STUDY OF
THE PRODUCTION OF ASPHALTIC CONCRETE HOT MIXES
IN LEBANON

THESIS

Presented to the Faculty of Engineering and Architecture of
the American University of Beirut in Partial Fulfilment
of the Requirements

For the Degree of

MASTER OF ENGINEERING
MAJOR - CIVIL

by
Haik Mikael Kurkdjian, B.C.E.
Beirut, Lebanon
August, 1968.

STUDY OF
THE PRODUCTION OF ASPHALTIC CONCRETE HOT MIXES
IN LEBANON

APPROVED:

Supervising Professor - H.Papazian

Professor N.E. Manassah

Professor Y. Avedissian

Professor N. Jouzy

ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks to Dr. Hratch S. Papazian, Associate Professor of Civil Engineering, for his help and guidance in all phases of this investigation.

The author also wishes to thank the Beirut Municipality and the Lebanese Ministery of Public Works and Transport for the permission granted to him to take samples from the three batch plants under study, and particularly Mr. Nicolas Wakil, head of the laboratory of the above Ministery, for his suggestions and kind assistance.

At last, the author wishes to thank the staff of the Soil Mechanics and Materials Laboratories at the American University of Beirut for their sincere cooperation.

ABSTRACT

This paper presents a study of the quality of asphaltic concrete hot mixes produced by three of the important batch plants that operate in Lebanon, namely, the Beirut Municipality plant (Beirut River Boulevard), the Mkalles plant and the Mdayrej plant. The first is under the supervision of the Beirut Municipality, while the latter two are administered by the Lebanese Ministery of Public Works and Transport.

In this investigation the mechanical properties of the samples obtained from the plant mixes are studied using the Marshall Test and a Modified Triaxial Test.

Furthermore, the constituent materials, i.e. the bitumen and the aggregates used, are subjected to various tests to determine their important physical properties. The values obtained from these tests are then compared with standard specifications given by the AASHO and the Asphalt Institute.

A general description of plant operation practices, with several recommendations for improving the plant management, is also included in the study.

From the results of this investigation it is found that the mixes produced by the above-mentioned three plants do not comply fully with standard specifications for acceptable performance. Consequently, for each plant under study, a mix design is prepared, making use of the given aggregate and bitumen, that improves considerably the quality of the mix.

In addition, it is observed that a Modified Triaxial Test can be conducted, by making use of the Hveem Stabilometer and applying the principles underlying the Smith Triaxial Test, to find the angle of internal friction and the cohesion of the specimen under study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

1.0 INTRODUCTION

1.1 General

An important and major part of roads and streets in Lebanon are asphalt-surfaced. Presently, 4000 miles of flexible pavements serve 130,000 motor vehicles in this country.

Proper design of asphaltic concrete hot mixes is most essential, and should be studied thoroughly to assure the safety and soundness of the rural highways and city streets. Two main requirements must be satisfied; namely, the constituent materials must satisfy the minimum requirements for satisfactory performance, and the resulting mix must have mechanical properties that will enable it to withstand the applied design loads during the lifetime of the pavement.

In order to assess properly the performance of any highway pavement, one must have some conception of what factors or qualities are desirable, necessary, and sufficient in the pavement itself. To function properly, a pavement (1) must be stable (i.e., able to support the traffic loads imposed upon it without cracking or distorting), (2) must be durable (i.e., able to resist the forces of weathering and abrasive action without decomposing or disintegrating), (3) must be flexible (i.e., able to adapt itself to those inevitable adjutments in the base and/or subgrade, including deep-seated settlements), and (4) must be safe (i.e., able to provide adequate resistance to skidding and freedom from ruts and bumps which may effect in any way the driver's control over the vehicle.

The present investigation aims at giving a comprehensive analysis of the production and plant operation practices of three of the important batch plants that operate in Lebanon in order to find out why most of the flexible pavements in this country lack the desirable qualities given previously. The first two of the factors mentioned are the ones that are of interest to us in the present study.

The plants under investigation are the Beirut Municipality plant located on the Beirut River Boulevard and operating under the administration of the Beirut Municipality, the Mkalles plant located in the suburb of Beirut, and the Mdayrej plant located on the road to Damascus. The latter two plants are under the supervision of the Lebanese Ministery of Public Works and Transport.

The first of these plants supplies asphalt mixes that are used mainly for maintenance purposes within the city of Beirut and for resurfacing of old roads. The second provides asphalt mixes that are used to pave new streets and highways within and in the vicinity of the capital; while the production of the third plant serves the surfacing of highways and rural roads in Mount - Lebanon.

1.2 Objectives of Investigation

The principal objectives of this investigation are the following:

a) To determine the strength properties of the mixes produced by the three plants under study using empirical and semi-empirical procedures. Similarly, to evaluate the physical properties of the constituent materials of the mixes.

b) To compare the test results with standard specifications for satisfactory pavement performance.

c) For a plant mix not satisfying the specification requirements, to suggest a mix using the same constituent materials, i.e. the dry aggregates and bitumen, that is presently at use in the plants. To evaluate the strength properties of the mixes thus produced using the same tests as in item"a" above.

d) To give a general description of plant operation practices of the three batch plants under investigation. Furthermore, to suggest recommendations that will help improve the efficiency of the plants and the quality of their product.

1.3 Scope of Investigation

The strength properties of the samples obtained from the plants are determined by the Marshall Test and a Modified Tri-axial Test conducted in the Hveem Stabilometer.

The constituent materials are tested for identification purposes and for the determination of their physical properties. This includes the Penetration, Viscosity and Distillation Tests for the asphalt cement, and the Sieve Analysis, Specific Gravity, Los Angeles Abrasion and Sand Equivalent Tests for the aggregates.

The asphalt cement content of the samples obtained from the plants is found by the Centrifugal Extraction Test.

The test results are compared with the AASHO and the Asphalt Institute specifications for acceptable pavement performance. For a plant mix not satisfying the above specification requirements, a mix design is suggested by making use of the coarse and fine aggregates and the filler material to meet the specification limits. Using the optimum asphalt cement content determined from the Marshall Test and the proposed aggregate gradation, test specimens are prepared and their strength properties determined by the Marshall and Modified Triaxial Tests.

A concise description of plant operation practices is included, with several suggestions for the improvement of the quality of mix produced by the plants.

CHAPTER TWO

2.0 REVIEW OF LITERATURE AND MIX DESIGN METHODS

2.1 Review of Literature

Great significance was at one time attached to the grading of the sand in asphaltic mixes and the methods by which the combined grading of the sand and stone could be adjusted in order to obtain a dense graded mixture. The significance of the asphalt content in relation to the aggregate grading was not fully understood, but during and after the Second World War a great deal of research work was carried out on the properties of dense asphaltic concrete mixes. Probably the most important contribution to the understanding of the performance of these mixes has come from the Shell laboratories in Amsterdam. Van der Poel, Saal, Nijboer[12] and others investigated the plastic behaviour of asphalt mixes.

It was quite suddenly appreciated that asphalt was an elasto-plastic material and that the plastic properties of the mix could be more important than the previously accepted strength criteria. At the same time, research workers in America and Canada, notably Hveem and Marshall and, later, Mack and McLeod, became concerned with deformation in asphalt surfaces on roads with heavy traffic, and on runways carrying heavy aircraft. There was a sudden realisation that the behaviour of asphalt under stress was in many ways similar to that of soil under stress, and the plastic and elastic properties of various asphaltic mixes were investigated by means of the triaxial cell. The analogy between soil and as-

Note References are indicated by their number in the bibliography.

phalt thus proved useful.

From the results of the triaxial tests the values of the internal friction and cohesion were determined as in the case of a soil. The grading of the mineral aggregate in an asphaltic mix was shown by Nijboer[12] to have a relatively small influence on the angle of internal friction provided sufficient air was contained within the mixture to prevent all the stress being transmitted as fluid pressure to the asphalt. If the asphalt content were increased to such a figure that the voids were nearly filled with asphalt, then the value of internal friction fell rapidly and the strength or stability of the asphaltic mix was greatly reduced.

With the advent of the Marshall, Hubbard-Field, Hveem and Smith Triaxial mix design methods, it was assumed, for some time, that the stability or the resistance to deformation of an asphalt concrete surfacing was measured by the Marshall or other stability tests. There seems to have been a desire to increase the stability of road-surfacing and airfield-surfacing mixtures as measured by, for example, the Marshall test, which in general led to the use of lower asphalt contents. Metcalf[10] has suggested that the bearing capacity is a function of the ratio of the Marshall Stability to the Marshall Flow, but this seems to be contradicted by White[23], who shows that low stabilities in asphaltic concrete in Oregon are not indicative of pavement instability. Puzinauskas[14] has further shown that the orientation of the aggregate particles in a test specimen significantly affects the measured stability. He concludes that, since the orientation of the aggregate particles in a pavement differs from that in the laboratory-compacted specimens it is not possible to relate the stability measured on laboratory specimens to that measured on cores cut from a pavement. Furthermore, Csanyi, Cox and Teagle[4] have investigated the effect of the filler on the Marshall and Hveem stability measurements and have also concluded that there is no correlation between the laboratory-measured stability and the trafficability of the pavement. In light of this work it is difficult to understand the emphasis that has been placed on laboratory-measured stabilities when there seems to be no strict relationship between these and the performance of the finished pavement, at least as far as road pavements are concerned.

Hatherly and Leaver[6] think that the desire to achieve high values for laboratory-measured stability applies mainly to the use of the Marshall design method, possibly because this method has been very widely used for the particular problem of the design of military airfield surfacings, where a very high shear strength is necessary to prevent pushing and rutting of the surfacing, particularly on taxi-ways and at the runway ends.

2.2 Review of Mix Design Methods

2.2.1 General

In order to study and evaluate the performance of asphaltic concrete hot mixes, several tests have been developed, some empirical and some semi-empirical. The following are the major types of tests used in the United States[5]:

i) Marshall

ii) Hubbard-Field

iii) Hveem

iv) Smith Triaxial

The above tests may be used for both design and evaluation. Specifically, they aim at accomplishing one or more of the following[11]:

(1) Providing a quantitative measure of the resistance of the material to deformation and flow.

(2) Assisting in the design of the mixture i.e. the determination of suitable proportions of constituents and the suitability of a given constituent.

(3) Studying the effect of changing the properties of a constituent.

(4) Controlling the manufacture of a mixture.

In achieving these purposes for the plant mixes under study, the empirical Marshall Test and the semi-empirical Triaxial Test were used, and these test methods will be reviewed herein:

a - Marshall Method (U.S. Corps of Engineers Method of Mix Design)

The concepts of the Marshall Method of designing paving mixtures were formulated by Bruce Marshall, formerly Bituminous Engineer with the Mississippi State Highway Department. The U.S. Corps of Engineers, through extensive research and correlation studies, improved and added certain features to Marshall test procedure, and ultimately developed mix design criteria. This method is possibly the most widely used of all the available design methods. It probably owes its popularity to the fact that it is essentially simple to perform and does not require a great deal of sophisticated equipment.

The Marshall Method is applicable only to hot-mix asphalt paving mixtures using penetration grades of asphalt cement and containing aggregates with maximum sizes of 1 inch or less; the method may be used for both laboratory design and field control of asphalt hot-mix paving.

The Marshall Method uses standard test specimens of $2\frac{1}{2}$ inches height and 4 inches diameter. These are prepared using a specified procedure for heating, mixing and compacting the asphalt-aggregate mixtures. The two principal features of the Marshall Method of mix design are a density-voids analysis and a stability-flow test of the compacted test specimens.[19]

The stability of the test specimen is the maximum load resistance in pounds which the standard test specimen will develop at 140°F when tested as specified by the Corps. The flow value is the total movement or strain, in units of 1/100 inch, occurring in the specimen between no load and maximum load during the stability test.

Suitable criteria based upon results obtained from the Marshall Test that were established by the U.S. Corps of Engineers are the following:

TABLE 1

Criteria for Marshall Test Limits

(From Highway Engineering Handbook[24])

Test Property	Type of Mix	Criteria for 100 psi tires
Stability	All[x]	Min. 500 Lbs.
Unit Weight	-	Not Used
Flow	All[x]	Max. 20
% Air Voids Total Mix	Asphaltic Concrete	3 - 5
	Sand Asphalt	5 - 7
	Binders	4 - 6
% Agg. Voids Filled	Asphaltic Concrete	75 - 85
	Sand Asphalt	65 - 75
	Binders	65 - 75

[x]Asphaltic Concrete, sand asphalt, and binders.

Note The criteria shown above for 100 psi tires are often used in the design of highway pavements, but they are subject to modification where substantial experience indicates the need for such a change.

b - <u>Triaxial Compression Method</u>

The empirical procedures for mixture design all have a major weakness in that their use must be limited to the conditions for which the initial correlations between results obtained on laboratory specimens and field performance of the mixture in place were established. In spite of this serious limitation, many thousands of miles of asphalt paving mixtures have been designed by these empirical methods and have given adequate service. There has always been a need for a more rational approach to the problem of bituminous-mixture design. The triaxial compression test is a step in this direction.

It is known that the area of a flexible pavement under a wheel load tends to be confined by the frictional forces of the load and by support from the surrounding material. Therefore, a much higher bearing capacity of the mixture results than if the mixture were in the unconfined state. The effect of this lateral support obtained in the field is duplicated in the triaxial test. This type of test is generally applied to the class of materials that are somewhat plastic in nature like soils and bituminous mixtures.

A paving mixture develops resistance to displacement due to load by two means. The first is by interlocking and internal friction of the aggregate. The second is due to the shearing resistance of the bituminous material. The first of these resistances has become known as internal friction. The second is usually referred to as cohesion.

There are two methods of conducting triaxial tests to evaluate paving mixtures. The first method, known as the open system, is the usual type, wherein a constant confining pressure is applied to a specimen placed in a triaxial cell, and the compressive strength determined under those conditions. The second method is called the closed system. This is the method used by Smith in developing his method of mix design. The specimen is confined on its lateral surface only by a liquid inside a rigid cell. A vertical load is applied to the specimen, which causes pressure to develop in the confining liquid. For fixed increments of vertical load, the transmitted lateral pressure is determined. These values are plotted in a fashion similar to Figure 1. In the early stages of the test, the relationship between lateral transmitted pressure and vertical applied stress is curved. Eventually, a straight line results. The slope of this straight line is found, from which the angle of internal friction and the cohesion of the mix are determined. The details of this procedure are found in Appendix A.

Compared with the open system triaxial test, the closed system test has the main advantage of requiring fewer specimens to obtain the values of cohesion and angle of internal friction. Whereas at least three specimens are required in the open system to determine the cohesion and angle of internal friction values of a mix from the Mohr Circles' envelope, only one specimen is enough in the closed system to give the magnitude of these strength properties.

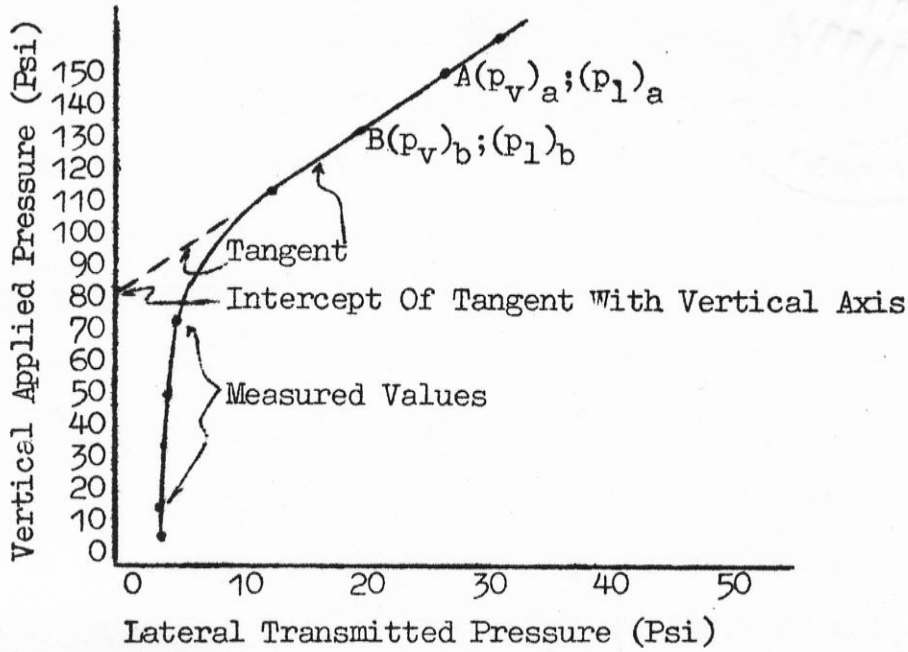


FIG. 1. Smith Triaxial Compression Stability Test Curve[16]

The closed system triaxial compression method proposed in this study is in fact a combination of the Smith Triaxial Method and the Hveem Method of Mix Design.

The Smith Triaxial Method is applicable only to dense paving mixtures using penetration grades of asphalt cement and containing aggregates up to 1 in. maximum size. This method, developed by Vaughn R. Smith of the California Research Corporation after considerable research and investigation, is intended only for the laboratory design of paving mixes[16]. It is a powerful research tool for determining the fundamental strength properties of compacted paving mixtures.

The Smith Triaxial Method uses standard test specimens of 3.82 in. diameter and 8 in. height. These are prepared using a specified procedure for heating, mixing, and compacting the asphalt-aggregate mixtures. The two principal features of the Smith Triaxial Method are a density-voids analysis and a triaxial stability test of the compacted test specimens. The latter utilizes a closed system triaxial test cell, in which the lateral transmitted pressures are determined for corresponding vertical loadings on the test specimens at ordinary room temperature[9].

2.2.2 Particular to this Study

In this investigation a modified triaxial test was developed to evaluate dense graded hot asphalt paving mixtures in the laboratory, which consists of conducting the Smith Triaxial Test in the Hveem apparatus. This test will be referred to hereinafter as the Modified Hveem Triaxial Test. The above method has the advantage of allowing the performance of the closed triaxial test in laboratories which may not be equipped by the Smith Triaxial cell but may possess the Hveem Stabilometer. Furthermore, the adoption of the Hveem method of compacting the test specimen by the use of the mechanical kneading compactor permits a better approximation to the type of compaction obtained in the field by using conventional tamping equipment[25].

The Hveem Method, developed by Francis N. Hveem for the California Division of Highways, is applicable to paving mixtures using both penetration grades and liquid grades of asphalt and containing aggregates up to 1 in. maximum size. The method is applicable to the design of hot asphalt paving mixtures. To date, the method has been used principally for the design of dense paving mixtures. This method may be used for both laboratory design and field control of hot-mix asphalt paving[17].

The Hveem Method uses standard test specimens of 2.5 in. height and 4 in. diameter. The Stabilometer Test (to determine the Hveem Stability value) utilizes a special triaxial type testing cell for measuring the resistance of the compacted mix to lateral displacement under vertical loading. The test specimens are maintained at 140°F.

The principle behind this design method is quite different from that in the Marshall Method. The aim in this instance is to use the highest bitumen content which will provide an adequate resistance to deformation, taking thus advantage of the greater durability that undoubtedly results from the use of the highest possible bitumen content, while at the same time retaining a minimum percentage of air voids. It is also general practice in the Smith Triaxial Method to use the highest asphalt content that satisfies the other strength requirements, but the only indication that a minimum asphalt content is desirable to acquire an adequate durability and length of life is given by the Asphalt Institute in their modification of the Marshall test procedure, which requires a minimum void content in the compacted aggregate. A similar requirement associated with all the design methods would be advantageous since it seems to have been established quite clearly that the durability of an asphaltic concrete wearing course, and to a much less extent of an asphaltic concrete base course, is a function of the asphalt content of the mixture[6].

CHAPTER THREE

3.0 SAMPLING PROCEDURE

3.1 Introduction

For each of the plants under study, five samples of constituent materials and bituminous mixtures were taken. The sampling was done during the period September 1 to November 15, 1967 at approximately regular intervals.

3.2 Sampling of the Coarse Aggregate, Fine Aggregate and Filler.

The sampling was performed following AASHO Designation: T 2-60.

The coarse and fine aggregates and the filler material are stockpiled in all three plants under study. In sampling material from stockpiles it is very difficult to ensure representative samples, due to the segregation which usually occurs when material is stockpiled, with the coarser particles rolling to the outside base of the pile. To minimize this effect, material was taken from various levels and locations and the required amount of material chosen by quartering.

For the Municipality Plant, where the maximum size of aggregate was $\frac{3}{8}$ in. approximately five kg. samples were taken of each of the aggregates, to satisfy AASHO sampling requirements as detailed in T 2-60[22].

For the Mkalles and Mdayrej Plants where the maximum size of coarse aggregate was $\frac{1}{2}$ in. 10 kg. samples of coarse aggregate and 5 kg. samples of fine aggregate and of filler material were taken at every visit to satisfy AASHO sampling specifications.

3.3 Sampling of the Asphalt Cement

The sampling of the asphalt cement was done following the recommendations of AASHO Designation: T 40-56[22].

The asphalt cement was sampled with a small-mouth can while the bitumen was in the liquid state.

Great care was taken to insure that the samples were not contaminated with dirt or other extraneous matter and that the sample container was perfectly clean and dry before filling.

Immediately after filling, the sample container was tightly closed and properly marked for identification.

3.4 Sampling of the Bituminous Paving Mixtures

AASHO Designation: T 168-55 was followed to sample the bituminous paving mixtures.

Every precaution was used to obtain samples that were truly representative.

Care was taken in sampling to avoid segregation of coarse aggregate and bitumen. Care was also taken to prevent contamination by dust or other foreign matter.

The amount of the sample was governed by the maximum size of particle of mineral aggregate in the mixture. The maximum size of particle for the Beirut Municipality Plant being $\frac{3}{8}$ in., approximately 4 kg. samples of bituminous mixture was taken for each sample to satisfy the AASHO Designation: T 168-55[22] requirements.

For the Mkalles and Mdayrej Plants, approximately 6 kg.

samples of the bituminous mixture was taken for the same purpose.

A batch freshly discharged from the pugmill into the truck was sampled by means of a shovel which was moved from the bottom to the top of the pile in a straight groove and the sample was then reduced to the required size by remixing and quartering. The sample was then put in a box, properly covered and taken to the laboratory for testing.

CHAPTER FOUR

4.0 DESCRIPTION OF TESTS AND PROCEDURES

4.1 Marshall Test

The Marshall Test was performed using standard methods given by ASTM Designation: D 1559-60T[7] and the Asphalt Institute's Manual Series No 2[16,17].

For each plant under study, eighteen samples were prepared having asphalt contents varying from 3.5 to 6.0 per cent by total weight of mix, with three specimens prepared for each asphalt content. For the three plants therefore, fifty four samples were tested by the Marshall Method. The mix gradation was that actually in use at the plants. From the test results the optimum asphalt content value was determined.

Similarly, for each plant, five samples of the actual plant mix were sampled and tested by the Marshall Method, a total of fifteen tests. Two more samples per plant, i.e. six test specimens, were tested using the proposed mix gradation and the optimum asphalt content determined previously. All test results appear in Appendix B.

4.2 Modified Hveem Triaxial Test

In studying the proposed mix gradation for each plant by the Modified Hveem Triaxial Test four specimens were prepared per plant: two at the optimum value of asphalt content as obtained by the Marshall Test and two having asphalt contents differing by ½ per cent on either side of optimum. In addition to the above, two specimens were prepared from the actual mix sampled from each plant and tested by the Modified Triaxial technique. Therefore, for the three plants under investigation, a total of eighteen Modified Triaxial Tests were conducted, twelve using proposed mixes, and six using existing mixes.

4.2.1 Preparation of Batch Mixes

The aggregate was left in the oven at 110°C for 24 hours prior to testing. 1100 grams of the aggregate was put in a mixing pan and tared. Then the aggregate was heated to a temperature of 135 - 149°C on a Bunsen Burner.

The asphalt cement was heated in a pouring pan on hot plate to a temperature of 149 - 176°C and was stirred frequently to avoid local overheating.

As soon as the temperature of the aggregate and asphalt cement was within the specified range, the asphalt cement was added to the aggregate and the two mixed thoroughly in an electric mixer. Immediately after, the mixture was compacted.

4.2.2 Compaction

In advance of preparing the batch mix, the compaction mold assembly was heated to approximately 65°C.

After drying the heated mold, it was oiled with a vegetable oil together with the compaction foot. The mold was then fixed tightly on the compactor base. A filter paper was put at the mold-bottom.

The hot mixture was introduced into the heated mold by means of a large spoon. The mix was rodded twenty times in the center of the mass and twenty times around the edge with a bullet-nosed steel rod, $\frac{3}{8}$ in. diameter and 16 in. long.

The compaction of the test specimen was accomplished by a special tamping shoe or kneading compactor which imparts a kneading action consolidation by a series of individual impressions made with a ram having a face shaped as a sector of a 4 in. diameter circle. This method was adopted because laboratory test results on samples so compacted and those of the same mix cored from completed pavements gave comparable results. Like correlation was not found between field samples and those compacted in the laboratory solely by static or impact methods[13].

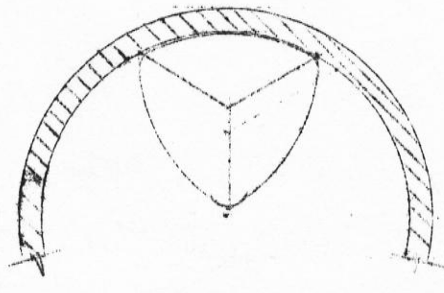


Diagram of Tamping Foot for Kneading Compactor

At each application of the foot a pressure of 900 psi was applied, subjecting the specimen to a kneading action without impact over an area of approximately 2.13 in^2. Each pressure was maintained for 2 seconds and 100 tamping blows were applied.

Immediately after, the mold assembly was carried to the compression machine and was subjected to a "leveling-off" load of 1000 psi. This static load was maintained for a period of 3 minutes. Afterward, the mold was cooled with running water and the specimen carefully extruded.

The determination of the bulk specific gravity was achieved by weighing the compacted specimen in air and water. Finally, the height of the specimen was measured by a Vernier caliper.

The compaction procedure was not standard to any mix-design method and was adopted for this project after experimenting with scores of specimens of different combinations of applied pressure and number of tamping blows. The specimens were then cut with an electric saw and the mix texture observed. The arrangement that gave a uniformly compact mix with a bulk specific gravity of approximately 2.3 for the proposed mix was adopted.

4.2.3 Testing

Prior to testing, the specimen was capped carefully, using a cement mortar consisting roughly of 3 cement + 2 gypsum by volume. By capping, we were able to achieve a specimen of constant height with flat and square surfaces and thus insure a uniform application of vertical stress throughout the specimen surface.

The specimen was left in a water bath at 60°C for a minimum period of 1 hour before testing.

The Tinius - Olsen compression machine was then adjusted for a head speed of 0.05 in. per minute.

The Hveem Stabilometer stage was adjusted such that 2.40 in.

of rubber diaphragm was effective upon the test specimen and the clamp at the base of the stabilometer shell was tightened.

The specimen was removed from the water bath, dried and firmly seated in the stabilometer.

The follower was then placed on top of the specimen and the entire assembly positioned in the compression machine for testing.

Using the displacement pump, the pressure in the stabilometer system was raised until the test gauge read exactly 5 psi. The test gauge was tapped lightly to assure an accurate reading.

The displacement pump valve was closed, taking care not to disturb the 5 psi initial pressure.

Test loads were then applied using a head speed of 0.05 in. per minute. Readings of test gauge were then recorded at test loads of 500 lbs., 1000 lbs., and each 1000 lbs. thereafter up to a maximum of 17,000 lbs.

At the end of the test, the test load was removed and the pressure on the test gauge reduced to zero by means of the displacement pump and the specimen removed carefully from the stabilometer chamber.

It is very important that all air, even the smallest bubbles, be excluded from the system. After finishing the test, the displacement pump was filled with the stabilometer oil, with the angle valve connecting the inner chamber closed. The rubber diaphragm was tapped lightly with fingers to remove any air. The machine was rocked about to eliminate bubbles near the opening.

4.3 Sand Equivalent Test

F.N. Hveem of the California Division of Highways has developed this test for quick field determination of the presence of undesirable quantities of clay-like materials in soil-aggregate mixtures on a volume rather than a weight basis. The standard test was performed according to AASHO Designation T 176-56. The "sand equivalent" is the ratio between the volume of sand (Sand Reading) and the combined volumes of sand and expanded, saturated clay (Clay Reading), expressed as a percentage. Thus, higher values of the sand equivalent indicate superior materials.

4.4 Sieve Analysis Test for Fine and Coarse Aggregates and Filler

Standard test performed according to ASTM C136.

4.5 Los Angeles Abrasion Test

Standard test performed according to ASTM C131.

4.6 Specific Gravity Test for Coarse Aggregate

Standard test performed according to ASTM C127.

4.7 Specific Gravity Test for Fine Aggregate and Filler

Standard test performed according to ASTM C128.

4.8 Penetration Test

Standard test performed according to ASTM D5.

4.9 Saybolt Furol Viscosity Test

Standard test performed according to ASTM E102.

4.10 Extraction Test

Standard test performed according to ASTM D2172.

4.11 Distillation Test

Standard test performed according to ASTM D402.

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

5.1 Marshall Test Method

5.1.1 Determination of Optimum Asphalt Content

The optimum asphalt content for each of the plants was found by the Marshall Method using the aggregate batch mix that is used in each of the plants.

The optimum asphalt content of a paving mix is determined from the data obtained from the Marshall Test, i.e. the bulk specific gravity, the stability, the flow and the aggregate specific gravity. Consideration is given to four of the test property curves illustrated in Fig.2 (Appendix B) in making this determination. From these data curves, asphalt contents are determined which yield the following:

(a) Maximum stability.

(b) Maximum unit weight.

(c) Median of limits given in Table 1 (Chapter Two) for per cent voids in total mix.

(d) Median of limits given in Table1for per cent aggregate voids filled with asphalt.

The optimum asphalt content of the mix is then the numerical average of the values of the asphalt content determined as noted above.

i) BEIRUT MUNICIPALITY PLANT

In applying the above criteria to the mix produced at this plant, it was found that the percent voids in the total mix as well as the per cent aggregate voids filled with asphalt fall outside the acceptable limits. For this reason, the optimum asphalt content was determined based on factors (a) and (b) alone.

(a) Asphalt content at maximum stability (per cent) 5.00

(b) Asphalt content at maximum unit weight (per cent) 5.50

Optimum asphalt content $\frac{5.00 + 5.50}{2}$ 5.25

Table 3 (Appendix B) gives the values of asphalt content actually in use at the plant. A comparison between the optimum asphalt content value and the plant values shows that the mix produced by the plant is deficient in asphalt cement.

Similarly, the sieve analysis data (Figs.23, 24 and 25, Appendix D) show that the gradation of the mix used actually in the plant falls almost completely outside specification limits given by the Asphalt Institute[18] for dense graded mixes.

Therefore, to improve the quality of the plant mix using the Marshall Method, it is necessary to use the optimum asphalt content value found above and a mix gradation that meets the specification limits.

Based on the sieve analysis data of the fine aggregate and filler (Figs.26 and 27, Appendix D) a mix is proposed, obtained by trying with numerous combinations between the two constituents, that meets much better the specification requirements than the actual plant mix. This mix (Fig.28, Appendix D) represents the best gradation that can be obtained by using the given fine aggregate and filler material now available at the plant.

The proposed mix composition is 35 per cent fine aggregate and 65 per cent filler by weight.

