AN EXPERIMENTAL INVESTIGATION OF THE FEASIBILTY OF STABILIZING A SILTY GRAVEL FOR HIGHWAY BASE COURSE CONSTRUCTION

A Thesis

Presented to

the Faculty of Graduate Studies

The University of Manitoba

In Partial Fulfillment

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Master of Science in Engineering

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by

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CHAPTER I

INTRODUCTION

The object of the work undertaken was to investigate the possibilities of rendering a local material which is unsuitable for highway base course construction suitable, through the addition of one of several possible soil-stabilizing additives, to compare directly the effects of the common stabilizing additives on certain properties of the soil investigated, and to appraise the value of the triaxial compression test in evaluating strength properties of base course materials.

At present, many deposits of materials which are considered unsuitable, primarily because of poor size gradation, are bypassed in highway construction. This frequently necessitates importation of better-graded materials from less accessible deposits or expensive blending and selective wasting of fractions of accessible materials. The net result is higher construction costs, weaker design, or both. It is felt that many of the "unsuitable" materials could be used economically with admixtures which would improve their characteristics to the point of acceptability.

Manitoba highway practice in the field of stabilizing additives has been chiefly confined to the waterproofing and improvement of good base course materials, sometimes to the point of converting them to lower class pavements and sub-pavements, generally with asphalt admixtures, and to the stabilizing of subgrade soils in place, using asphalt, Portland cement, and lime. The work described here deals with that part of the road structure between the subgrade and the pavement, the base course, and its synthesis from materials generally considered unsuitable.

Testing was performed on one type of soil material only, a gravel-silt-clay mixture, which is representative in general gradation of many Manitoba deposits and also of material which frequently occurs in layers and pockets with "cleaner" gravel and has previously been used for fill or simply wasted. The preponderance of the fraction passing a no. 200 sieve, composed of clay and silt, is such that it cannot be economically "washed," and it generally occurs in such quantities that it cannot be used in appreciable amounts in the blending of mechanically stabilized base course material or asphalt aggregates. Further work toward the same object would involve similar testing on other materials with size gradation unbalanced in ways different to that of the soil investigated.

The development of theory and accumulation of test data on stabilizing additives has largely been done by or for additive producers and persons concerned with one type of stabilizer only. Consequently the data and test methods

