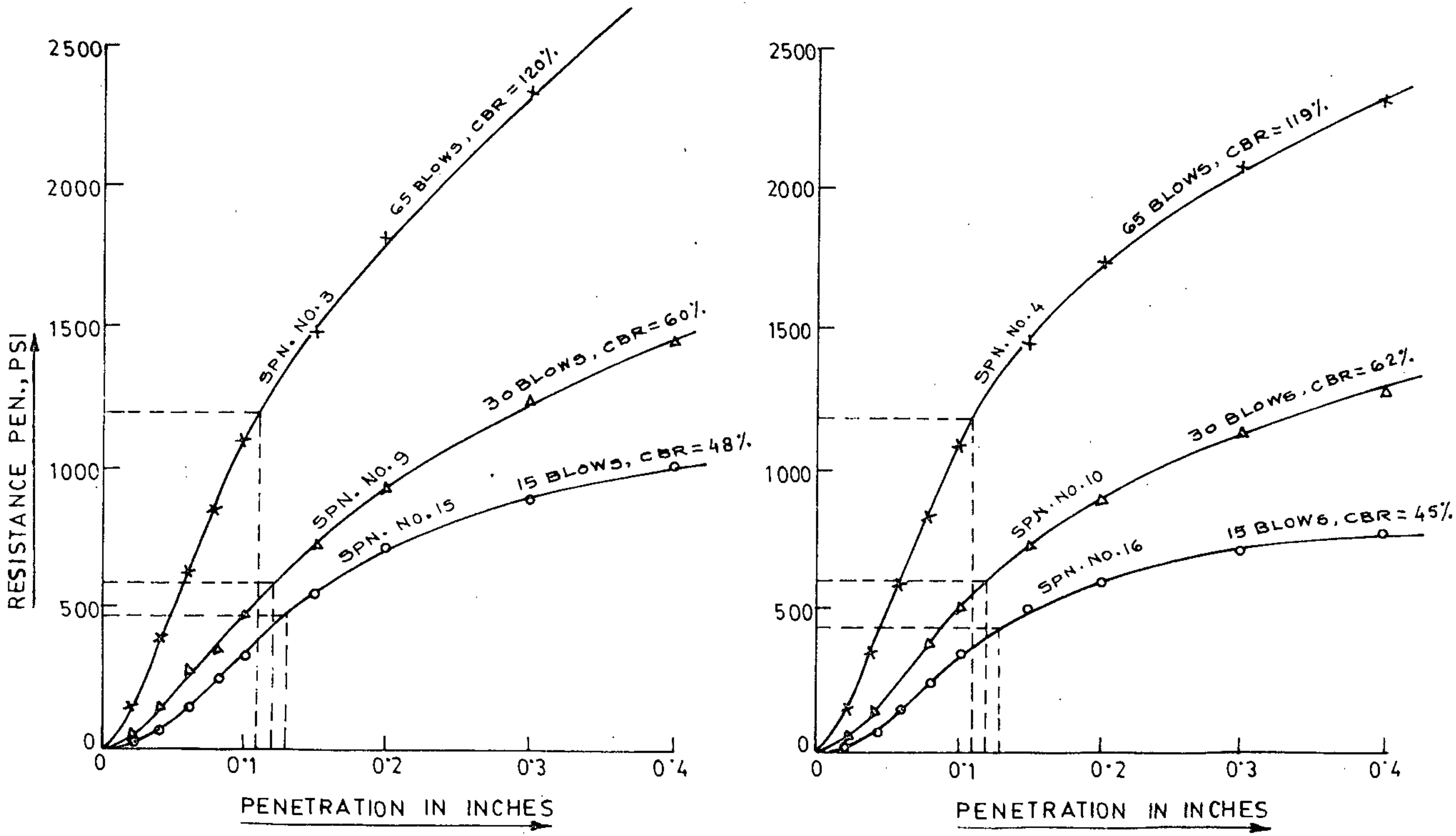


FIG. 4.16 b CBR FOR DIFFERENT SPECIMENS OF GAS BURNT PICKED JHAMA BRICK (GRADATION Z)

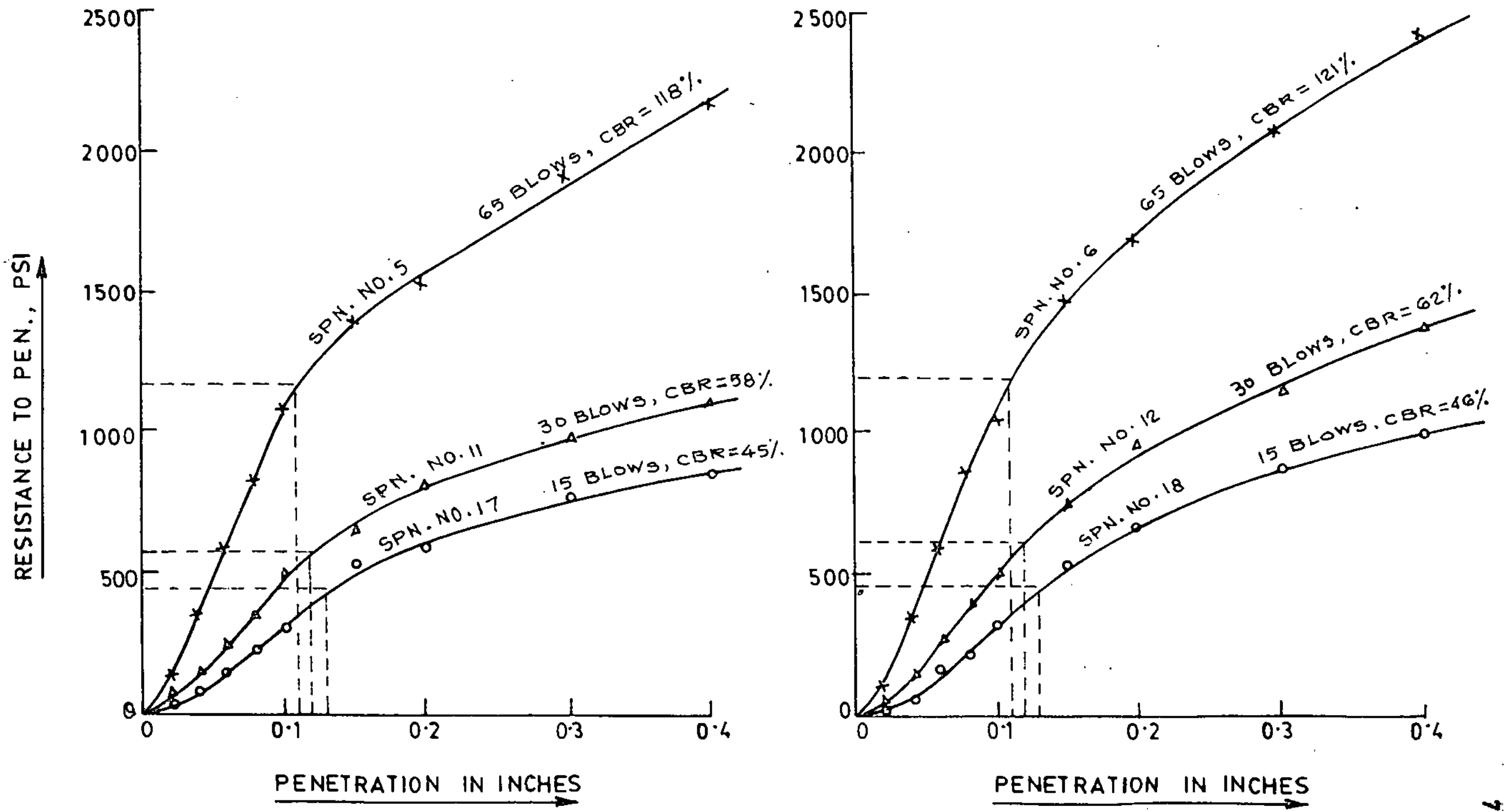


FIG. 4.16c CBR FOR DIFFERENT SPECIMEN OF GAS BURNT PICKED JHAMA BRICK (GRADATION Z)