Table 3 (Appendix B) gives the Marshall Test data for 5 samples from the plant. It is obvious that all the samples fail to meet the requirements for air voids (3 - 5 per cent) and voids in mineral aggregates filled (75 - 85 per cent).

Table 4 (Appendix B) shows the Marshall Test data for 2 samples obtained by using the proposed mix and the optimum asphalt content. The increase in stability value and decrease in the flow value show that a great improvement in the quality of the mix is achieved. Here again the requirements for air voids and voids in mineral aggregates filled are not met chiefly because the fine aggregate and the filler material available at the plant presently in no case will yield a blend that meets fully the specification requirements for a dense graded mix. The difference from the accepted values, however, is narrowed.

To achieve a mix that meets the U.S. Corps of Engineers criteria fully, it is necessary to change the gradation of the fine aggregate and the filler themselves. At the same time it is advisable to use aggregates of higher density by quarrying them from a different source. In this way we shall be able to get a mix that meets fully the specification limits for the gradation as well as per cent air voids and per cent voids in mineral aggregate filled.

ii) MKALLES PLANT

Here again, the optimum asphalt content was determined by using criteria (a) and (b) discussed earlier:

(a) Asphalt content at maximum stability (per cent)	4.75
(b) Asphalt content at maximum unit weight (per cent)	4.25
Optimum asphalt content $\frac{4.75 + 4.25}{2}$	4.50

Table 6 (Appendix B) shows the values of per cent asphalt content used actually in the Mkalles plant. It is seen that these values are slightly lower than the optimum value found above.

Similarly, the sieve analysis data (Figs.29, 30 and 31, Appendix D) show that the gradation used actually in the plant falls almost entirely outside the specification limits given by the Asphalt Institute[18] for dense graded mixes.

To overcome these shortcomings, a mix is proposed that uses the optimum asphalt content found above and a new aggregate gradation.

The proposed mix composition is 20 per cent coarse aggregate, 35 per cent fine aggregate and 45 per cent filler by weight.

The gradation of this mix falls almost wholly within the specification limits (Fig.35, Appendix D). This gradation was obtained after several trials and represents the best result that can be achieved by using the available coarse aggregate, fine aggregate and filler. The sieve analysis data of these constituents appear in Appendix D (Figs. 32,33 and 34).

In Table 6 (Appendix B) we find the Marshall Test data for 5 samples from the plant. Whereas the stability values are exceeding the minimum of 500 lbs. specified for highways, the flow value specified is not always satisfied. On the other hand, the air voids and air voids in the mineral aggregate filled are seen to fall outside the range given by the U.S. Corps of Engineers,[24] as well as the range specified by the Asphalt Institute.[17]

Table 7 (Appendix B) gives the Marshall Test data for 2 samples obtained by using the proposed mix and the optimum asphalt content determined previously. The increase in the stability and per cent air voids in aggregate filled is seen to be appreciable when compared to the corresponding values of the plant mix (Table 6). The per cent air voids in mix value (6 per cent) is quite near the required value (3 - 5 per cent). In fact, the Asphalt Institute stipulates that " In extreme cases where it is not possible or practical ... to meet the requirements of the design criteria, a tolerance of one per cent of air voids may be permitted"[17].

Thus, with the flow values of the proposed mix quite within the allowable range, it is seen that only the per cent aggregate voids filled requirement is not met.

Here again, as in the case of the Beirut Municipality plant, it is necessary to alter the gradation of the constituent materials (coarse aggregate, fine aggregate and filler) and have aggregates of a higher density to be able to meet the minimum requirements for per cent of aggregate voids filled.

iii) MDAYREJ PLANT

The optimum asphalt content was found by the same procedure as before:

(a) Asphalt content at maximum stability (per cent) 5.00

(b) Asphalt content at maximum unit weight (per cent) 4.00

Optimum asphalt content $\frac{5.00 + 4.00}{2}$ 4.50

Comparing the per cent asphalt content values actually in use at the plant, appearing in Table 9 (Appendix B), with this optimum value, it is found that in the case of this plant also the mix produced has an asphalt content lower than the optimum value. Furthermore, the sieve analysis data (Figs.36, 37 and 38, Appendix D) show that the actual plant dry mix does not satisfy the Asphalt Institute[18] specification requirements.

For improved results, it then becomes necessary to use the optimum asphalt content and a different aggregate gradation from the one presently in use at the plant.

This proposed mix is composed of 30 per cent coarse aggregate, 10 per cent fine aggregate and 60 per cent filler by weight. The resulting mix gradation (Fig.42, Appendix D) is seen to almost satisfy the specification limits given by the Asphalt Institute[18] for a dense graded mix. The proposed mix was achieved after many trials with the constituent materials, the sieve analysis of which appear in Appendix D (Figs.39, 40 and 41).

Table 9 (Appendix B) gives the Marshall Test data for 5 samples from the plant. The minimum stability and flow values are met by all the specimens tested. Once again the per cent air voids and the per cent aggregate voids filled are out of the acceptable range. This is due mainly to the poor gradation of the plant mix used.

Table 10 (Appendix B) gives the Marshall Test data for 2 samples prepared by using the proposed mix and the optimum asphalt content. The improvement in all the test properties is obvious. It is to be noted that the per cent voids in the total mix and the per cent aggregate voids filled are out of the specified ranges. However, it is seen that these values for the proposed mix are much closer to the design criteria than the values obtained from the plant mixes.

5.1.2 Test Data and Property Curves

The test data and property curves of the Beirut Municipality, Mkalles and Mdayrej plants appear in Appendix B.

5.2 Modified Hveem Triaxial Test

The mixes resulting from the best possible combinations of the various aggregates of each plant, and the corresponding optimum asphalt content obtained by the Marshall Method were tested for stability by the Modified Hveem triaxial procedure described earlier. For purposes of comparison, for each proposed plant mix, two more samples were prepared, the asphalt content of which differed by 0.5 per cent from the optimum (one above and one below the optimum value).

It was found that by using the Hveem Stabilometer, the shape of the Vertical Applied Pressure vs. Lateral Transmitted Pressure curve was similar to that of the standard Smith Triaxial Test curve, where a much taller specimen is used (See Fig.1, Chapter Two, and Figs.5 - 22, Appendix C). It is noteworthy, however, that a much higher vertical stress is required to give the same lateral pressure. This phenomenon can be considered to be due to the bulging of the taller specimen.

The specimens prepared by the proposed mix gradation at optimum asphalt content gave the highest value for the angle of internal friction among all the specimens tested. Thus, the optimum asphalt content determined by the Marshall Method is seen to agree with that of this method.

It was observed that the specimens prepared by the actual plant mix resulted in slightly higher cohesion values than those prepared by the proposed mix at the optimum asphalt content (See Figs. 5 - 22, Appendix C). To explain this result, note that the intercept on the vertical axis of the tangent to the Triaxial Compression Stability Test curve was found to equal $2c \tan(45 + \phi/2)$, as proved in Appendix A. The values of the intercepts for the plant and proposed mixes were found to be very close to each other. However, as the angle of internal friction ϕ of the plant mixes was appreciably lower than that of the proposed mix, the cohesion c for the plant mixes came of the above pattern.

The relatively high values of the cohesion can be considered to be due to some air being trapped in the Hveem Stabilometer even after taking all the necessary precautions to avoid its happening.

Comparing the results of the proposed mix specimens for the Municipality and Mkalles plants, we find that the values of internal friction of the specimens of the latter plant are lower than those obtained from the Municipality plant. Here, it is worth noting that the highest value of Marshall stability for the Mkalles plant is smaller than the corresponding value for the Municipality plant.

As to the bulk specific gravity of the specimens tested, it was found that here too the agreement was close with the Marshall Method results. The optimum asphalt content for stability is the same as that for maximum bulk density. Thus, it becomes evident that a considerable increase in the bulk specific gravity can be achieved by using the proposed mix at the optimum asphalt content.

5.3 Sand Equivalent Test

Minimum permissible values from the 1960 California specifications are 35 to 50 per cent for aggregates for various types of asphaltic concrete[13].

For the filler from the Beirut Municipality plant, it is seen that the sand equivalent values largely exceed the minimum specifications (Table 10, Appendix E).

The sand equivalent values for the filler material from the Mkalles plant fall within the minimum permissible range of 35 to 50. This shows that the filler material is quite rich in montmorillonite and other troublesome clays which have high lubricating effects (Table 11, Appendix E).

The sand equivalent values for the filler material from the Mdayrej plant exceed satisfactorily the minimum permissible values (Table 12, Appendix E).

5.4 Sieve Analysis Test

The sieve analysis test results appear in Appendix D.

5.5 Los Angeles Abrasion Test

The Asphalt Institute stipulates that " ... the percentage of wear for coarse aggregate used in base, binder or leveling courses shall not be greater than 50 when tested by Method of Test Abrasion of Coarse Aggregate (ASTM Designation C131). The percentage of wear of coarse aggregate used in wearing course mixes shall not be greater than 40"[18]. In all three plants under investigation, Tables 13, 14 and 15 (Appendix E) give the percentage of wear at most equal to 40, showing that the coarse aggregate actually in use in these plants is strong enough to be used in a wearing course mix.

5.6 Specific Gravity Test for Coarse Aggregate

The coarse aggregate specific gravity test results appear in Appendix E (Tables 17 and 18).

5.7 Specific Gravity Test for Fine Aggregate and Filler

The fine aggregate and filler specific gravity test results appear in Appendix E (Tables 16, 17 and 18).

5.8 Penetration Test

The penetration values (Tables 19, 20 and 21, Appendix F) show that the grade of the asphalt cement in use at the three plants is 85 - 100 penetration. The samples from the Mkalles plant gave results exceeding penetration 100 slightly; however, the asphalt cement from this plant can still be considered of the above grade as the next higher grade is 120 - 150.

It is preferable to replace the 85 - 100 penetration asphalt cement actually in use at the plants with a 60 - 70 grade. In fact, for a country like Lebanon having a hot and temperate climate, the Asphalt Institute[20] recommends to design heavy traffic streets and highways by using a 60 - 70 penetration asphalt cement. On the other hand, streets and highways serving medium to light traffic are recommended by the Institute to be paved with 85 - 100 penetration asphalt cement.

The selection of the correct grade of bitumen for a particular application is still a matter about which it is difficult to be precise. There are sound economic and technical reasons for selecting the softest grade of bitumen that will give a satisfactory performance. The temperature at which an asphaltic concrete can be mixed and laid increases as the penetration of the bitumen decreases. More heat input during manufacture is therefore required per unit weight of material, with a consequent increase in cost.

The performance of asphaltic concrete obviously depends on the properties of the bitumen after the material has been mixed and laid. This matter has recently received quite a lot of attention, and Bright and Reynolds[2] investigated the effect of mixing temperature on the penetration of a number of bitumens whose original penetration was in the range of 85 - 100. Normally, mixes containing this type would be mixed at a temperature[6] of between about 290 - 320°F (143 - 160°C), and the investigation showed that the particular bitumens studied retained only 60 per cent of their penetration when used in mixtures heated to a temperature of 290°F, and only 50 per cent of their penetration was retained when they were heated to 350°F.

The length of mixing time exerts a significant influence on the loss of penetration of the bitumen. Jackson and Brien[7] suggest that the mixing time should be the minimum required to give uniform coating of the aggregate particles, and indicate a progressive reduction in penetration of bitumen with increasing mixing time. A further example of this is given by Kenis[8], who reported on the changes in the properties of asphaltic concrete in service in experimental pavements.

It is perhaps ironical that much effort is put nowadays into testing asphalt cement on arrival at site to establish that itspenetration falls within the specified range, when it will have entirely different and generally unpredictable properties when it is finally in position in an asphaltic concrete road surfacing. This is particularly true of asphaltic concrete mixtures which are mixed at a relatively high temperature and which may be pervious to air after compaction[6].

5.9 <u>Saybolt Furol Viscosity Test</u>

Test results appear in Table 22, Appendix F.

5.10 <u>Extraction Test</u>

Test results appear in Tables 3, 6 and 9 of Appendix B.

5.11 <u>Distillation Test</u>

The Distillation Test results (Table 24, Appendix F) show that petroleum asphalt cement containing very little volatile constituents, capable of being evaporated at a temperature below 680°F, is used in the three plants under study.

CHAPTER SIX
GENERAL DESCRIPTION OF PLANT OPERATION PRACTICES

6.1 Beirut Municipality Plant

This plant includes three batch mix plants, out of which only the biggest (WIBAU) is in operation. Of the other two (both BARBER - GREENE) one is not completely fixed yet, while the second not put to operation as present mix demand is met by the WIBAU plant alone.

The aggregate to this plant is supplied from the Nahr el Mot quarry while the asphalt cement is an ESSO product. The plant is capable of producing up to 150 tons of asphaltic concrete daily, the normal range of production being 50 - 125 tons in 7 hours.

The plant has a staff of 20 to 30 persons, the actual number depending on the demand of mix.

The mix produced by the plant is used primarily for resurfacing and maintaining the streets of Beirut. The dry mix is made up of fine aggregate (80 per cent by weight) and filler (20 per cent by weight).

The aggregates are piled separately and then mixed together by a payloader. In rare instances, coarse aggregate is also brought, whenever new roads are to be paved.

The dry mix is fed through a cold elevator to the dryer, where the dry aggregate is heated to a temperature of 110 - 130°C.

The dryer consists of a long hollow steel cylinder lined with firebrick and containing projecting radial fins. The inlet end is set slightly higher than the outlet. Heat is supplied by a jet of flame, which is directed into the lower end of the dryer. As the cylinder rotates, the aggregate is carried to the top by the fins, from where it falls downward and a little toward the outlet. By the time the aggregates have traveled the length of the dryer, they are free from moisture and heated to the required temperature.

After passing through the dryer, the hot aggregate is lifted by a bucket elevator to screens. From there the aggregate passes to the pugmill mixer, asphalt added by manipulating the asphalt meter, and after mixing for about a minute dropped into a truck.

The asphalt cement is brought to the plant in barrels and stored as such. Before its use, it is heated in an open air tank to a temperature of approximately 120°C.

In Lebanon, asphaltic concrete for paving is usually referred to as idealite. Apart from it, this plant mixes sheet asphalt as well, locally called stucable, which consists of filler and asphalt cement. It includes a higher percentage of asphalt (6 to 8 per cent by total weight of mix) and is used mainly for filling up holes and depressions.

The Beirut Municipality plant produces large quantities of sheet asphalt particularly during the winter months.

The principal shortcomings of this plant are the following:

(1) There is no control over the weighing of the aggregate. Thus, the aggregate that is being fed into the cold

elevator has practically the same grading as that which is fed into the pugmill mixer from the screens.

(2) The asphalt cement is not heated sufficiently (120°C).

(3) The body of the transporting vehicles is not covered.

(4) The temperature of the plant mix is lower than the specified range (140 - 150°C).

The first of these shortcomings can be rectified by making proper use of the weighing device. The aggregate can be separated into several predetermined sizes (usually from two to four) for temporary storage in the hot bins. Then, as aggregate is needed for proportioning into the mix, the correct amount can be drawn from the hot bins by weight into the pugmill mixer.

Concerning the second shortcoming, the Asphalt Institute[22] specifies that for dense-graded mixes the most effective temperature for plant mixing is that at which the asphalt viscosity is within the range of 75 - 150 seconds, Saybolt Furol. For this, 85 - 100 penetration asphalt cement should have a temperature, when introduced into the mix, in the range of 255 - 320°F (124 - 160°C).

To reduce the loss of heat to a minimum, it is advisable to cover the bodies of the transporting vehicles.[21]

It was observed that the temperature of the mix at the time of rolling was in the range of 80 - 90°C. This value is lower than the range specified by the Road Research Laboratory[15] which recommends a temperature range of 90 - 110°C. The low temperature values at time of rolling are due mainly to the fact that the plant mix is not sufficiently hot as indicated earlier, the numerous traffic jams a truck is subjected to within the city of Beirut, the fact that the truck body is not covered and finally to the delays at the laying site.

To remedy this situation, it is necessary to have the mixed materials at the plant in the range of 140 - 150°C as specified by the Road Research Laboratory[15]. Furthermore, it is important to improve the organization of work at the laying site so that the dump truck discharges the mix into the hopper of the finishing machine without unnecessary delays.

6.2 Mkalles Plant

Two batch plants (both BARBER - GREENE) are in actual operation at the Mkalles plant. Their production, averaging 100 tons of asphalt concrete for a 7 hour working day, is used mainly to pave newly opened streets in Beirut and suburbs of the capital.

The plant is operated by a staff of 20 persons.

The dry mix consists of 40 per cent coarse aggregate, 40 per cent fine aggregate and 20 per cent filler (all by weight).

The aggregates are stockpiled separately in the open and then mixed by a payloader.

The plant produces asphalt concrete as well as sheet asphalt.

The mix production passes through the same steps as described earlier for the Municipality plant.

The aggregate is obtained from a near-by quarry, while the asphalt cement is of 85 - 100 penetration and is produced by ESSO.

The principal shortcomings of this plant are the following:

(1) The gradation control unit of the plant is not operated efficiently.

(2) Inefficient plant operation, and poor organization of work.

(3) Asphalt cement not sufficiently heated (about 120°C).

(4) Aggregate is not protected against rain-water.

(5) Body of transporting vehicle not covered.

(6) Plant mix not sufficiently heated (110°C).

(7) Intermixing of stockpiles.

(8) Improper cold feeding.

By making proper use of the plant weighing apparatus, the first of these shortcomings can be eliminated.

The plant organization can be improved by several ways:

(a) Introducing and enforcing strict regulations to the personnel of the plant.

(b) Having the trucks come and leave at a regular sequence.

(c) Having a steady supply of aggregate and asphalt cement at all times.

The temperature of the asphalt cement should be brought to 124 - 160°C range before being mixed with the aggregate, to achieve a better mix.

Sufficient protection against rain-water can be achieved by properly covering the aggregate with canvasses.

The bodies of the transporting vehicles should be covered to reduce heat loss to a minimum level.

Intermixing of stockpiles can be avoided by piling the different aggregates sufficiently apart and by paying attention to the unloading of the aggregates.

Proper cold feeding is essential because a sudden rush of cold aggregate may cause a considerable change of temperature in the aggregate leaving the dryer. Furthermore, a sudden increase in the cold feed can overload the screens, creating a carry-over of the fine aggregate into the coarse aggregate bins. Therefore, the cold feeding should be done at a uniform rate by experienced workers.

6.3 Mdayrej Plant

Two batch plants operate at Mdayrej (the first SPOT - MIX PARKER, the second unmarked).

The production, averaging 110 tons for a 8 hrs. working day, is mainly used to pave newly opened rural roads in the Chouf province of Lebanon. A staff of 22 operate the plant.

The aggregate is brought from a quarry adjacent to the plant itself. The asphalt cement is produced by ESSO.

The dry mix consists by weight of 40 per cent coarse aggregate, 40 per cent fine aggregate and 20 per cent of filler.

In this plant also, there are no special bins to store the aggregate in; thus, the aggregate is stockpiled on the ground.

A payloader is used to mix the different aggregates (coarse, fine and filler) together.

The period of operation of the plant extends from the beginning of May to the end of October.

The process of production of the mix is very similar to that of the other two plants.

The production of the plant consists of asphaltic concrete (idealite) alone.

The main shortcomings of this plant are the following:

(1) The aggregates are not covered. As it rains in this region even during the summer, the aggregates can be subjected to occasional wetting. Some of this water will find its way into the final mix. Water serves as a lubricant, just as bitumen does, so that any appreciable amount of water may produce instability.
Mixes with too much moisture often have an appearance similar to ones with excess bitumen, in that they are sloppy and tend to slump in the lorry. The fact that moisture is the cause of the trouble can be detected by steam rising from the mix, and also sometimes the mix may appear to be bubble-covered as if it was boiling.

(2) The body of transporting vehicles not covered.

(3) No way of determining the temperature of the asphalt cement and the aggregate prior to mixing.

(4) Low asphalt cement temperature (100°C), and mix temperature.

(5) Poor plant organization.

The first of these shortcomings can be eliminated by covering properly the stockpiles and thus protecting them adequately from rain-water.

A proper heat insulating cover on the truck will ensure us minimal heat losses during the haul of the mix to the site of laying.

There should be a properly functioning thermometric device to determine correctly the temperature of the asphalt cement and the dry aggregate in order to make sure that the plant production quality remains unchanged[1].

Again, it is necessary to heat the asphalt cement to a temperature of 124 - 160°C before mixing it with the dry aggregate in order to get better end results. Similarly, it is imperative that the plant mix be heated to the temperature range specified earlier[15].

The time it takes for a truck leaving this plant to reach the site of laying is almost always greater than 30 minutes, during which time the mixed aggregate is subject to cooling. At two instances, the temperature of the mixed material was measured at the site of laying and it was found that it was in the range of 75 - 80°C. The specified range of temperature for rolling a mix containing 85 - 100 penetration asphalt cement being 90 - 110°C[15], it is apparent that one of the main reasons of poor pavement performance in Lebanon is the fact that the mix is not sufficiently hot when rolled. This situation can be remedied by further heating of the mix at the plant or at the laying site, and, as noted previously, by covering the truck body.

A smoother flow of work can be assured in this plant by achieving a greater degree of order in the plant operation practices.

CHAPTER SEVEN

7.0 CONCLUSIONS

From the results of this investigation the following observations may be made:

1- It was found in this investigation that a modified triaxial test may be used to study asphaltic concrete mixes in the laboratory. This method consists of adopting the theory of the Smith Triaxial Test to the Hveem Stability Testing procedure, whereby specimens prepared in accordance with the Hveem Method are tested in the Hveem Stabilometer following the procedure of the Smith Triaxial Test (closed system). This has the distinct advantage over the conventional triaxial test method of reducing the number of test specimens required to determine the angle of internal friction and the cohesion of the mix, and allowing the performance of these tests in laboratories which do not possess the standard Smith Triaxial Testing machine, but are equipped with the Hveem Stabilometer.

2- Concerning the quality of the mix produced in the three asphalt plants operating in Lebanon studied in this investigation, it was found that generally the proportions of the aggregates used do not meet accepted specification limits for hot-mixed dense graded bituminous concrete mixes. As a matter of fact, it was further found that the aggregates available at these plants do not allow the proportioning of these aggregates in such a way as to meet fully accepted specification limits.

3- The method of processing of the aggregates at the above plants, of the control of their gradation and of the method of checking the temperature of the bitumen prior to introducing it into the pugmill are far from the standard accepted methods in well operated central asphalt plants.

4- The aggregate in use at the plants of Beirut Municipality, Mkalles and Mdayrej satisfies the standard specification requirements as far as results of Los Angeles Abrasion Test and Sand Equivalent Test are concerned.

5- With the coarse aggregate, fine aggregate and filler presently in use at these plants, it is possible to achieve mixes that almost completely satisfy the specification limits. The proposed mix proportions are as follows:

Plant	Per cent coarse agg.	Per cent fine agg.	Per cent filler
Beirut Municipality		35	65
Mkalles	20	35	45
Mdayrej	30	10	60

6- The hot mix produced by the three plants is deficient in asphalt cement content.

7- The optimum values of asphalt cement content, as determined by the Marshall Method, are the following:

Plant	Optimum percentage of asphalt cement by weight of mix
Beirut Municipality	5.25
Mkalles	4.50
Mdayrej	4.50

8- Most of the samples tested from the plants satisfy the Marshall stability and flow requirements, however they fail to meet the requirements of per cent air voids and per cent aggregate voids filled.

9- The mix produced by using the proposed gradation for each plant with the optimum asphalt content as determined by the Marshall Method shows a considerable improvement over the mix actually produced by these plants as far as results by the Marshall Test and the Modified Hveem Triaxial Test are concerned.

10- The optimum asphalt content determined by the Marshall Test agrees closely with that found by the Modified Hveem Triaxial Test.

11- The 85 - 100 penetration asphalt cement presently in use at the three plants under investigation should be replaced with a 60 - 70 grade for better road performance.

12- The mixes produced by the three plants are below the specified plant temperature (140 - 150°C). Furthermore, at the laying site the mixes are below the specified rolling temperature (90 - 110°C). The recommended temperatures are for a 85 - 100 penetration asphalt cement.

13- The following subjects can be considered as worthy of future investigation in Lebanon:

(a) Advantages of using 60 - 70 penetration asphalt cement over the 85 - 100 grade presently in use in the batch plants under study.

(b) Hot mix laying methods by finishing machines.

(c) In situ compacted mix density determination.

(d) The effect of crude oil (mazout) on hot mix asphaltic concrete performance.

(e) Advantages of using 60 - 70 penetration asphalt cement over a cutback asphalt or an asphalt emulsion.

APPENDICES

APPENDIX A

Determination of the Angle of Internal Friction and Cohesion from the Triaxial Compression Stability Test Curve.

APPENDIX A

<u>Determination of the Angle of Internal Friction and Cohesion from the Triaxial Compression Stability Test Curve.</u>

(Refer to Fig.1, p.13)

Let points A $(p_v)_a;(p_1)_a$ and B $(p_v)_b;(p_1)_b$ be considered on the straight line. Designating the Angle of Internal Friction by ϕ, and the Cohesion by c we can write the following equations:

$$(p_v)_a = (p_1)_a\tan^2(45 + \phi/2) + 2c\tan(45 + \phi/2)$$

$$(p_1)_a = (p_v)_a\tan^2(45 - \phi/2) - 2c\tan(45 - \phi/2)$$

$$(p_v)_b = (p_1)_b\tan^2(45 + \phi/2) + 2c\tan(45 + \phi/2)$$

$$(p_1)_b = (p_v)_b\tan^2(45 - \phi/2) - 2c\tan(45 - \phi/2)$$

$$\text{Slope} = \frac{(p_v)_a - (p_v)_b}{(p_1)_a - (p_1)_b}$$

$$= \frac{(p_1)_a\tan^2(45 + \phi/2) - (p_1)_b\tan^2(45 + \phi/2)}{(p_v)_a\tan^2(45 - \phi/2) - (p_v)_b\tan^2(45 - \phi/2)}$$

$$= \frac{\tan^2(45 + \phi/2)\left[(p_1)_a - (p_1)_b\right]}{\tan^2(45 - \phi/2)\left[(p_v)_a - (p_v)_b\right]}$$

$$\left[\frac{(p_v)_a - (p_v)_b}{(p_1)_a - (p_1)_b}\right]^2 = \frac{\tan^2(45 + \phi/2)}{\tan^2(45 - \phi/2)}$$

$$(\text{Slope})^2 = \left[\frac{\tan(45 + \phi/2)}{\tan(45 - \phi/2)}\right]^2$$

$$\text{Slope} = \frac{\tan(45 + \phi/2)}{\tan(45 - \phi/2)}$$

but

$$\tan(45 + \emptyset/2) = \frac{\cos(\emptyset/2) + \sin(\emptyset/2)}{\cos(\emptyset/2) - \sin(\emptyset/2)}$$

and

$$\tan(45 - \emptyset/2) = \frac{\cos(\emptyset/2) - \sin(\emptyset/2)}{\cos(\emptyset/2) + \sin(\emptyset/2)}$$ consequently,

$$\tan(45 - \emptyset/2) = \frac{1}{\tan(45 + \emptyset/2)}$$ substituting we get

$$\text{Slope} = \frac{\tan(45 + \emptyset/2)}{\frac{1}{\tan(45 + \emptyset/2)}}$$

$$\text{Slope} = \underline{\underline{\tan^2(45 + \emptyset/2)}}$$

To find the value of the Cohesion c, note that at the point where the tangent line to the curve intersects the vertical applied pressure axis we have $p_1 = 0$. Therefore, the general expression

$$p_v = 2c \tan(45 + \emptyset/2) + p_1 \tan^2(45 + \emptyset/2)$$

reduces to

$$p_v = \underline{\underline{2c \tan(45 + \emptyset/2)}}$$

APPENDIX B

Marshall Test Results for the Municipality, Mkalles and Mdayrej Plants

APPENDIX B

Marshall Test Results for the Municipality, Mkalles and Mdayrej Plants

TABLE 2

Municipality Plant Marshall Test Data

Per cent Asphalt Cement by weight of mix	Corrected Stability Value (Pounds)	Average Stability Value (Pounds)	Flow (1/100 inch)	Average Flow (1/100 inch)	Bulk Specific Gravity	Average Bulk Specific Gravity
3.5	485		18		2.20	
3.5	516	503	15	16	2.26	2.25
3.5	509		15		2.28	
4.0	715		16		2.25	
4.0	707	674	17	17	2.28	2.26
4.0	600		19		2.25	
4.5	938		15		2.27	
4.5	821	891	19	17	2.25	2.27
4.5	915		16		2.29	
5.0	1150		16		2.26	
5.0	934	1053	20	18	2.30	2.28
5.0	1075		18		2.28	
5.5	965		17		2.28	
5.5	1025	898	15	19	2.28	2.29
5.5	704		26		2.32	
6.0	639		20		2.26	
6.0	613	667	23	21	2.32	2.28
6.0	750		21		2.26	

FIGURE 2

Test Property Curves for Design Data by the Marshall Method for the Beirut Municipality Plant

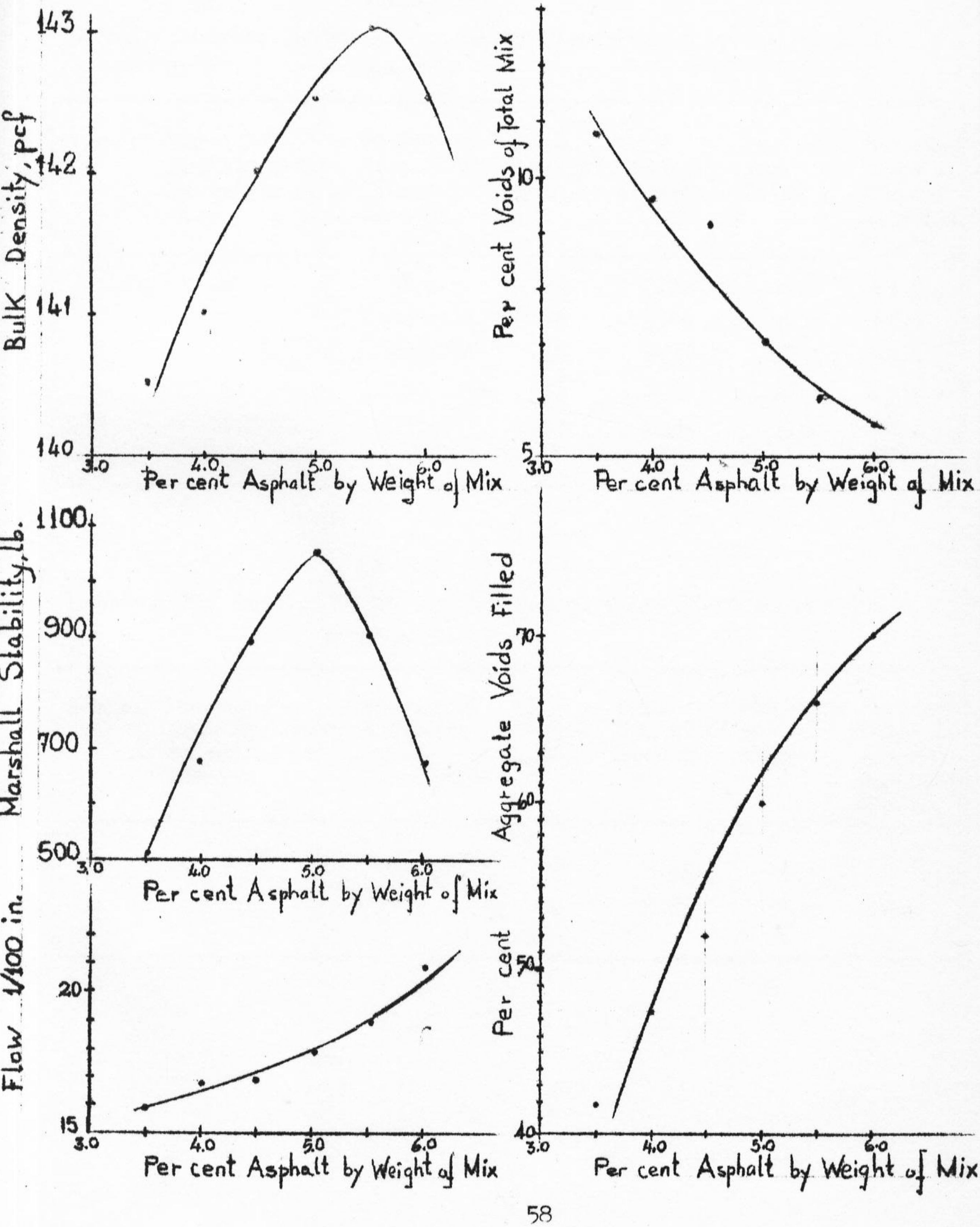


TABLE 3

Samples from the Beirut Municipality Plant Tested by the Marshall Method

Sample	Per cent Asphalt Cement by weight of mix	Corrected Stability Value (Pounds)	Flow (1/100 inch)	Bulk Specific Gravity	Per cent Air Voids	Per cent Voids in Mineral Aggregate Filled
1	4.0	372	24	2.22	11.0	43.5
2	4.0	630	20	2.19	12.0	41.0
3	3.9	555	10	2.22	11.0	43.4
4	4.1	660	17	2.24	10.5	47.4
5	4.2	685	18	2.24	10.0	47.7