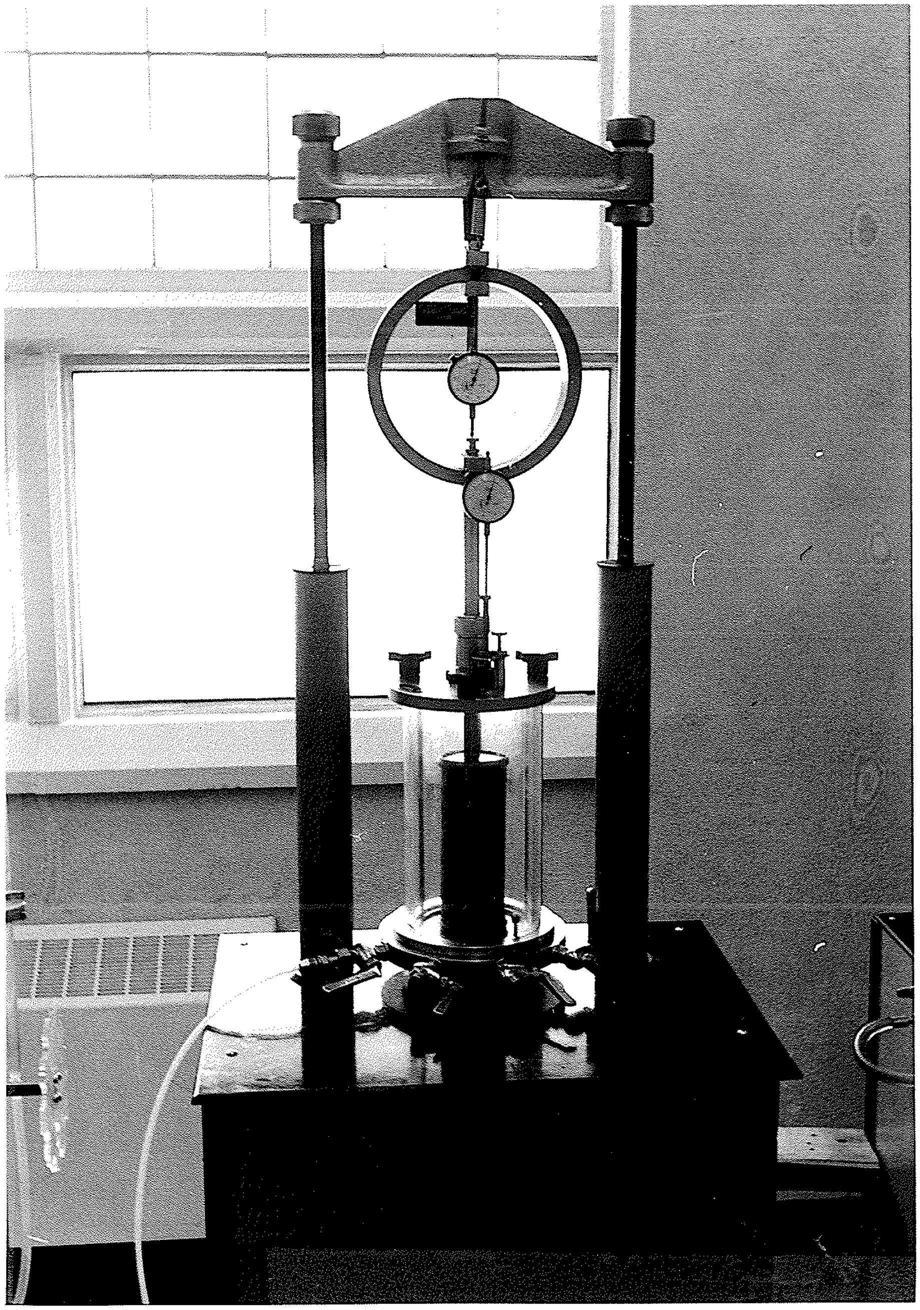

Figure I Triaxial Compression Testing Machine employed do not lend readily to the comparison of the effects of the different products. The unconfined compression test has been widely used to obtain strength values used as criteria for comparison of the stabilities of lime-treated specimens.[1] The Hveem Stabilometer and unconfined compression tests have been used in studies of asphalt-stabilized soils, in projects including that of Moreland Herrin on the drying phase of soil asphalt construction.[2] The triaxial compression test has been used in lime stabilization studies[3] and the pre-soaked unconfined compression test for comparing additives.[4] This latter method does not permit comparison of treated soils with accepted mechanically stabilized base course materials as these untreated materials fail during soaking.

The triaxial test, with confining pressures during testing, must most closely represent field conditions where the base course is subject to confinement. In adopting the triaxial

[1]O.L. Lund, "Experimental Lime Stabilization in Nebraska," Lime and Lime-Flyash as Soil Stabilizers, Highway Research Board Bulletin 231 (Washington, D.C.: Nat'l. Research Council, 1959)

[2]Moreland Herrin, "Drying Phase of Soil - Asphalt Construction," Asphalt-Soil Stabilization, Highway Research Board Bulletin 204 (Washington, D.C.: National Research Council, 1958)

[3]National Lime Association, Lime Stabilization of Roads (Baltimore Md.: Pridemark Press, 1954)

[4]J.M. Hoover and D.T. Davidson, "Organic Cationic Chemicals as Stabilizing Agents for Iowa Loess," Chemical and Mechanical Stabilization, Highway Research Board Bulletin 129 (Washington, D.C.: National Research Council, 1956)

compression test as the criterion for comparing all specimens, and using the same method of specimen preparation, an attempt has been made to obtain data for direct comparison. The undrained, or "quick" triaxial test was selected as being most representative of the sudden stresses imposed on a road structure by fast-moving wheel loads.