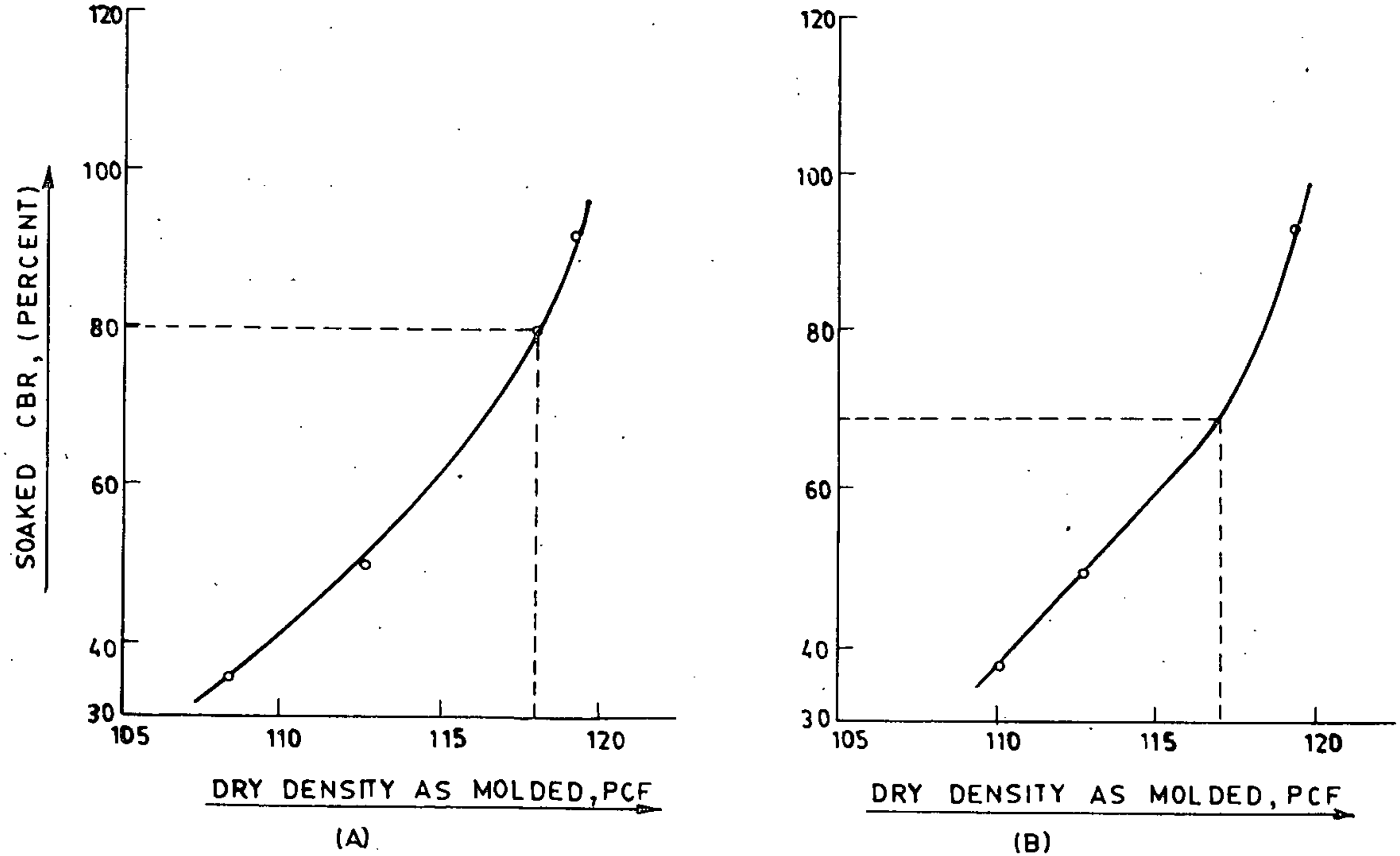


FIG. 4.17 CBR DENSITY RELATION: (A) GRADATION X_1 (B) GRADATION X_2

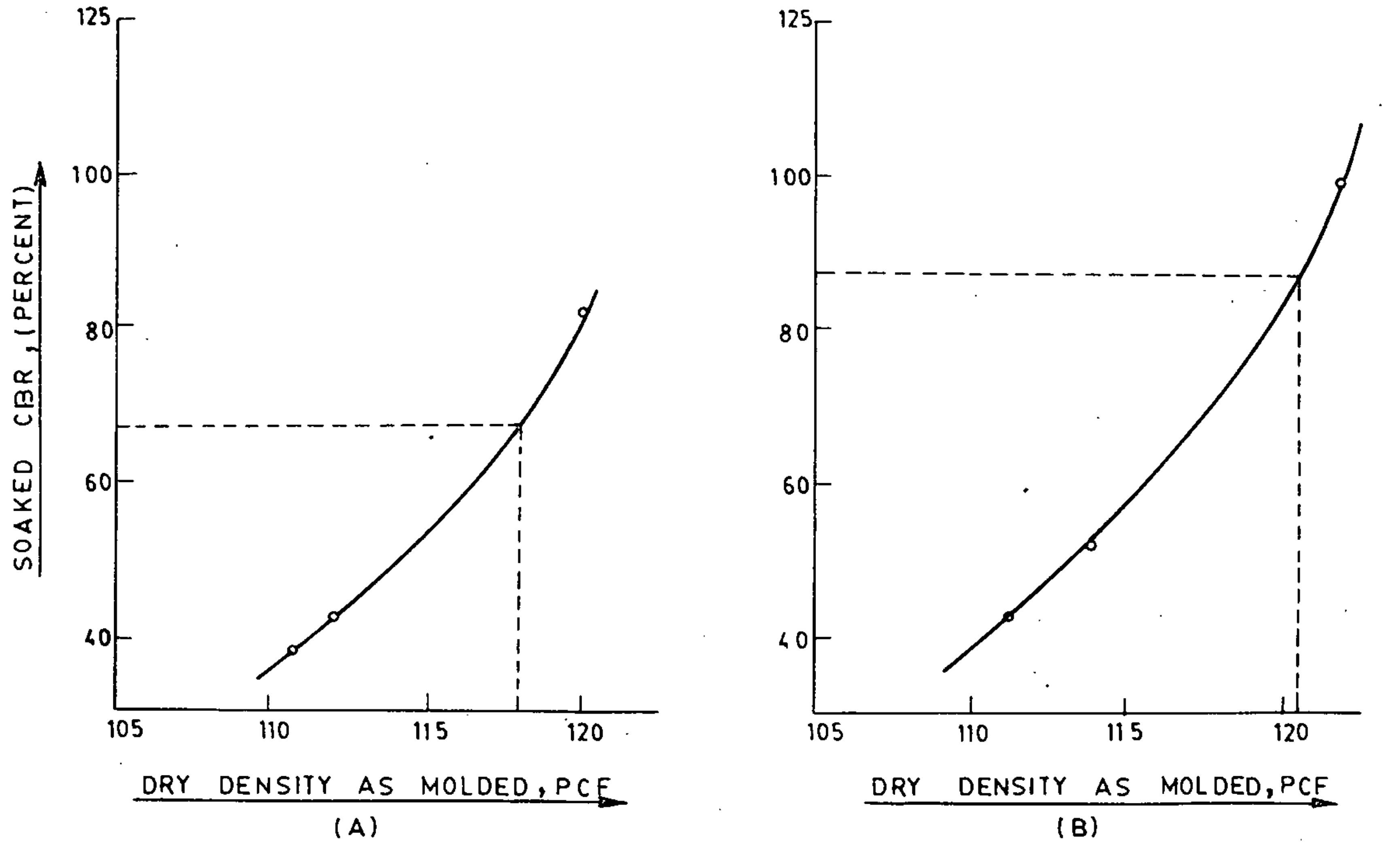


FIG. 4.18 CBR DENSITY RELATION: (A) GRADATION X_3 (B) GRADATION X_4

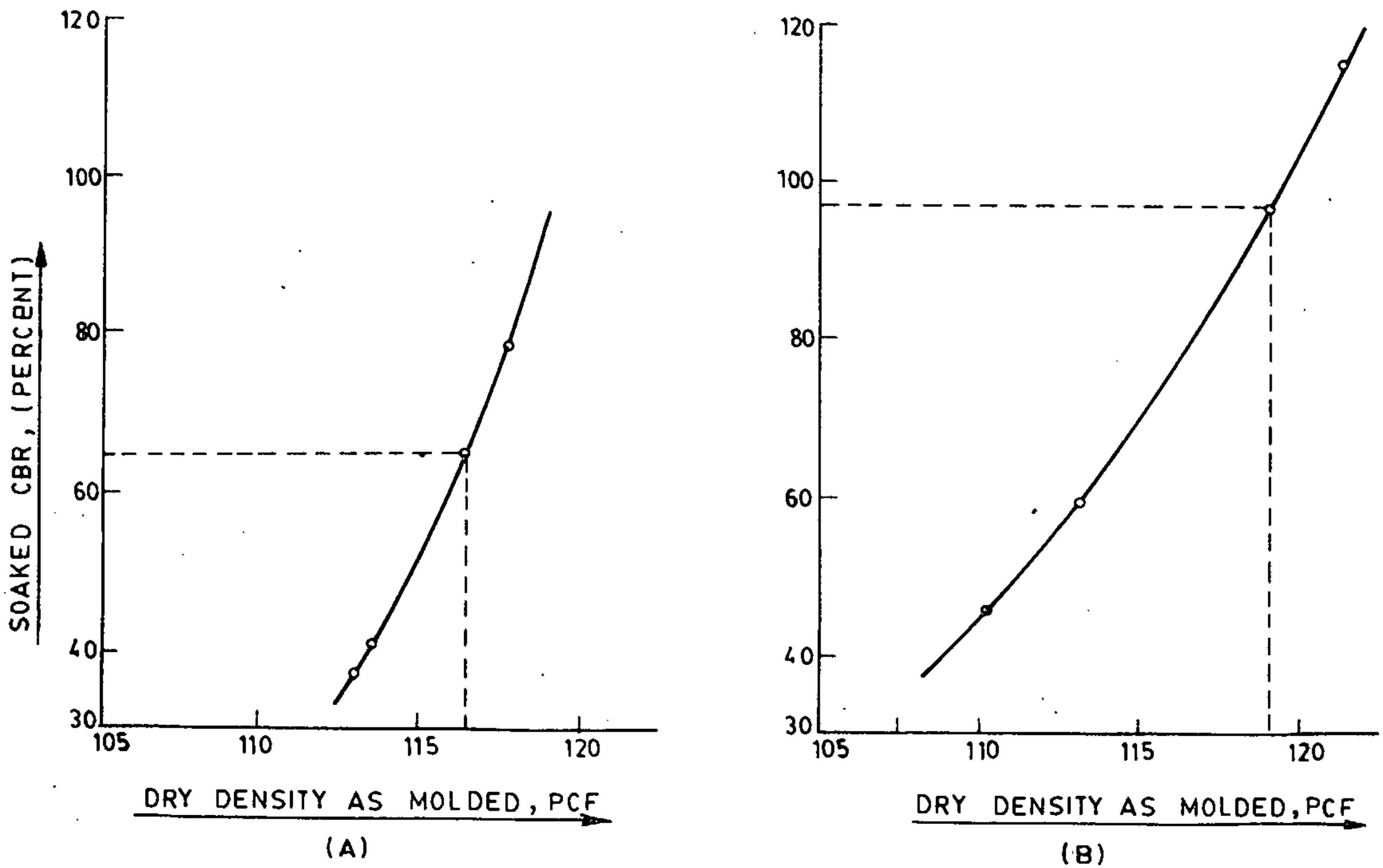


FIG. 4.19 CBR DENSITY RELATION: (A) GRADATION X_5 (B) GRADATION Z

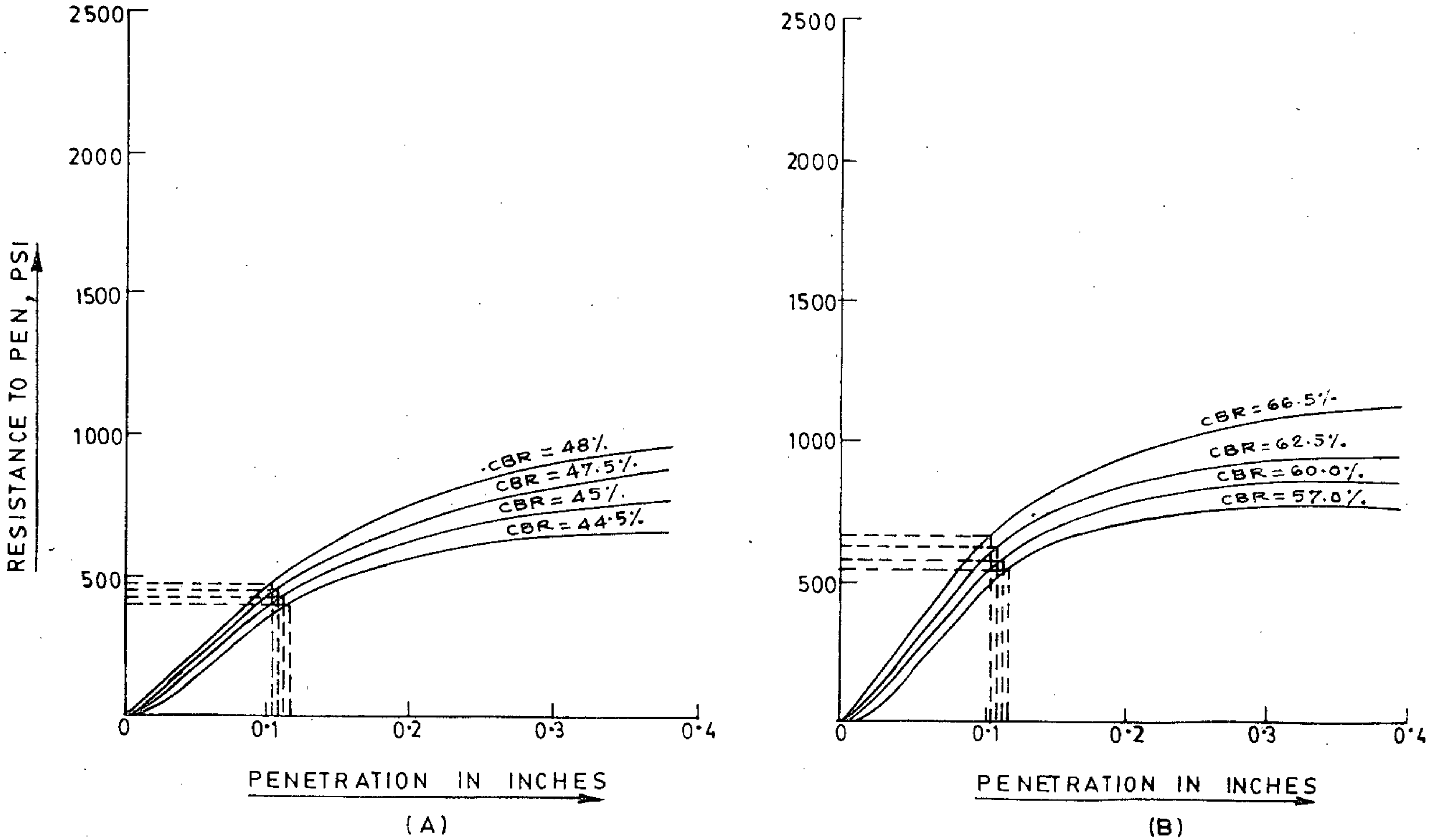


FIG. 4.20a CBR FOR DIFFERENT PERCENT OF FINES : (A) 0% FINES (B) 4% FINES

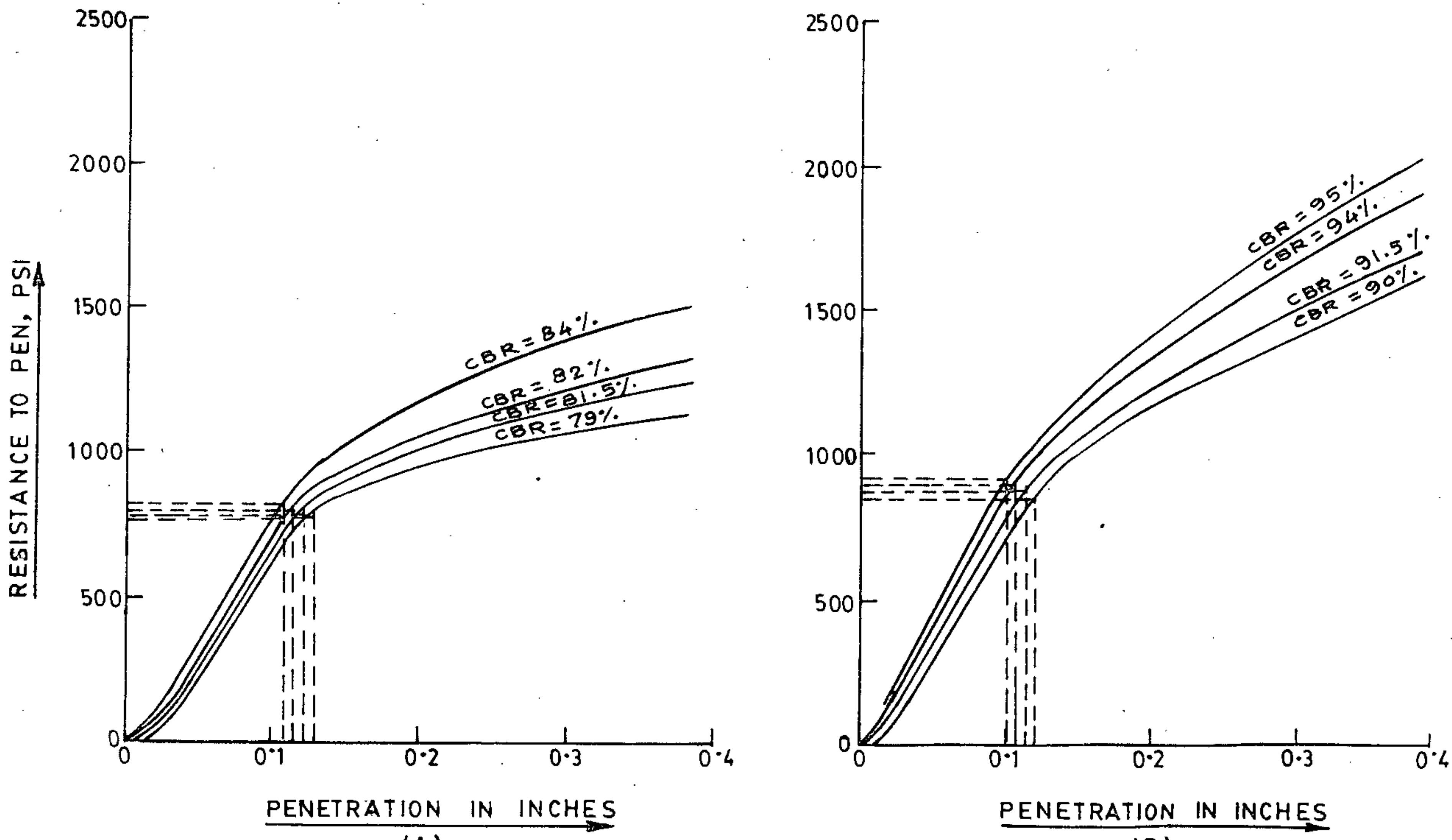


FIG.4·20b CBR FOR DIFFERENT PERCENT OF FINES%(A) 8% FINES (B) 12% FINES

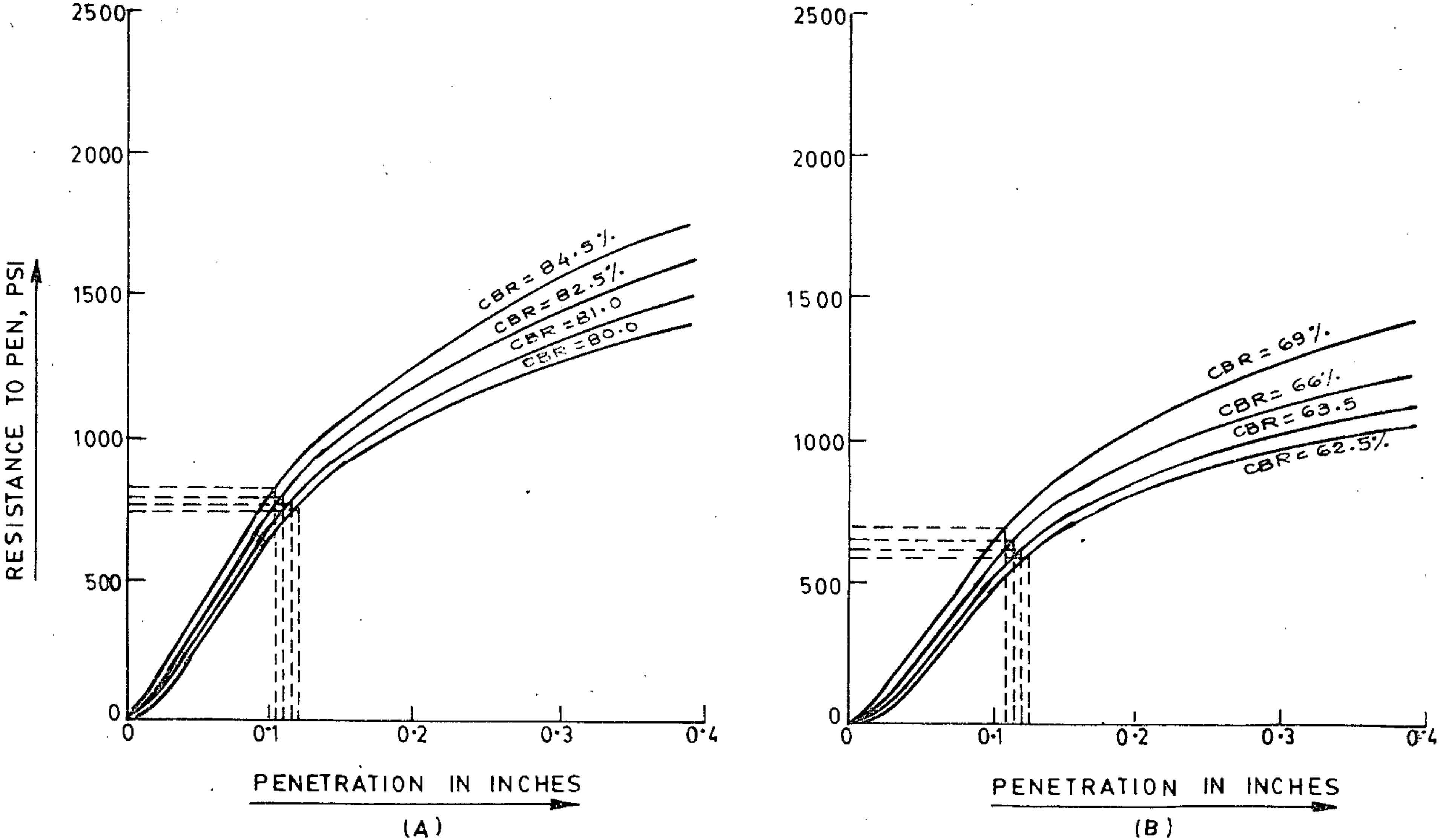


FIG.4.20c CBR FOR DIFFERENT PERCENT OF FINES: (A) 16% FINES (B) 20% FINES

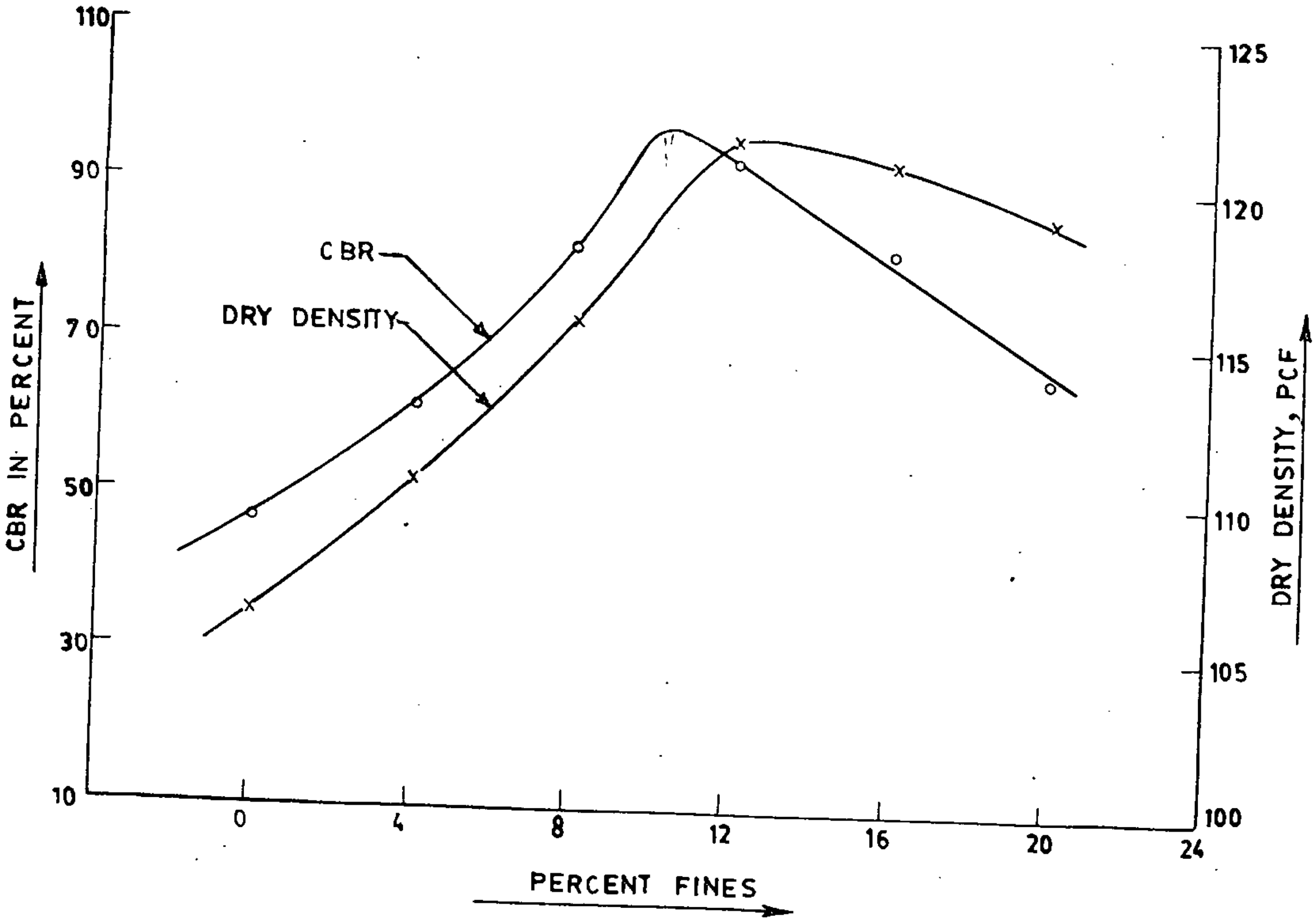


FIG. 4.21 CBR DRY DENSITY PERCENT FINES RELATION

Table 4.3 CBR-Density-Gradation Relationship

Gradation	Optimum moisture content percent	Maximum dry density standard AASHO lb/cft	CBR at 100 percent maximum AASHO density percent
X_1	13.0	117.9	79.5
X_2	12.5	117.0	71.0
X_3	13.5	118.0	77.5
X_4	12.5	120.5	87.0
X_5	13.0	116.5	65.0
Z	13.0	119.0	97.0

Table 4.4 CBR-Density-Percent Fines Relationship

Percent of fines	Maximum density lb/cft	Soaked CBR at 100 percent maximum AASHO density
0	46.1	106.4
4	61.5	110.35
8	81.3	115.55
12	92.5	121.2
16	82.0	120.7
20	65.3	118.9

4.4 CBR for Different Types of Aggregates

Sand and soil were mixed with crushed chips of coal burnt picked jhama brick, first class brick, third class brick and crushed stone in gradation Z for the comparison of their stabilities in terms of CBR values. The molds were compacted in accordance with standard AASHO procedure applying optimum moisture content. The moisture content density relationships of these materials are shown in Fig. 4.22. The CBR graphs of mixtures containing crushed stone, coal burnt picked jhama brick, first class brick, third class brick are shown in Figs. 4.23, 4.24, 4.25, and 4.26 respectively. The CBR density relationships for crushed stone and coal burnt picked jhama brick are shown in Fig. 4.27 and those for first class brick and third class brick are shown in Fig. 4.28. The penetration and resistance to penetration relations are shown in Table A-1 to A-10 in Appendix-A. The stability in terms of CBR value of these materials are compared with that of gas burnt picked jhama brick in Table 4.5.

Table 4.5 CBR for Different Types of Materials

Parameter	Gas burnt picked jhama brick	Coal burnt picked jhama brick	First class brick	Third class brick	Crushed stone
Optimum moisture content in percent	13.0	14.5	15.0	16.5	10.5
Maximum dry-density, lb/cft	119.0	118.74	115.6	113.5	149.0
CBR value in percent	97.0	74.0	62.5	42.0	94.0

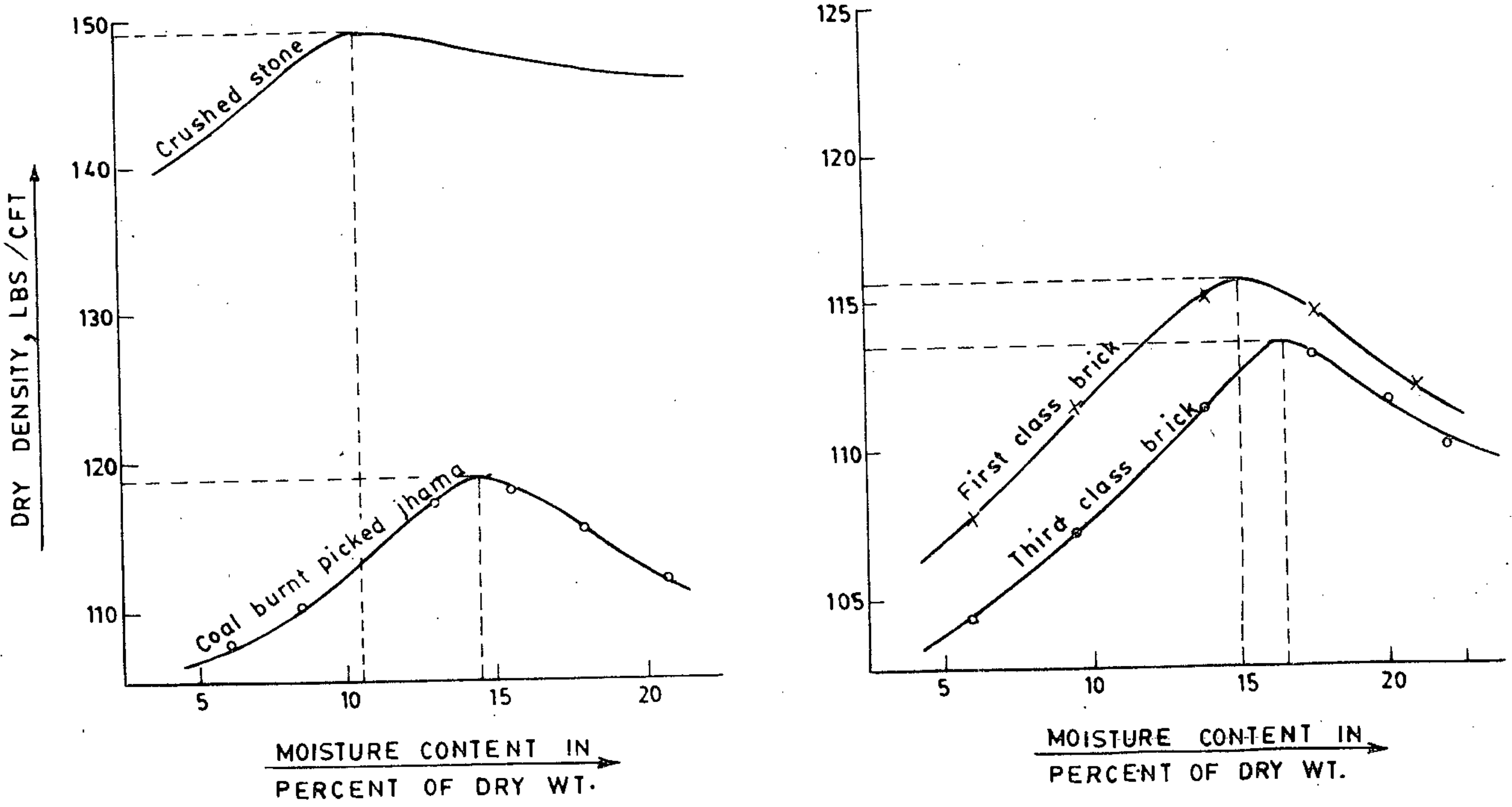


FIG. 4.22 MOISTURE CONTENT – DENSITY RELATIONSHIP (GRADATION – Z)