TABLE 4

Proposed Mix Samples of the Beirut Municipality Plant at Optimum Asphalt Content

Sample	Per cent Asphalt Cement by weight of mix	Corrected Stability Value (Pounds)	Flow (1/100 inch)	Bulk Specific Gravity	Per cent Air Voids	Per cent Voids in Mineral Aggregate Filled
1	5.25	1445	13	2.29	8.5	54.6
2	5.25	1415	14	2.29	8.5	54.6

TABLE 5

Mkalles Plant Marshall Test Data

Per cent Asphalt Cement by weight of mix	Corrected Stability Value (Pounds)	Average Stability Value (Pounds)	Flow (1/100 inch)	Average Flow (1/100 inch)	Bulk Specific Gravity	Average Bulk Specific Gravity
3.5	564		14		2.16	
3.5	597	572	8	10	2.18	2.17
3.5	554		8		2.17	
4.0	634		13		2.19	
4.0	710	674	9	11	2.21	2.20
4.0	676		11		2.21	
4.5	780		11		2.19	
4.5	633	710	11	11	2.21	2.20
4.5	716		12		2.20	
5.0	960		11		2.18	
5.0	627	799	13	12	2.18	2.18
5.0	810		12		2.19	
5.5	832		11		2.15	
5.5	500	623	13	12	2.21	2.18
5.5	537		13		2.17	
6.0	610		12		2.16	
6.0	554	585	13	13	2.13	2.15
6.0	591		13		2.16	

FIGURE 3

Test Property Curves for Design Data by the Marshall Method for the Mkalles Plant

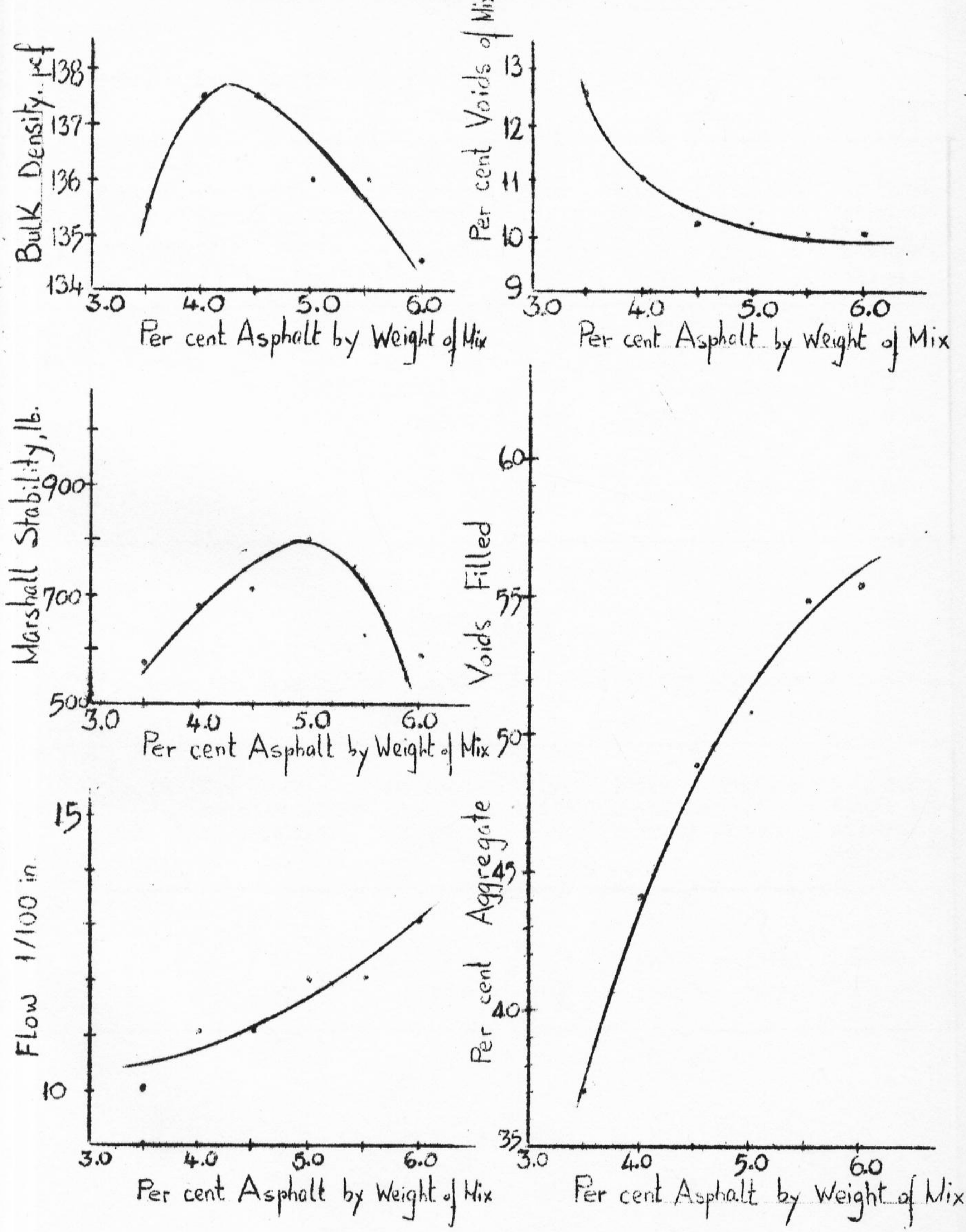


TABLE 6

Samples from the Mkalles Plant Tested by the Marshall Method

Sample	Per cent Asphalt Cement by weight of mix	Corrected Stability Value (Pounds)	Flow (1/100 inch)	Bulk Specific Gravity	Per cent Air Voids	Per cent Voids in Mineral Aggregate Filled
1	4.3	1010	7	2.29	7.0	58.6
2	4.4	1360	14	2.30	6.0	62.0
3	3.7	641	20	2.20	11.0	42.0
4	4.1	720	20	2.24	10.0	50.0
5	3.9	667	21	2.22	10.0	46.0

TABLE 7

Proposed Mix Samples of the Mkalles Plant at Optimum Asphalt Content

Sample	Per cent Asphalt Cement by weight of mix	Corrected Stability Value (Pounds)	Flow (1/100 inch)	Bulk Specific Gravity	Per cent Air Voids	Per cent Voids in Mineral Aggregate Filled
1	4.5	1430	14	2.31	6.0	62.0
2	4.5	1362	14	2.31	6.0	62.0

TABLE 8

Mdayrej Plant Marshall Test Data

Per cent Asphalt Cement by weight of mix	Corrected Stability Value (Pounds)	Average Stability Value (Pounds)	Flow (1/100 inch)	Average Flow (1/100 inch)	Bulk Specific Gravity	Average Bulk Specific Gravity
3.5	595		6		2.20	
3.5	414	508	10	8	2.25	2.23
3.5	515		8		2.23	
4.0	715		6		2.23	
4.0	562	635	8	8	2.24	2.24
4.0	630		9		2.24	
4.5	717		8		2.20	
4.5	701	696	9	9	2.24	2.22
4.5	675		10		2.21	
5.0	720		9		2.24	
5.0	815	770	8	9	2.19	2.21
5.0	777		10		2.21	
5.5	796		11		2.20	
5.5	554	670	10	10	2.18	2.19
5.5	662		10		2.20	
6.0	487		11		2.17	
6.0	656	582	11	11	2.19	2.18
6.0	602		12		2.18	

FIGURE 4

Test Property Curves for Design Data by the Marshall Method for the Mdayrej Plant

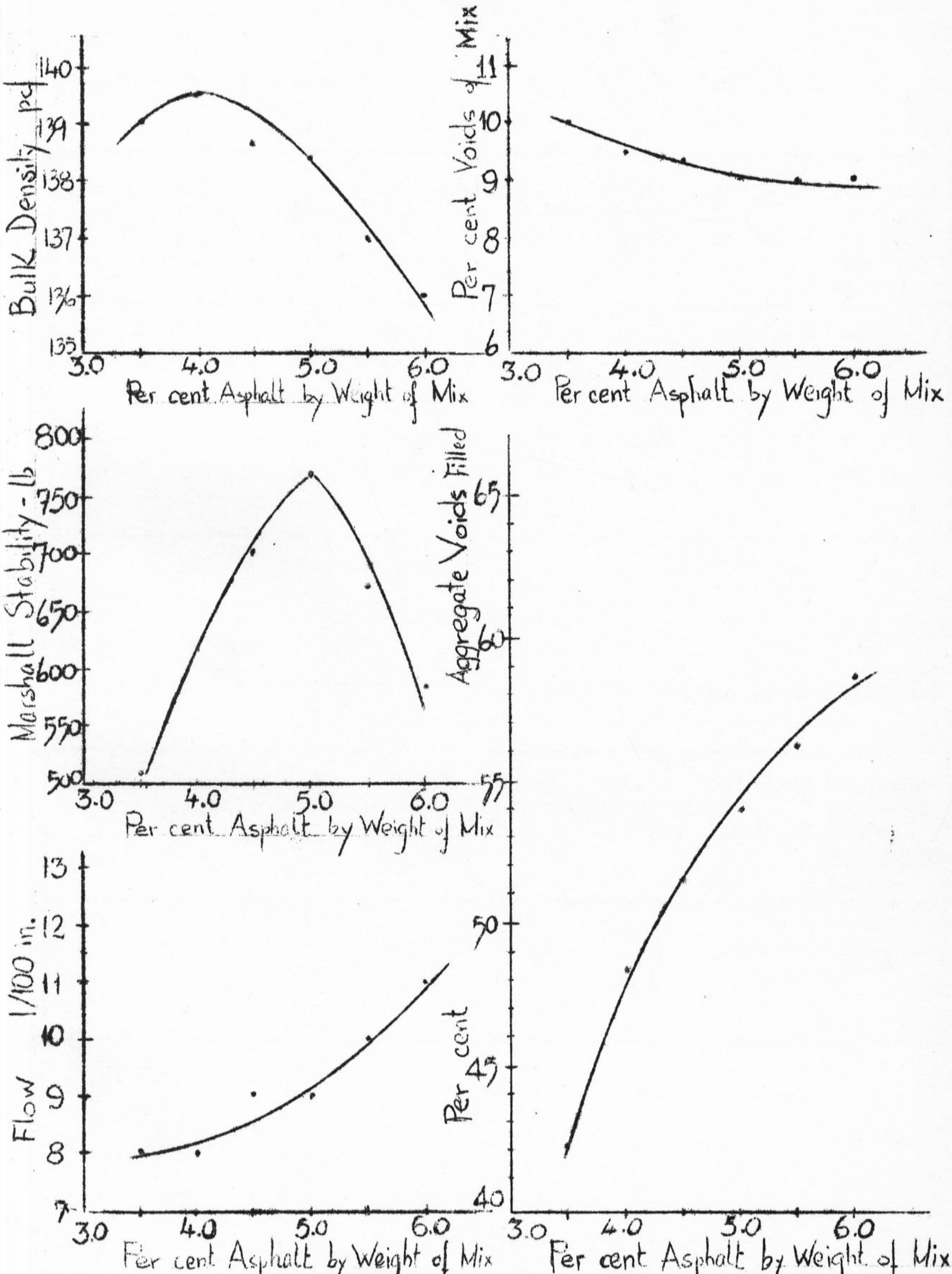


TABLE 9

Samples from the Mdayrej Plant Tested by the Marshall Method

Sample	Per cent Asphalt Cement by weight of mix	Corrected Stability Value (Pounds)	Flow (1/100 inch)	Bulk Specific Gravity	Per cent Air Voids	Per cent Voids in Mineral Aggregate Filled
1	4.2	1000	17	2.22	10.0	48.0
2	4.3	1185	8	2.21	10.0	48.5
3	4.3	1145	12	2.24	9.0	51.5
4	4.2	900	19	2.20	10.5	46.1
5	4.2	935	18	2.21	10.0	48 0

TABLE 10

Proposed Mix Samples of the Mdayrej Plant at Optimum Asphalt Content

Sample	Per cent Asphalt Cement By weight of mix	Corrected Stability Value (Pounds)	Flow (1/100 inch)	Bulk Specific Gravity	Per cent Air Voids	Per cent Voids in Mineral Aggregate Filled
1	4.5	1430	14	2.31	6.0	62.0
2	4.5	1362	15	2.31	6.0	62.0

APPENDIX C

Modified Hveem

Triaxial Compression Test Results for the Beirut Municipality , Mkalles and Mdayrej Plants

APPENDIX C
Modified Hveem
Triaxial Compression Test Data For The Municipality, Mkalles and Mdayrej Plants

A - Municipality Plant

Sample 1

Beirut Municipality Plant Proposed Mix having an asphalt content of 5.25 per cent. Height of specimen 6.5 cms. Bulk Specific Gravity of specimen 2.30.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	5
3000	240	6
4000	320	6
5000	400	7
6000	480	7
7000	560	8
8000	640	10
9000	720	15
10000	800	19
11000	880	21
12000	960	23
13000	1040	42
14000	1120	62
15000	1200	75
17000	1360	110

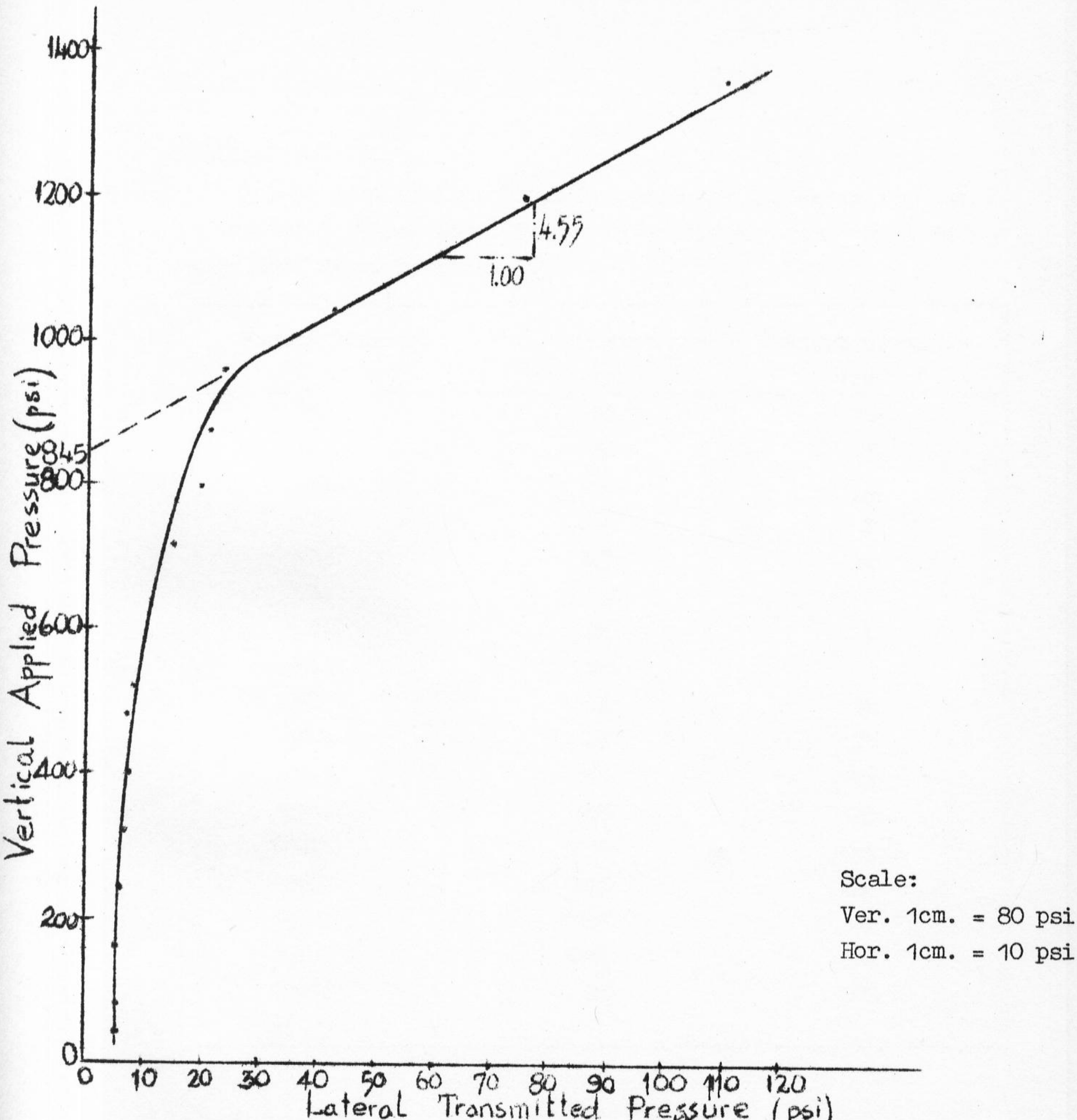


FIG.5. Municipality Proposed Mix Triaxial Compression Stability Test Curve at 5.25 per cent Asphalt Content.

Slope = 4.55 = $\tan^2(45 + \phi/2)$; 2.13 = $\tan(45 + \phi/2)$; $\underline{\phi = 39.8^\circ}$

845 = $2c \tan(45 + \phi/2)$; 845 = 2c(2.13); $\underline{c = 199 \text{ psi}}$

Sample 2

Beirut Municipality Plant Proposed Mix having an asphalt content of 5.25 per cent. Height of specimen 6 cms. Bulk Specific Gravity of specimen 2.31.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	5
3000	240	6
4000	320	6
5000	400	7
6000	480	8
7000	560	9
8000	640	11
9000	720	15
10000	800	19
12000	960	25
13000	1040	45
13500	1080	60
15000	1200	80
15500	1240	100
17000	1360	120

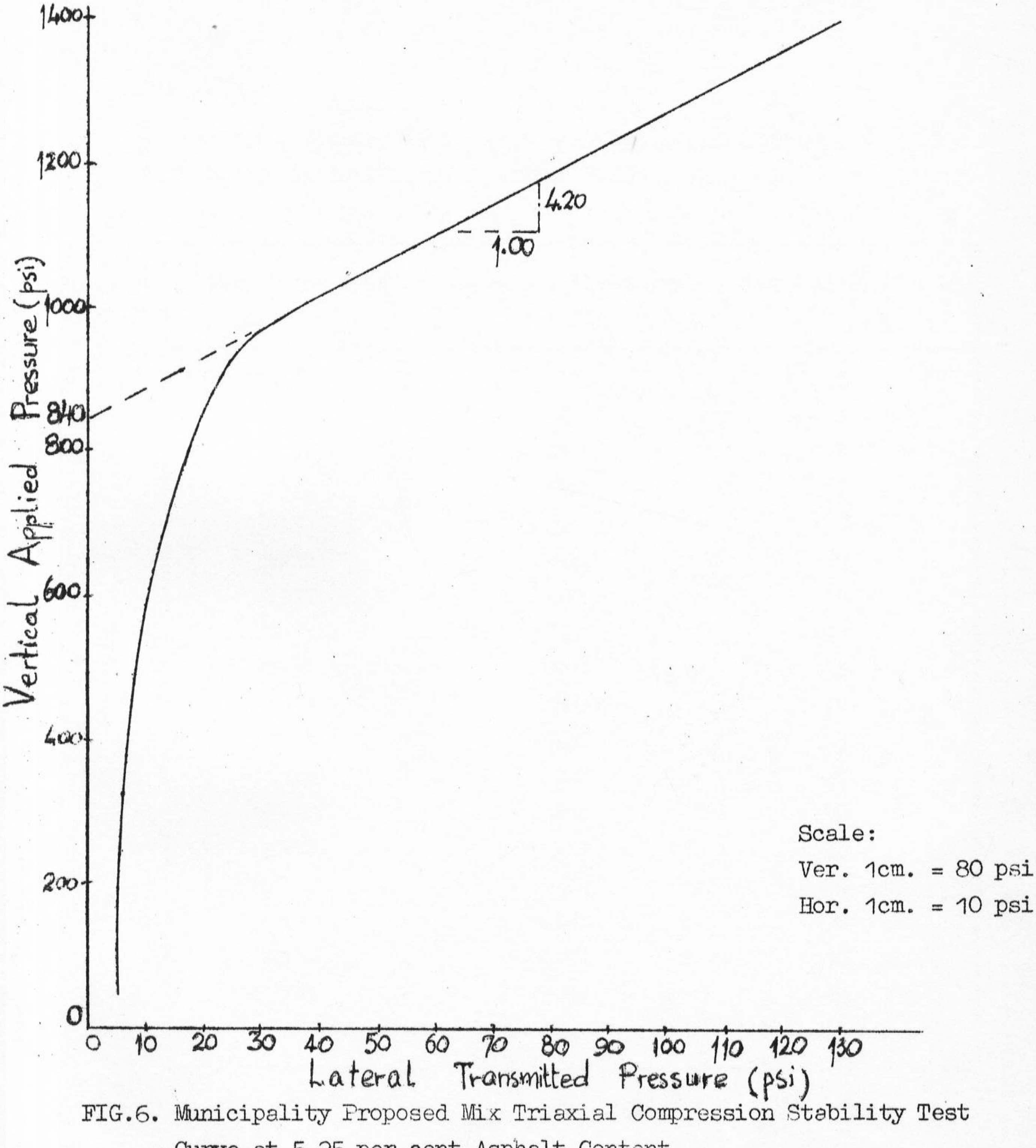


FIG.6. Municipality Proposed Mix Triaxial Compression Stability Test Curve at 5.25 per cent Asphalt Content.

Slope = 4.20 = $\tan^2(45 + \varnothing/2)$; 2.05 = $\tan(45 + \varnothing/2)$; $\underline{\varnothing = 38.0^{\circ}}$

840 = $2c \tan(45 + \varnothing/2)$; 840 = $2c(2.05)$; $\underline{c = 205 \text{ psi}}$

Sample 3

Beirut Municipality Plant Mix. Height of specimen 6.5 cms. Bulk Specific Gravity of specimen 2.22.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	6
3000	240	7
4000	320	7.5
5000	400	8
6000	480	9
7000	560	11
8000	640	13
9000	720	17
10000	800	19
11000	880	20
12000	960	29
13000	1040	50
14000	1120	70
15000	1200	90
16000	1280	110
17000	1360	135

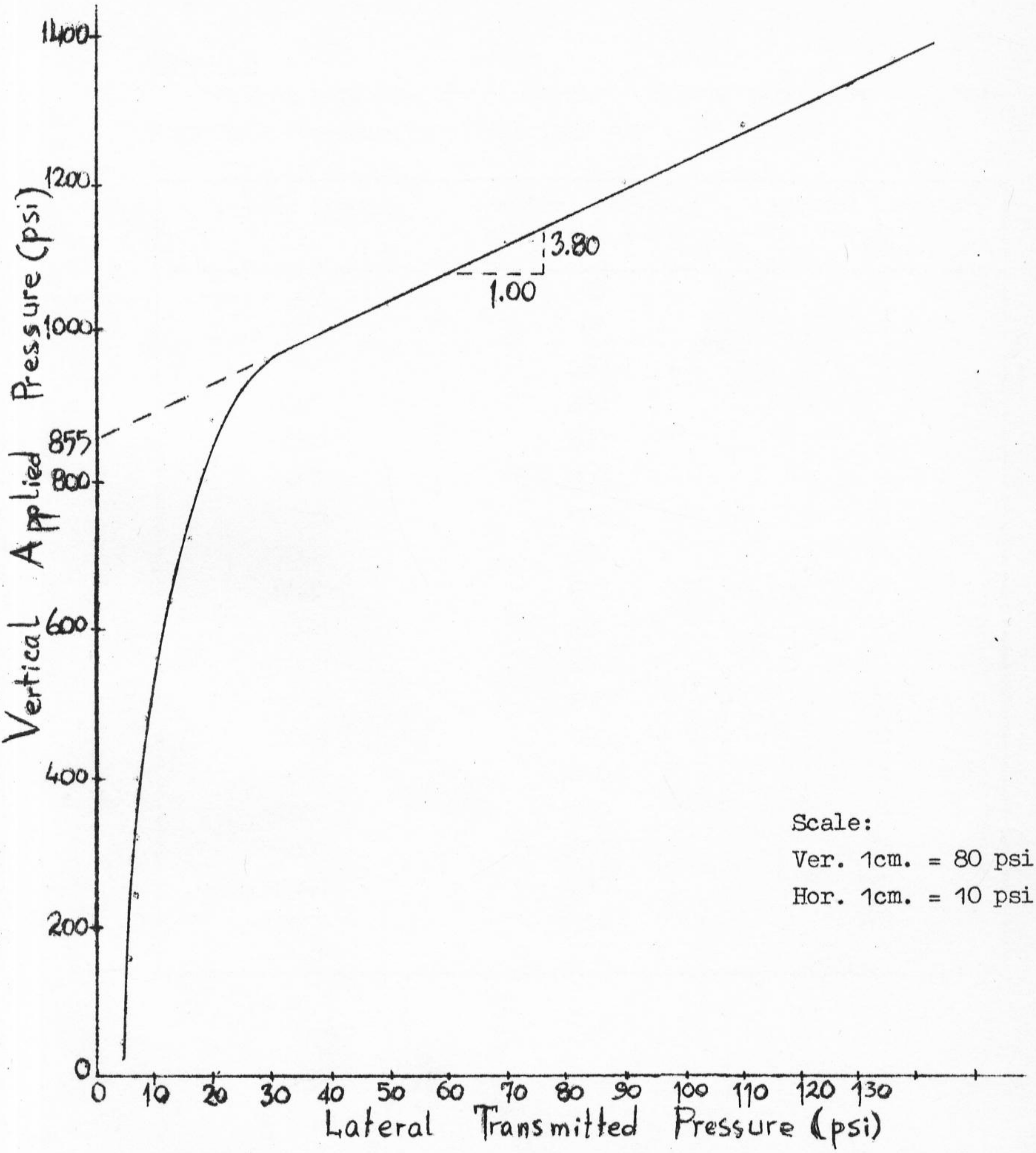


FIG.7. Municipality Plant Mix Triaxial Compression Stability Test Curve.

Slope = 3.80 = $\tan^2(45 + \phi/2)$; 1.95 = $\tan(45 + \phi/2)$; $\underline{\phi = 35.7^\circ}$

855 = $2c \tan(45 + \phi/2)$; 855 = $2c(1.95)$; $\underline{c = 220 \text{ psi}}$

Sample 4

Beirut Municipality Plant Mix. Height of specimen 6.3 cms. Bulk Specific Gravity of specimen 2.21.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	6
3000	240	7
4000	320	8
5000	400	9
6000	480	10
7000	560	11
8000	640	14
9000	720	18
10000	800	20
11000	880	22
12000	960	30
13000	1040	54
14000	1120	74
15000	1200	95
16000	1280	117
17000	1360	142

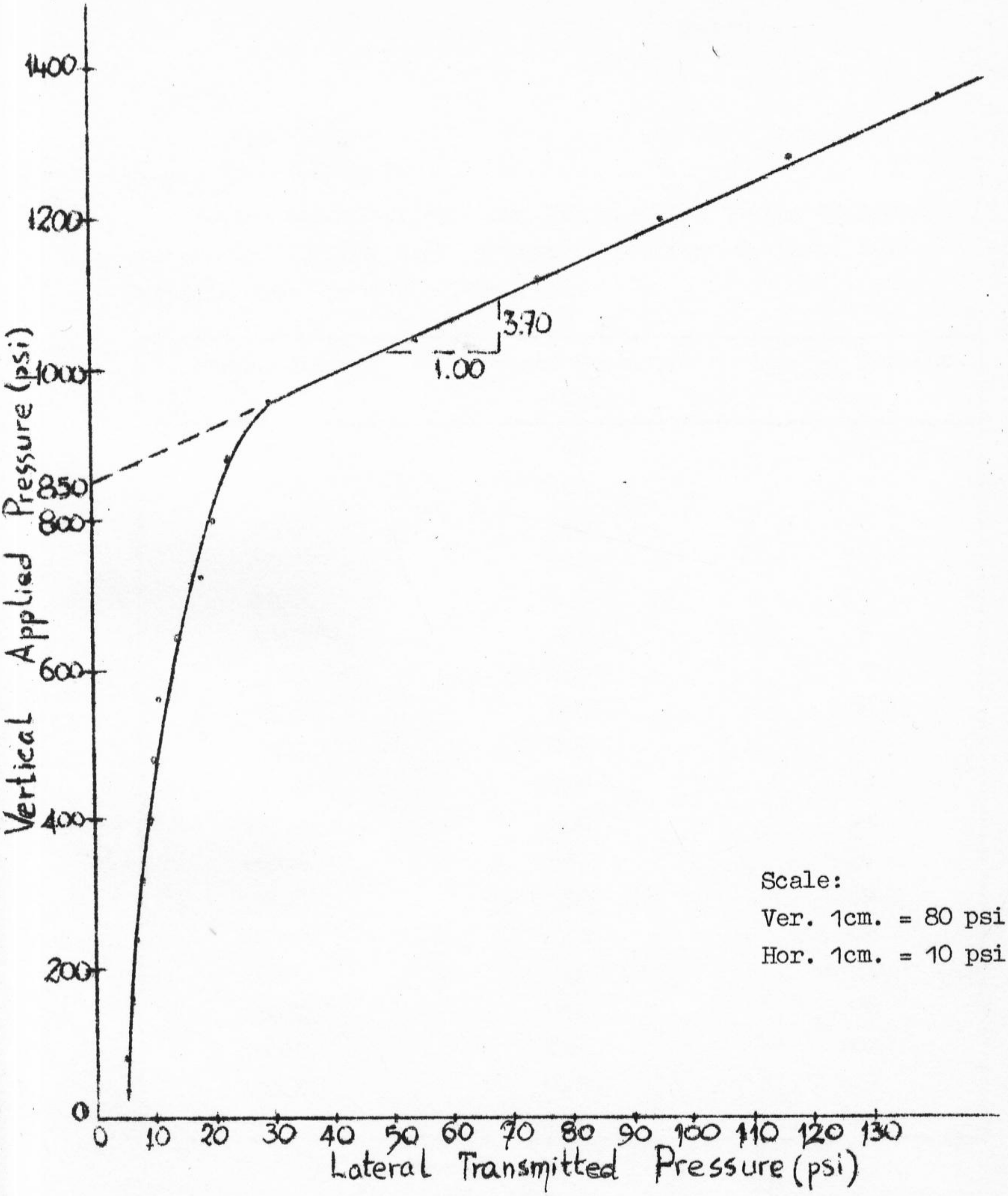


FIG.8. Municipality Plant Mix Triaxial Compression Stability Test Curve.