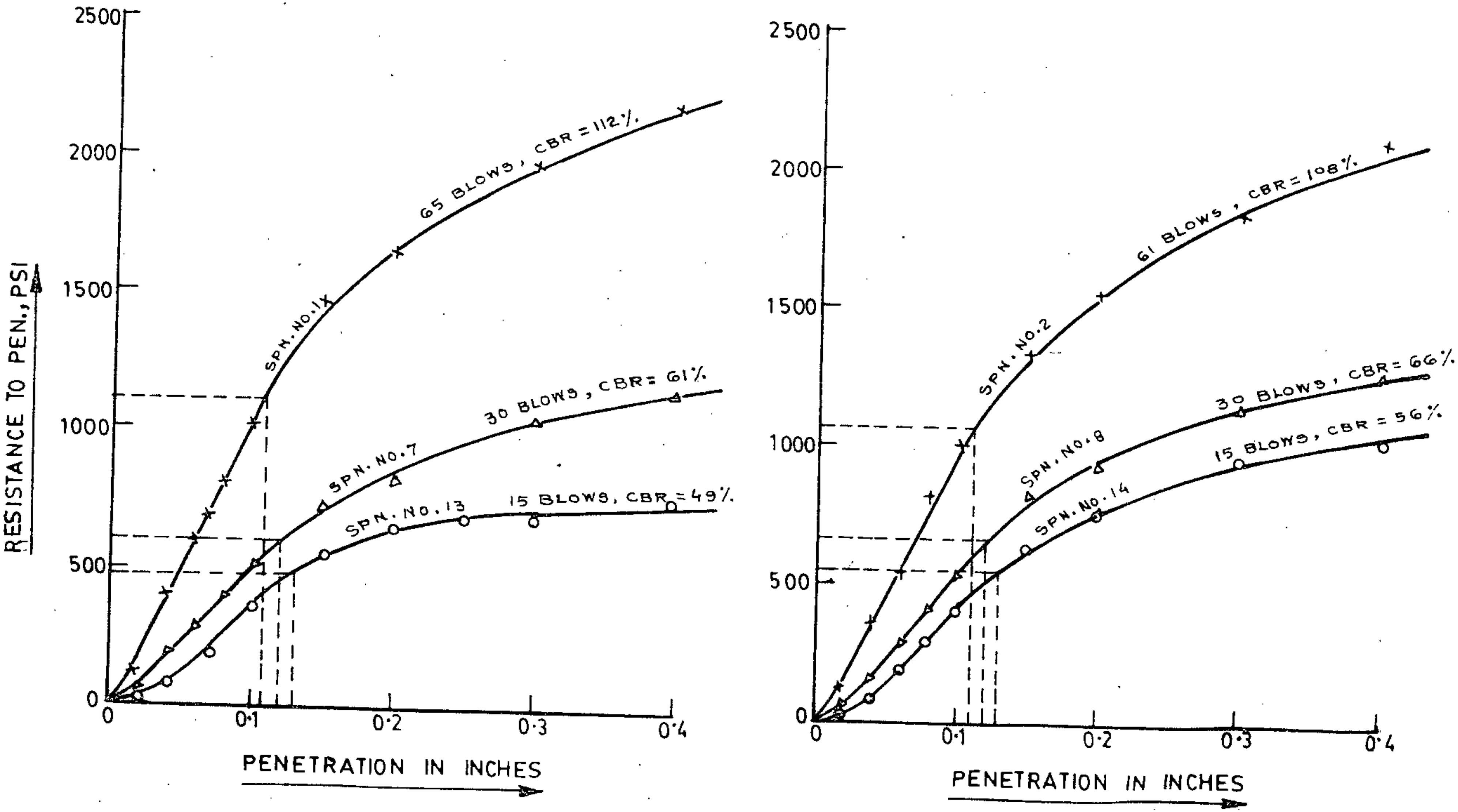


FIG. 4.23a CBR FOR DIFFERENT SPECIMENS OF CRUSHED STONE (GRADATION Z)

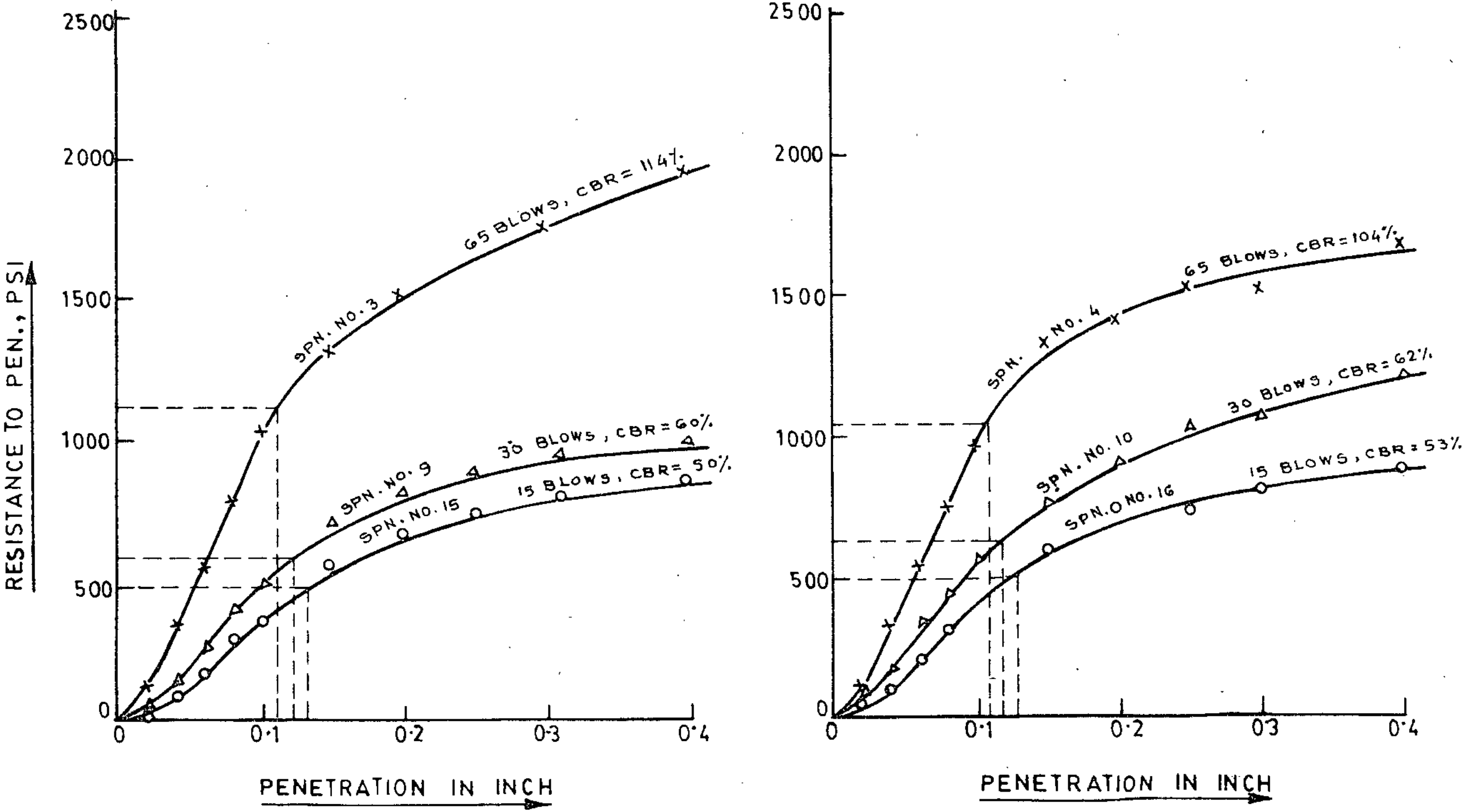


FIG. 4.23b CBR FOR DIFFERENT SPECIMENS OF CRUSHED STONE (GRADATION Z)

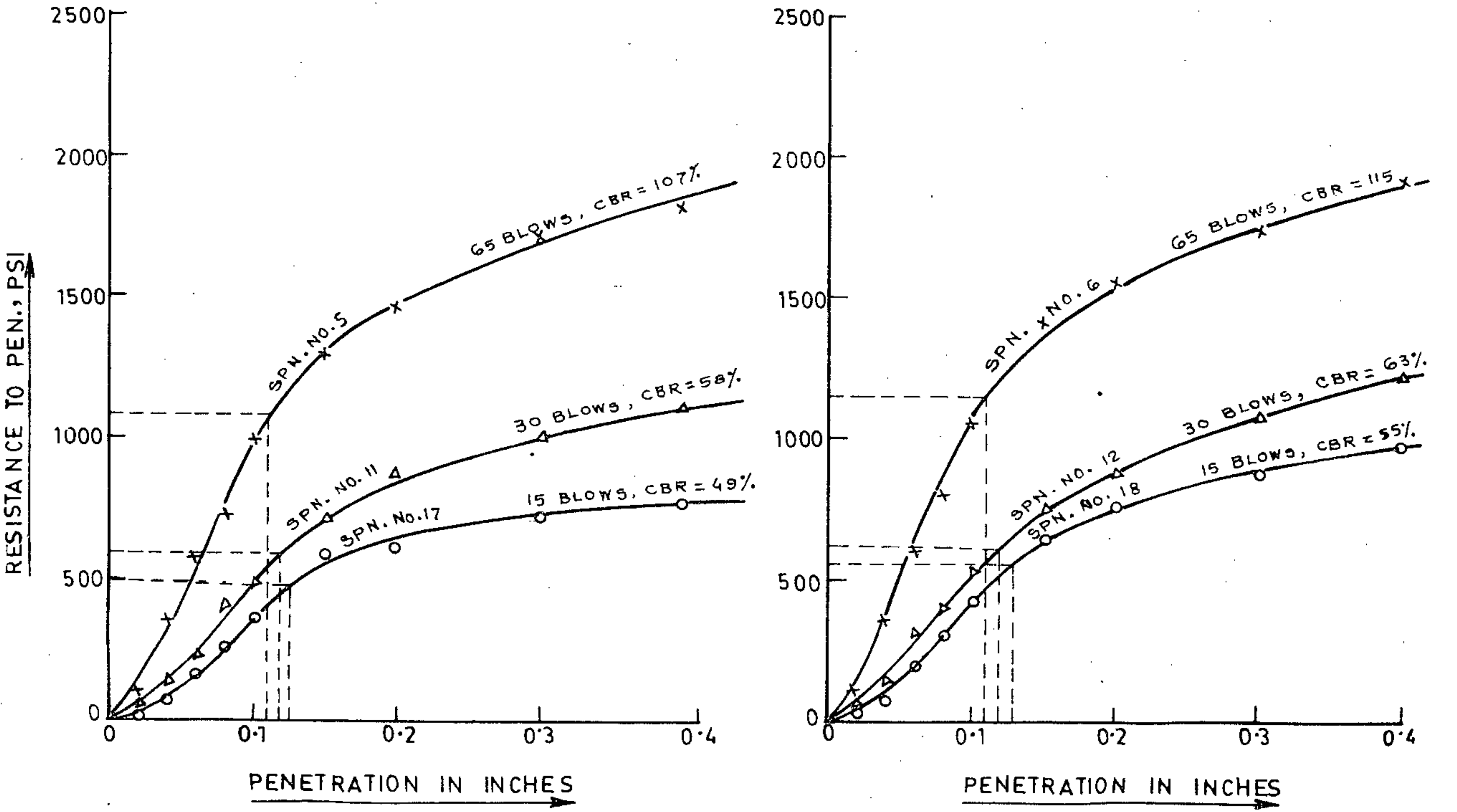


FIG. 4.23c CBR FOR DIFFERENT SPECIMENS OF CRUSHED STONE (GRADATION Z)

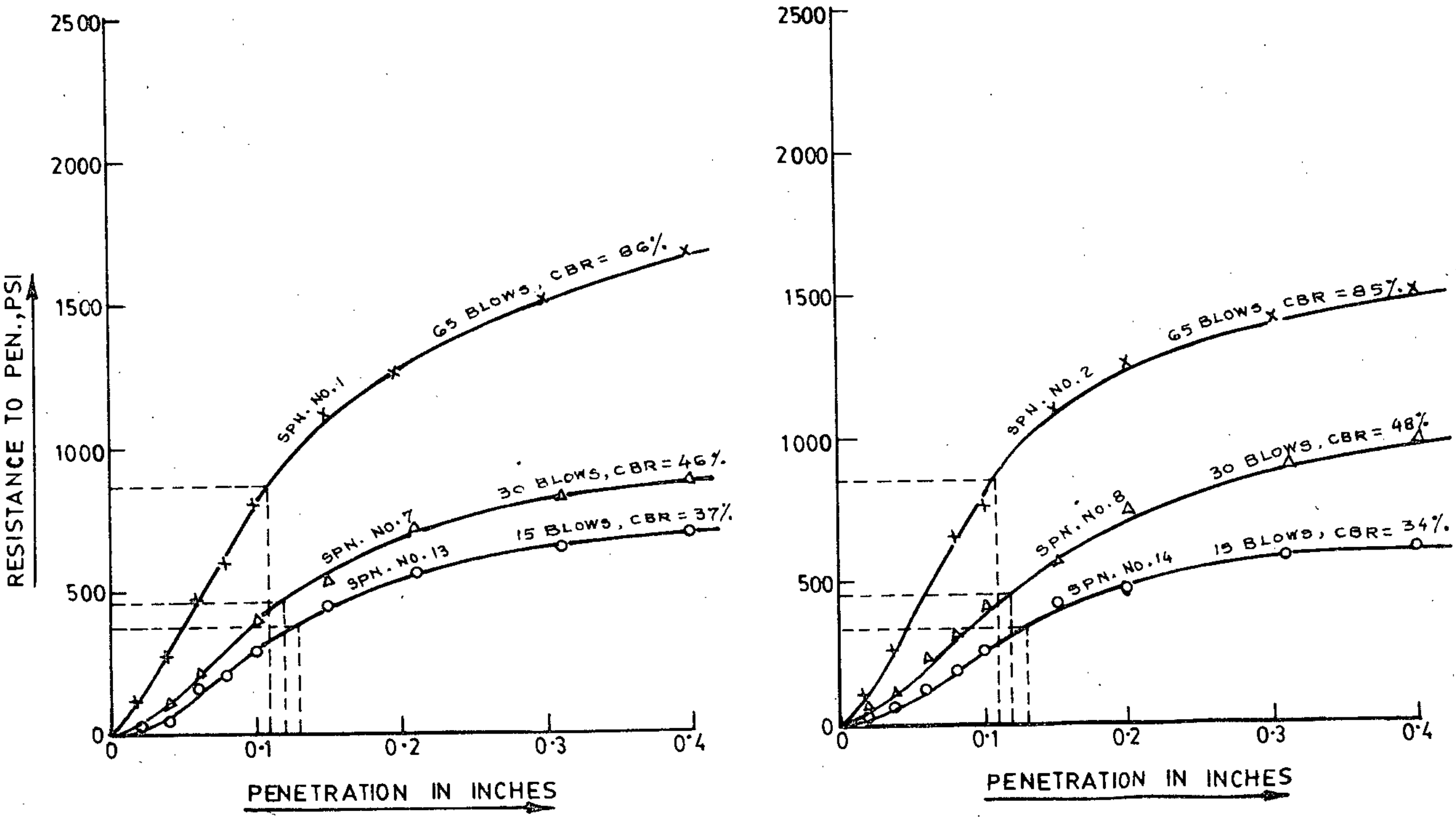


FIG. 4.24a CBR FOR DIFFERENT SPECIMENS OF COAL BURNT PICKED JHAMA BRICK (GRADATION Z)

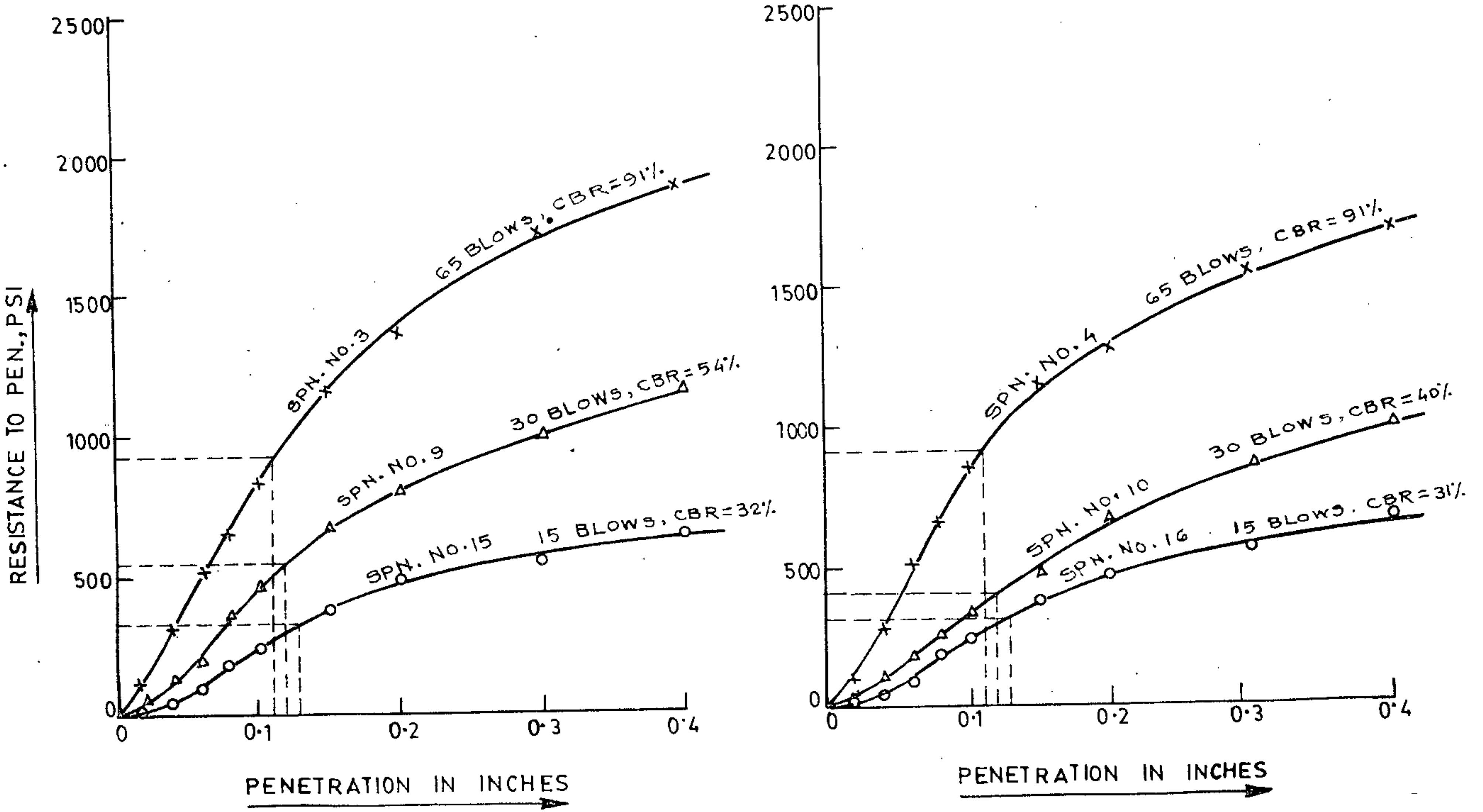


FIG. 4.24 b CBR FOR DIFFERENT SPECIMENS OF COAL BURNT PICKED JHAMA BRICK (GRADATION Z)

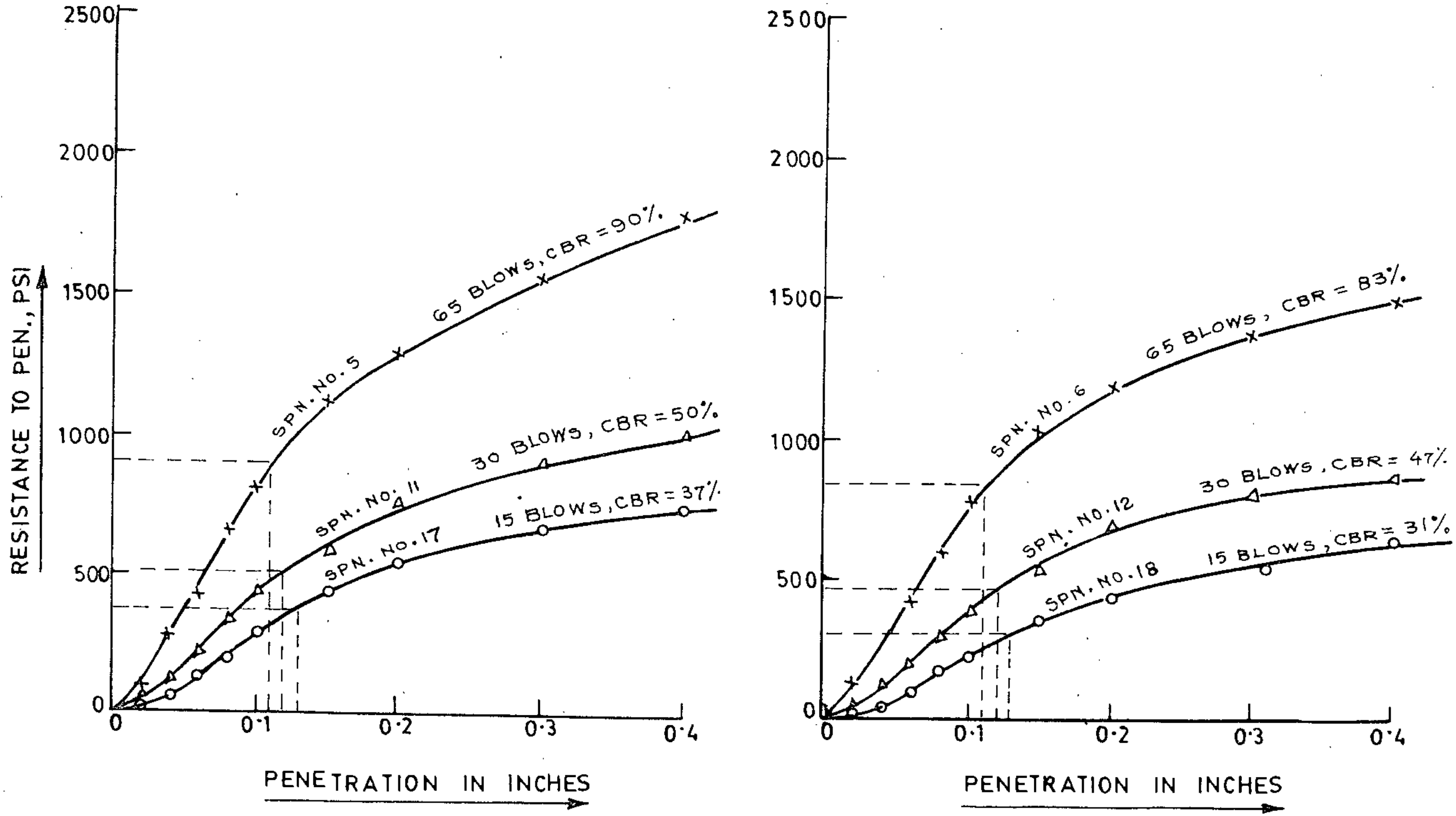


FIG.4.24c CBR FOR DIFFERENT SPECIMENS OF COAL BURNT PICKED JHAMA BRICK (GRADATION Z)

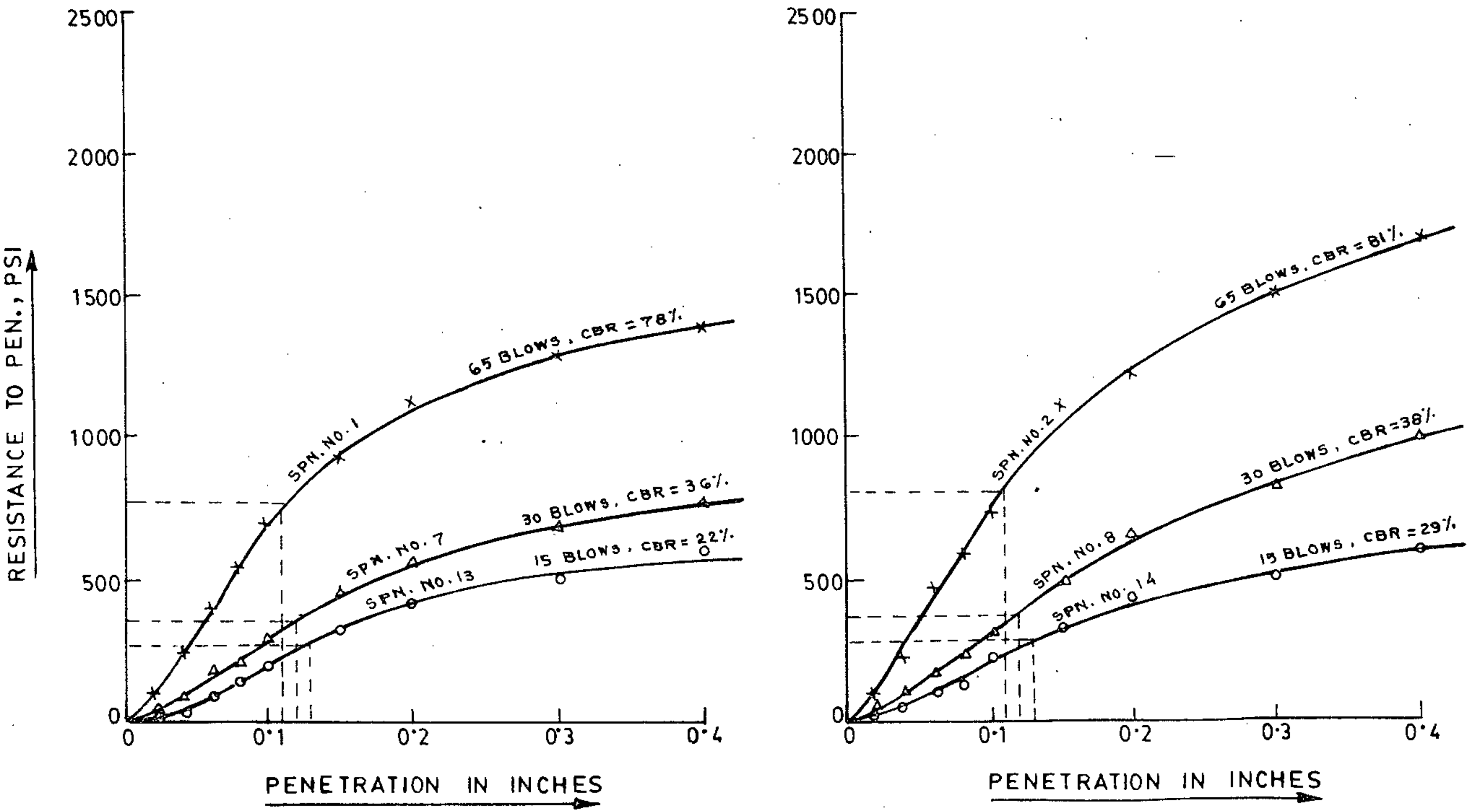


FIG. 4.25a CBR FOR DIFFERENT SPECIMENS OF FIRST CLASS BRICK (GRADATION Z)

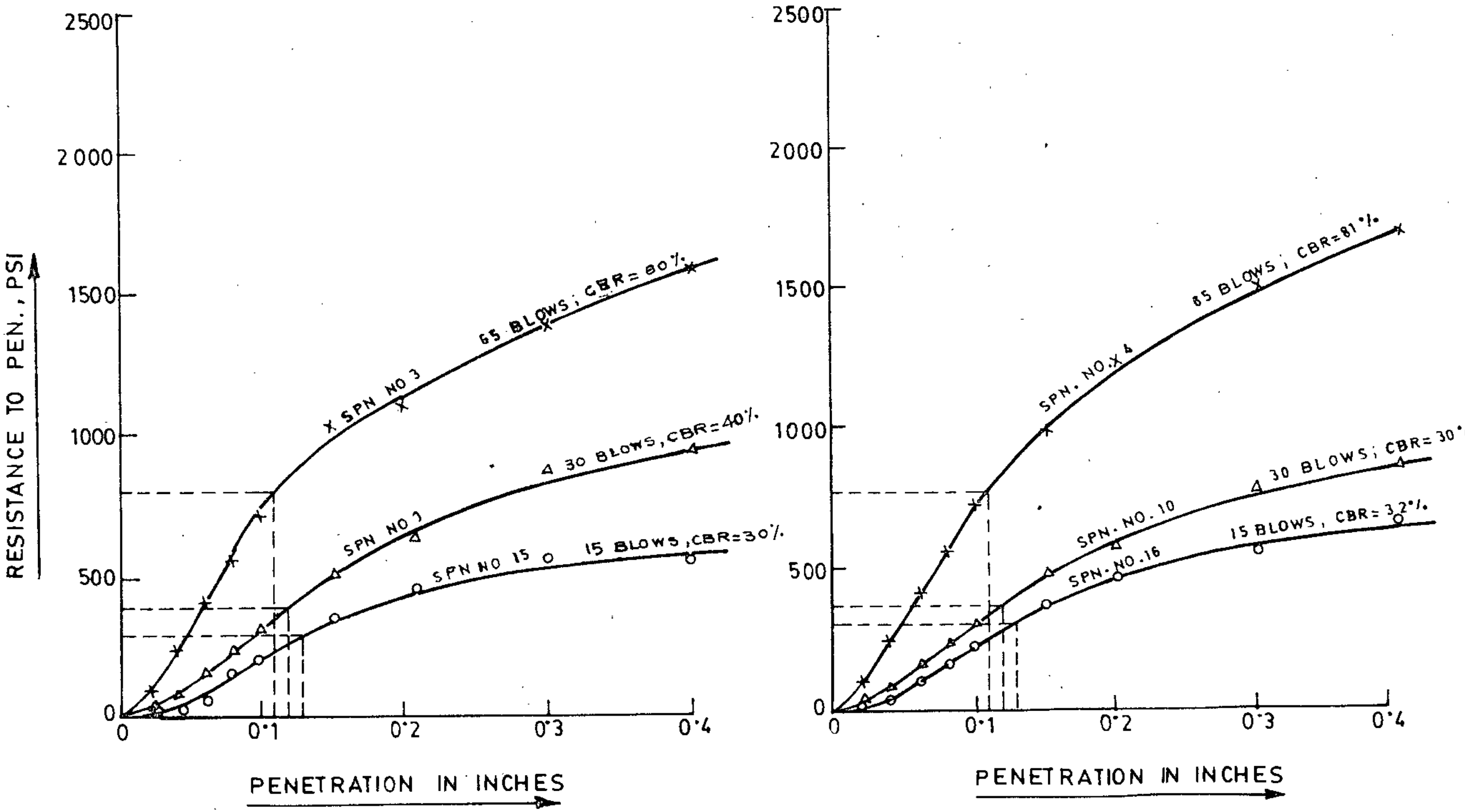


FIG. 4-25b CBR FOR DIFFERENT SPECIMENS OF FIRST CLASS BRICK (GRADATION Z)

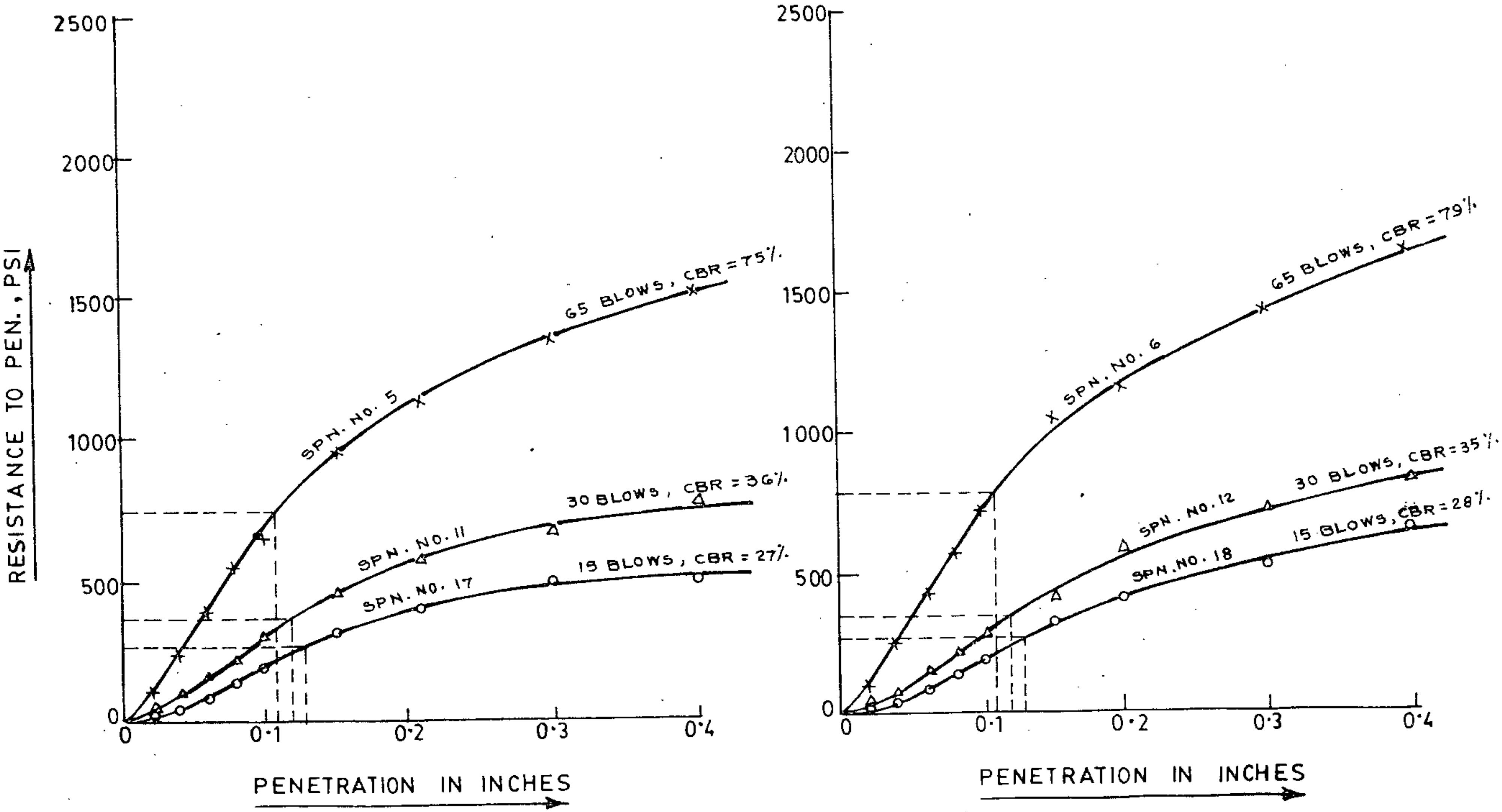


FIG. 4.25c CBR FOR DIFFERENT SPECIMENS OF FIRST CLASS BRICK (GRADATION Z)

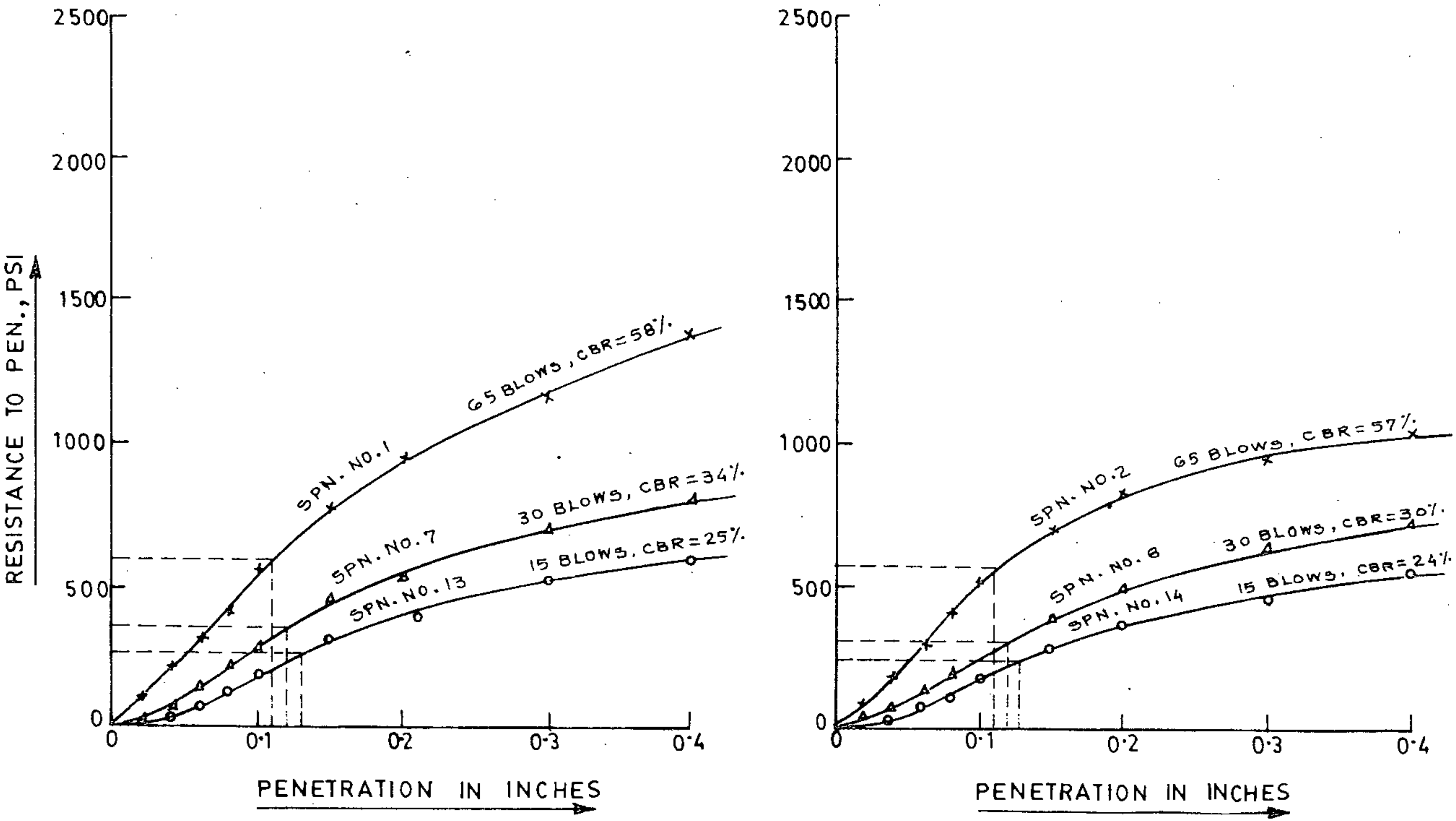


FIG.4.26a CBR FOR DIFFERENT SPECIMENS OF THIRD CLASS BRICK (GRADATION Z)

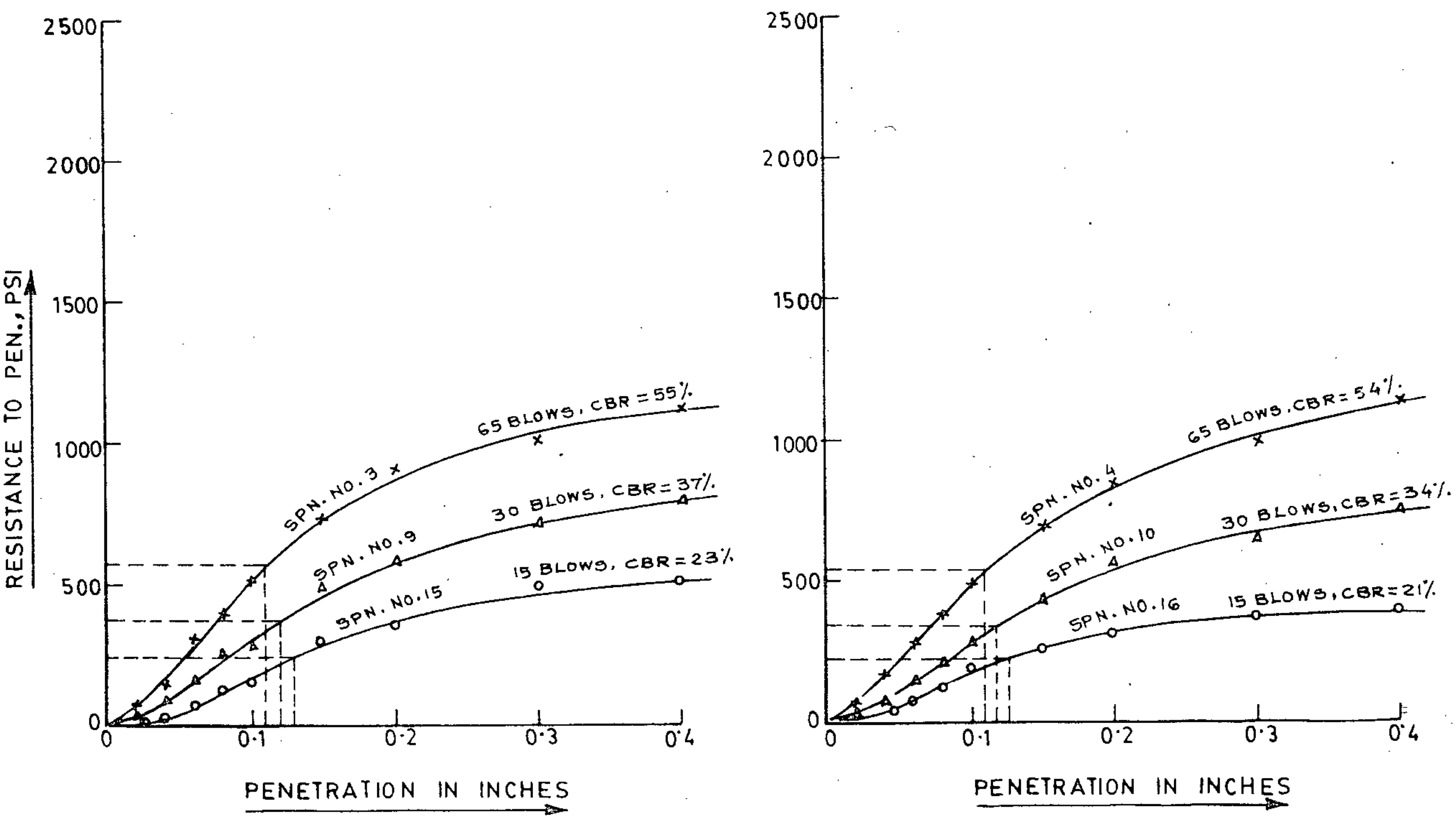


FIG. 4.26b CBR FOR DIFFERENT SPECIMENS OF THIRD CLASS BRICK (GRADATION Z)