Slope = 3.70 = $\tan^2(45 + \emptyset/2)$; 1.92 = $\tan(45 + \emptyset/2)$; $\underline{\emptyset = 35.0^{\circ}}$

850 = $2c \tan(45 + \emptyset/2)$; 850 = $2c(1.92)$; $\underline{c = 222 \text{ psi.}}$

Sample 5

Beirut Municipality Plant Proposed Mix having an asphalt content of 4.75 per cent. Height of specimen 6.1 cms. Bulk Specific Gravity of specimen 2.26.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	5
3000	240	6
4000	320	6
5000	400	8
6000	480	9
7000	560	10
8000	640	12
9000	720	16
10000	800	21
11000	880	24
12000	960	27
13000	1040	48
14000	1120	63
15000	1200	86
16000	1280	107
17000	1360	129

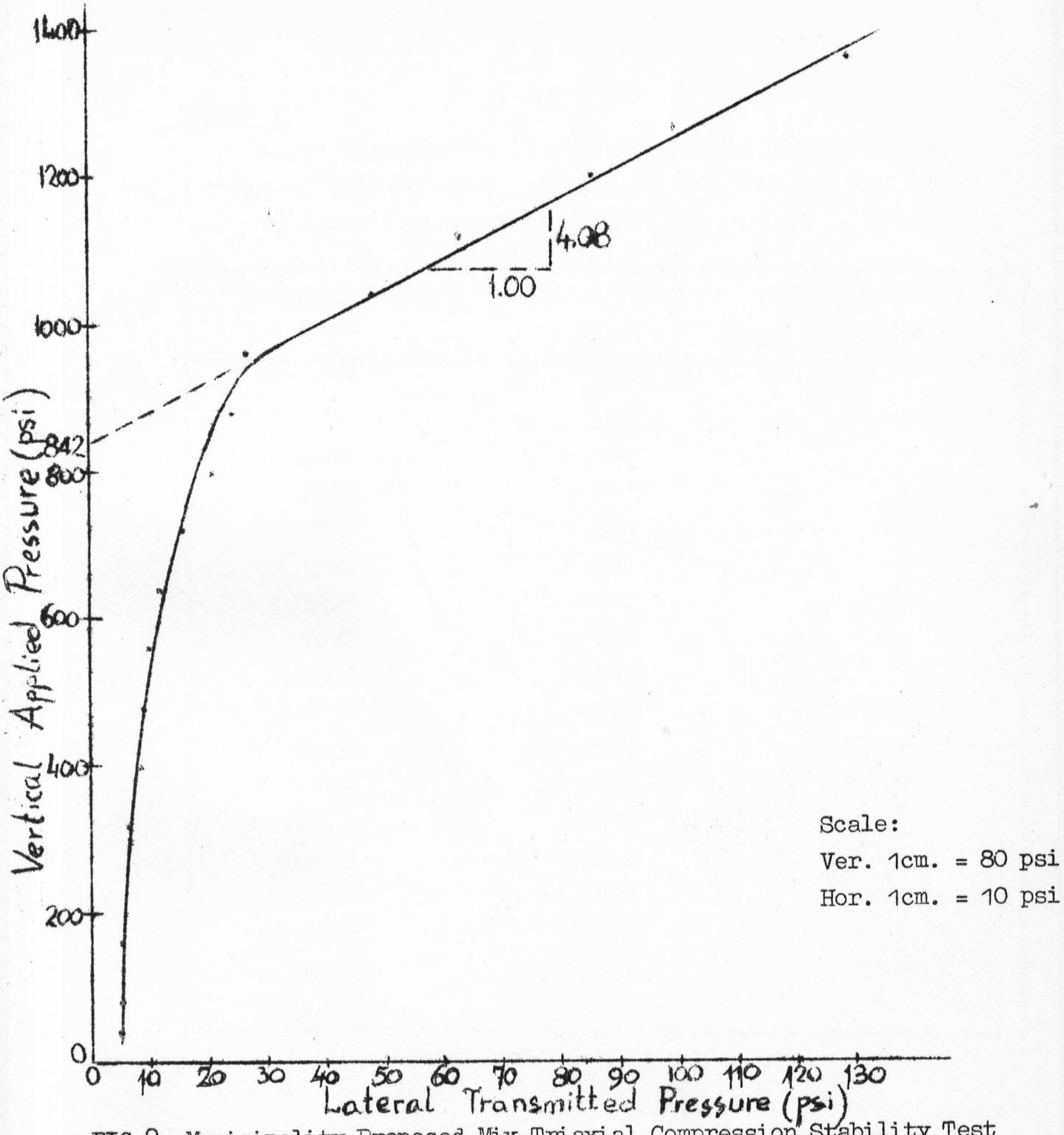


FIG.9. Municipality Proposed Mix Triaxial Compression Stability Test Curve at 4.75 per cent Asphalt Content.

Slope = 4.08 = $\tan^2(45 + \emptyset/2)$; 2.02 = $\tan(45 + \emptyset/2)$; $\underline{\emptyset = 37.4^{o}}$

842 = $2c \tan(45 + \emptyset/2)$; 842 = 2c(2.02); $\underline{c = 208 \text{ psi}}$

Sample 6

Beirut Municipality Plant Proposed Mix having an asphalt content of 5.75 per cent. Height of specimen 6.2 cms. Bulk Specific Gravity of specimen 2.22.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	5
3000	240	6
4000	320	6
5000	400	8
6000	480	10
7000	560	11
8000	640	12
9000	720	17
10000	800	21
11000	880	23
12500	1000	29
13000	1040	51
14000	1120	68
15000	1200	90
17000	1360	134

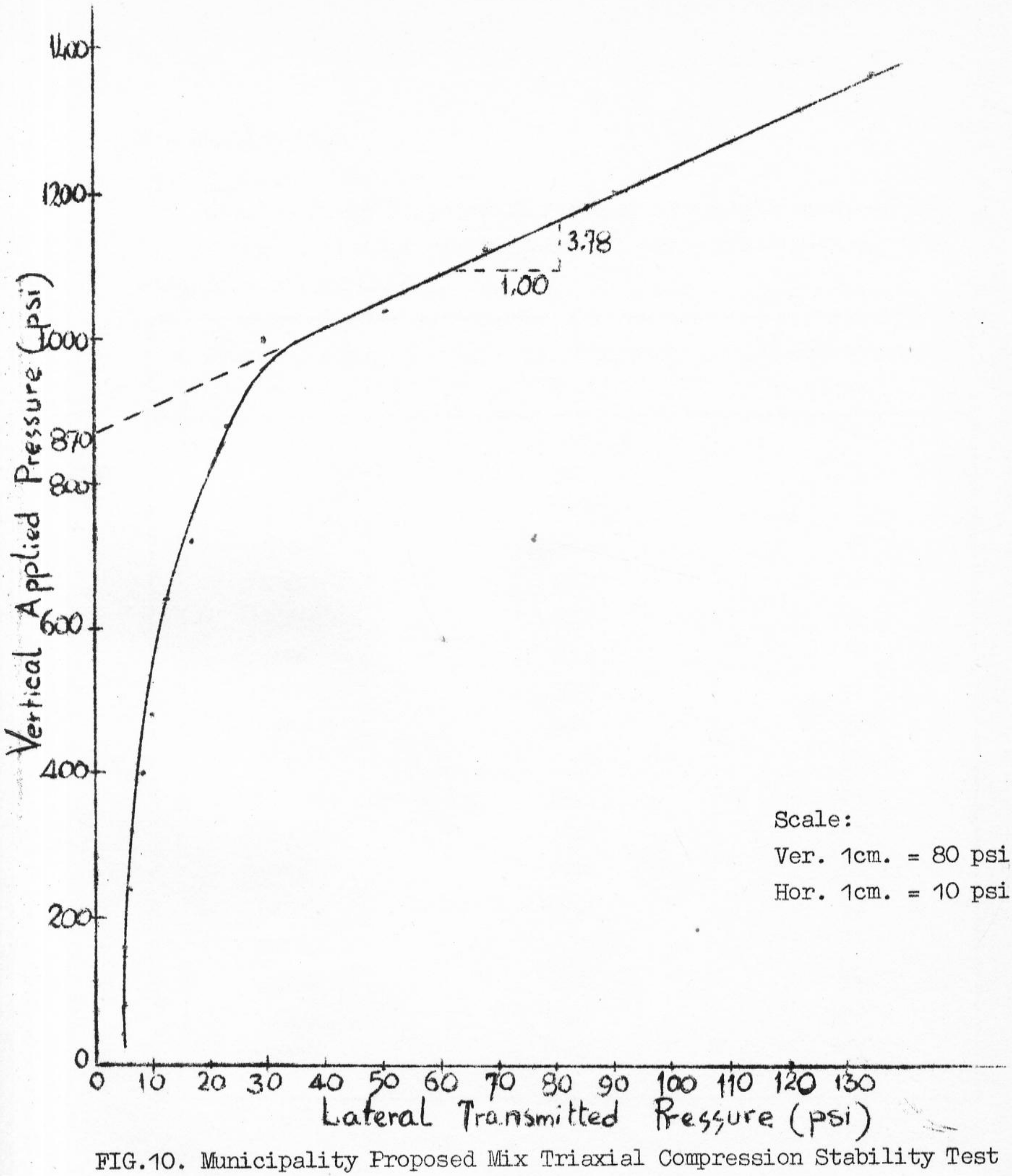


FIG.10. Municipality Proposed Mix Triaxial Compression Stability Test Curve at 5.75 per cent Asphalt Content.

Slope = 3.78 = $\tan^2(45 + \phi/2)$; 1.94 = $\tan(45 + \phi/2)$; $\underline{\phi = 35.5^{\circ}}$

870 = $2c \tan(45 + \phi/2)$; 870 = 2c(1.94); $\underline{c = 224 \text{ psi}}$

B - Mkalles Plant

Sample 1

Mkalles Plant Proposed Mix having an asphalt content of 4.5 per cent. Height of specimen 6.3 cms. Bulk Specific Gravity of specimen 2.31.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	6
3000	240	6
4000	320	7
5000	400	8
6000	480	9
7000	560	11
8000	640	14
9000	720	18
10000	800	23
11000	880	27
12000	960	30
13000	1040	52
14000	1120	67
15000	1200	88
16000	1280	110
17000	1360	130

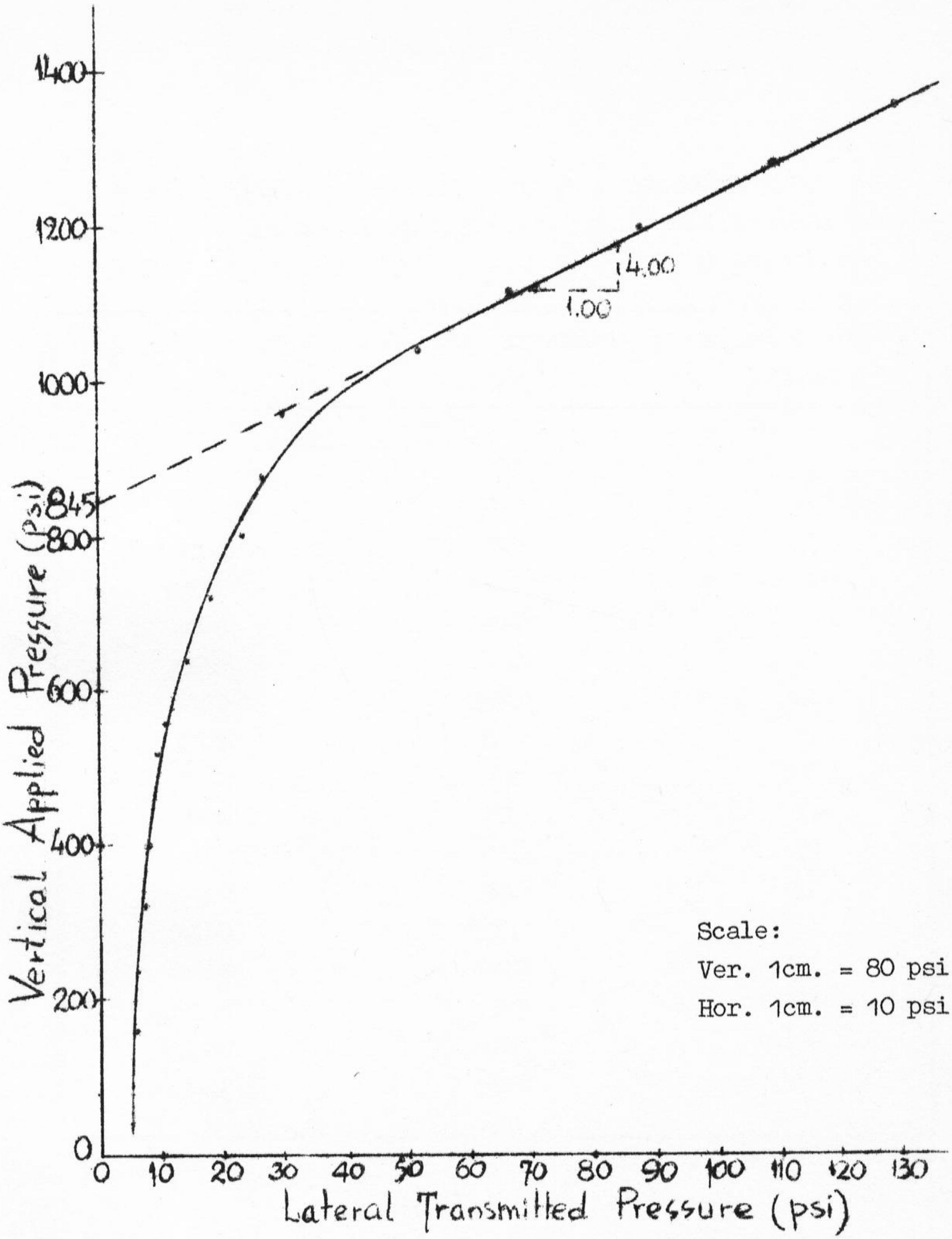


FIG.11. Mkalles Proposed Mix Triaxial Compression Stability Test Curve at 4.5 per cent Asphalt Content.

Slope = 4.00 = $\tan^2(45 + \emptyset/2)$; 2.00 = $\tan(45 + \emptyset/2)$; $\underline{\emptyset = 37.0^\circ}$

845 = $2c \tan(45 + \emptyset/2)$; 845 = $2c(2.00)$; $\underline{c = 211 \text{ psi}}$

Sample 2

Mkalles Plant Proposed Mix having an asphalt content of 4.5 per cent. Height of specimen 6.2 cms. Bulk Specific Gravity 2.29.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	6
3000	240	6
4000	320	7
5000	400	8
6000	480	10
7000	560	12
8000	640	15
9000	720	20
10000	800	25
11000	880	29
12000	960	37
13000	1040	55
14000	1120	70
15000	1200	91
16000	1280	114
17000	1360	135

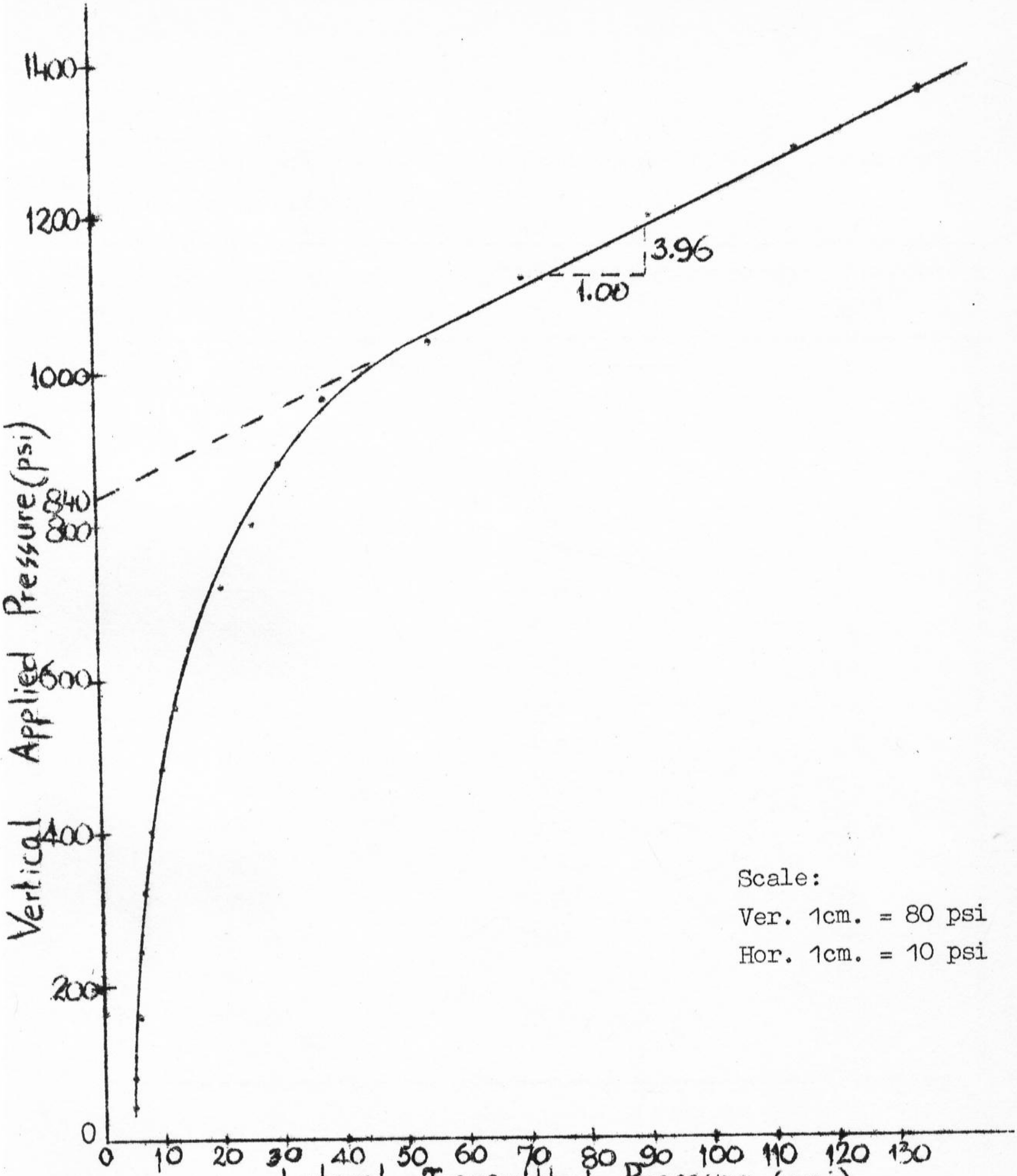


FIG.12. Mkalles Proposed Mix Triaxial Compression Stability Test Curve at 4.5 per cent Asphalt Content.

Slope = 3.96 = $\tan^2(45 + \text{Ø}/2)$; 1.98 = $\tan(45 + \text{Ø}/2)$; $\underline{\text{Ø} = 36.4^\circ}$

840 = 2c $\tan(45 + \text{Ø}/2)$; 840 = 2c(1.98); $\underline{c = 212 \text{ psi}}$

Sample 3

Mkalles Plant Mix. Height of specimen 6.5 cms. Bulk Specific Gravity of specimen 2.20.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	6
3000	240	7
4000	320	8
5000	400	9
6000	480	11
7000	560	13
8000	640	15
9000	720	19
10000	800	21
11000	880	23
12000	960	33
13000	1040	54
14000	1120	75
15000	1200	98
16000	1280	120
17000	1360	146

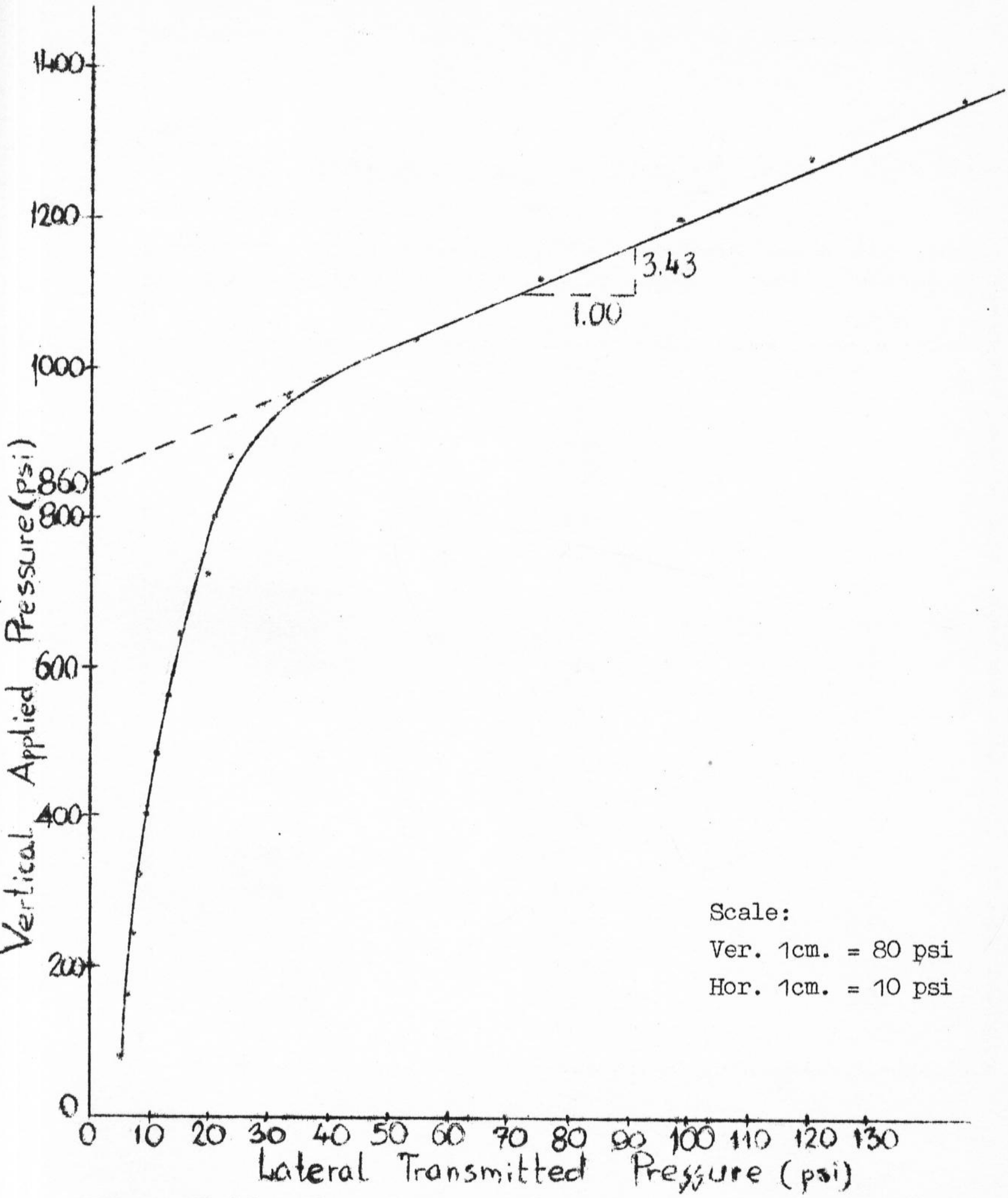


FIG.13. Mkalles Plant Mix Triaxial Compression Stability Test Curve.

Slope = 3.43 = $\tan^2(45 + \emptyset/2)$; 1.83 = $\tan(45 + \emptyset/2)$; $\emptyset = 32.7^{\circ}$

860 = $2c \tan(45 + \emptyset/2)$; 860 = 2c(1.83); c = 235 psi

Sample 4

Mkalles Plant Mix. Height of specimen 6.4 cms. Bulk Specific Gravity of specimen 2.18.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	7
3000	240	8
4000	320	9
5000	400	10
6000	480	11
7000	560	14
8000	640	17
9000	720	21
10000	800	22
11000	880	24
12000	960	35
13000	1040	57
14000	1120	79
15000	1200	100
16000	1280	127
17000	1360	153

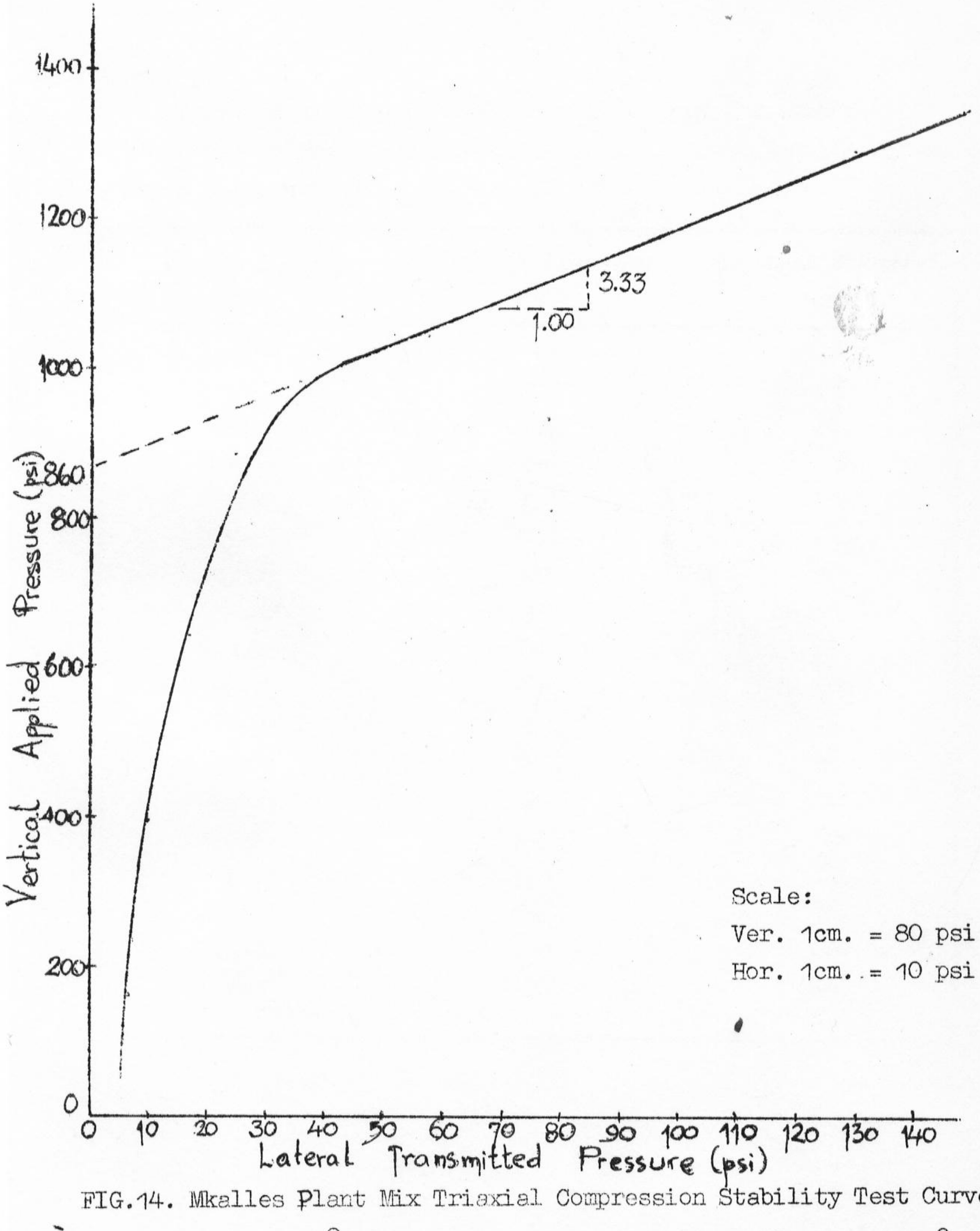


FIG.14. Mkalles Plant Mix Triaxial Compression Stability Test Curve

Slope = 3.33 = $\tan^2(45 + \phi/2)$; 1.82 = $\tan(45 + \phi/2)$; $\underline{\phi = 32.4^\circ}$

860 = $2c \tan(45 + \phi/2)$; 860 = $2c(1.82)$; $\underline{c = 236 \text{ psi}}$

Sample 5

Mkalles Plant Proposed Mix having an asphalt content of 4.0 per cent. Height of specimen 6.2 cms. Bulk Specific Gravity of specimen 2.27.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	.160	6
3000	240	6
4000	320	7
5000	400	8
6000	480	10
7000	560	13
8000	640	15
9000	720	21
10000	800	25
11000	880	30
12000	960	38
13000	1040	56
14000	1120	72
15000	1200	93
16000	1280	118
17000	1360	140

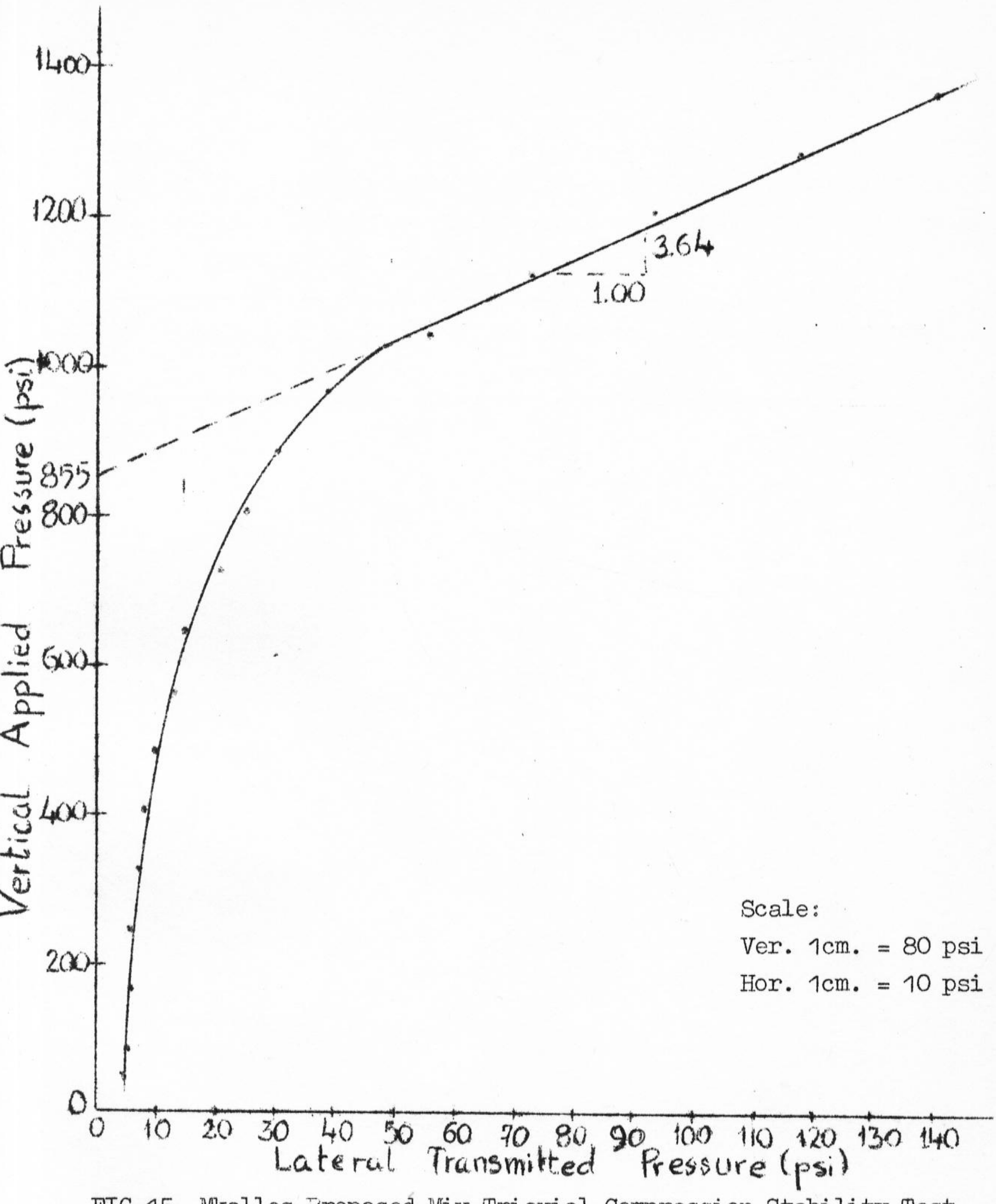


FIG. 15. Mkalles Proposed Mix Triaxial Compression Stability Test Curve at 4 per cent Asphalt Content.