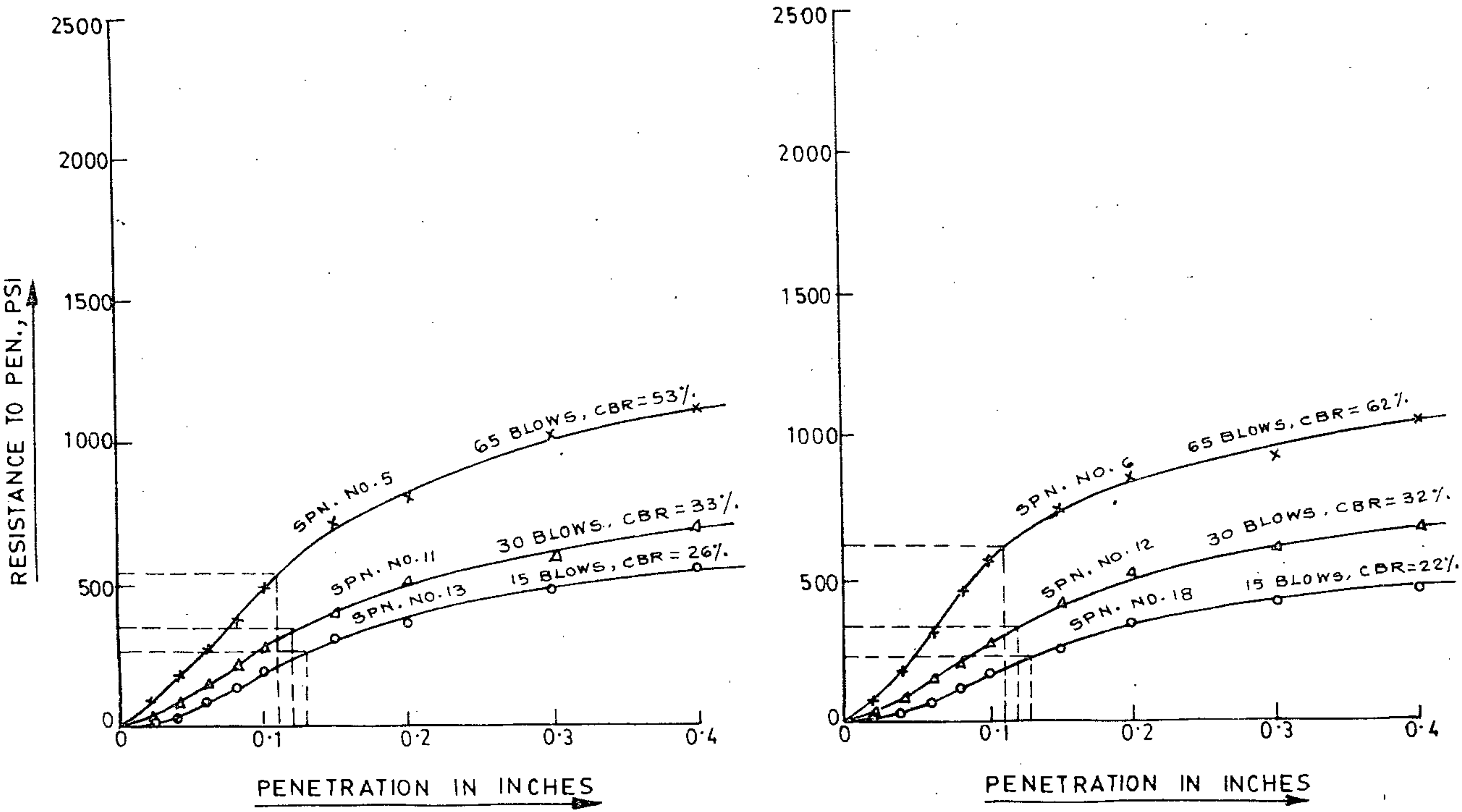


FIG.4.26c CBR FOR DIFFERENT SPECIMENS OF THIRD CLASS BRICK (GRADATION Z)

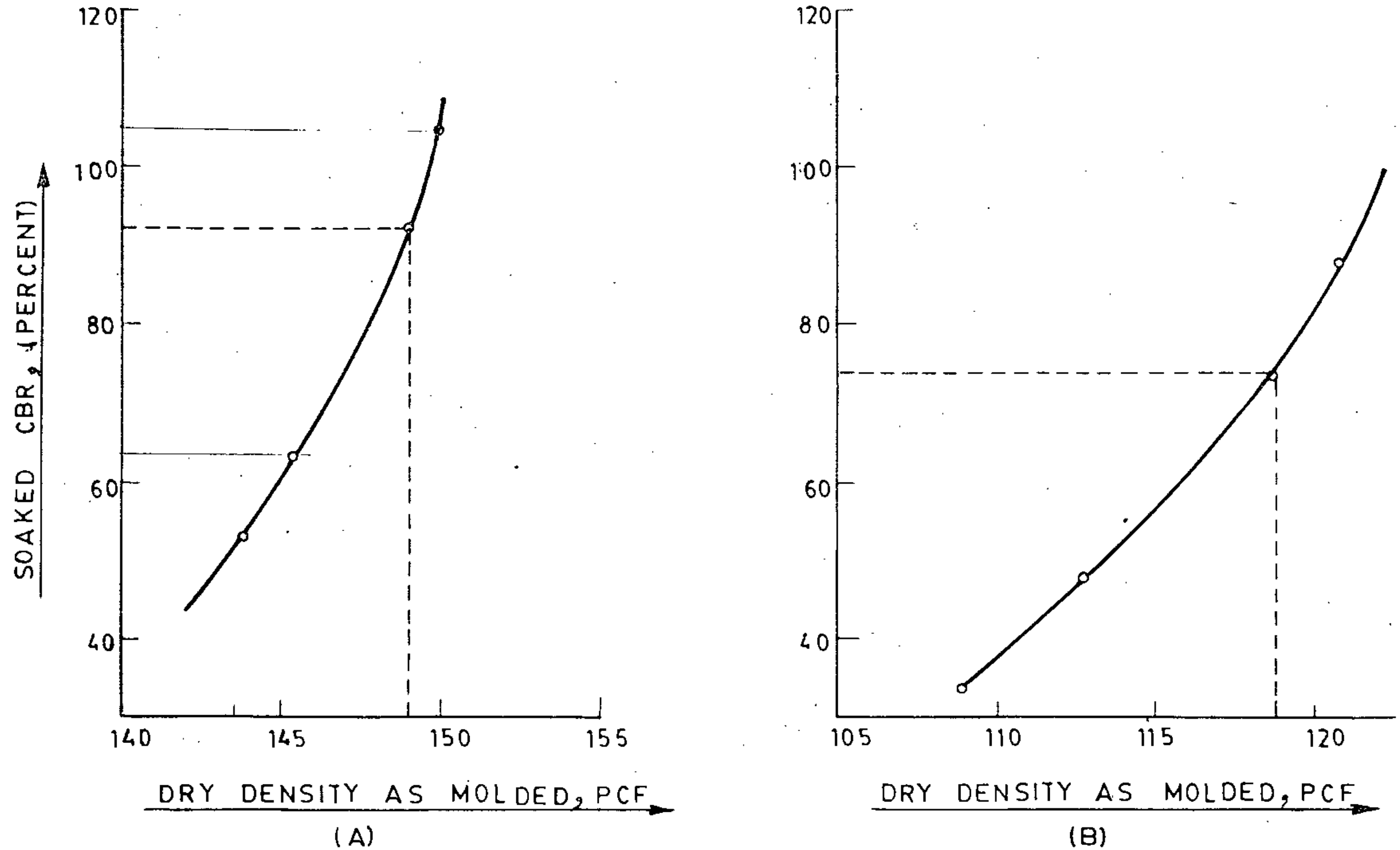


FIG. 4.27 CBR DENSITY RELATION: (A) CRUSHED STONE (B) COAL BURNT PICKED JHAMA

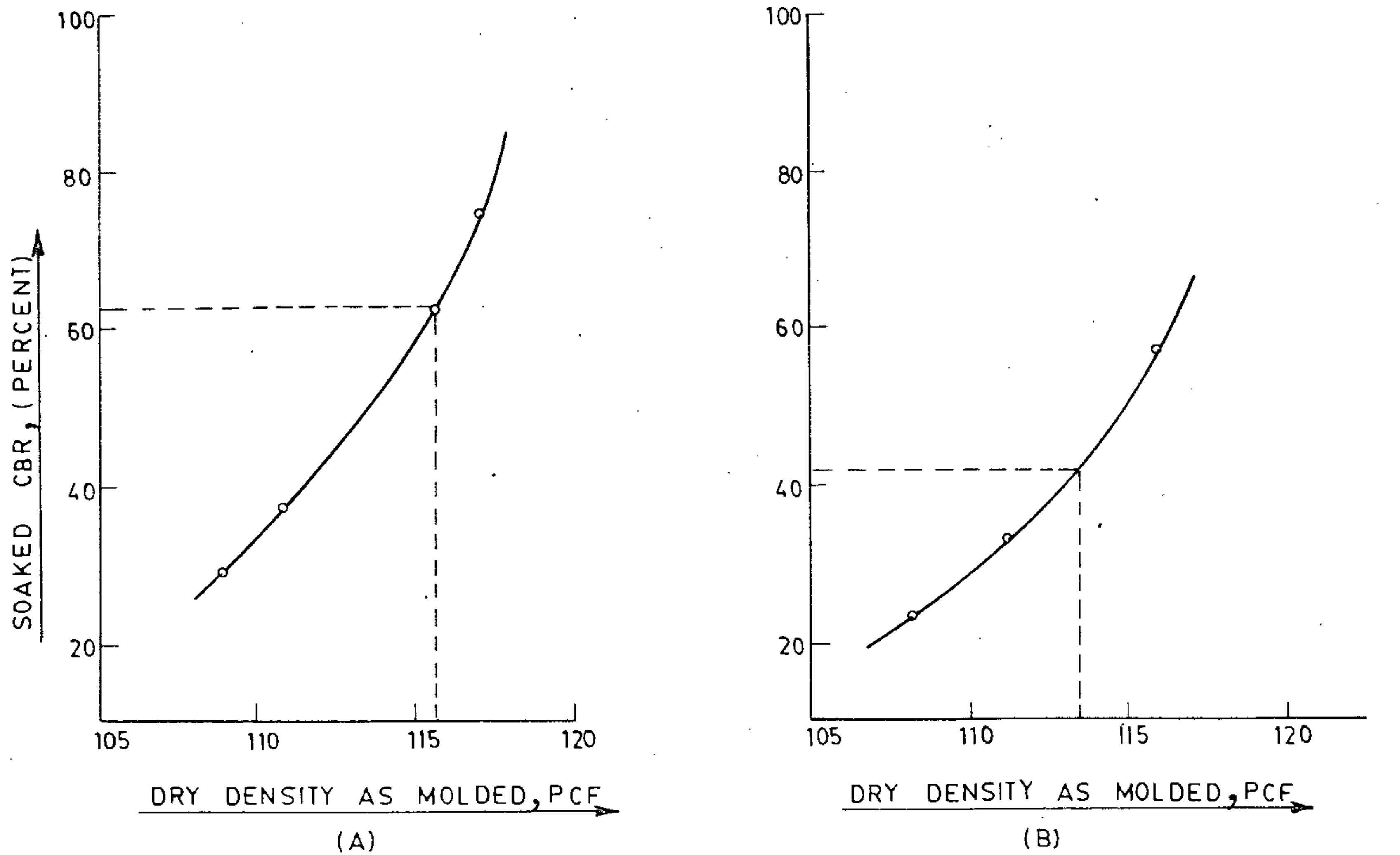


FIG. 4.28 CBR DENSITY RELATIONSHIP: (A) FIRST CLASS BRICK (B) THIRD CLASS BRICK

4.5 CBR at Different Compactive Efforts

CBR molds were compacted at different compactive efforts and soaked CBR values were determined. The mixtures were taken in gradation Z for gas burnt picked jhama brick aggregates and crushed stone. The values obtained are compared in Table 4.6 and graphs of the average CBR values are shown in Fig. 4.29.

Table 4.6 CBR-Compactive Effort Relation

Compactive effort applied in ft-lb/cft	CBR-value in percent	
	Gas burnt picked jhama	Crushed stone
56,000 (Modified AASHO)	156.0	169.0
12,320 (Standard AASHO)	97.0	94.0
14,300	115.5	110.0
6,600	59.5	61.5
3,300	45.6	52.8

4.6 Decrease in Volume After Compaction

For the mixture in gradation Z the volume of loose mixture and the volume after compaction was measured for different specimens. The average decrease in volume after compaction was 20 to 22 percent.

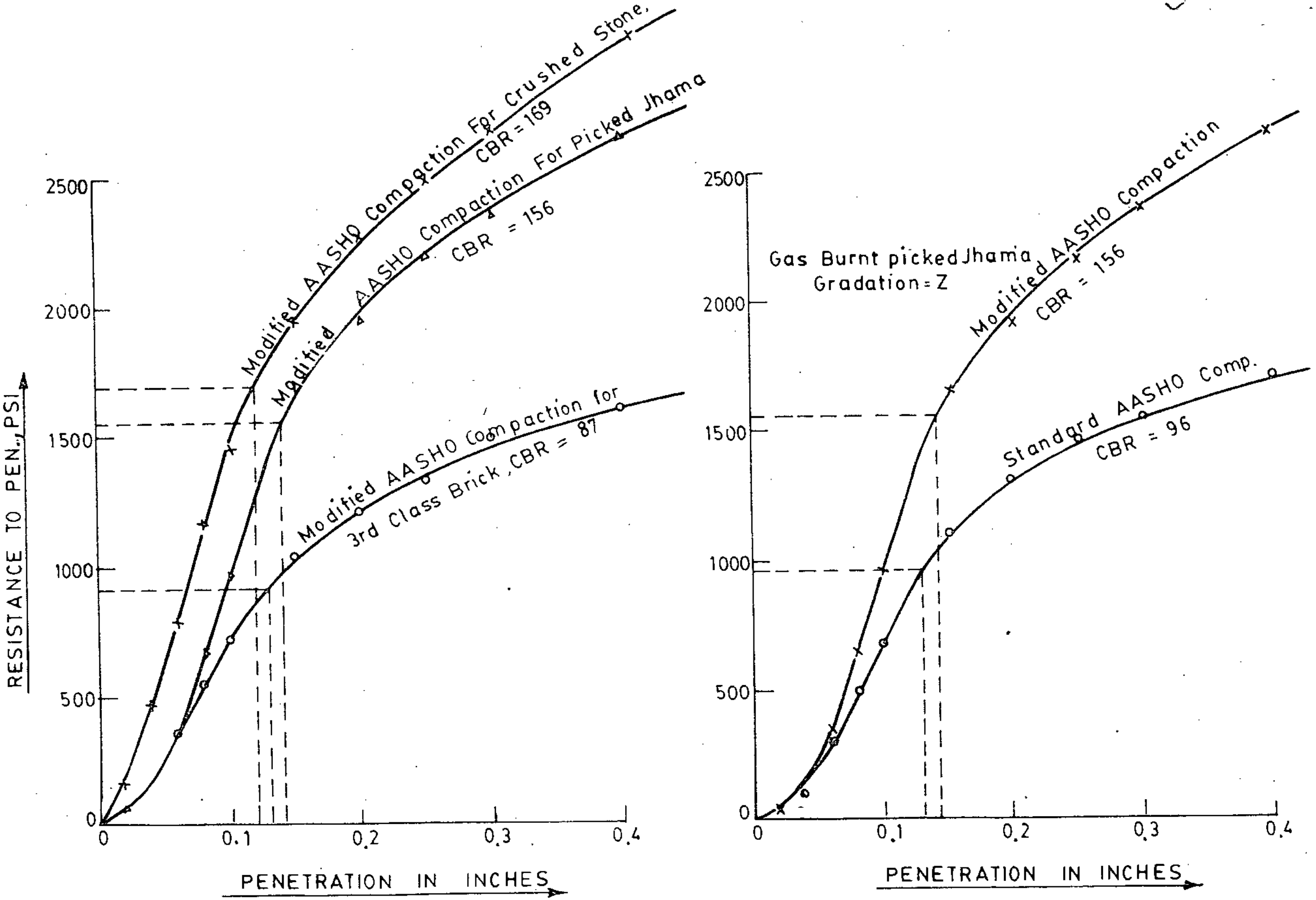


FIG. 4 29 CBR AT DIFFERENT COMPACTIVE EFFORTS

4.6 Plasticity Characteristics

Plasticity characteristics of the soil binder in the mixture was determined. The liquid limit and plastic limit tests were performed in accordance with ASTM/ANSI D423-66 (Reapproved in 1972) and ASTM/ANSI 424-59 (Reapproved in 1971) respectively. The material passing No. 40 sieve was taken from the mixture for these determinations. Results are shown in Appendix-C (Table C-12).

A hydrometer analysis of the fine portion of the mixture was done according to the procedure described by LAMBE[18]. The results of this analysis is shown in Table 4.7 and in Table C-11 in Appendix-C.

Table 4.7 Results of Hydrometer Analysis of the Fines of the Mixture

D in m.m.	0.0699	0.052	0.037	0.0264	0.019	0.014	0.01	0.00712
Percent finer	33.66	24.0	18.27	11.52	6.72	5.76	4.8	3.24

CHAPTER-5

ANALYSIS AND DISCUSSIONS OF TEST RESULTS

5.1 Appropriate Materials

For a dense mixture, the general requirements for coarse and fine aggregates are that, 'aggregates should be hard, tough, durable and free from excess amount of flat and elongated pieces and vegetable particles or other organic compounds'. From the results of the tests of coarse and fine aggregates summarised in Table 3.2 and 3.3 it can be said that the crushed brick aggregates satisfy the general criteria of the aggregates.

The quality of coarse aggregate is controlled by specifying that the percentage of wear by Los Angeles Abrasion test should not exceed 50 percent (According to AASHO) and 34 percent (according to BRRL) for high type bituminous pavement construction. Table 3.2 reveals that all types of bricks for the study satisfy the requirements of AASHTO but only gas burnt picked jhama bricks satisfy the requirement of BRRL. The percentage of wear for coal burnt bricks slightly exceeds the BRRL limit.

5.2 Gradation

Six gradation X_1, X_2, X_3, X_4, X_5 and Z shown in Table 4.2 were selected with a view to obtaining the densest mixture giving maximum stability. Gas burnt picked jhama aggregates and sand-soil mixtures were used for obtaining these gradations. The maximum dry density and the CBR values for these mixtures are summarized in Table 4.3. The CBR curves for all these gradations are presented in Figs. 4.11 to 4.16. These curves are similar in nature indicating increasing resistances for higher values of penetrations. But the moisture density graphs shown in Figs. 4.8 to 4.10 are not identical in shape and varies according to the finenesses of the mixtures. The finer mixture gives sharper curve and coarser mixture have flater ones. The CBR values at 100 percent maximum AASHO density varies from 65.0 percent for gradation X_5 to 97.0 percent for gradation Z. A close study of these results reveals that the CBR values increase as the densities of the mixture increases and at maximum density there is maximum CBR value. The maximum CBR value is obtained for gradation Z shown in the last column of Table 4.2.

The other requirements for gradation by AASHO and TRRL as discussed in Chapter 2 are that:

i) the fraction passing No. 200 sieve shall not be greater than two thirds of the amount passing No. 40 sieve;

ii) not less than 10 percent should be retained between each pair of successive sieves except for the top two largest sieves.

The gradation 'Z' satisfies all the above requirements.

5.3 Combination of Aggregates to Produce Gradation 'Z'

In most cases no suitable single aggregate may be available to meet the requirements of gradation Z. In such cases aggregates from different sources may have to be blended to meet the requirements of the specifications as in gradation Z. The blending should be such that the composition of the mixture which is to be designed must be within the limits of the gradation.

The specified gradation Z employs 66.0 percent coarse aggregates, 24.0 percent fine aggregates and 10.0 percent fines in the aggregate mixture. The author made an additional study regarding the gradation of the hand crushed brick aggregate sources in Bangladesh. The study is contained in Appendix-B. It is found in the study that the crushed brick aggregate obtained when the labours were assigned to crush $\frac{1}{2}$ inch downgrade is the suitable source to supply most of the coarse aggregates and some portion of the fine aggregates in gradation Z. To obtain the rest of the fine aggregates and the fines of the mixture, a medium to coarse sand and some soil were mixed with crushed brick aggregates. The sand may be classified as well graded (SW) according to unified soil classification system. The value of the uniformity coefficient C_u is 8.48 and that of gradation coefficient C_g is 2.34. The fineness modulus of the sand is 2.80. The soil used in the blending is silty and plasticity index is less than 6. The grain size distributions of the components of the mixture are shown in Fig. B-1. The band of the grain size distribution of gradation Z is shown in Fig. B-2 which also shows the position of the blended mixture within the band.

In the Table 5.1 a job mix formula for the blending of crushed brick, sand and soil is found out.

It is seen from the table that 70 percent crushed brick aggregates, 20 percent of medium sand and 10 percent crushed brick aggregates, 20 percent of medium sand and 10 percent of silty soil are mixed. The combined aggregate in the above percentage proportions falls within the grading band of Gradation Z. In most sieve the value of the percent finer is very near to the mid point of limits of gradation Z. Hence the above percentages of the respective aggregates may serve as a job mix formula to produce crushed brick aggregate-sand-soil mixture in gradation Z.

5.4 Moisture Content

The moisture content-dry density relationships for six mixtures shown in Figs. 4.8 to 4.10 indicate that the density increases with an increase in the moisture content. After a certain percentage of moisture in the mixture, the dry-density decreases with the increase of moisture. The moisture contents for maximum densities for these mixtures varies from 12.50 percent to 13.50 percent shown in Table 4.2.

Table 5.1 Job Mix Formula for Gradation Z.

Sieve size	Percent Passing								
	½" max. size crushed brick aggregate		Medium sand F.M=2.80		Silty soil		Combined grading	Mid point of Z	Limits of Z.
	Total	Contribution in the mix, 70%	Total	Contribution in the mix, 20%	Total	Contribution in the mix, 10%			
1½"	100	70	100	20	100	10	100	97.5	95-100
½"	70	19.0	100	20	100	10	79	80.0	70-90
⅜"	32	22.4	100	20	100	10	52.4	59.0	50-68
No. 4	20	14.0	100	20	100	10	44.0	44.0	38-50
No. 8	13.5	4.55	30	6.0	97	9.7	20.0	18.5	15-22
No. 200	1.5	1.05	3	0.60	87	8.7	10.35	10.0	8-12

For brick aggregates, it is said in article 5.2 that maximum CBR values are obtained at maximum dry densities and the maximum dry density is obtained at optimum moisture content. In other words it can be said that the maximum CBR value is obtained when the mixture is compacted at optimum moisture content. From the test results it is seen that for gradation Z, the mixture with which maximum CBR value is obtained has an optimum moisture content of 13.0 percent of the dry weight of the mixture. The maximum dry density for this mixture at this moisture content is 119.0 lbs/cft.

5.5 Percent Fines

Like moisture content the amount of fines applied in the aggregate-sand-soil mixture controls the density of the mixture and also the stability. An optimum amount of fines which is just sufficient to fill most of the voids in aggregate combination gives the maximum stability. For gas burnt picked jhama brick-sand-soil mixtures, the CBR tests were done by varying the percentages of fines. Results are shown in Fig. 4.21. The soaked CBR values for different amount of fines are shown in Table 4.4.

It is seen in Fig. 4.21 that the maximum dry density occurs at 12.5 percent of fines whereas the maximum CBR value is obtained at about 10 percent of fines. The maximum dry density at optimum moisture content and 10 percent fines was 119.0 lbs/cft for gradation Z. But when the percent of fines was increased to 12.5 percent the density increased to 121.5 lbs/cft and the CBR value decreased by 2 percent. Thus it can be seen that fines in excess of optimum may sometimes increase the density but decreases the stability of the mixture.

5.6 Compaction

The density as well as the stability of the mixture is very much dependent on the compactive efforts applied during compaction. The compactive efforts applied by standard AASHO compaction method is 12,320 ft-lb/cft. The loose mixture in gradation Z was compacted applying this amount of effort. The volume of the loose mixture was decreased by about 20 to 22 percent after compaction. The density of the mixture increased from 105.0 lbs/cft to 119.0 lbs/cft. From the compactive effort - CBR relationship shown in Table 4.6 it is seen that for gas burnt picked jhama brick the CBR value at modified AASHO compaction is about 1.6 times the CBR at standard AASHO compaction. The compactive effort applied in modified AASHO is 4.5 times the standard AASHO effort.

Crushed stone aggregates were also studied to have a comparison with brick aggregates. Sand, silt and clay fractions of soil were blended with hand crushed stone aggregates in gradation Z. The CBR values were then determined following standard AASHO procedure. It is found in Table 4.6 that at modified AASHO compaction the CBR value is about 1.8 times the CBR value at standard AASHO compaction. From the results it is also observed that at lower compactive efforts the crushed stone aggregate mixture has comparatively higher CBR values than brick aggregate mixture.

5.7 CBR for Different Types of Aggregates

Four types of brick and stone aggregates were taken for the comparative study. All the mixtures compacted were in gradation Z. The physical properties of these aggregate types are shown in Tables 3.2 and 3.3. The maximum dry density, CBR values for these materials are shown in Table 4.5. A study of these Tables indicates that the higher the crushing strength, the higher is the CBR value. For the crushed stone used CBR vâlue of 94 percent is attained for gradation Z. Among the four types of bricks, the gas burnt picked jhama brick aggregate gives the maximum CBR value, maximum dry density and minimum optimum moisture content. The bricks classified here as third class are the under burnt low quality bricks collected from different kilns. The average crushing strength of these bricks is 1375 psi and this aggregate gives the minimum CBR value of 42.0 percent at 100 percant standard AASHO density.

5.8 Plasticity Characteristics

With crushed brick or stone aggregates some sand and soil were mixed to satisfy the designed gradation. Normally the fines produced during hand crushing of bricks or stones are nonplastic. The amount thus obtained is very small in quantity. To have specified percentage of fines in the mixture silt and clay fraction of soil (material passing No. 200 sieve) is used in the mixture. The combined mixture may sometimes be plastic (PI greater than 6) if there is excess clay particles. Hence plasticity tests were performed according to standard procedure with the portion of the mixture passing No. 40 sieve.

The plasticity tests described in article 4.6 shows that the material used in this investigation fulfil the requirements.

CHAPTER-6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The conclusions derived from the test results of the present study may be classified into two major groups depending upon

A) the properties of different types of aggregates used in the mixtures and

B) the behaviour of the mixture with a particular type of aggregate.

A. Conclusions based on the properties of different types of aggregates.

The search for appropriate material was done with different types of bricks viz gas burnt picked jhama, first class and third class bricks. For comparison, crushed stone mixtures were also studied. The search reveals that :

i) Crushed brick aggregates satisfy the general criteria of aggregates for base and subbase constructions.

ii) The gas burnt picked jhama brick aggregate is the most satisfactory among all the bricks, considering the wearability of the aggregates.

iii) Among four types of brick aggregate mixtures, the gas burnt picked jhama brick aggregate mixture has the maximum density and minimum optimum moisture content. When compacted in the standard AASHO procedure the maximum drydensity is 119.0 pounds per cubic feet and the optimum moisture content is 13.0 percent. The mixture was compacted as in gradation Z shown in Table 6.1.

iv) Using suitable gradation, the CBR value of the mixture is the most important characteristic for the base or subbase constructions. The capacity in terms of CBR value was the highest for gas burnt picked jhama brick aggregate mixture. The CBR value at 100 percent standard AASHO compaction is found to be 97.0 percent when the aggregates and soil were mixed in gradation Z. The CBR values for other types of brick aggregate mixtures were as follows:

for coal burnt brick aggregate mixture: 74.0 percent
for first class brick " " : 62.5 percent
for third class brick " " : 42.0 percent.

Although the CBR value for crushed stone aggregates should be 100 percent, but in gradation Z, a CBR value of only 94.0 percent is attained.

For base course constructions gas burnt brick aggregate mixtures can be used satisfactorily.

For subbase course constructions, any type of the brick aggregates can be used.

B. Conclusions based on the behaviour of the mixture with a particular type of aggregate mixture.

i) Gradation of the aggregate mixture is an important factor determining the load carrying capacity of base or subbase courses.

The gradation of the crushed brick sand and soil mixture shown below in Table 6.1 gives the maximum CBR value and is suggested to be used in base or subbase courses.

Table 6.1 Gradation Z

Sieve size	Percent Finer
2 inch	
$1\frac{1}{2}$ inch	95-100
$\frac{3}{4}$ inch	70-90
$\frac{3}{8}$ inch	50-68.0
No. 4	38.0-50
No. 8	28.0-40
No. 30	15-22.0
No. 200	8.0-12.0

ii) The fines used in the mixture increase or decrease the CBR value depending on their percentage in the mixtures. At optimum percent fines the CBR value is the maximum. For gradation Z, the optimum percent fines (combined silt and clay) is 10.0 percent.

iii) The optimum moisture content at which maximum CBR value is attained in the mixture varies with the type of the aggregates, gradation of the mixtures and the percent fines in the mixture. For gas burnt picked jhama brick aggregates with ten percent fines, the optimum moisture content is 13.0 percent and the maximum dry density is 119.0 pounds per cubic foot at 100 percent standard AASHO compaction.

iv) The CBR value is depndent on the compactive efforts applied. For crushed gas burnt picked jhama brick aggregate mixture, the CBR value at 100 percent standard AASHO compaction is 97.0 percent and at 100 percent modified AASHO compaction, the CBR value is 156.0 percent.

6.2 Recommendations

6.2.1 Recommendations for the Future Study

i) In the present study six gradations were used for investigation. More gradations could be taken to find the CBR values. In the future more close investigation should be taken to find a suitable gradation at which maximum CBR value would be attained.

ii) In the present study the CBR values of all mixtures were determined in the laboratory. The same materials should be compacted in the field at the same densities and field CBR values should be determined. Correlations should be developed between laboratory and field CBR values.

6.2.2 Recommendations for Field Constructions

i) For the construction of base courses for high type pavements, gas burnt picked jhama bricks are recommended to be used.

ii) The mixture is to be blended as in gradation Z (Table 6.1) found in the study.

iii) During construction in the field, the gradation of the mixture should be maintained.

iv) The optimum moisture content should be present in the mixture during compaction. For thorough distribution of moisture water should be added several hours in advance of compaction.

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APPENDIX-A

AVAILABILITY OF MATERIALS

APPENDIX-A

Availability of Materials Used in the Study for Base and Sub-base Constructions.

The materials used to blend together for getting the desired gradations are:

i) Bricks

ii) Stones

iii) Sand

iv) Silt and clay fraction from soil.

i) Bricks: Bricks are most widely used artificial building stone in Bangladesh. Bricks can be prepared any where in Bangladesh. The qualities, of which strength and durability are important are functions of constituent materials and burning process. Day by day coal burning process is becoming obsolete where gas is available. Fortunately Bangladesh has an abundant storage of natural gas which are being supplied to almost all parts of Bangladesh at a cheaper rate. Use of gas as the fuel in Brick kilns is undoutedly more economic and efficient than any other burning method.

Where gas is not available, only there, coal or oil can be used for burning bricks. This study reveals that the gas burnt picked jhama bricks and jhama bricks are the most suitable type of bricks for base ans subbase construction. Other types of bricks were also used for comparison.

These types are classified by Bangladesh Public Works Department (P.W.D.).

1. Picked Jhama Bricks: These bricks are uniformly varified throughout, but must be of good shape, heavy and of selected quality. They must not be spongy.

2. Jhama Bricks: These are slightly over burnt bricks but not quite so well shaped as picked jhama bricks. They must not be spongy and must be free from cinders and projecting lumps and of fairly good shape.

3. First class Bricks: They should be of uniform size and colour, thoroughly and evenly burnt. They should ring clearly when struck with a hammer or anohter brick. They should be well shaped with even surfaces and without cracks, rainspots or flaws of any kind. They should not absorb water more than one sixth of their weight when wat in water for 24 hours.

4. Second class Bricks: These bricks must posses the hardness and colour of first class bricks but are slightly irregular in shape, size or rough on the surface.

5. Third Class Bricks: These are bricks which are not sufficiently burnt to the class as first or second but which are burnt sufficiently and of uniform shape and size for use in unimportant works.

On the basis of fuel two varities of picked jhama and jhama bricks were used - gas burnt and coal burnt.

Actually for the construction of pavements the bricks are evaluated by their crushing strength values and percent wear in Los Angeles Abrasion machine. In Chapter 3 a comparison is given for different types of bricks used in this study. Now these bricks can be prepared at places near job sites and after crushing brick aggregates can be obtained.

ii) Stone: Boulders can be crushed to the desired sizes to have crushed stone aggregates. The smaller sized stones - shingles and pea-gravels can also be mixed to have the aggregate mixture. The general name of these natural aggregates is gravel and includes Granite, Trap, Basalt, Sandstone, Limestone, Argillaceous Limestone (Kankar), Dolomite, Laterite, Quartzite, Slates and Marbles.

In Bangladesh most of the big quarries for the collection of stones are in Sylhet District. Bholagonj, Jafflong, Shella and Bhowal quarries are important for the collection of Boulders and Shingles. Small quantities of stones are also available at Shita Kundu, Rangamati, Cox's Bazar of Chittagong district and in the beds of Mohadeo and other river coming from Garo Hills in Mymensingh. Stones are also available in some places of the northern districts like Rangpur and Dinajpur.

iii) Sand: Some sand is required to be blended with soil and aggregate to meat the standard gradations. The fineness of sand which is to be used depends on the proportions in the aggregate mixture and the type of the soil employed in the mixture. The sand may be from coarse to fine according to grain size. It can be obtained from river bed or from pits.

Sand is abundantly available all over Bangladesh. Vary good variety of river sand is available in the districts of Dacca, Mymensingh and Sylhet. Both sea sand and river sand of good quality are found in the coastal districts. Sands are also available in the northern districts of Bangladesh but not of good quality.

iv) Soil (for silt and clay fractions): Some minimum amount of silt and clay fraction of soil (material passing No. 200 mesh sieve) is raquired in the mixture. Normally bed soil, after drying and pulverizing, can be mixed with aggregates. But if thera is excess amount of clay fractions in the soil, lumps, clay balls may be formed during mixing which deteriorates the quality of the mixture. In such cases, suitable soil from adjacent areas can be used.

APPENDIX-B

HAND CRUSHING OF BRICKS AND BOULDERS

APPENDIX-B

Hand Crushing of Bricks and Boulders

This appendix pertains to the construction of any structure where crushed aggregates are used. The naturally occuring shingles and pea-gravels are round shaped with polished surfaces. The strength of these smaller sized aggregates are less than that from large sized stones named as boulders. To ensure proper interlocking and increased surface roughness, boulders are crushed to smaller sized aggregates. Bricks are normally crushed to smaller sized angular rough surfaced aggregates for use in construction work.

The crushing of bricks or boulders can be done manually by a hammer or by using machines. It is an accepted fact that machine crushing produces uniformly graded aggregates. For concrete works and for the construction of dense graded pavement components well graded aggregates are required. By hand crushing of bricks or boulders a well graded or close to well graded aggregate is expected to be obtained.

Bangladesh is a populous poor country. The economy prevailing now in this country desires to undertake labour intensive methods rather than capital intensive methods for construction works. Therefore in most of the construction works, bricks or boulders are crushed manually to get graded crushed aggregates.

The author used crushed bricks and boulders for this study. To meet the standard gradation it was found that some aggregate of particular sizes are to be blended with, and some aggregate are to be discarded from the mixture of aggregates obtained from hand crushed sources. In this connection additional informations were collected regarding the gradation of typical hand crushing which is most common in this country. The information are obtained in the following forms:

i) Comparison of gradations for crushed boulders and crushed bricks (Picked jhama).

ii) Typical gradations for crushed bricks (picked jhama) under the following circumstances: Labours were recruited at random of different ages and sex. A group of labours were directed to crush bricks into 1" maximum size. The crushed materials were collected and gradations for different labours of a particular group were found out. Average values of these gradations of that particular group was taken. Similarly gradations for other maximum sizes were also obtained.

iii) Typical gradations for crushed bricks of a particular maximum sizes by labours of different ages and sex.

Table B-1 Comparison of Gradations for Crushed Boulders and Crushed Bricks (Picked Jhama)

Sieve size	Percent Finer	
	Avg. gradation for crushed stone broken by typical labours	Avg. gradation for crushed bricks broken by typical labours
	Max. size 1"	Max. size 1"
1½"	100	100
1"	79.5	92.59
¾"	47.0	64.68
½"	26.0	41.47
⅜"	16.75	15.20
¼"	9.50	5.07
No. 4	6.34	2.71
No. 8	3.00	0.55
No. 16	1.85	0.36
No. 30	1.15	0.20
No. 50	0.50	0.05
No. 100	0.20	0.02
No. 200	0.05	0.01

It is seen from the above comparison that stones after crushing remains more oversized than bricks. It can also be said that crushed bricks are more well graded than the stones. For bricks therefore hand crushing is more suitable than for stones.

Table B-2 Typical Gradations for Different Maximum Sizes (Crushed Picked Jhama Bricks)

Sieve size	Percent Finer		
	1"	¾"	½"
1½"	100	100	100
1"	92.6	94.0	96.0
¾"	64.65	71.75	69.60
½"	41.45	39.30	39.95
⅜"	15.20	27.35	31.95
¼"	5.10	16.65	23.40
No. 4	2.70	13.00	19.95
No. 8	0.55	7.20	13.40
No. 16	0.35	4.40	9.60
No. 30	0.20	2.45	6.20
No. 50	0.05	1.45	4.10
No. 100	0.02	0.50	2.50
No. 200	0.01	0.10	1.10

It is seen from the above table that more over sized materials are obtained for lower sizes and lower sized materials after crushing are more well graded.

Table B-3 Typical Gradations of Crushed Bricks (¾" max.size) Broken by Labours of Different Ages and Sex. (Crushad Picked Jhama Bricks)

Sieve size	Percent Finer					
	Male			Female		
	Gr. 1	Gr. 2	Gr. 3	Gr. 1	Gr. 2	Gr. 3
1"	87.00	96.0	91.20	71.18	85.80	77.80
¾"	66.35	69.6	67.55	27.82	57.20	49.85
½"	41.65	39.9	41.85	12.42	30.40	27.50
⅜"	32.65	31.9	31.00	6.58	21.90	19.65
¼"	19.20	23.5	19.80	4.16	14.75	11.40
No. 4	15.35	19.95	15.75	2.52	11.75	8.65
No. 8	8.65	13.40	8.45	2.10	7.45	4.75
No. 16	4.40	9.60	4.90	1.98	4.90	2.95
No. 30	0.85	6.15	2.95	1.74	3.25	2.00
No. 50	0.40	4.16	1.75	1.44	0.80	1.45
No. 100	0.15	2.50	1.00	0.82	0.35	0.90
No. 200	0.00	1.10	0.35	0.00	0.00	0.45

Gr. 1: Age between 12-20 yrs.

Gr. 2: Age between 25-35 yrs.

Gr. 3: Age above 50 yrs.

From Table B-3 it reveals that the quality of crushing is better by group 2 labours for both male and female. Also this group having age between 25-35 years crush more well graded materials.