Slope = 3.64 = $\tan^2(45 + \emptyset/2)$; 1.91 = $\tan(45 + \emptyset/2)$; <u>$\emptyset = 34.7^\circ$</u>

855 = $2c \tan(45 + \emptyset/2)$; 855 = 2c(1.91); <u>c = 224 psi</u>

Sample 6

Mkalles Plant Proposed Mix having an asphalt content of 5.0 per cent. Height of specimen 6.3 cms. Bulk Specific Gravity of specimen 2.26.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	6
3000	240	6
4000	320	7
5000	400	8
6000	480	11
7000	560	13
8000	640	16
9000	720	22
10000	800	27
11000	880	33
12000	960	43
13000	1040	55
14000	1120	75
15000	1200	97
16000	1280	122
17000	1360	145

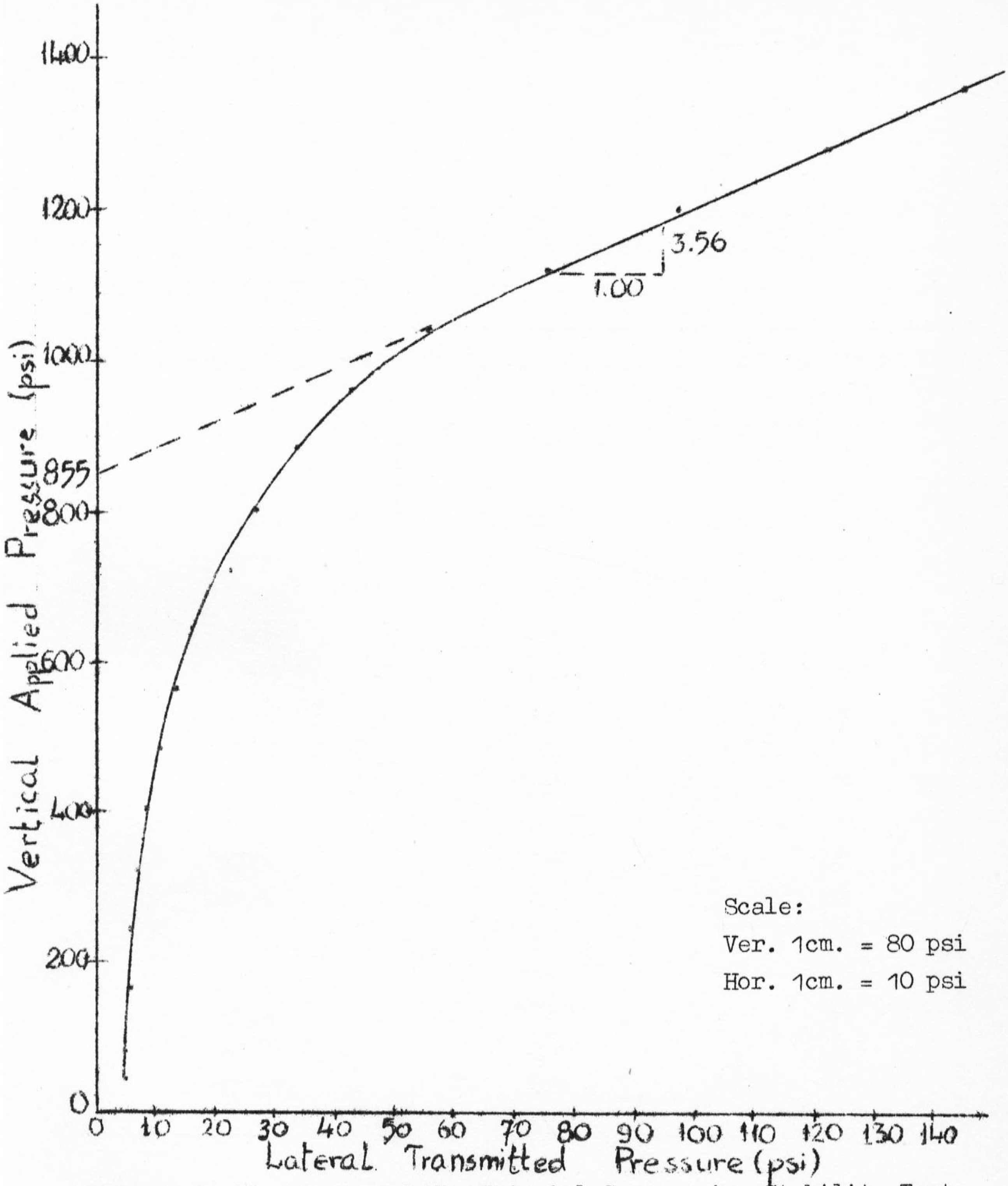


FIG. 16. Mkalles Proposed Mix Triaxial Compression Stability Test Curve at 5 per cent Asphalt Content.

Slope = 3.56 = $\tan^2(45 + \phi/2)$; 1.89 = $\tan(45 + \phi/2)$; $\underline{\phi = 34.2^\circ}$

855 = $2c \tan(45 + \phi/2)$; 855 = 2c(1.89); $\underline{c = 226 \text{ psi}}$

C - Mdayrej Plant

Sample 1

Mdayrej Plant Proposed Mix having an asphalt content of 4.5 per cent. Height of specimen 6.5 cms. Bulk Specific Gravity of specimen 2.32.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	6
3000	240	6
4000	320	7
5000	400	8
6000	480	9
7000	560	12
8000	640	14
9000	720	19
10000	800	24
11000	880	28
12000	960	32
13000	1040	54
14000	1120	70
15000	1200	92
16000	1280	114
17000	1360	135

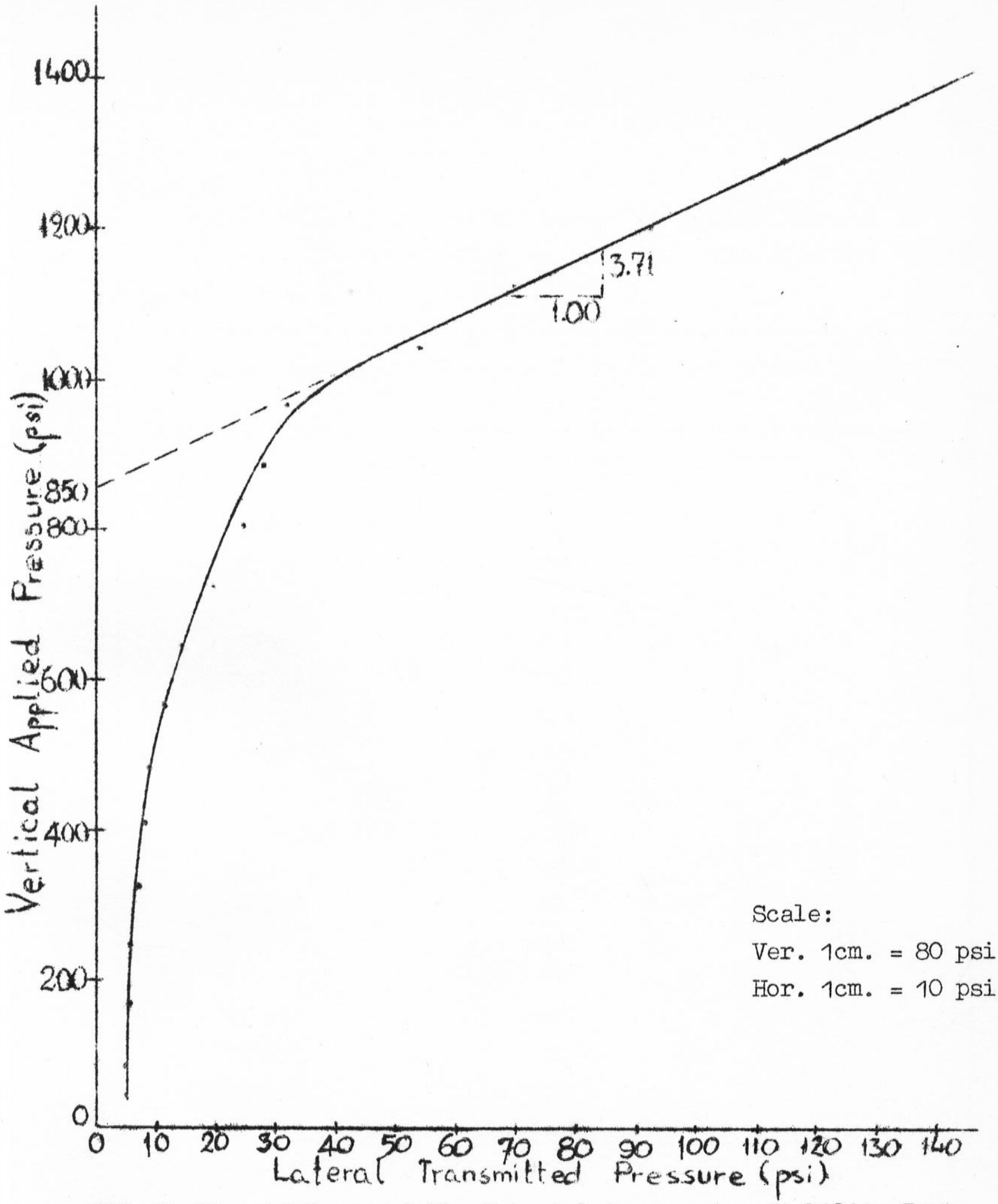


FIG. 17. Mdayrej Proposed Mix Triaxial Compression Stability Test Curve at 4.5 per cent Asphalt Content.

Slope = $3.71 = \tan^2(45 + \phi/2)$; $1.93 = \tan(45 + \phi/2)$; $\underline{\phi = 35.2^\circ}$

$850 = 2c \tan(45 + \phi/2)$; $850 = 2c(1.93)$; $\underline{c = 221 \text{ psi}}$

Sample 2

Mdayrej Plant Proposed Mix having an asphalt content of 4.5 per cent. Height of specimen 6.5 cms. Bulk Specific Gravity of specimen 2.31.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	6
3000	240	6
4000	320	7
5000	400	8
6000	480	9
7000	560	11
8000	640	13
9000	720	17
10000	800	20
11000	880	27
12000	960	32
13000	1040	52
14000	1120	69
15000	1200	90
16000	1280	110
17000	1360	133

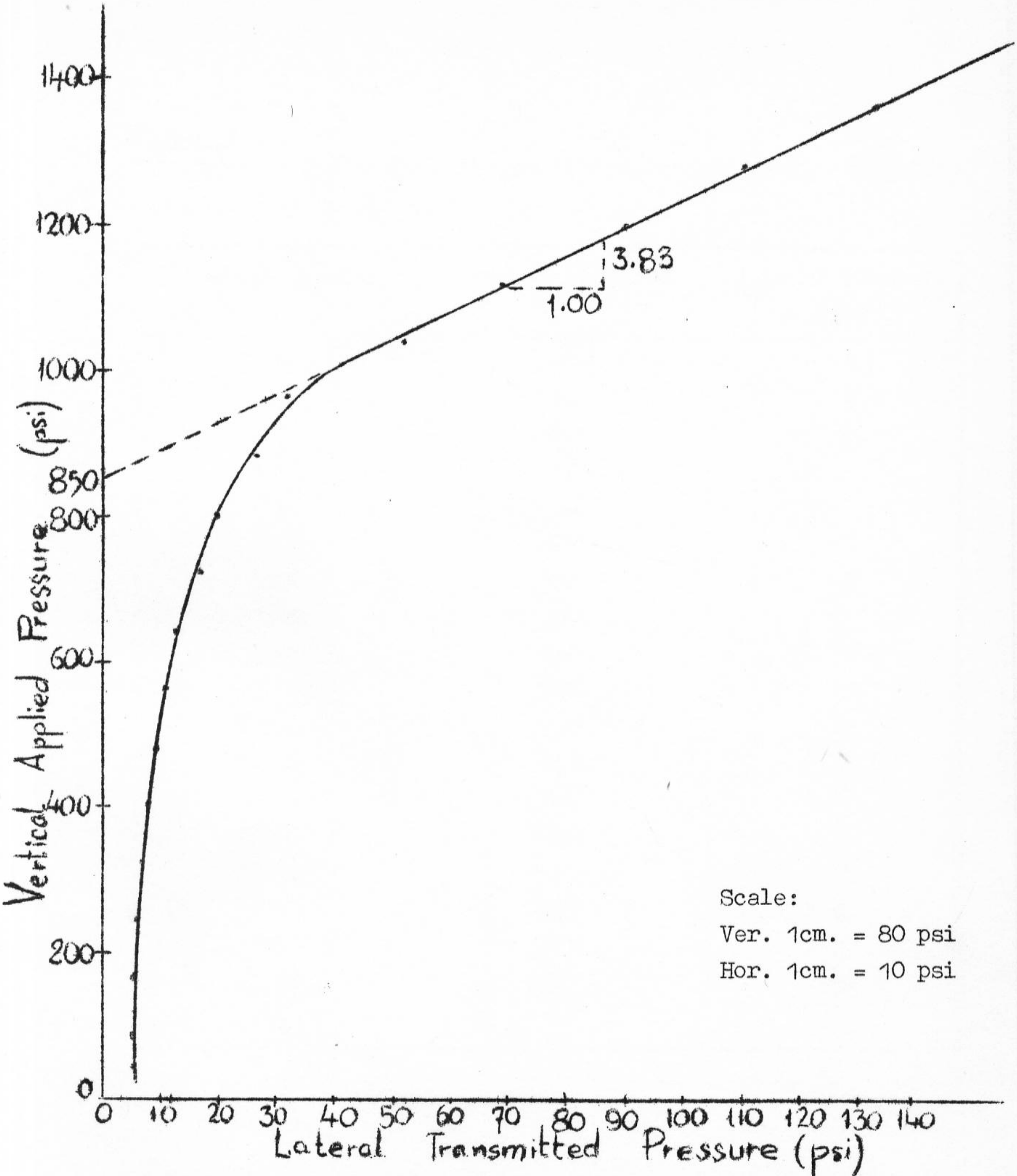


FIG.18. Mdayrej Proposed Mix Triaxial Compression Stability Test Curve at 4.5 per cent Asphalt Content.

Slope = 3.83 = $\tan^2(45 + \emptyset/2)$; 1.96 = $\tan(45 + \emptyset/2)$; $\underline{\emptyset = 35.8^{\circ}}$

850 = $2c \tan(45 + \emptyset/2)$; 850 = 2c(1.96); $\underline{c = 218 \text{ psi}}$

Sample 3

Mdayrej Plant Mix. Height of specimen 6.3 cms. Bulk Specific Gravity of specimen 2.23.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	6
3000	240	6
4000	320	7
5000	400	8
6000	480	9
7000	560	11
8000	640	13
9000	720	17
10000	800	20
11000	880	24
12000	960	30
13000	1040	51
14000	1120	71
15000	1200	93
16000	1280	115
17000	1360	138

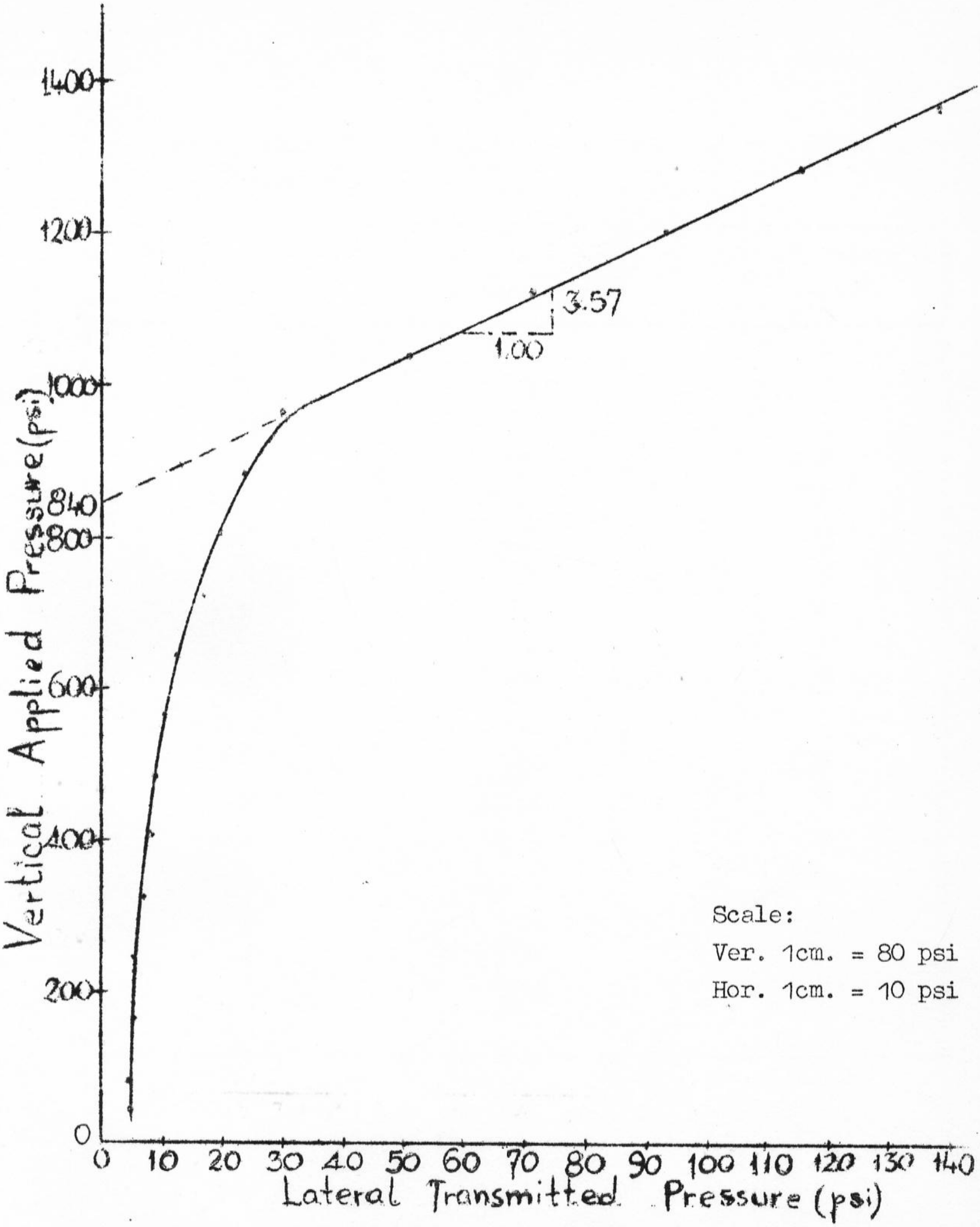


FIG.19. Mdayrej Plant Mix Triaxial Compression Stability Test Curve

Slope = 3.57 = $\tan^2(45 + \phi/2)$; 1.89 = $\tan(45 + \phi/2)$; $\underline{\phi = 34.2^\circ}$

840 = $2c \tan(45 + \phi/2)$; 840 = 2c(1.89); $\underline{c = 222 \text{ psi}}$

Sample 4

Mdayrej Plant Mix. Height of specimen 6.2 cms. Bulk Specific Gravity of specimen 2.24.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	7
3000	240	8
4000	320	10
5000	400	11
6000	480	13
7000	560	16
8000	640	20
9000	720	22
10000	800	27
11000	880	28
12000	960	40
13000	1040	64
14000	1120	86
15000	1200	110
16000	1280	140
17000	1360	168

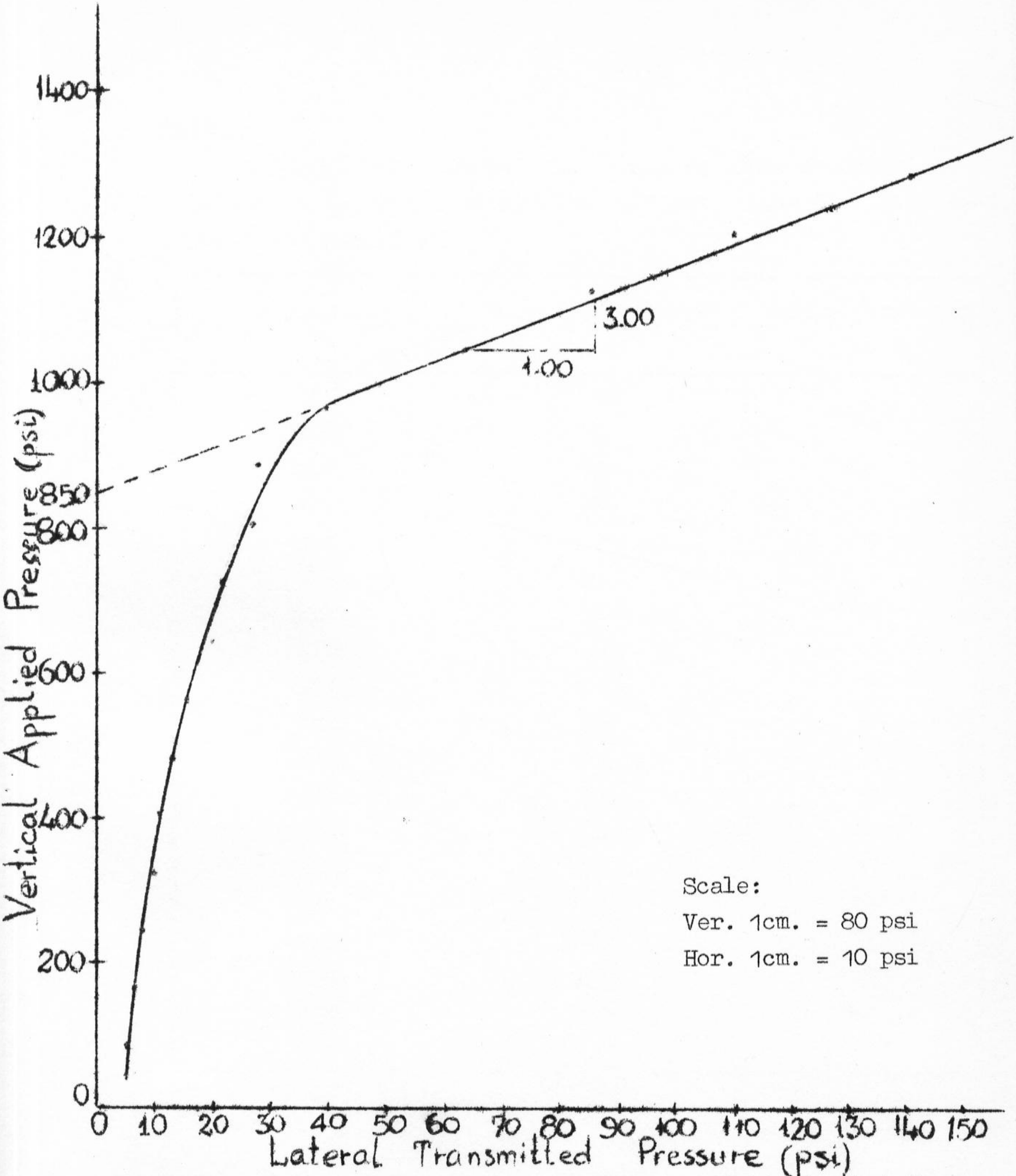


FIG.20. Mdayrej Plant Mix Triaxial Compression Stability Test Curve

Slope = 3.00 = $\tan^2(45 + \phi/2)$; 1.73 = $\tan(45 + \phi/2)$; $\underline{\phi = 30.0^{o}}$

850 = 2c $\tan(45 + \phi/2)$; 850 = 2c(1.73); <u>c = 246 psi</u>

Sample 5

Mdayrej Plant Proposed Mix having an asphalt content of 4.0 per cent. Height of specimen 6.1 cms. Bulk Specific Gravity of specimen 2.29.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	6
3000	240	6
4000	320	7
5000	400	8
6000	480	10
7000	560	13
8000	640	16
9000	720	22
10000	800	26
11000	880	32
12000	960	40
13000	1040	57
14000	1120	75
15000	1200	95
16000	1280	120
17000	1360	144

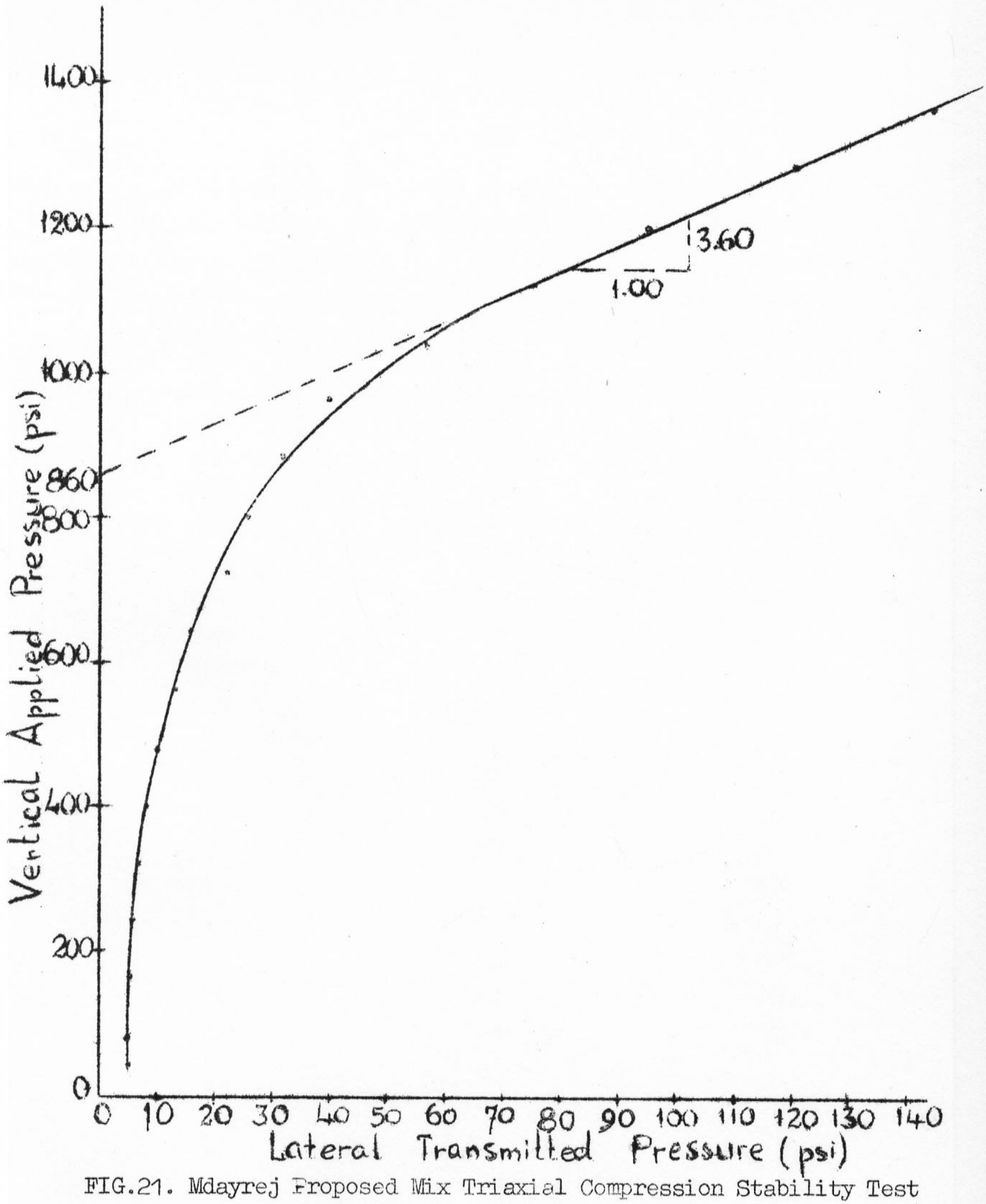


FIG.21. Mdayrej Proposed Mix Triaxial Compression Stability Test Curve at 4 per cent Asphalt Content.

Slope = 3.60 = $\tan^2(45 + \phi/2)$; 1.90 = $\tan(45 + \phi/2)$; $\underline{\phi = 34.5^{\circ}}$

860 = $2c \tan(45 + \phi/2)$; 860 = 2c(1.90); $\underline{c = 226 \text{ psi}}$

Sample 6

Mdayrej Plant Proposed Mix having an asphalt content of 5.0 per cent. Height of specimen 6.1 cms. Bulk Specific Gravity of specimen 2.30.