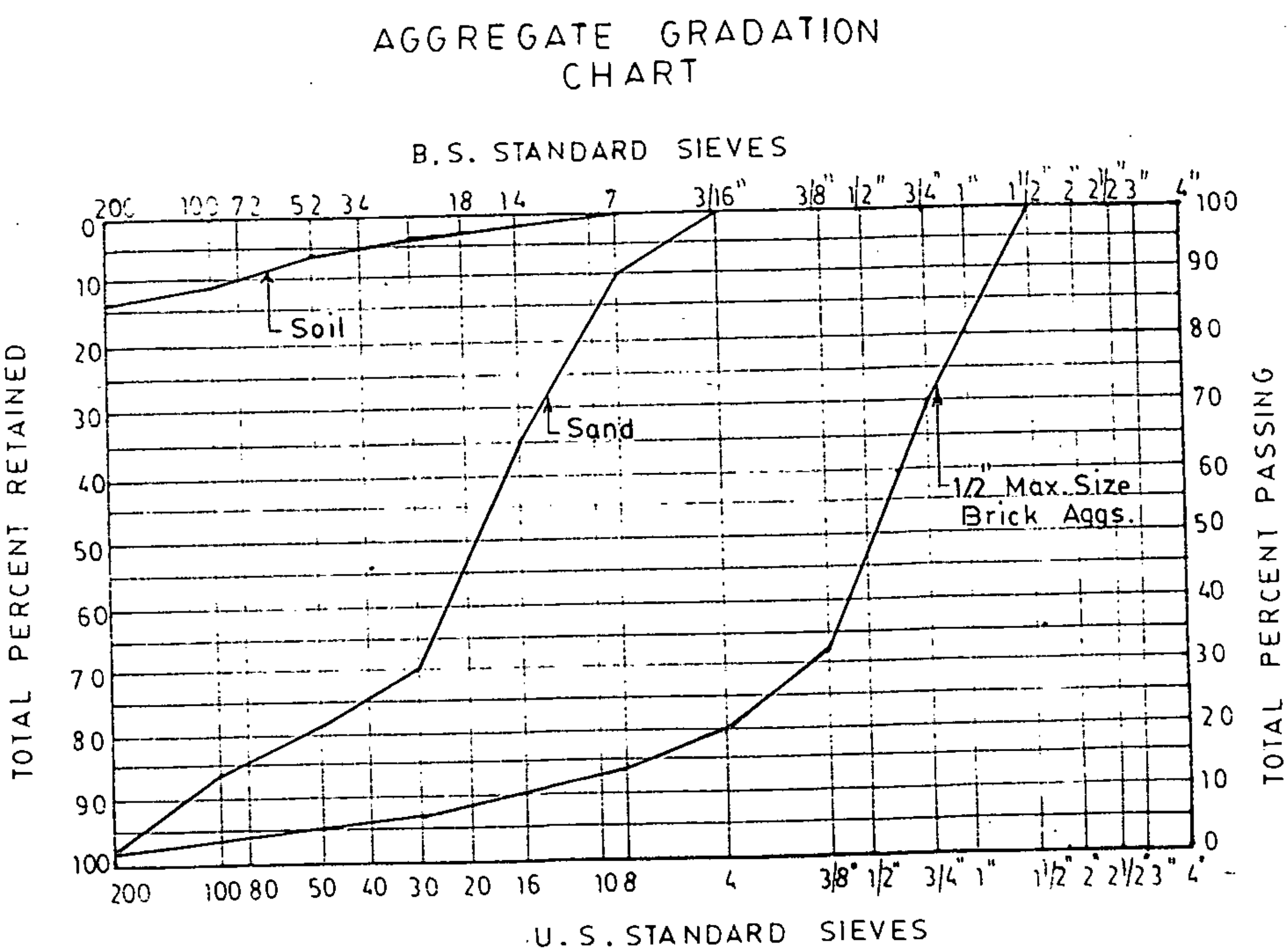


FIG. B-1 GRAIN SIZE DISTRIBUTION OF THE COMPONENT AGGREGATES OF GRADATION 'Z'

AGGREGATE GRADATION CHART

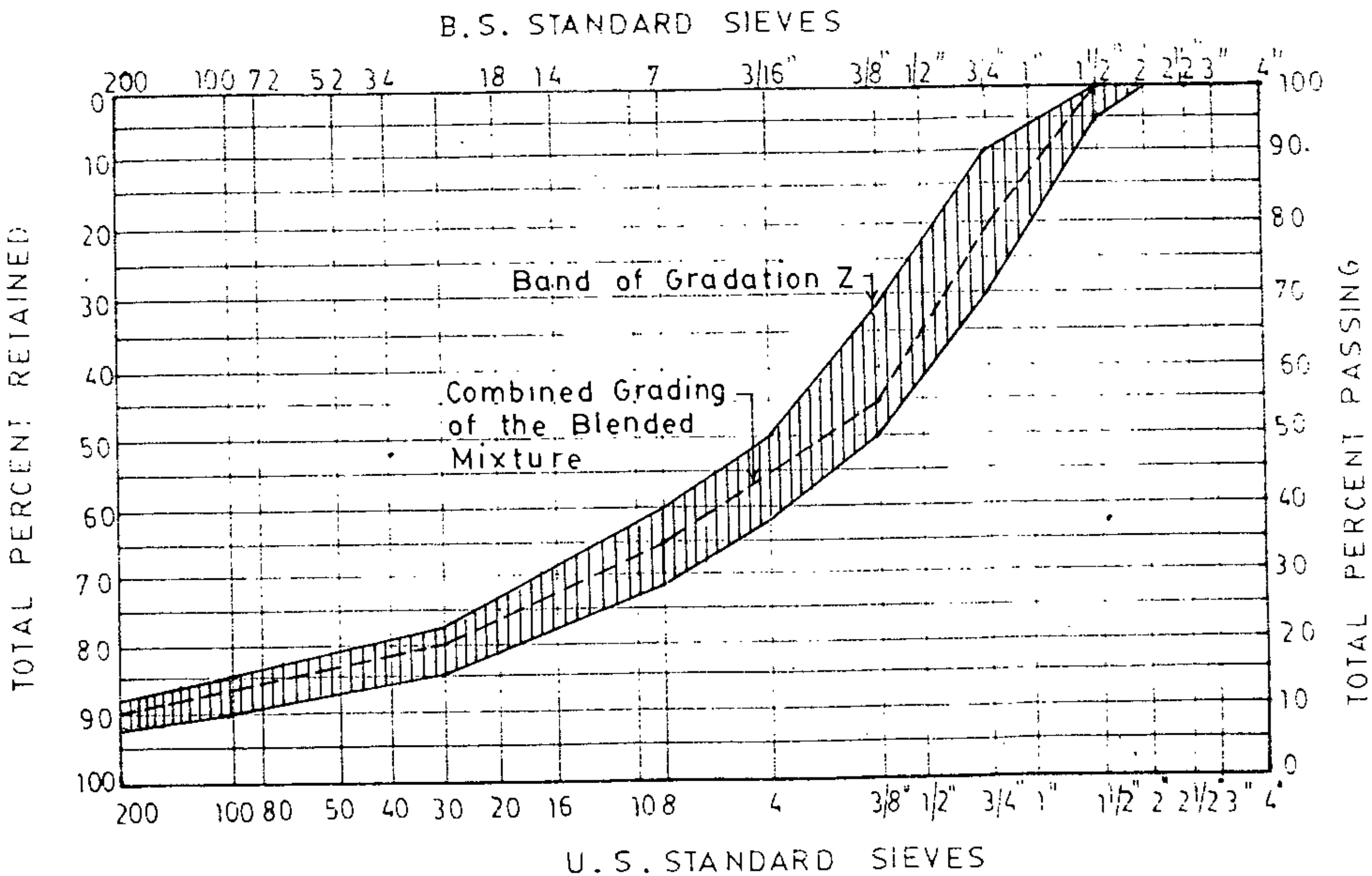


FIG. B-2 GRADATION BAND OF GRADATION 'Z' AND GRADATION OF THE BLENDED MIXTURE

APPENDIX-C

TABLES OF TEST RESULTS

AND

FIGURES OF TEST EQUIPMENTS

Table C-1 CBR Test Results for Gas Burnt Picked Jhama Brick; Gradation X_1

Compactive effort, lb-ft/cft	Spn. No.	Penetration load in psi required for penetrations in inches									Dry density lbs/cft	Avg. dry density lbs/cft	Corrected CBR in %	Avg. Cor. CBR in %
		0.02	0.04	0.06	0.08	0.10	0.15	0.20	0.30	0.40				
14,300 (65 blows per layer)	1	103	297	470	652	835	1100	1252	1525	1712	118.8	119.3	90	91.8
	2	115	305	495	673	855	1115	1300	1602	1800	119.1		92	
	3	113	320	525	736	900	1192	1395	1720	1980	121.9		95	
	4	115	318	523	715	906	1209	1402	1680	1413	121.3		97	
	5	103	275	450	648	810	1105	1250	1460	1642	117.7		88	
	6	110	280	455	665	800	1048	1220	1465	1645	117.0		89	
6,6000 (30 blows per layer)	1	52	121	235	330	410	583	675	815	882	112.7	112.7	50	49.2
	8	50	103	190	280	376	550	652	805	804	110.8		46	
	9	50	125	217	328	432	640	775	950	1090	113.3		53	
	10	51	120	203	302	400	614	762	976	1135	113.2		49	
	11	50	100	195	300	395	588	755	810	895	112.0		48	
	12	45	116	210	320	425	617	720	855	960	114.2		49	
3,300 (15 blows per layer)	13	24	48	87	162	235	452	545	640	672	107.4	108.4	39	39.0
	14	35	61	72	210	300	455	573	660	713	108.7		40	
	15	21	51	131	208	302	465	550	630	665	109.3		42	
	16	20	58	125	218	300	445	570	720	825	109.3		39	
	17	22	55	120	207	297	425	510	596	620	107.9		38	
	18	20	52	105	185	255	400	490	570	622	107.8		36	

From CBR-density plot (Fig.4.17A), CBR at 100 percent standard AASHO density is 79.5 percent.

Table C-2 CBR Test Result for Gas Burnt Picked Jhama Brick; Gradation X_2

Compactive effort, lb-ft/cft	Spn. No.	Penetration load in psi required for penetrations in inches									Dry density lbs/cft	Avg. dry density lbs/cft	Corrected CBR in %	Avg. cor. CBR in %
		0.02	0.04	0.06	0.08	0.10	0.15	0.20	0.30	0.40				
14,300 (65 blows per layer)	1	122	285	512	648	875	1142	1301	1515	1620	119.0		92	
	2	118	295	487	627	782	1051	1234	1367	1518	118.3		94	
	3	127	274	500	610	820	1150	1350	1671	1910	120.9	119.3	91	92.6
	4	108	280	474	622	878	1128	1324	1500	1675	119.1		95	
	5	106	248	403	637	778	1070	1252	1415	1596	118.8		86	
	6	126	300	505	676	903	1195	1330	1475	1650	119.6		95	
6,600 (30 blows per layer)	7	48	107	200	296	384	562	759	878	972	112.3		48	
	8	45	105	197	300	403	540	700	860	980	112.4		49	
	9	54	133	226	350	400	620	800	1001	1246	113.7	112.6	51	48.6
	10	50	130	175	268	371	550	642	890	998	112.0		47	
	11	45	105	180	267	370	525	700	824	905	111.9		46	
	12	47	108	202	307	408	650	762	922	1031	113.2		51	
3,300 (15 blows per layer)	13	18	58	124	208	303	446	550	690	785	111.8		38	
	14	15	56	130	204	297	445	526	647	648	110.5		37	
	15	16	54	141	223	300	457	565	729	775	110.7	110.1	41	37.3
	16	17	50	124	183	252	402	507	600	732	109.4		35	
	17	18	38	82	150	240	405	460	635	660	106.7		34	
	18	15	50	125	200	267	450	557	720	825	109.5		39	

From CBR-density plot (Fig.4.17B), CBR at 100 percent standard AASHO density is 71.0 percent.

Table C-3 CBR Test Result for Gas Burnt Picked Jhama Brick; Gradation X_3

Compactive effort, lb-ft/cft	Spcn. No.	Penetration load in psi required for penetrations in inches									Dry density lbs/cft	Avg. dry density lbs/cft	Corrected CBR in %	Avg. cor. CBR in %
		0.02	0.04	0.06	0.08	0.10	0.15	0.20	0.30	0.40				
14,300 (65 blows per layer)	1	135	286	457	575	760	1035	1162	1375	1540	121.5	120.2	84	86
	2	101	247	470	600	770	1020	1140	1332	1772	120.1		84	
	3	199	253	438	550	742	1033	1152	1315	1455	119.4		82	
	4	110	290	475	636	820	1055	1225	1380	1550	119.6		87	
	5	123	272	450	597	803	12023	1163	1370	1538	118.4		86	
	6	102	290	475	650	842	1075	1170	1436	1639	122.6		90	
6,600 (30 blows per layer)	7	45	140	187	300	403	605	710	865	980	113.3	112.1	50	46
	8	37	104	201	296	350	532	655	800	920	112.0		44	
	9	42	102	180	260	340	495	638	747	816	112.0		42	
	10	47	126	183	300	405	570	674	900	973	110.8		48	
	11	50	102	160	255	332	501	556	674	740	111.1		41	
	12	46	121	252	310	430	600	684	853	994	113.5		51	
3,300 (15 blows per layer)	13	16	50	122	200	276	421	512	642	655	112.7	110.75	37	35
	14	18	52	140	202	300	435	522	620	670	11.4		38	
	15	13	51	98	200	250	400	470	535	560	110.5		34	
	16	20	54	107	175	253	410	450	550	605	109.6		34	
	17	18	52	108	155	238	350	421	517	562	109.4		31	
	18	22	51	124	200	270	424	500	591	673	110.9		36	

From CBR-Density plot (Fig.4.18A), CBR at 100 percent standard AASHO density is 77.5 percent.

Table C-4 CBR Test Result for Gas Burnt Picked Jhama Brick; Gradation X_4.

Compactive effort, lb-ft/cft	Spn. No.	Penetration load in psi required for penetrations inches 0.02	0.04	0.06	0.08	0.10	0.15	0.20	0.30	0.40	Dry density lbs/cft	Avg. dry density lbs/cft	Corrected CBR in %	Avg. Cor. CBR in %
14,300 (65 blows per layer)	1	142	325	509	735	940	1138	1295	1545	1730	121.7	121.8	102	99.0
	2	115	323	505	697	882	1165	1307	1600	1774	121.0		98	
	3	136	364	550	705	938	1242	1460	1665	1847	123.4		101	
	4	112	273	525	675	868	1197	1350	1570	1754	121.7		97	
	5	115	297	495	698	840	1158	1365	1593	1806	120.8		96	
	6	118	320	504	700	902	1165	1375	1550	1695	121.8		100	
6,600 (30 blows per layer)	7	50	130	220	322	425	630	750	915	1025	115.0	114.0	53	52
	8	48	108	196	305	403	596	732	853	902	114.1		49	
	9	45	125	237	330	426	634	750	915	1028	114.2		52	
	10	50	108	218	320	410	590	786	960	1120	112.5		52	
	11	51	136	210	373	435	622	755	925	1063	115.1		54	
	12	50	125	262	323	410	598	728	870	928	113.0		50	
3,300 (15 blows per layer	13	16	65	150	240	332	500	580	650	695	111.9	111.2	46	43.3
	14	15	54	132	231	320	487	602	695	730	111.5		45	
	15	13	52	106	200	301	471	632	652	722	110.9		41	
	16	17	65	117	222	307	475	605	760	925	109.7		43	
	17	13	66	160	200	310	500	605	800	850	112.4		44	
	18	23	67	114	240	300	475	573	675	680	110.8		41	

From CBR-density plot (Fig.4.188), CBR at 100 percent standard AASHO density is 87.0 percent.

Table C.5 CBR Test Result for Gas Burnt Picked Jhama Brick; Gradation X_5.

Compactive effort, lb-ft/cft	Spn. No.	Penetration load in psi required for penetrations in inches									Dry density lbs/cft	Avg. dry density lbs/cft	Corrected CBR in %	Avg. cor. CBR in %
		0.02	0.04	0.06	0.08	0.10	0.15	0.20	0.30	0.40				
14,300 (65 blows per layer)	1	106	303	440	600	806	1060	1255	1524	1695	116.90	117.75	86	79.0
	2	98	268	453	628	795	1065	1225	1495	1520	116.73		87	
	3	87	217	375	535	670	876	990	1112	1205	116.8		73	
	4	72	215	406	520	712	954	1040	1225	1400	117.0		79	
	5	75	210	355	518	623	865	1003	1142	1250	116.3		70	
	6	110	255	410	603	712	965	1120	1355	1547	118.75		79	
6,600 (30 blows per layer)	7	47	100	175	204	355	517	600	760	875	113.76	113.5	42	41.0
	8	48	86	180	235	330	500	605	702	800	113.45		41	
	9	37	98	153	236	315	483	570	668	725	113.42		40	
	10	35	56	156	240	310	470	580	715	810	112.95		39	
	11	36	82	153	245	325	990	575	685	750	113.34		40	
	12	82	184	262	352	550	665	675	822	960	114.08		43	
3,300 (15 blows per layer)	13	13	50	112	170	252	426	520	623	744	112.8	112.8	36	33.0
	14	15	50	125	198	270	400	500	560	605	112.9		36	
	15	11	47	100	165	245	350	442	455	600	112.95		34	
	16	10	26	87	152	220	325	347	387	400	112.55		30	
	17	10	42	92	173	185	335	425	535	565	112.7		30	
	18	45	97	145	200	270	366	507	560	655	112.9		31	

From CBR-Density plot (Fig. 4.19A), CBR at 100 percent standard AASHO density is 65.0 percent.

Table C-6 CBR Test Result for Gas Burnt Picked Jhama; Gradation Z.

Compactive effort, lb-ft/cft	Span. No.	Penetration load in psi required for penetrations in inches 0.02	0.04	0.06	0.08	0.10	0.15	0.20	0.30	0.40	Dry density lbs/cft	Avg. dry density lbs/cft	Corrected CBR in %	Avg. cor. CBR in %
14,300 (65 blows per layer)	1	142	350	552	7.55	993	1385	1676	2182	2490	120.3	121.3	107	115.5
	2	128	332	522	750	958	1243	1437	1692	1905	118.7		108	
	3	150	385	640	748	1100	1487	1815	2346		120.9		120	
	4	85	185	373	647	962	1435	1732	2076	2325	123.7		119	
	5	145	365	618	842	1060	1405	1529	1905	2200	120.8		118	
	6	110	360	585	870	1040	1485	1685	2100	2420	123.4		121	
6,600 (30 blows per layer)	7	70	156	260	372	472	651	778	950	1092	110.6	113.2	55	59.5
	8	53	141	256	337	500	716	877	1105	1253	114.1		60	
	9	52	148	285	350	465	740	945	248	1452	114.6		60	
	10	62	148	252	357	500	742	905	1146	1285			62	
	11	75	175	300	352	504	642	803	980	1102	111.2		58	
	12	72	155	273	404	508	740	952	1152	1385	114.8		62	
3,300 (15 blows per layer)	13	48	105	203	284	351	473	548	640	667	108.0	110.3	40	45.6
	14	32	77	150	252	349	548	670	892	1038	111.9		50	
	15	36	83	156	250	332	552	730	902	1010	111.9		48	
	16	43	123	203	300	376	510	607	724	780	108.2		45	
	17	53	140	241	343	405	545	646	760	802	109.7		45	
	18	48	75	60	216	322	540	657	865	1000	112.1		46	

From CBR-density plot (Fig. 4.19B), CBR at 100 percent standard AASHO density is 97.0 percent.

Table C-7 CBR Test Result for Crushed Stone; Gradation Z.

Compactive effort, lb-ft/cft	Span No.	Penetration load in psi required for penetrations in inches									Dry density lbs/cft	Avg. dry density lbs/cft	Corrected CBR in %	Avg. Cor. CBR in %
		0.02	0.04	0.06	0.08	0.10	0.15	0.20	0.30	0.40				
	1	105	402	580	802	1015	1450	1647	1960	2185	152.7		112	
14,300 (65 blows per layer)	2	107	347	540	805	1000	1335	1563	1828	2110	151.3		108	
	3	135	350	551	792	1020	1315	1506	1750	1936	148.0	149.9	114	110
	4	110	325	530	741	955	1326	1400	1512	1675	148.8		104	
	5	105	347	600	725	997	1302	1418	1720	1822	149.2		107	
	6	103	345	513	798	1050	1400	1550	1635	1908	149.9		115	
	7	48	182	290	400	515	720	825	1040	1145	145.0		61	
6,600 (30 blows per layer)	8	50	145	300	405	540	815	933	1135	1222	147.2		66	
	9	45	135	248	386	495	687	872	930	982	145.5	145.5	60	61.6
	10	72	155	320	426	548	748	897	1062	1198	145.6		62	
	11	46	126	224	402	486	704	810	996	1100	145.6		58	
	12	47	135	280	405	532	747	875	1080	1212	145.6		63	
	13	18	78	150	252	355	552	638	642	750	142.9		49	
3,300 (15 blows per layer)	14	20	85	182	300	400	620	750	955	1042	144.9		56	
	15	15	84	165	285	350	552	662	780	845	143.8	143.8	50	52.8
	16	43	107	205	303	408	582	730	803	864	144.2		53	
	17	15	68	155	250	305	585	610	721	760	143.8		49	
	18	35	74	196	306	420	648	758	880	976	142.5		58	

From CBR-density plot (Fig. 4.17A), CBR at 100 percent standard AASHO density is 94.0 percent.