Pounds Loading	Vertical Pressure (psi)	Lateral Pressure (psi)
500	40	5
1000	80	5
2000	160	6
3000	240	6
4000	320	7
5000	400	8
6000	480	11
7000	560	13
8000	640	17
9000	720	23
10000	800	28
11000	880	35
12000	960	45
13000	1040	58
14000	1120	77
15000	1200	99
16000	1280	125
17000	1360	149

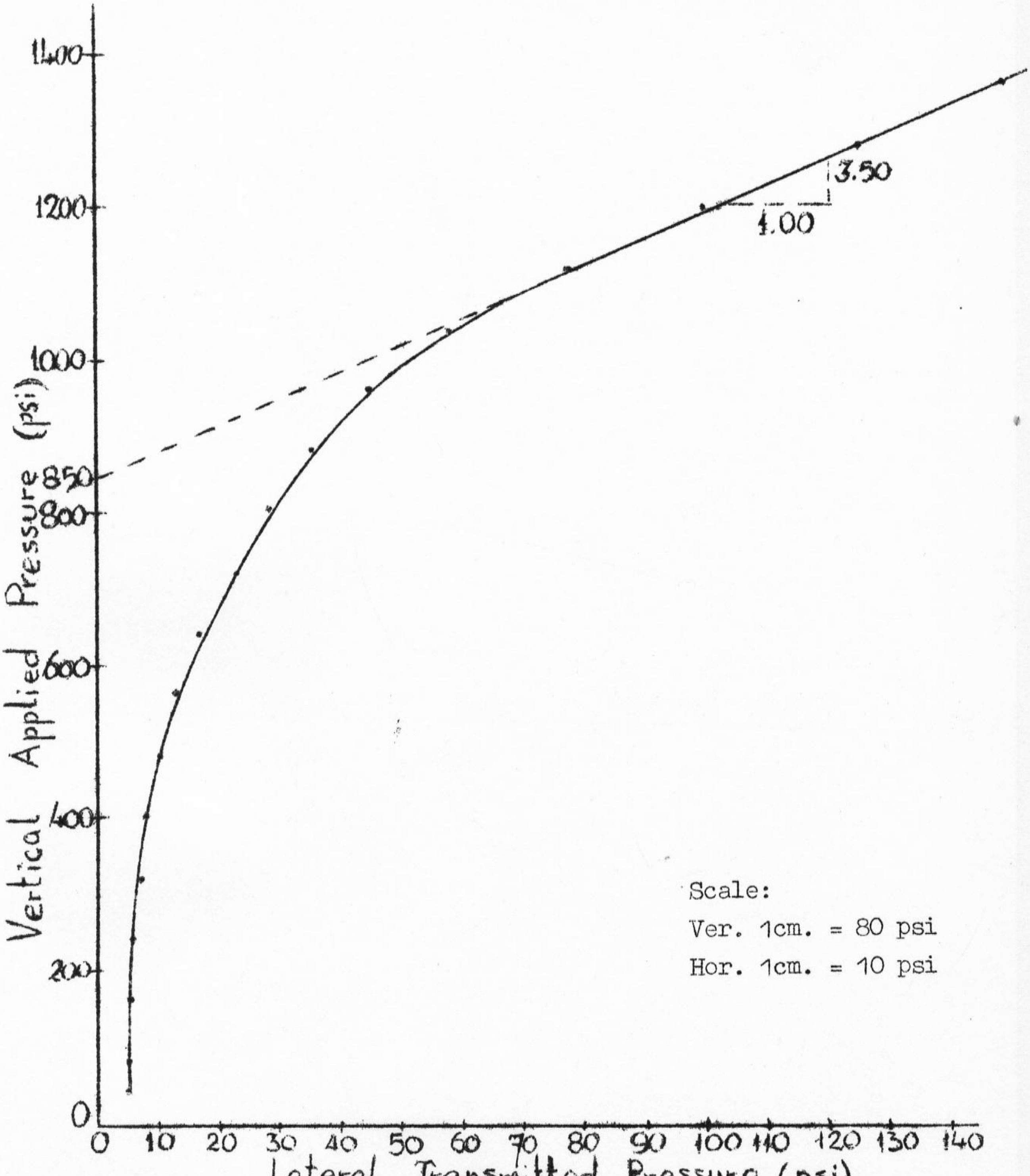


FIG.22. Mdayrej Proposed Mix Triaxial Compression Stability Test Curve at 5 per cent Asphalt Content.

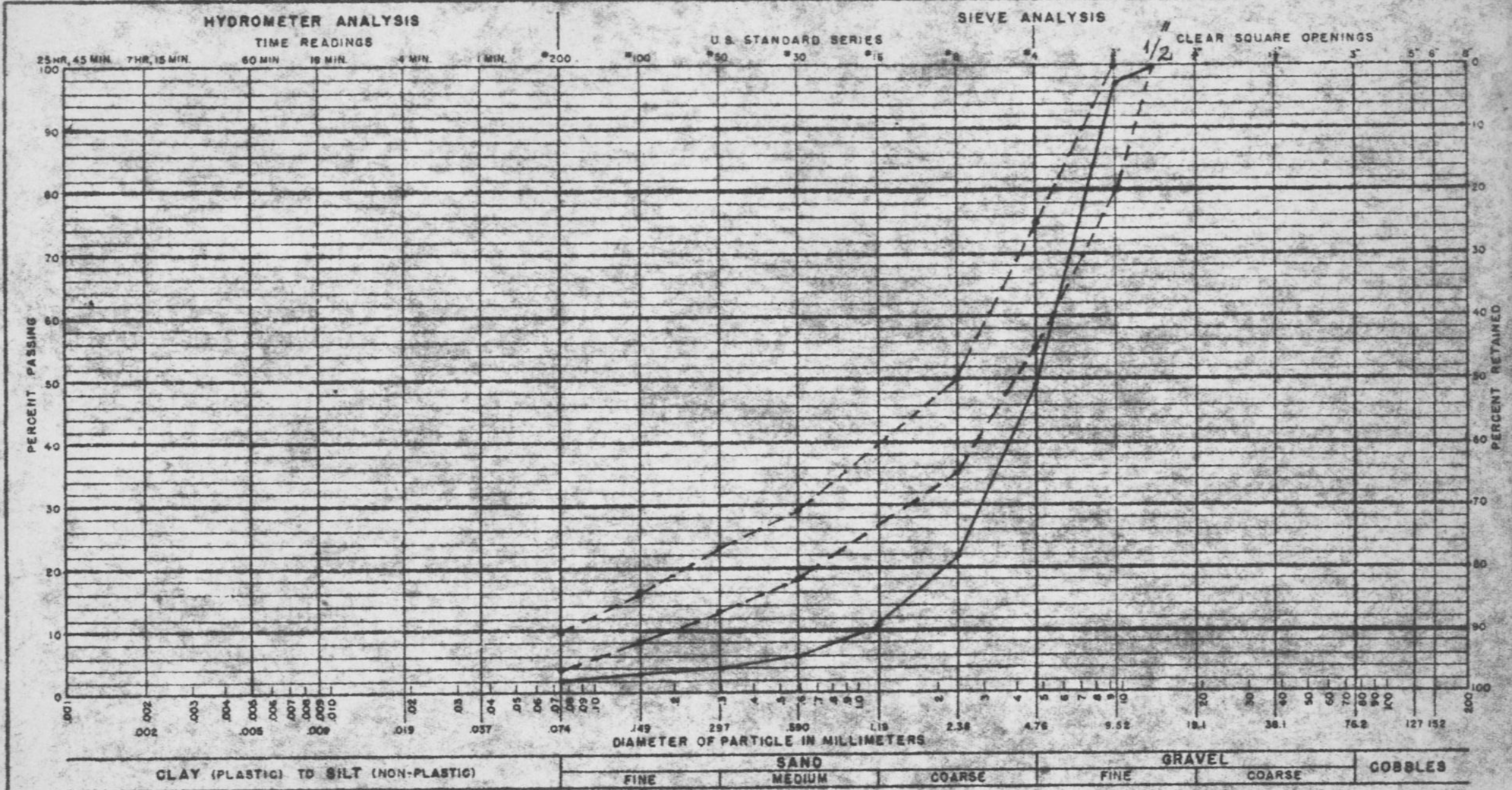
Slope = 3.50 = $\tan^2(45 + \emptyset/2)$; 1.87 = $\tan(45 + \emptyset/2)$; $\underline{\emptyset = 33.8^{\circ}}$

850 = 2c $\tan(45 + \emptyset/2)$; 850 = 2c(1.87); $\underline{c = 228 \text{ psi}}$

APPENDIX D

Sieve Analysis Results of the Beirut Municipality, Mkalles and Mdayrej Plants

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

ACTUAL SAMPLE (SOLID)
SPECIFICATION LIMITS (HATCHED)

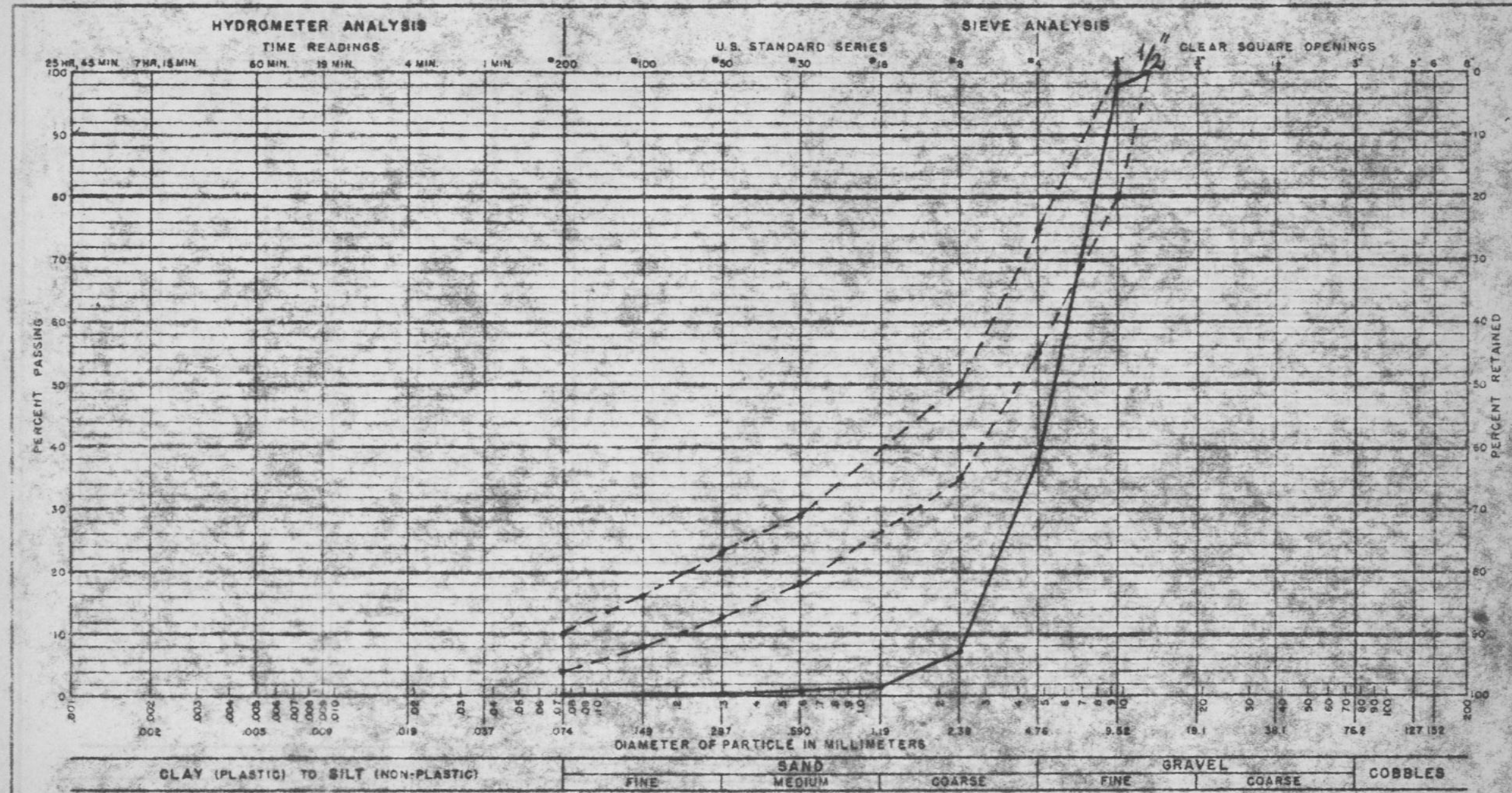
FIGURE 23

Materials Testing Laboratory
GRADATION TEST

SAMPLE 1
MUNICIPALITY PLANT MIX

DRAWN CHECKED DATE

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

Materials Testing Laboratory
GRADATION TEST

SAMPLE 2
MUNICIPALITY PLANT MIX

DRAWN CHECKED DATE

FIGURE 24

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.

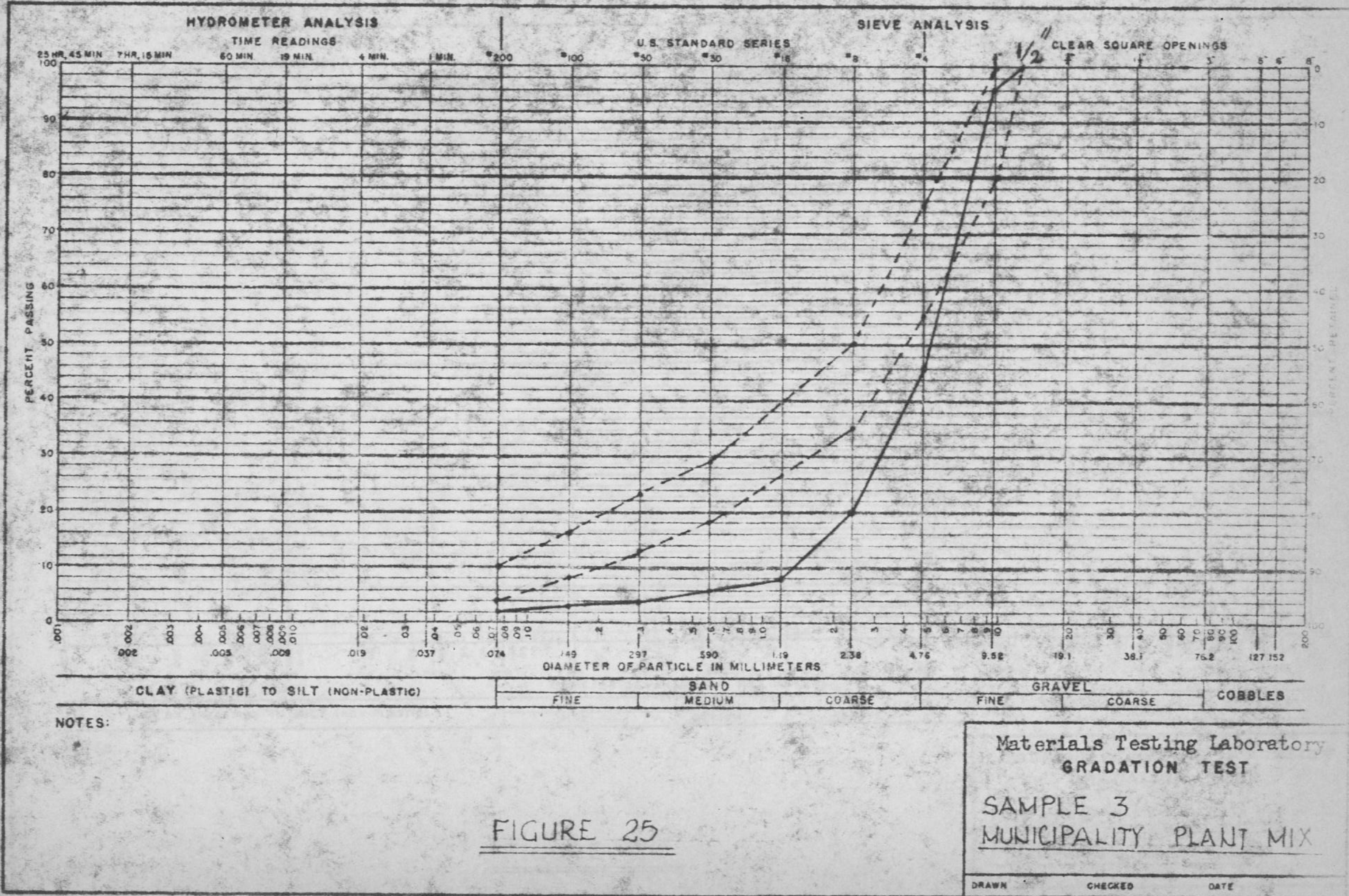
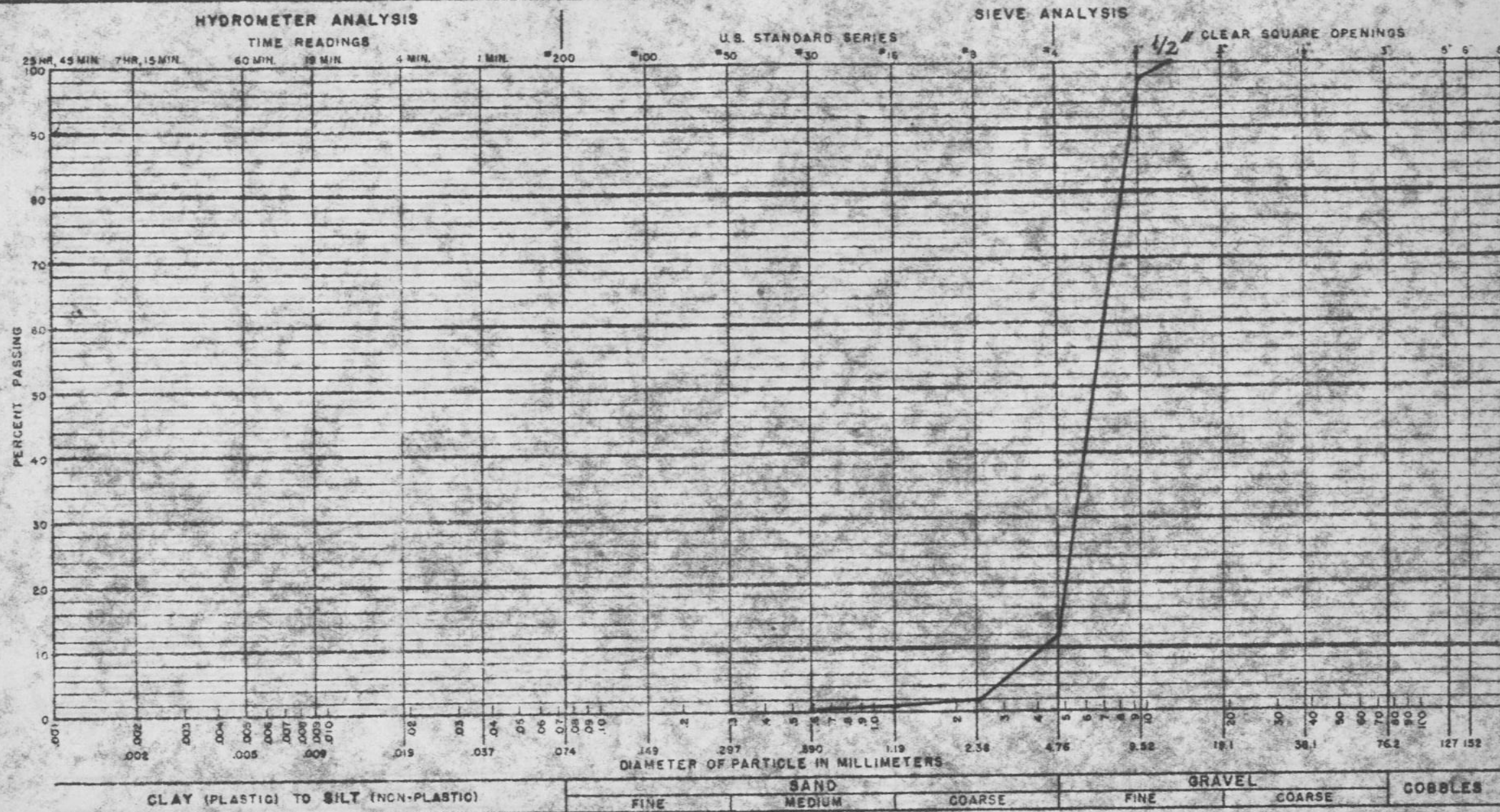


FIGURE 25

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

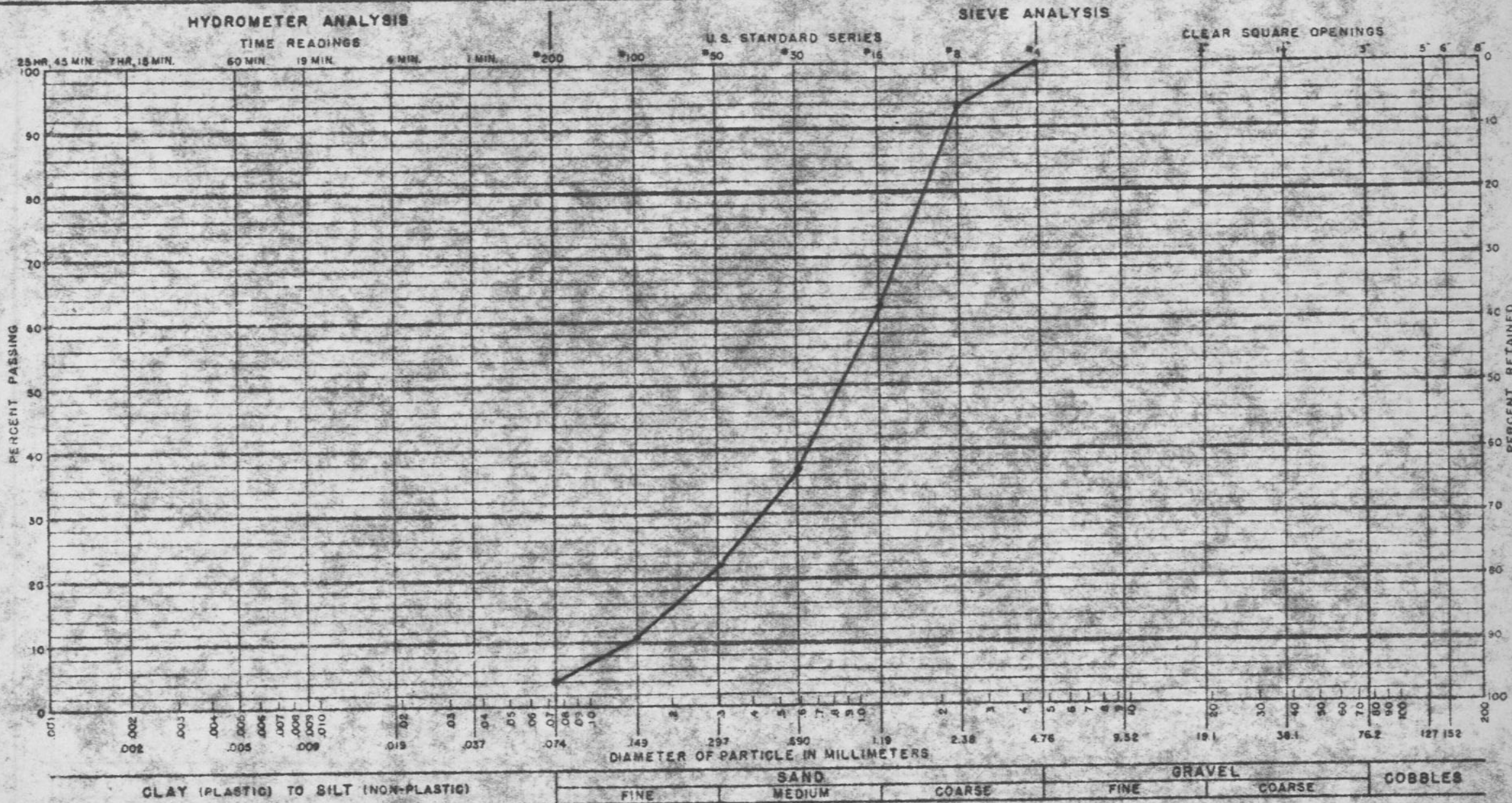
FIGURE 26

Materials Testing Laboratory
GRADATION TEST

MUNICIPALITY PLANT
FINE AGGREGATE

DRAWN | CHECKED | DATE

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.

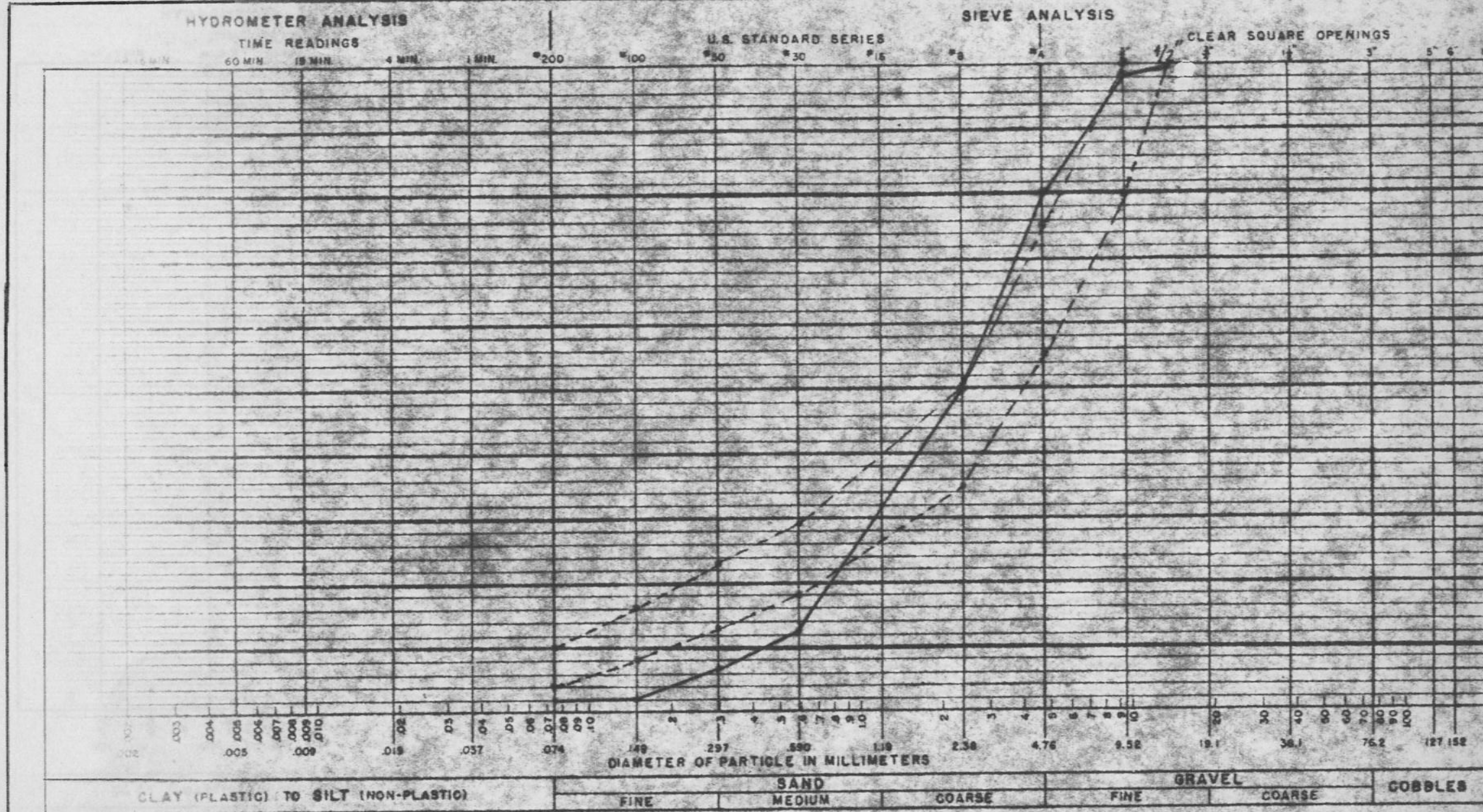


NOTES:

FIGURE 27

Materials Testing Laboratory
GRADATION TEST
MUNICIPALITY PLANT
FILLER

DRAWN CHECKED DATE

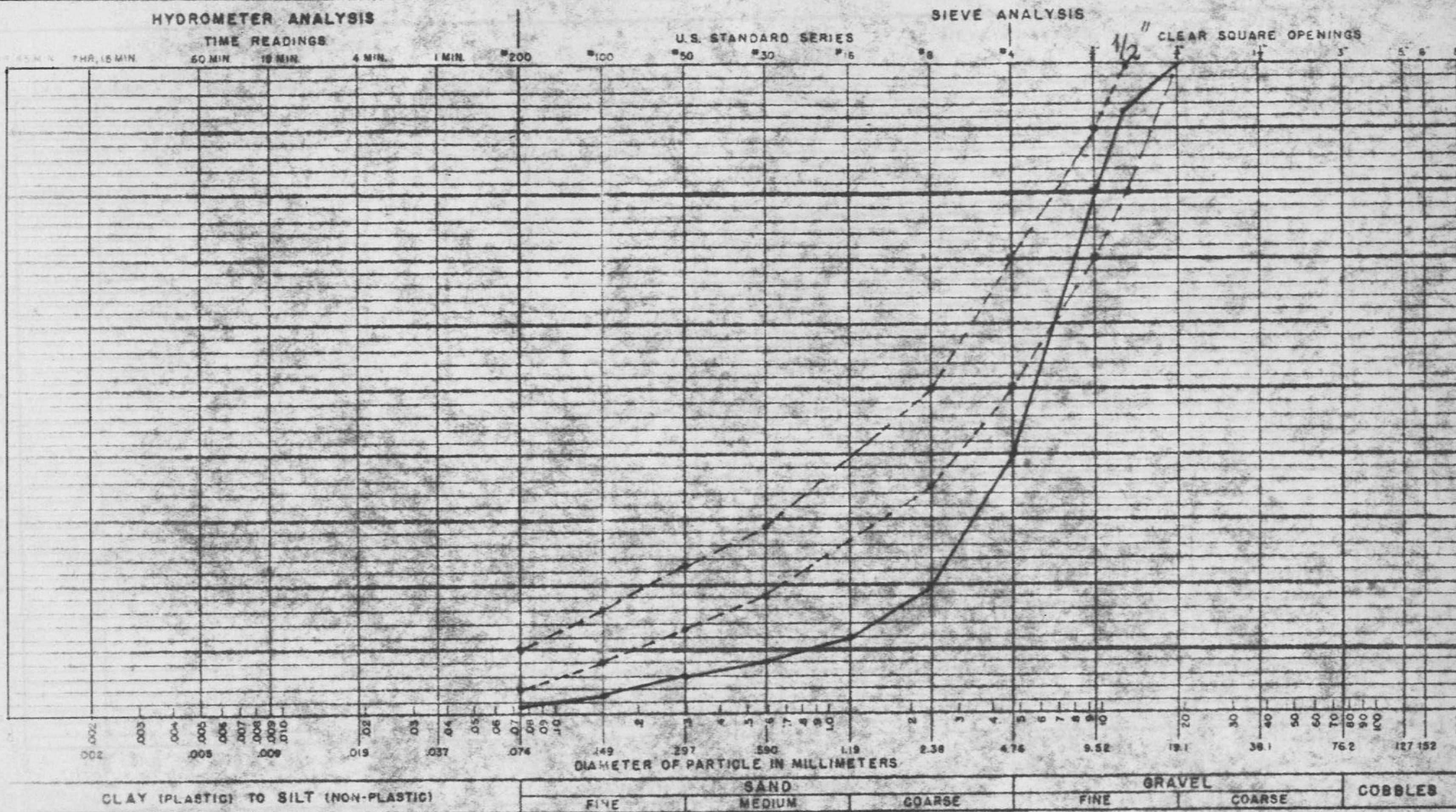


Materials Testing Laboratory
GRADATION TEST
MUNICIPALITY PLANT
PROPOSED MIX

DRAWN	CHECKED	DATE

FIGURE 28

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

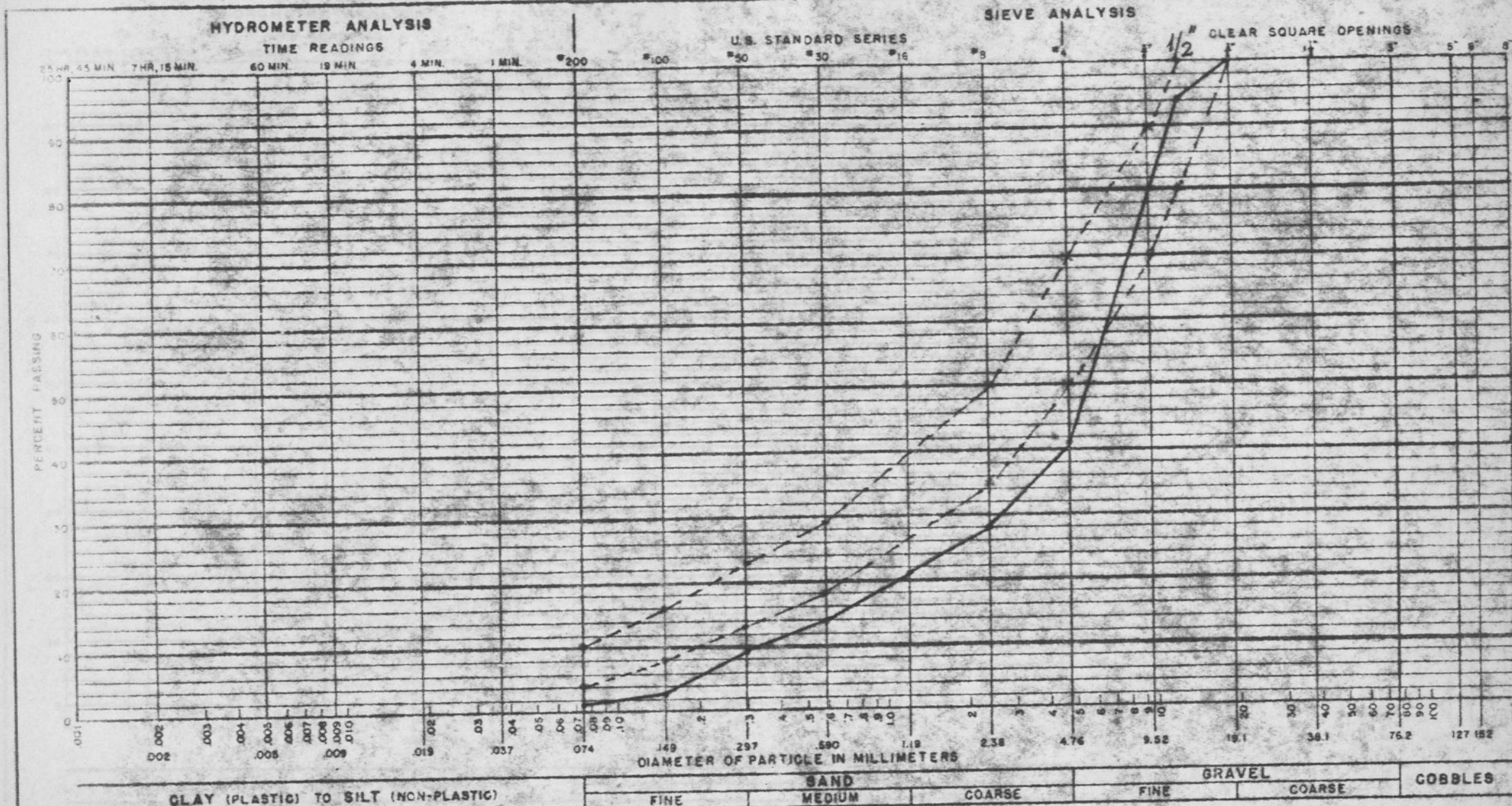
ACTUAL SAMPLE (SOLID)
SPECIFICATION LIMITS (HATCHED) FIGURE 29

Materials Testing Laboratory
GRADATION TEST

SAMPLE 1
MKALLES PLANT MIX

DRAWN CHECKED DATE

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

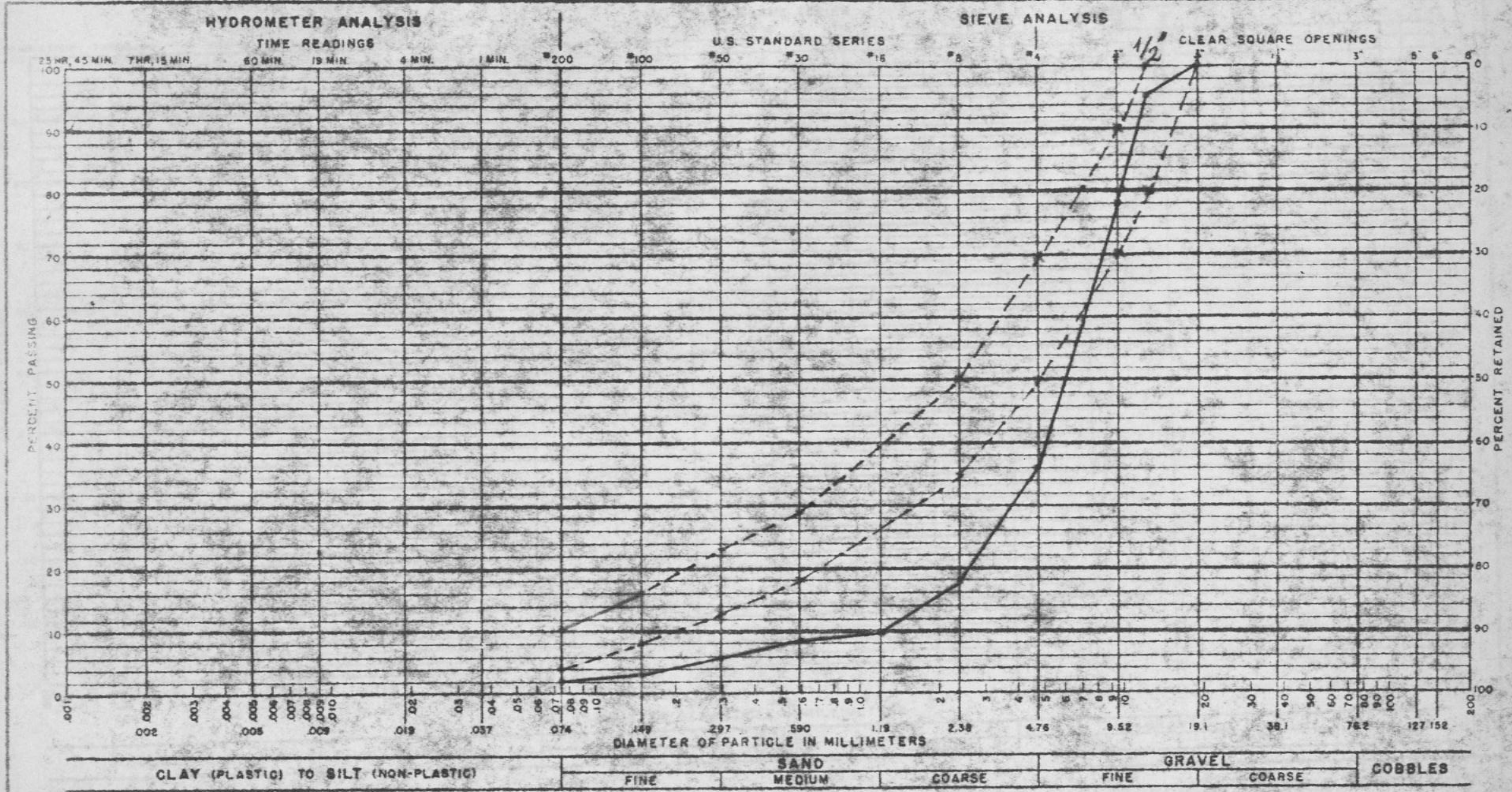
Materials Testing Laboratory
GRADATION TEST

SAMPLE 2
MKALLES PLANT MIX

DRAWN CHECKED DATE

FIGURE 30

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

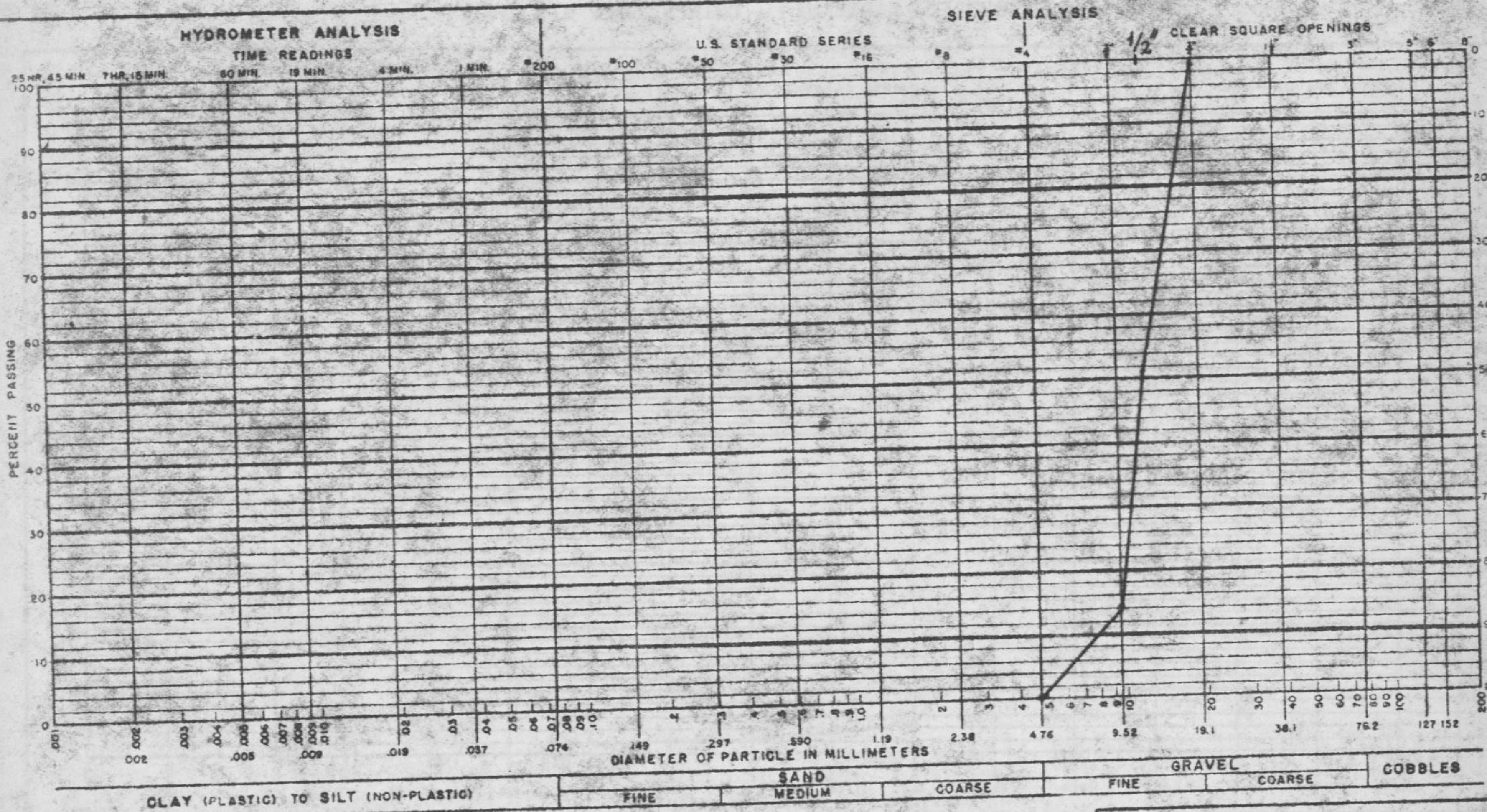
Materials Testing Laboratory
GRADATION TEST

SAMPLE 3
MIKALLES PLANT MIX

DRAWN CHECKED DATE

FIGURE 31

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

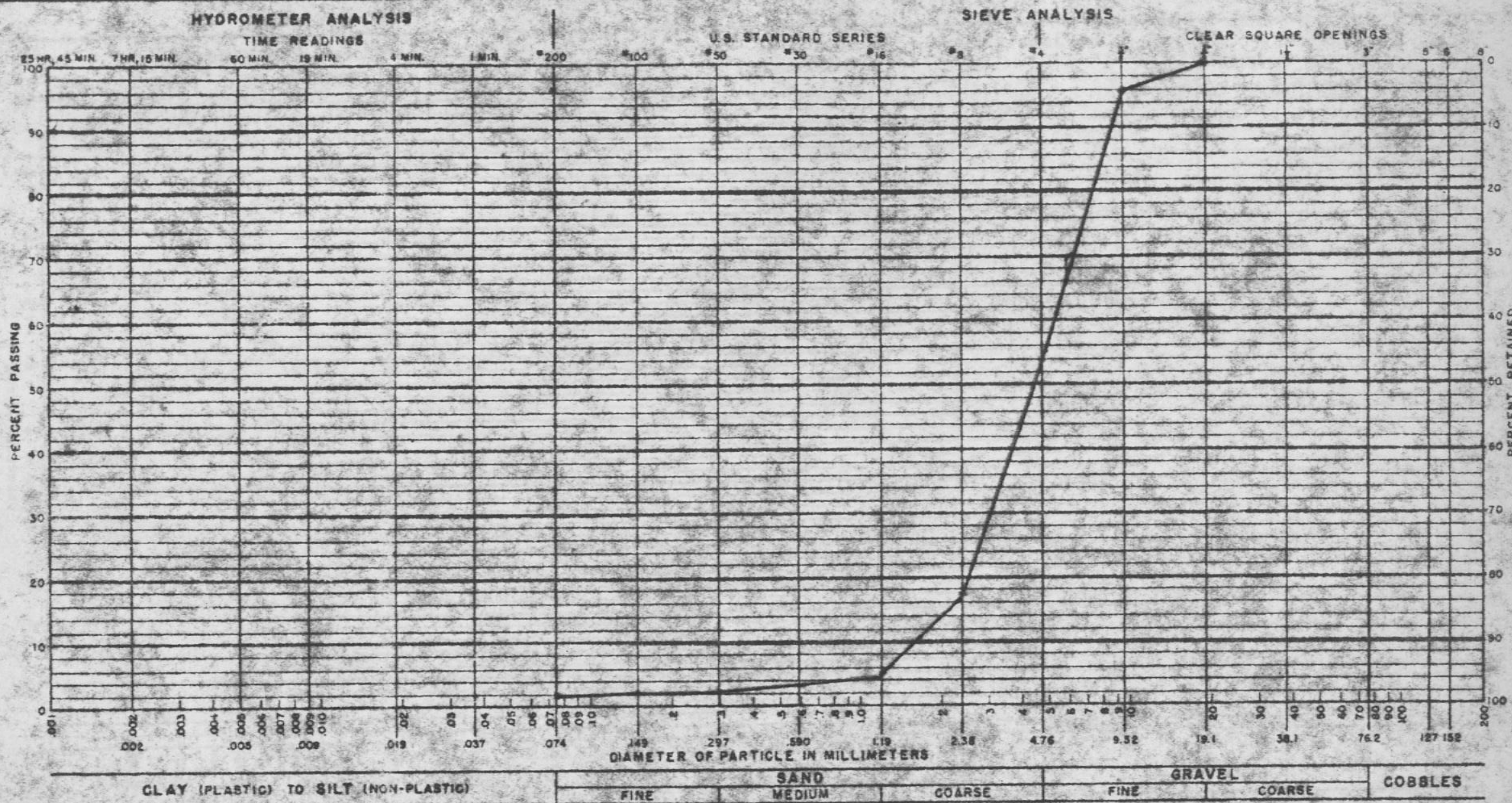
FIGURE 32

Materials Testing Laboratory
GRADATION TEST

MKALLES PLANT
COARSE AGGREGATE

DRAWN | CHECKED | DATE

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

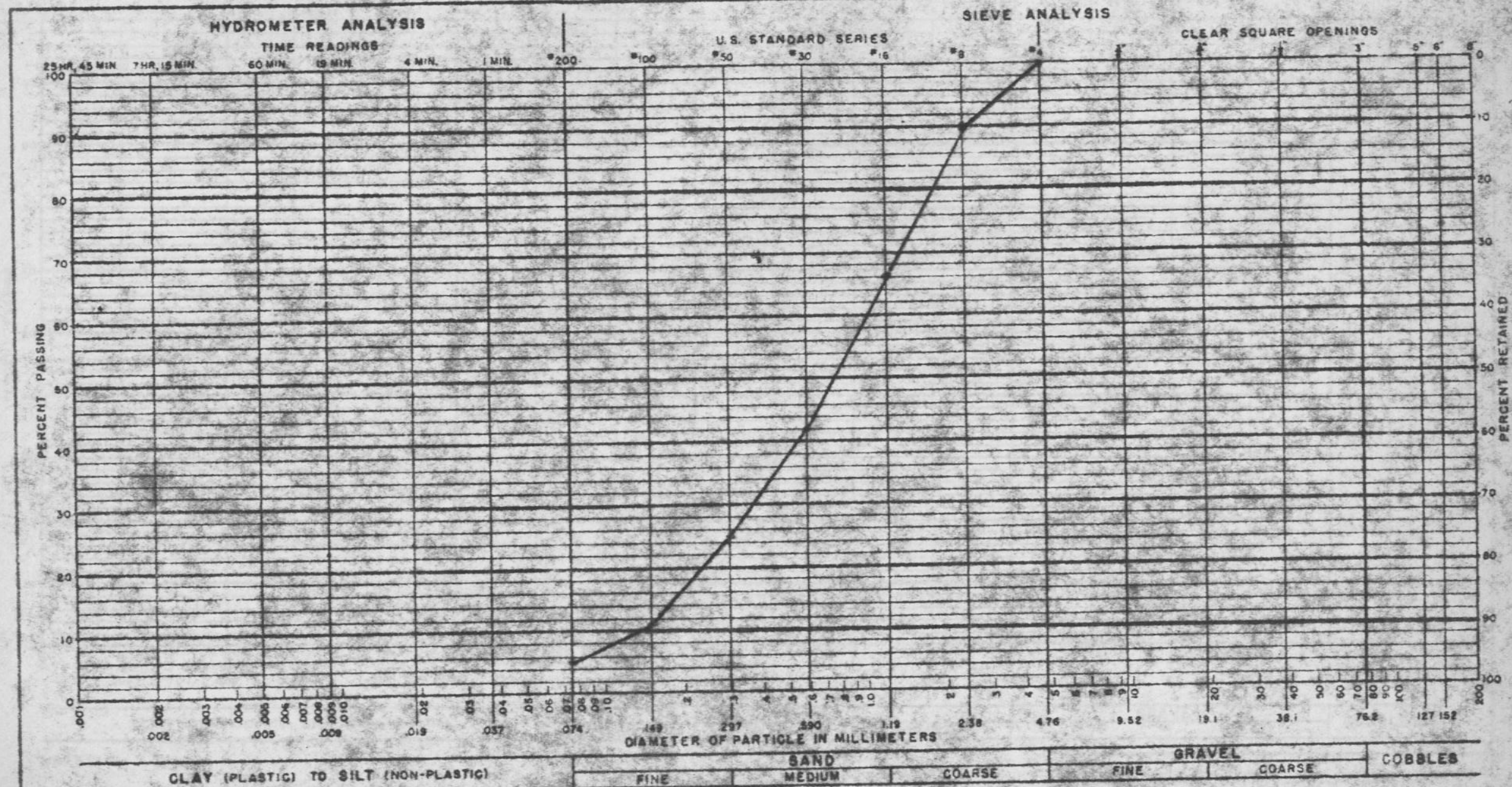
Materials Testing Laboratory
GRADATION TEST

MKALLES PLANT
FINE AGGREGATE

DRAWN CHECKED DATE

FIGURE 33

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

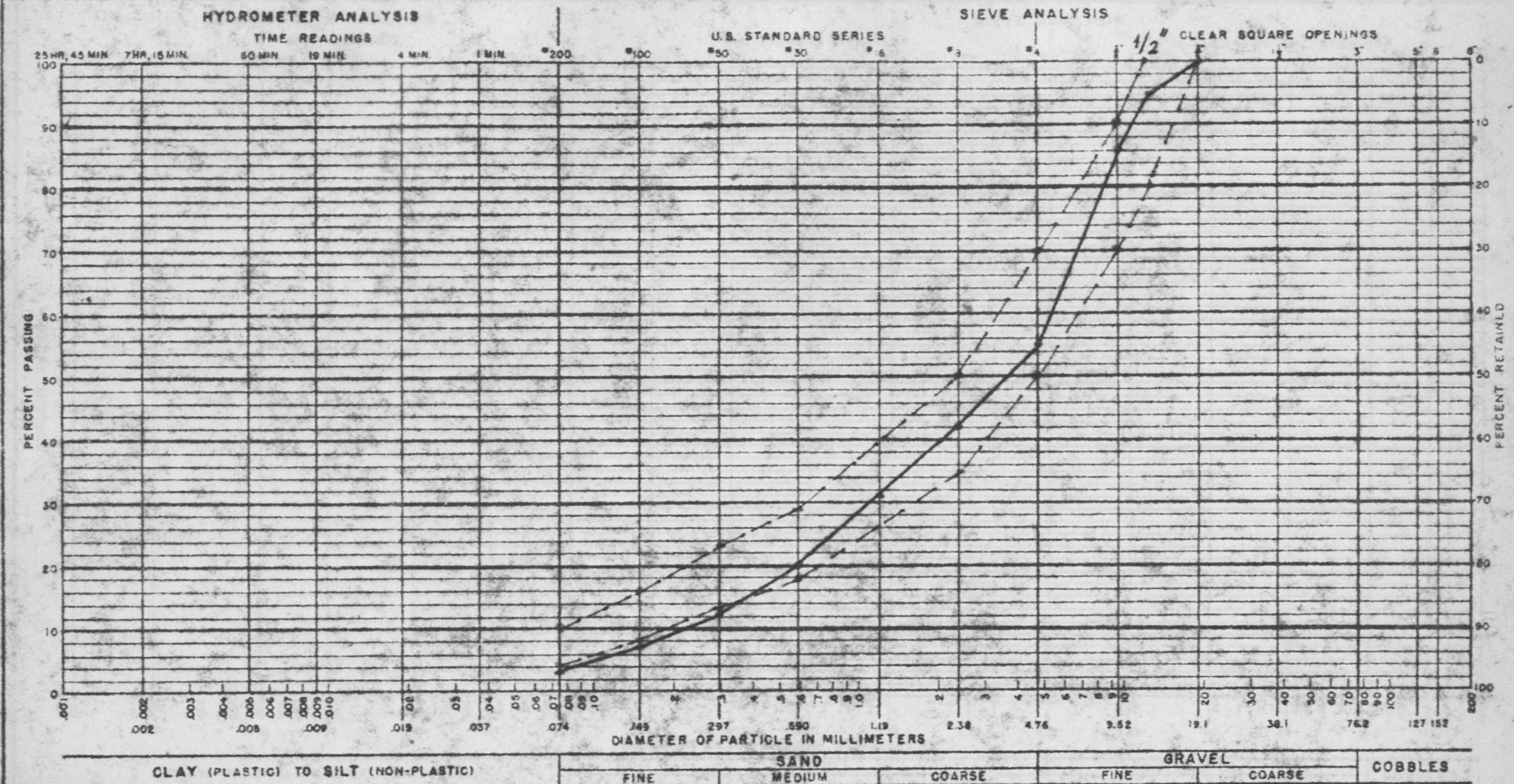
FIGURE 34

Materials Testing Laboratory
GRADATION TEST

MKALLES PLANT FILLER

DRAWN	CHECKED	DATE

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

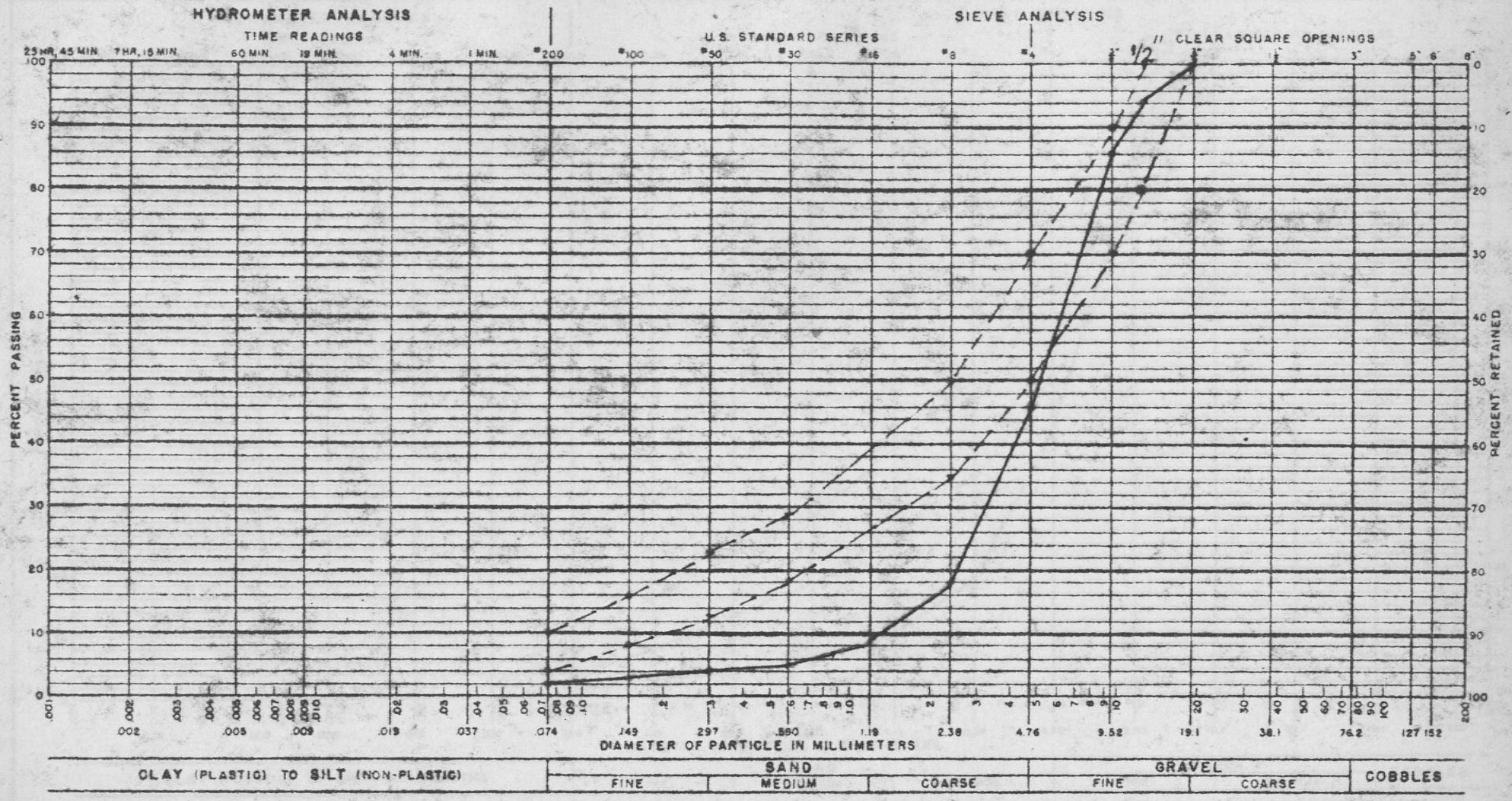
FIGURE 35

Materials Testing Laboratory
GRADATION TEST

MKALLES PLANT
PROPOSED MIX

DRAWN CHECKED DATE

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

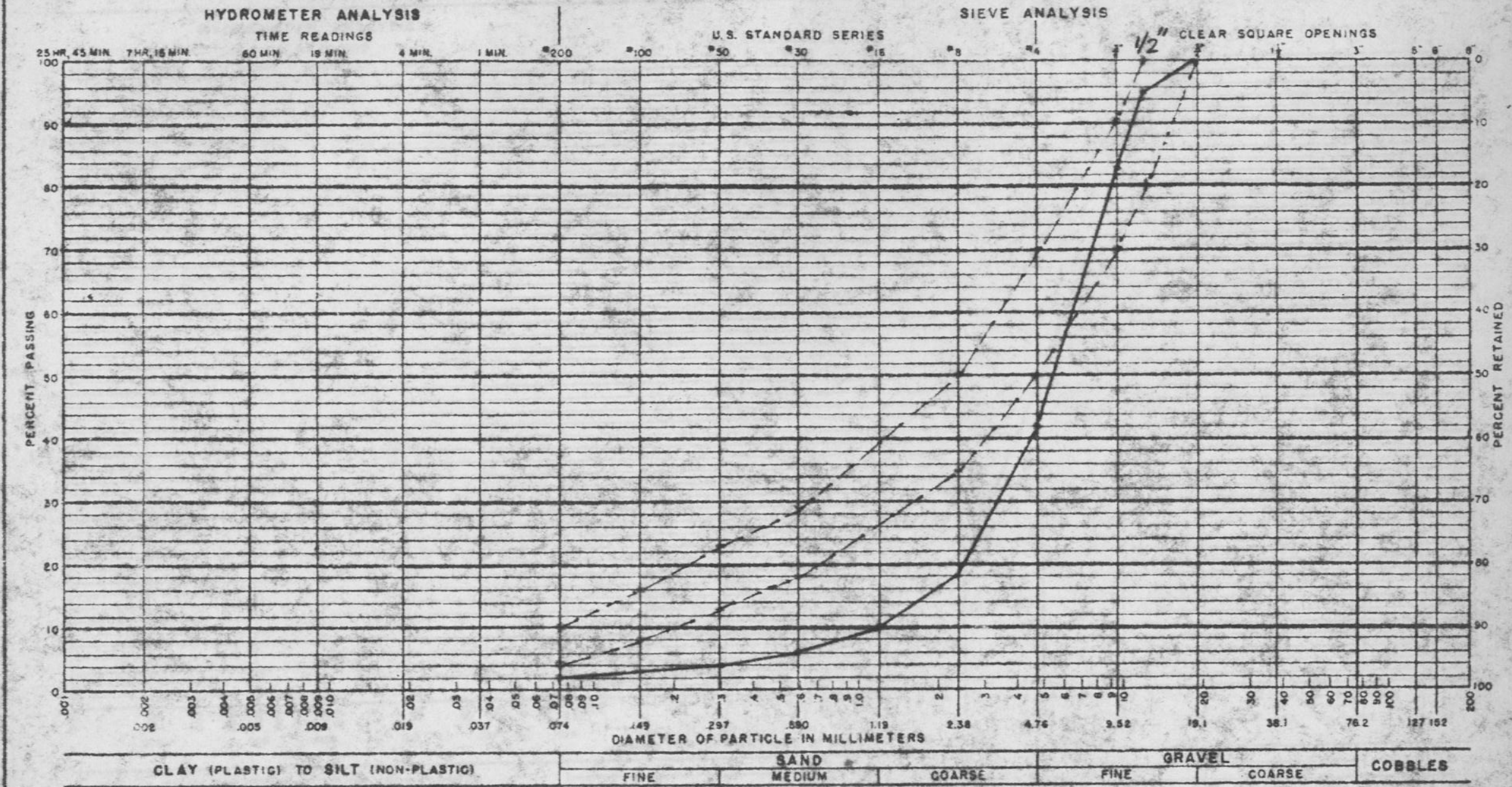
ACTUAL SAMPLE (SOLID)
SPECIFICATION LIMITS (HATCHED)

FIGURE 36

Materials Testing Laboratory
GRADATION TEST

SAMPLE 1
MDAYREJ PLANT MIX

DRAWN CHECKED DATE



NOTES:

FIGURE 37

Materials Testing Laboratory
GRADATION TEST

SAMPLE 2
MDAYREJ PLANT MIX

DRAWN CHECKED DATE

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.

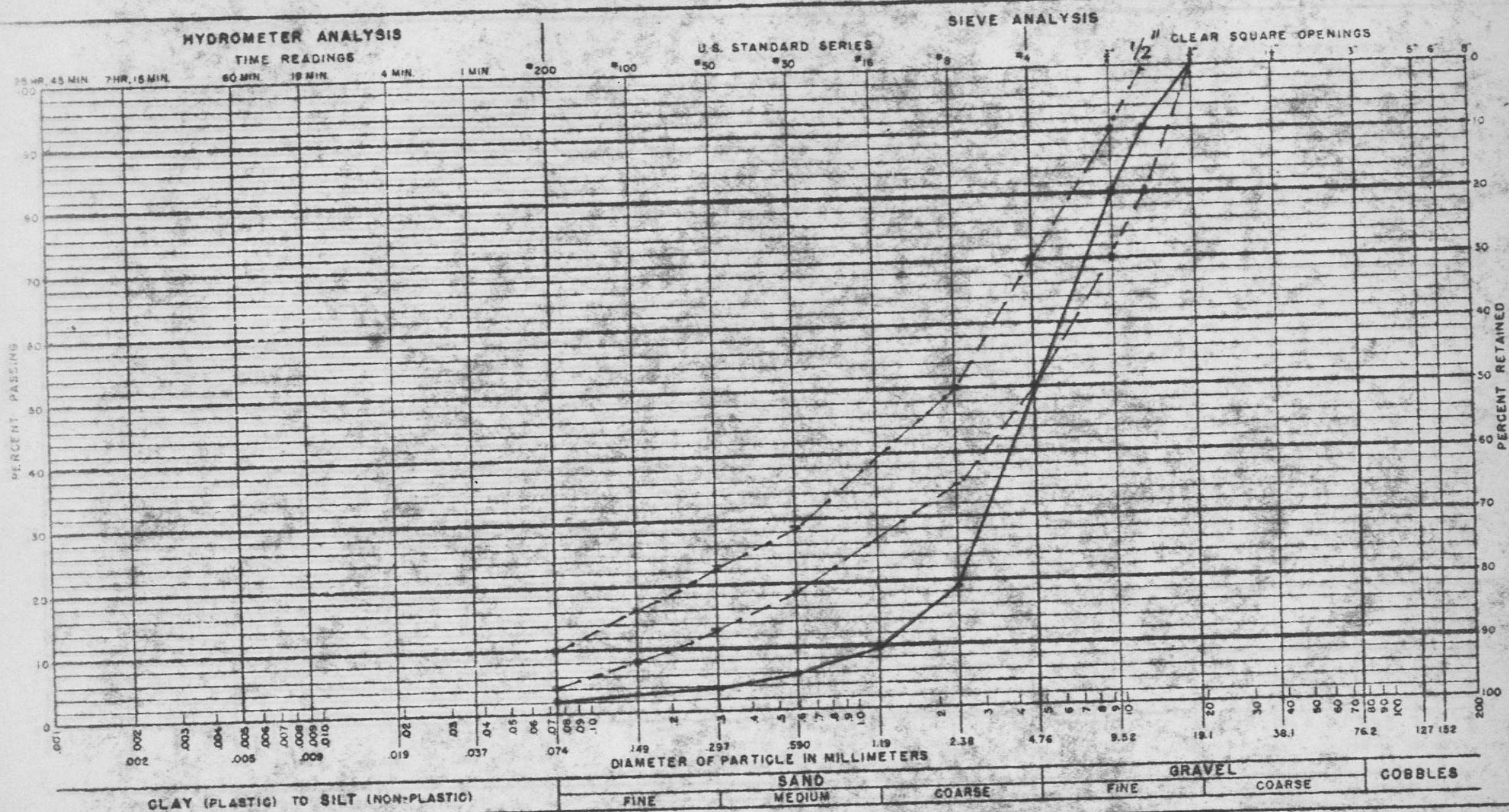


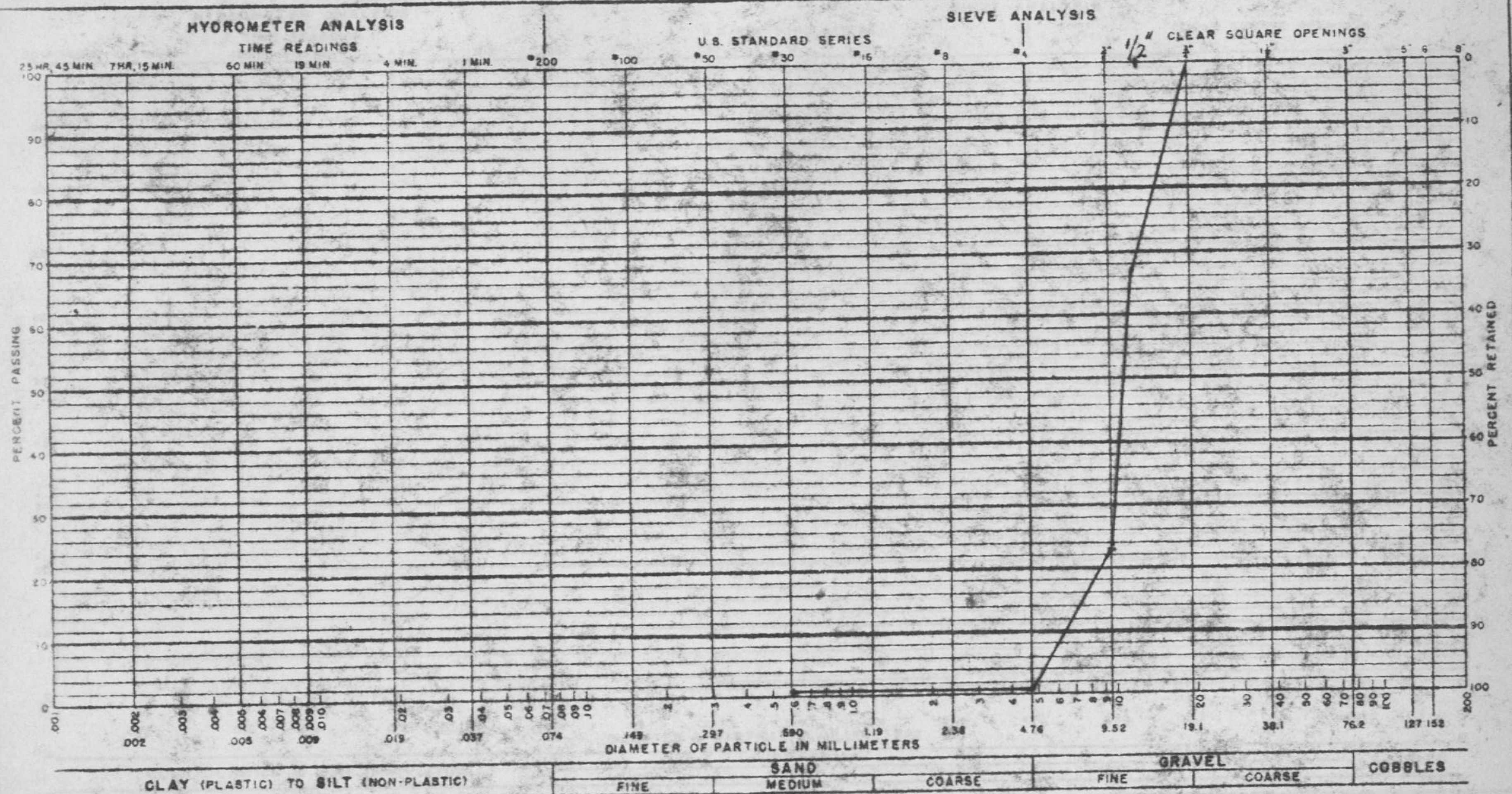
FIGURE 38

Materials Testing Laboratory
GRADATION TEST

SAMPLE 3
MDAYREJ PLANT MIX

DRAWN CHECKED DATE

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

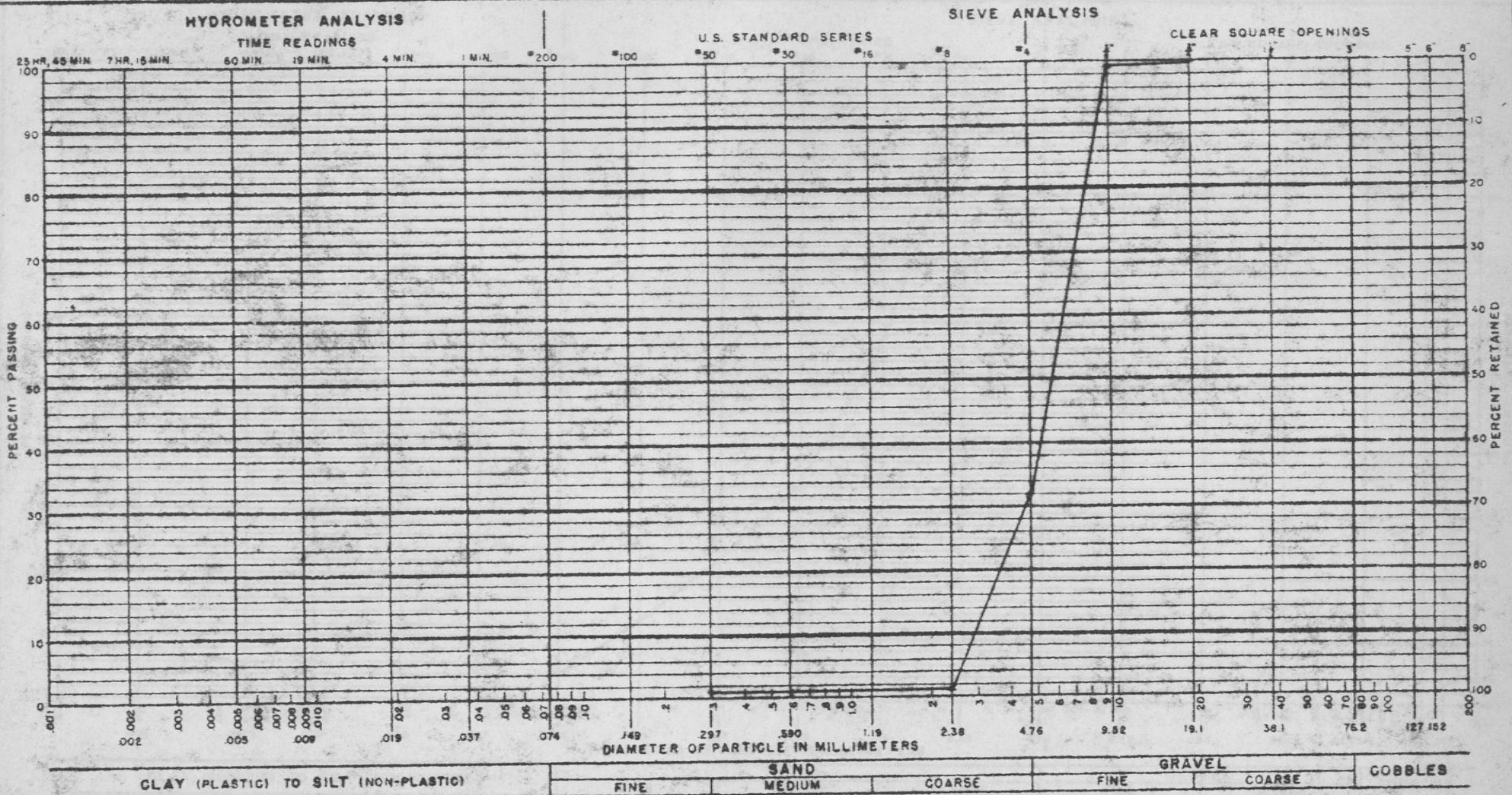
FIGURE 39

Materials Testing Laboratory
GRADATION TEST

MDAYREJ PLANT
COARSE AGGREGATE

DRAWN CHECKED DATE

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

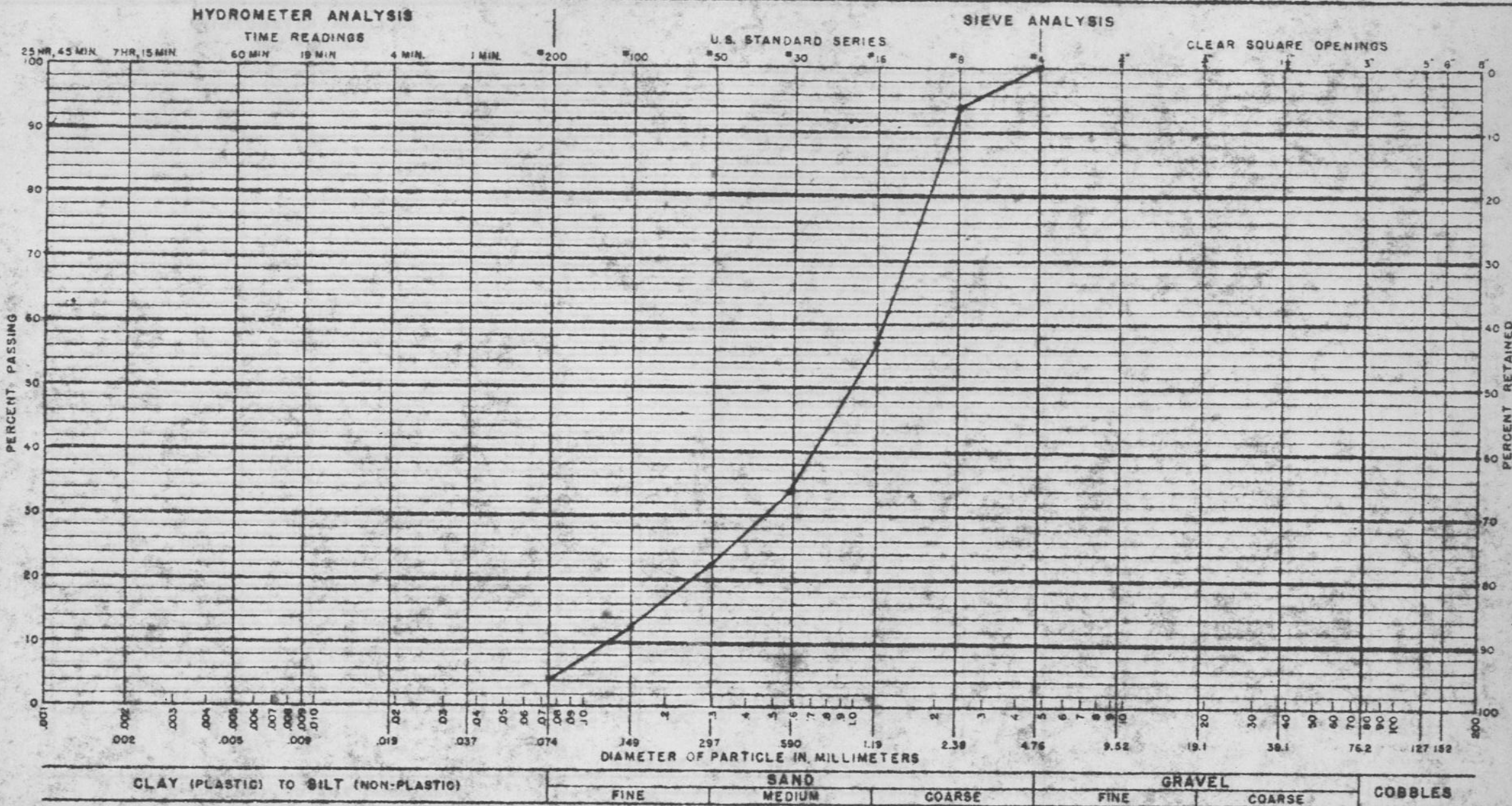
Materials Testing Laboratory
GRADATION TEST

MDAYREJ PLANT
FINE AGGREGATE

DRAWN CHECKED DATE

FIGURE 40

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

FIGURE 41

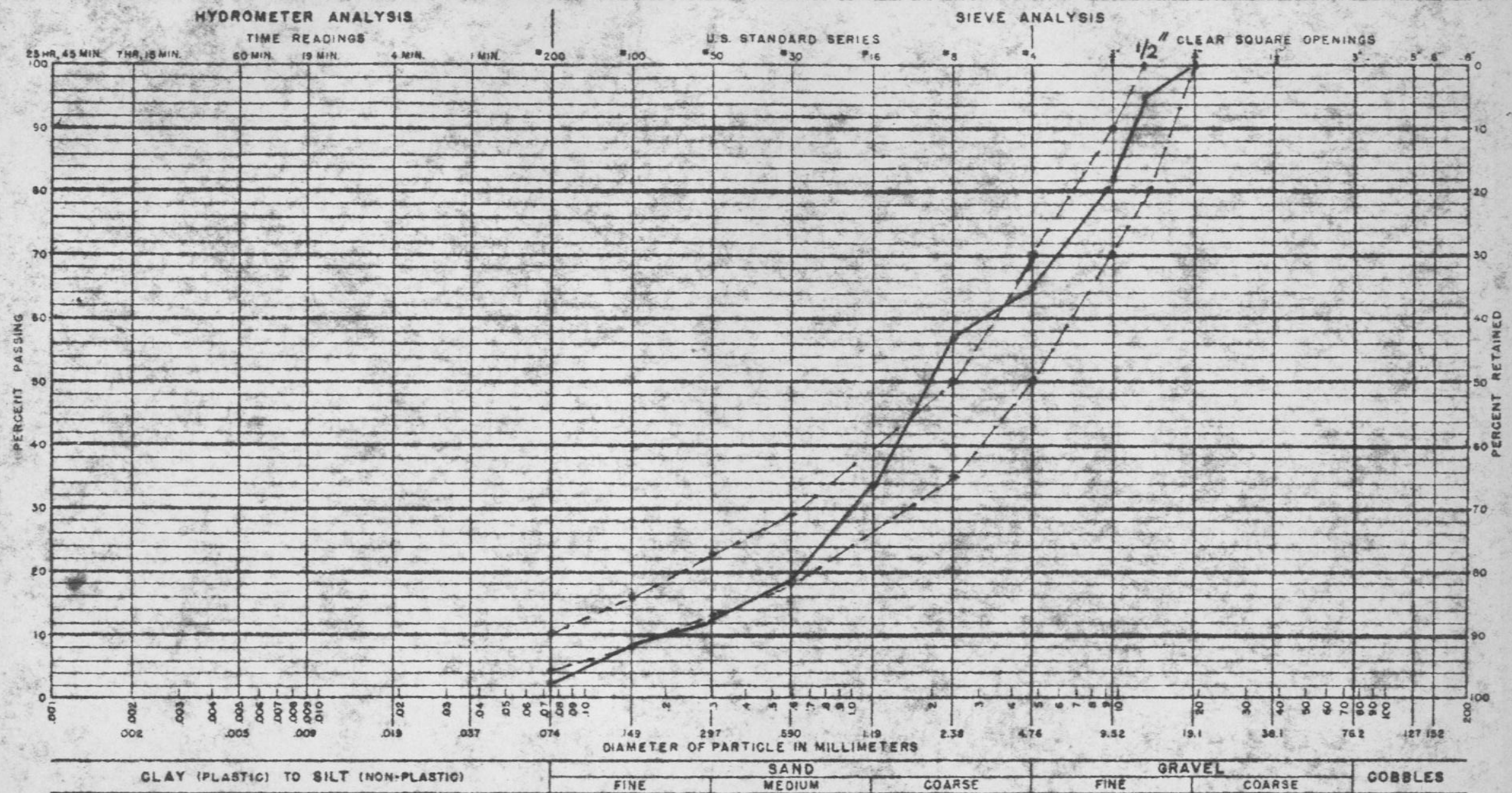
Materials Testing Laboratory

GRADATION TEST

MDAYREJ PLANT FILLER

DRAWN CHECKED DATE

FACULTY OF ENGINEERING - AMERICAN UNIVERSITY OF BEIRUT.



NOTES:

FIGURE 42

Materials Testing Laboratory
GRADATION TEST

MDAYREJ PLANT
PROPOSED MIX

DRAWN CHECKED DATE

APPENDIX E

Data of Tests on Coarse Aggregate, Fine Aggregate and Filler from the Beirut Municipality, Mkalles and Mdayrej Plants

APPENDIX E

Data of Tests on Coarse Aggregate, Fine Aggregate and Filler from the Beirut Municipality, Mkalles and Mdayrej Plants

TABLE 11

Sand Equivalent of Filler from Municipality Plant

Sample	Clay Reading Inches	Sand Reading Inches	Sand Equivalent Per cent
1	4.4	3.2	73
2	4.3	3.2	75
3	4.0	3.2	80
4	4.3	3.1	72
5	4.2	3.2	76

TABLE 12

Sand Equivalent of Filler from Mkalles Plant

Sample	Clay Reading Inches	Sand Reading Inches	Sand Equivalent Per Cent
1	6.6	2.7	41
2	6.1	2.4	39
3	6.3	2.5	40
4	6.4	2.5	39
5	6.4	2.6	41

TABLE 13

Sand Equivalent of Filler from Mdayrej Plant

Sample	Clay Reading Inches	Sand Reading Inches	Sand Equivalent Per Cent
1	5.4	3.6	67
2	5.4	3.4	63
3	5.4	3.5	65
4	5.2	3.4	65
5	5.4	3.6	67

TABLE 14

Los Angeles Abrasion Test on Fine Aggregate from Beirut Municipality

Sample	Original Weight Grams	Final Weight Grams	Percentage of Wear
1	5000	3644	27.2
2	5000	3670	26.6
3	5000	3631	27.4
4	5000	3610	27.8
5	5000	3600	28.0

TABLE 15

Los Angeles Abrasion Test on Coarse Aggregate from Mkalles Plant

Sample	Original Weight Grams	Final Weight Grams	Percentage of Wear
1	5000	3048	39.0
2	5000	3080	38.4
3	5000	3008	40.0
4	5000	3020	39.6
5	5000	3064	38.7

TABLE 16

Los Angeles Abrasion Test on Coarse Aggregate from Mdayrej Plant

Sample	Original Weight Grams	Final Weight Grams	Percentage of Wear
1	5000	3412	31.8
2	5000	3425	31.5
3	5000	3430	31.4
4	5000	3420	31.6
5	5000	3395	32.1

TABLE 17

Specific Gravity of Fine Aggregate and Filler from the Beirut Municipality Plant

Sample	Specific Gravity of Fine Aggregate	Specific Gravity of Filler
1	2.64	2.70
2	2.65	2.70
3	2.64	2.66
4	2.63	2.66
5	2.64	2.67

TABLE 18

Specific Gravity of Coarse and Fine Aggregate and Filler from the Mkalles Plant

Sample	Specific Gravity of Coarse Agg.	Specific Gravity of Fine Agg.	Specific Gravity of Filler
1	2.62	2.62	2.65
2	2.63	2.62	2.66
3	2.61	2.63	2.66
4	2.60	2.62	2.65
5	2.63	2.60	2.65

TABLE 19

Specific Gravity of Coarse and Fine Aggregate and Filler from the Mdayrej Plant

Sample	Specific Gravity of Coarse Agg.	Specific Gravity of Fine Agg.	Specific Gravity of Filler
1	2.60	2.62	2.67
2	2.62	2.62	2.66
3	2.60	2.63	2.68
4	2.59	2.61	2.68
5	2.59	2.63	2.65

APPENDIX F

Data of Tests on Asphalt Cement

APPENDIX F

Data of Tests on Asphalt Cement

TABLE 20

Penetration Values of Asphalt Cement from Beirut Municipality Plant

Sample	Penetration in 1/100 cm. 77°F, 100 g., 5 sec.
1	95.5
2	98.8
3	97.5
4	96.5
5	97.0

TABLE 21

Penetration Values of Asphalt Cement from Mkalles Plant

Sample	Penetration in 1/100 cm. 77°F, 100 g., 5 sec.
1	102.0
2	105.0
3	105.0
4	110.0
5	100.0

TABLE 22

Penetration Values of Asphalt Cement from Mdayrej Plant

Sample	Penetration in 1/100 cm. 77°F, 100 g., 5 sec.
1	101.0
2	98.0
3	97.0
4	95.0
5	97.0

TABLE 23

Saybolt Furol Viscosity of Asphalt Cement from Plants

Plant	Viscosity at 275°F SSF
Beirut Munici-pality	175
Mkalles	203
Mdayrej	214

TABLE 24

Specific Gravity of Asphalt Cement from Plants‡

Plant	Specific Gravity at 77°F
Beirut Munici-pality	1.024
Mkalles	1.024
Mdayrej	1.024

‡ Values obtained from the Suppliers (ESSO).

TABLE 25

Distillation of Asphalt Cement from Plants

Plant	Distillation at 680°F (per cent)
Beirut Munici-pality	99
Mkalles	98
Mdayrej	99

APPENDIX G

Testing Equipment

APPENDIX G

Testing Equipment

G.1 Equipment for the Marshall Test

The important pieces of equipment are the following:

1- Marshall Test Apparatus (TESTLAB Corporation), 115/230 V. 50 cycles.

2- Flow Meter.

3- Compaction Hammer.

4- Compaction Mold, consisting of a base plate, forming mold, and collar extension.

5- Electric Water Bath (Westinghouse).

6- Oven and Hot Plate.

7- Electric Mixer (Reynolds Electric Company).

8- Balance, 20 kg. capacity, sensitive to 1 gm.

9- Thermometer, armored, +50 to +450 F.

G.2 Equipment for the Triaxial Compression Test

The important pieces of equipment are the following:

1- Hveem Stabilometer.

2- Static Loading Machine (W. & T. Avery), 400 000 lb. capacity.

3- Electric Water Bath (Westinghouse).

4- Electric Mixer (Reynolds Electric Company).

5- Mechanical Kneading Compactor (Soiltest), 220 V. 50 c.

6- Compressor (Alemite), 3 HP, 220 V. 50 c. 1460 rpm.

7- Compaction Mold.

8- Testing Machine (Tinius Olsen), 190 V. 50 c. 1425/1725 rpm.

G.3 Equipment for the Sand Equivalent Test

1- No. 4 Sieve.

2- Graduated Cylinders.

3- Chronometer.

4- 1 kg. Steel Piston.

5- Funnel.

6- Tin Container.

7- Jars.

G.4 Equipment for the Sieve Analysis Test

1- Balance, 5 kg. capacity, sensitive to 0.5 gm.

2- Sieves of $\frac{3}{4}$", $\frac{1}{2}$", $\frac{3}{8}$", No. 4, 8, 16, 30, 50, 100, and 200.

3- Vibrator Machine (Pascall).

4- Brushes.

G.5 Equipment for the Los Angeles Abrasion Test

1- Los Angeles Machine.

2- Abrasive Charge.

3- No. 12 Sieve.

4- Balance, 20 kg. capacity, sensitive to 1 gm.

G.6 Equipment for Specific Gravity Test of Coarse Aggregate

1- Balance, 20 kg. capacity, sensitive to 1 gm.

2- Wire Basket.

3- Container full of water.

G.7 Equipment for Specific Gravity Test of Fine Aggregate and Filler

1- Balance, 20 kg. capacity, sensitive to 1 gm.

2- Flask.

3- Conical Mold.

4- Tamping Rod.

G.8 Equipment for the Penetration Test

1- Container, made of metal or glass, cylindrical in shape and having a flat bottom.

2- Needle, made from a cylindrical steel rod 50.8 mm. in length and 1 mm. in diameter.

3- Electric Water Bath (Westinghouse).

4- Penetration Apparatus.

5. Transfer Dish for Container.

G.9 Equipment for the Saybolt Furol Viscosity Test

1- Viscosity Tube.

2- Receiver.

3- Bath.

4- Viscosity Thermometers.

5- Bath Thermometers.

6- Displacement Ring.

7- Cover.

8- Strainer.

9- Hot Plate.

10- Timer.

G.10 Equipment for the Extraction Test

1- Motorized Centrifuge Extractor (Soiltest).

2- Carbon Tetrachloride Solution.

3- Graduated Cylinder.

4- Balance, 5 kg. capacity, sensitive to 0.5 gm.

G.11 Equipment for the Distillation Test

1- Flask, 500 ml. side-neck.

2- Condenser, 250 mm.

3- Adapter.

4- Shield.

5- Receiver.

6- Container for Residue.

7- Thermometer.

8- Bunsen Burner.

BIBLIOGRAPHY

1. American Association of State Highway Officials, Specifications for Construction, Bituminous Surfacing, Washington D.C., 1949.

2. Bright, R. and Reynolds, E.T. Effect of mixing temperature on hardening of asphaltic binder in hot bituminous concrete. Highway Research Board Bulletin 333. Washington D.C., 1962.

3. Broome, D.C., The Testing of Bituminous Mixtures, Edward Arnold & Co., London, 1949.

4. Csanyi, L.H., Cox, R.E. and Teagle, C.R. Effect of fillers on asphaltic concrete mixes. Highway Research Record No. 51. Washington D.C., 1964.

5. Edwards, J.M., Notes on Bitumen and Its Application to Roads, Shell International Petroleum Company Ltd., London, 1962.

6. Hatherly, L.W. and Leaver, P.C. Asphaltic Road Materials, First Edition, Edward Arnold Ltd. London, 1967.

7. Jackson, G.P., and Brien, D., Asphaltic Concrete, Shell International Petroleum Company Ltd., London, 1962.

8. Kenis, J.K., Progress report on changes in asphaltic concrete in service. Highway Research Board Bulletin 333. Washington D.C., 1962.

9. Martin, J.R. and Wallace, H.A., Design and Construction of Asphalt Pavements, McGraw - Hill Book Company Ltd., New York, 1958.

10. Metcalf, C.T., Use of Marshall stability test in asphalt paving mix design. Highway Research Board Bulletin 234. Washington D.C., 1959.

11. Monismith, C.L., Asphalt Paving Mixtures, University of California, Berkeley, 1961.

12. Nijboer, L.W., Plasticity as a Factor in the Design of Dense Bituminous Road Carpets. Elsevier Publishing Company Inc., New York, 1948.

13. Oglesby, C.H., and Hewes, L.I. Highway Engineering, Second Edition, John Wiley & Sons, Inc., New York, 1963.

14. Puzinauskas, V.P., Influence of mineral aggregate structure on properties of asphalt paving mixtures. Highway Research Record No. 51. Washington D.C., 1964.

15. Road Research Laboratory, Bituminous Materials in Road Construction, First Edition, Her Majesty's Stationery Office, London, 1962.

16. The Asphalt Institute, Mix Design Methods for Hot - Mix Asphalt Paving, Manual Series No.2, First Edition, College Park (Maryland), 1959.

17. The Asphalt Institute, Mix Design Methods for Asphalt Concrete and Other Hot - Mix Types, Manual Series No.2, Second Edition, College Park (Maryland), 1962.

18. The Asphalt Institute, Specification and Construction Methods for Asphalt Concrete and Other Hot - Mix Types, Specification Series No.1, Second Edition, College Park (Maryland), 1962.

19. The Asphalt Institute, Asphalt, Pocketbook of Useful Information, Manual Series No.6, Fourth Edition, College Park (Maryland), 1965.

20. The Asphalt Institute, The Asphalt Handbook, Manual Series No.4, April 1965 Edition, College Park (Maryland), 1966.

21. The Asphalt Institute, Miscellaneous Construction Specifications, Specification Series No.4, First Edition, College Park (Maryland), 1962.

22. The Asphalt Institute, Asphalt Plant Manual, Manual Series No.3, Second Edition, College Park (Maryland), 1963.

23. White, O.A., Service behaviour of asphaltic concrete, Highway Research Board Bulletin 300, Washington D.C., 1961.

24. Woods, K.B., Highway Engineering Handbook, First Edition, McGraw-Hill Book Company, Inc., New York, 1960.

25. Yoder, E.J., Principles of Pavement Design, First Edition, John Wiley & Sons, Inc., New York, 1959.

This thesis was typed by the author