Table C-8 CBR Test Result for Coal Burnt Picked Jhama Brick; Gradation Z.

Compactive effort, lb-ft/cft	Spn. No.	Penetration load in psi required for penetrations in inches									Dry density lbs/cft	Avg. dry density lbs/cft	Corrected CBR in %	Avg. Cor. CBR in %
		0.02	0.04	0.06	0.08	0.10	0.15	0.20	0.30	0.40				
14,300 (65 blows per layer)	1	103	252	458	560	787	1093	1230	1482	1652	119.6		86	
	2	98	248	450	642	743	1078	1241	1390	1489	120.8		85	
	3	105	286	516	650	822	1155	1354	1691	1832	123.3	120.8	91	87.3
	4	97	218	503	692	843	1145	1272	1537	1700	121.4		91	
	5	98	270	419	655	800	1109	1268	1550	1746	119.5		90	
	6	121	240	410	600	772	1028	1176	1368	1498	120.7		83	
6,600 (30 blows per layer)	7	46	105	202	282	395	522	697	701	850	112.9		46	
	8	47	96	205	300	401	401	550	730	825	915	112.7	48	47.5
	9	48	121	173	348	451	652	778	978	1150	113.3		54	
	10	40	100	160	233	320	460	650	847	942	111.9		40	
	11	51	112	200	320	412	578	746	896	998	112.8		50	
	12	45	115	184	295	378	526	690	800	871	112.6		47	
3,300 (15 blows per layer)	13	15	47	150	194	262	423	538	624	670	110.9		37	
	14	17	58	119	175	250	415	468	568	588	111.0		34	
	15	14	48	91	161	225	370	470	547	620	107.3	108.9	32	33.6
	16	15	49	90	177	227	364	957	550	653	107.9		31	
	17	20	64	128	200	275	425	533	648	730	108.9		37	
	18	15	48	96	173	226	350	426	557	648	107.2		31	

From CBR-density plot (Fig.4.27B), CBR at 100 percent standard AASHO density is 74.0 percent.

Table C-9 CBR Test Result for First Class Brick, Gradation Z.

Compactive effort, lb-ft/cft	Span No.	Penetration load in psi required for penetrations in inches									Dry density lbs/cft	Avg. dry density lbs/cft	Correc-ted CBR in %	Avg. cor. CBR in %
		0.02	0.04	0.06	0.08	0.10	0.15	0.20	0.30	0.40				
14,300 (65 blows per layer)	1	101	250	405	546	703	935	1102	1270	1365	119.1		78	
	2	102	235	462	590	747	1100	1210	1500	1692	116.3		81	
	3	98	241	410	550	712	1015	1098	1370	1565	116.0	117.0	80	79.0
	4	100	253	419	562	722	995	1230	1480	1675	116.1		81	
	5	99	248	390	550	648	950	1125	1315	1608	115.8		75	
	6	102	250	414	555	706	1027	1126	1407	1622	118.7		79	
6,600 (30 blows per layer)	1	42	77	180	200	286	455	545	672	765	112.8		36	
	2	49	98	162	228	310	480	650	815	968	111.8		38	
	3	29	70	151	240	316	500	624	820	945	109.9	110.8	40	37.5
	4	22	76	153	247	312	495	572	778	846	109.0		39	
	5	28	78	155	210	338	450	562	673	780	110.1		36	
	6	30	75	147	212	313	407	568	710	765	111.2		35	
3,300 (15 blows per layer)	1	25	47	78	147	200	326	415	500	602	111.2		28	
	2	22	51	100	132	225	327	430	505	595	109.4		29	
	3	13	28	62	152	200	350	442	545	556	108.2	108.9	30	29.0
	4	12	47	100	150	222	367	472	550	650	107.9		32	
	5	10	42	75	140	180	300	405	495	510	107.8		27	
	6	11	43	73	145	198	315	400	514	647	108.9		28	

From CBR-Density plot (Fig. 4.28A), CBR at 100 percent standard AASHO density is 62.5 percent.

Table C-10 CBR Test Result for Third Class Brick; Gradation Z.

Compactive effort, lb-ft/cft	Span. No.	Penetration load in psi required for penetrations in inches									Dry density lbs/cft	Avg. dry density lbs/cft	Corrected CBR in %	Avg. Cor. CBR in %
		0.02	0.04	0.06	0.08	0.10	0.15	0.20	0.30	0.40				
14,300 (65 blows per layer)	1	105	210	315	410	540	755	940	1165	1370	118.0	116.0	58	56.5
	2	85	120	295	402	515	702	835	950	1045	117.1		57	
	3	70	145	320	390	483	723	897	1000	1113	116.3		55	
	4	68	150	312	385	452	620	840	985	1145	114.0		54	
	5	82	120	268	375	501	710	805	1007	1100	115.1		53	
	6	74	157	302	455	557	728	845	922	1048	115.6		62	
6,600 (30 blows per layer)	7	25	75	130	205	270	445	525	705	805	112.8	110.75	34	33.4
	8	47	63	135	183	245	370	500	635	720	111.5		30	
	9	33	75	150	247	279	476	570	710	796	110.9		37	
	10	37	76	148	208	282	447	565	647	750	110.5		34	
	11	38	72	142	200	270	397	515	572	622	109.5		33	
	12	36	76	150	200	265	400	520	600	670	109.3		32	
3,300 (blows per layer)	13	15	45	75	120	180	300	375	520	580	109.9	108.2	25	23.5
	14	10	32	77	105	180	282	362	472	557	108.8		24	
	15	18	42	72	128	152	298	351	485	505	108.1		23	
	16	16	28	74	120	138	255	312	375	403	107.7		21	
	17	26	45	97	148	198	305	382	477	548	107.6		26	
	18	10	28	65	112	163	250	335	417	465	106.9		22	

From CBR-density plot (Fig.4.28B), CBR at 100 percent standard AASHO density is 42.0 percent.

Table C-12 Liquid Limit Test Result

No. of observation	1	2	3	4	5
No. of blows	9	12	18	30	41
Water content	28.5	26.5	23.5	20.5	19.5

The soil is non plastic

Table C-11 Hydrometer Analysis

Soil Sample: Materials passing No. 40 sieve from soil-aggregate mixture in gradation Z.

Wt. of dry soil = 50 gms. Specific gravity of soil = 2.67

N'= % finer = 60% = 0.60 Temp. = 32° Hyd. No. C02966.

Date	Elapsed Time in minutes	R=	R_w=	$R-R_w$	Z_r in cm	D in m.m	N in %	N' in %
21.12.81	1/4	1023	-0.5	23.5	11.36	0.0926	75.33	45.19
	1/2	1017	"	17.5	12.945	0.0699	56.10	33.66
	1	1012	"	12.5	14.215	0.052	40.0	24.0
	2	1009	"	9.5	15.025	0.037	30.45	18.27
	4	1005.5	"	6.0	14.83	0.0264	19.20	11.52
	8	1003	"	3.5	15.505	0.019	11.20	6.72
	15	1002.5	"	3.0	15.74	0.014	9.60	5.76
	30	1002	"	2.5	15.875	0.01	8.0	4.8
	60	1001.2	"	1.7	16.1	0.00712	5.4	3.24
	120	1000.8	"	1.3	16.28	0.005	4.16	2.496
	240	1000.2	"	0.7	16.60	0.0036	2.24	1.34

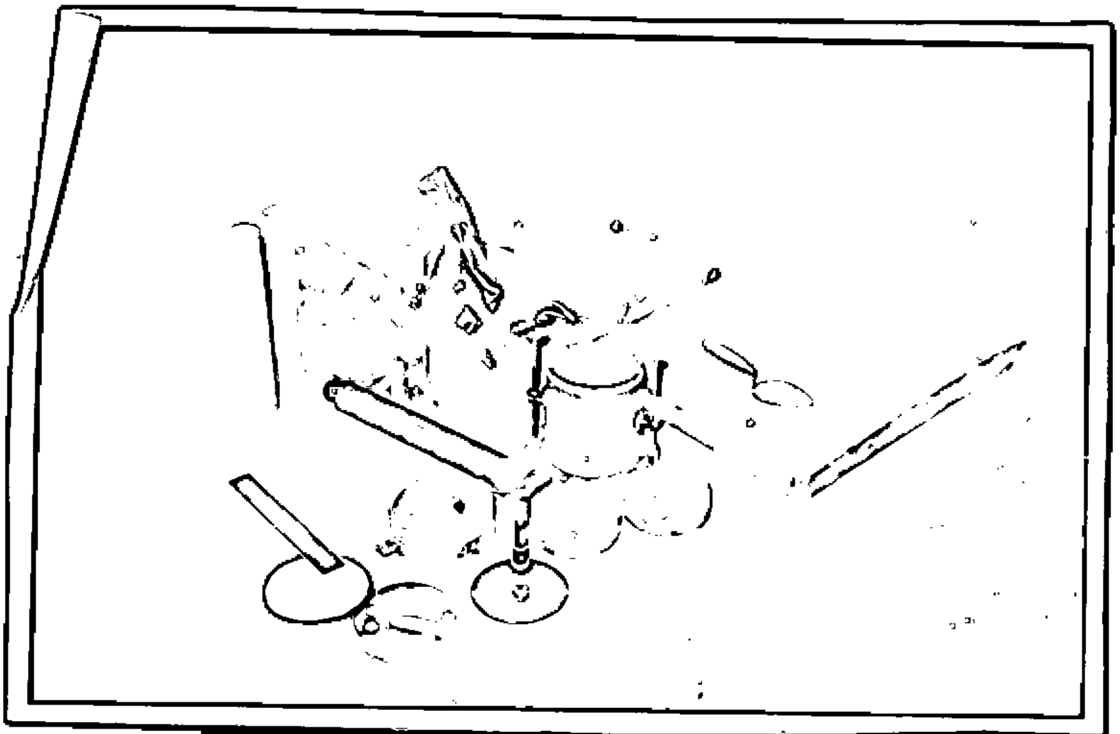


Fig.C-1 Equipment and materials for the compaction of CBR molds.

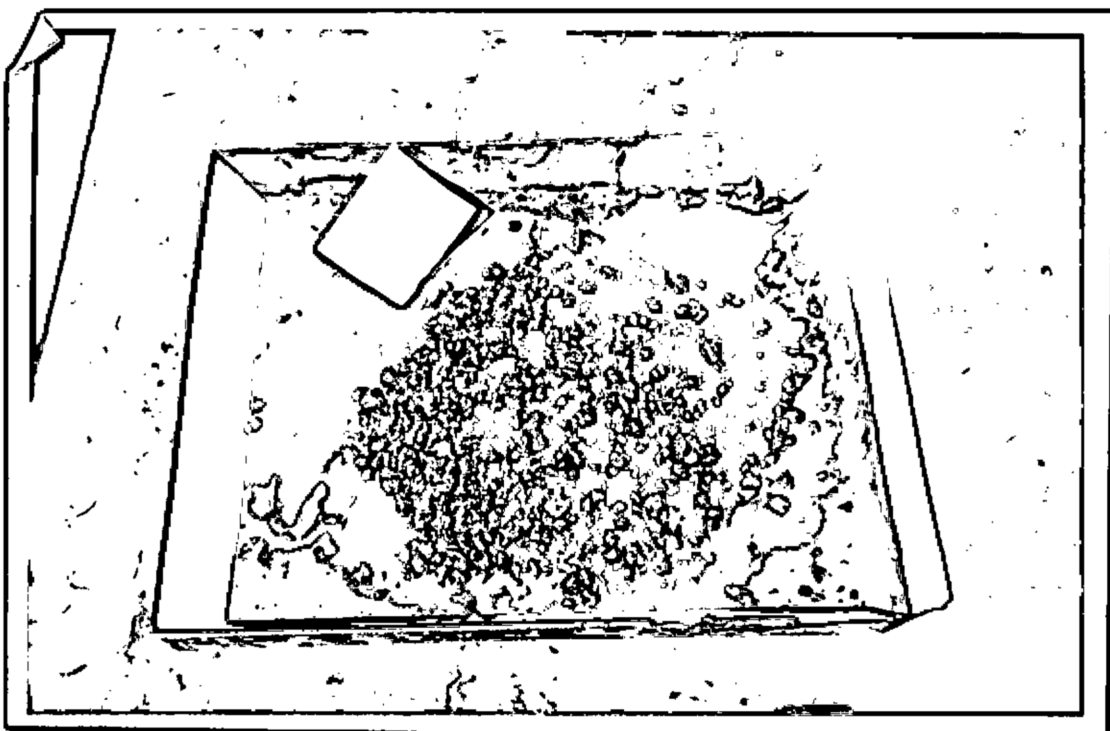
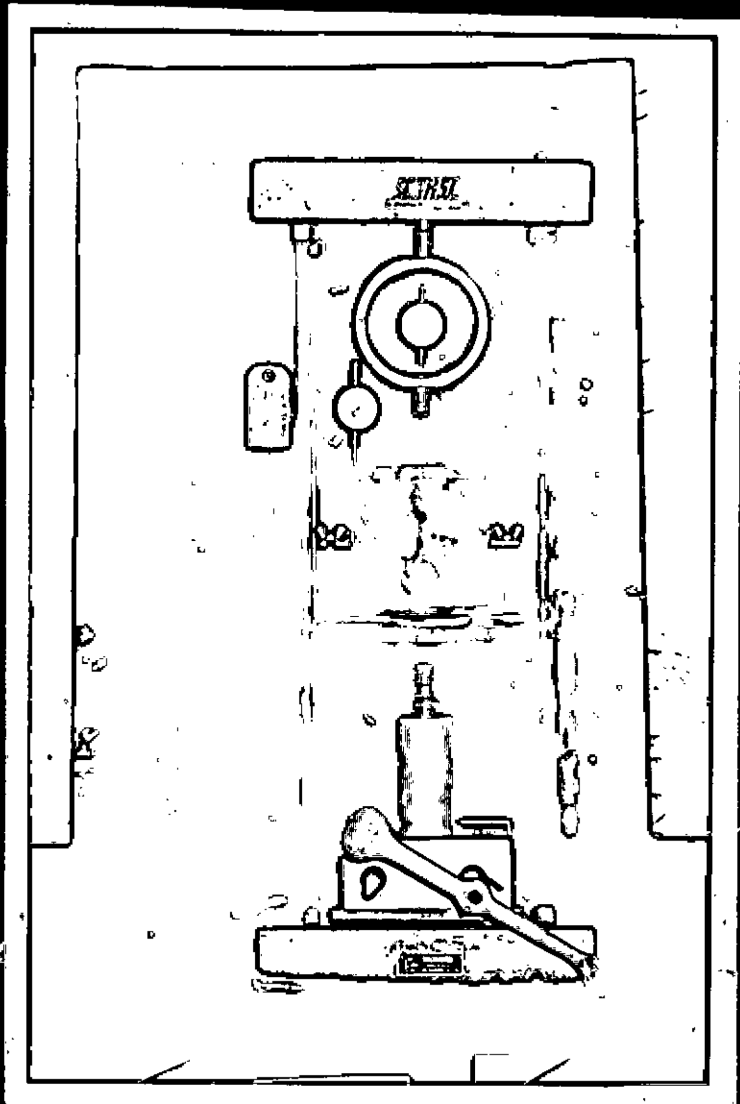


Fig.C-2 The mixture is ready for compaction.



The CBR specimen is being tested in a mechanical loading press.

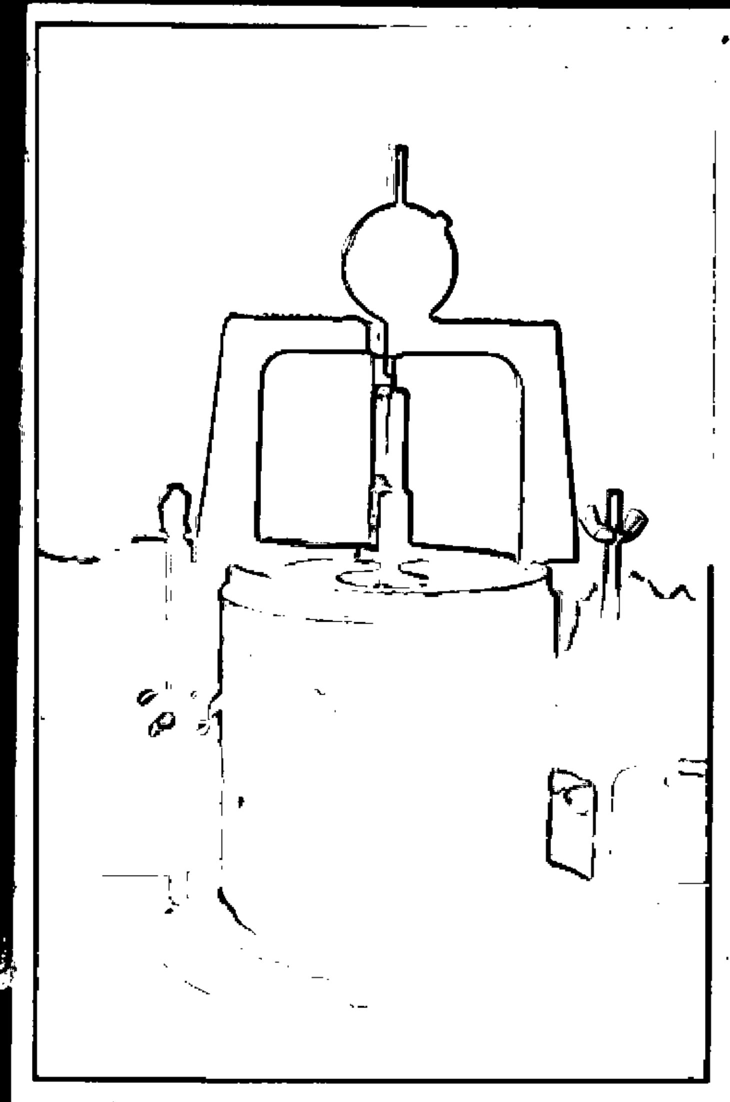


Fig C-3 The compacted mold is ready for submersion in water.

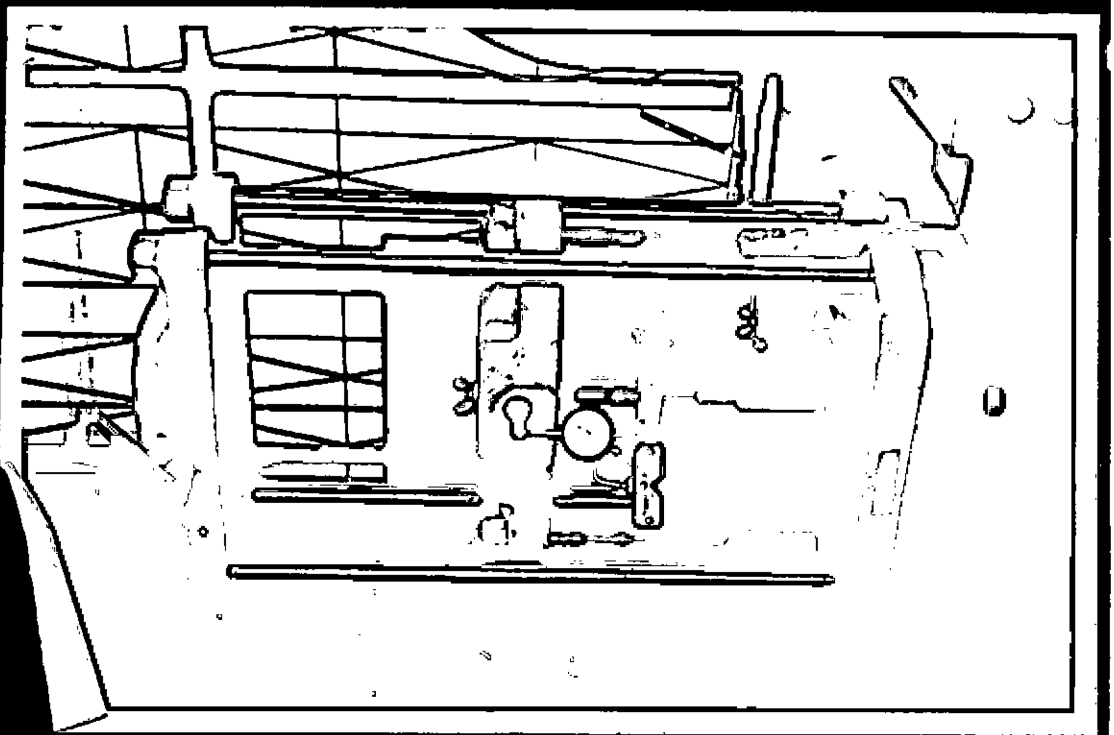


Fig. C-4 The sample is being tested in a universal testing machine.

Fig. C-5 The specimens after being tested.