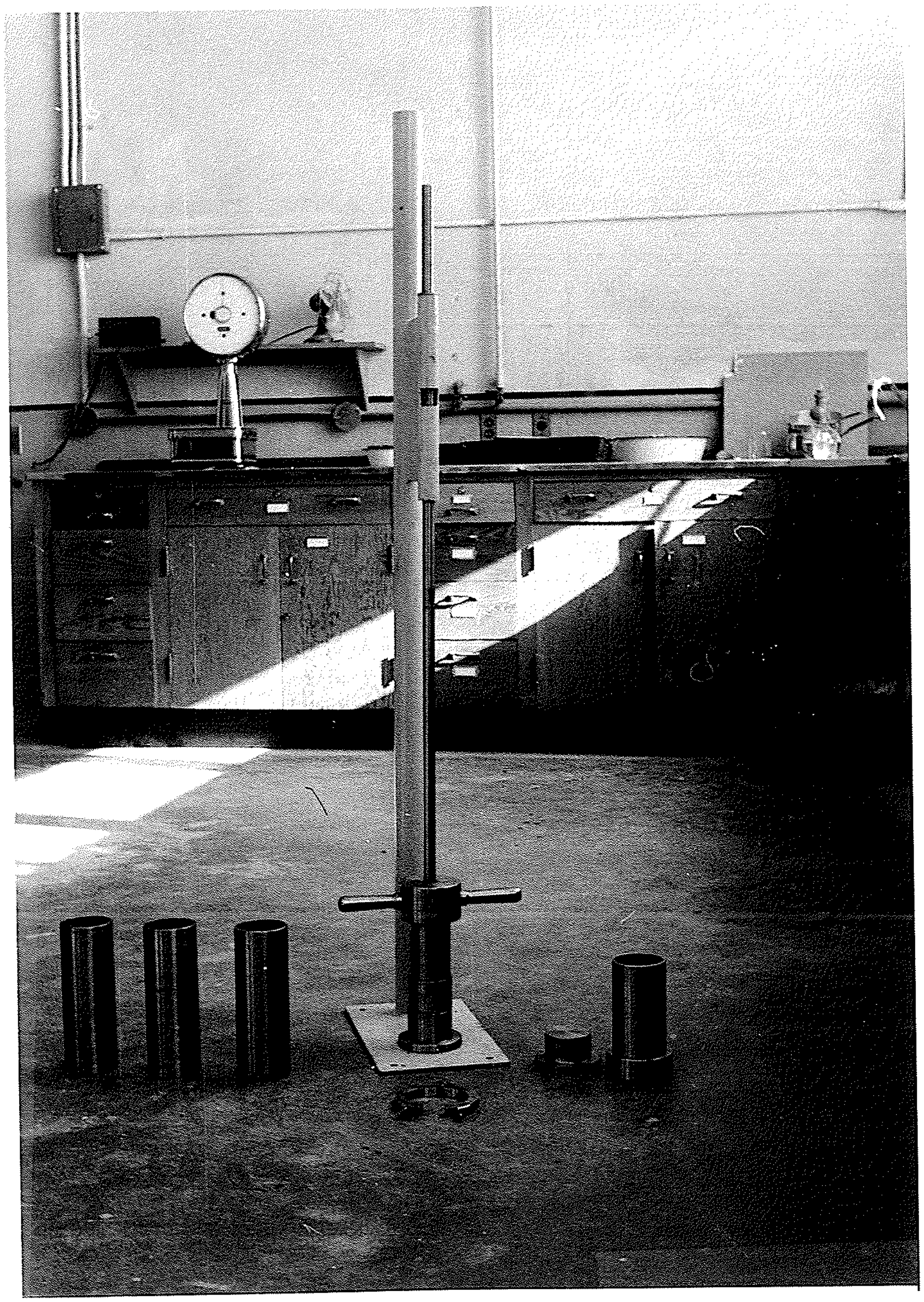

Figure II Specimen Moulding Apparatus

Figure III Moulding Apparatus in Use.

CHAPTER II

APPARATUS AND TEST METHODS

I APPARATUS

Special apparatus: To evaluate the strength characteristics of the standard material, the untreated unsuitable material and the soil samples treated with various admixtures, it was decided to perform triaxial compression tests on compacted test specimens. This necessitated special molding and compaction apparatus in order to obtain specimens of a size suitable for triaxial testing on a standard triaxial compression machine. The apparatus is described in the ASTM publication "Procedures for Testing Soils," under "Suggested Method of Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory."[5] The machinist drawings are included in the appendix, and photos in figures II and III.

The apparatus consists of cylindrical test molds, a mold extension with a collar, pistons and separating discs for molding specimens 5.6 inches high and 2.8 inches in diameter. These dimensions are in accord with the triaxial compression test specification that specimens have a length equal to twice their diameter. Also included in the molding apparatus is a

[5] Earl J. Felt and Melvin S. Abrams, "Suggested Method of Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory," Procedures for Testing Soils (Philadelphia: The American Society for Testing Materials, 1958)

compaction device to permit specimen compaction by means of a free-falling 15 pound hammer. Alternatively, the specimens may be compressed to size in a compression test machine.

Other apparatus. Other than the special equipment described above, the apparatus included the following:

Fennell triaxial compression machine. (Figure I)

Proctor compaction apparatus.

Moist curing room.

Drying oven.

Scales, sieves, containers and accessories.

II PREPARATION OF TRIAXIAL TEST SPECIMENS

General. The triaxial compression test specimens were prepared by combining soil and additives or water in mixing bowls in the desired proportions, and compacting them in the special molds. In order to avoid sample trimming which would be difficult for most of the test specimens, it was necessary to determine the amount of material which would be required to produce a specimen height of 5.6 inches at the desired degree of compaction. These critical amounts were determined by referring to the results of the compaction tests to obtain the dry density required and weighing out sufficient dry material to produce the required dry density in the constant volume of the specimens. The volume of the specimens was calculated to be 0.020 cubic feet. Thus, the required dry weight of material for each specimen was found by multiplying the desired dry density by the factor 0.020. The compaction tests are described on page 16.

The sample material in each case was made up from sieved fractions, introduced into the mold, and thoroughly rodded with a steel rod, compacting the material from the bottom. Aluminum separating discs were used to keep the specimens from adhering to the pistons, one being put into the mold under the sample and another before the top piston or ram was inserted. The specimens were then compressed to a height of 5.6 inches by means of the compaction device. The final height was indicated by alignment of the height index groove on the compaction ram with a notch on the side of the sight-hole of the ram guide. (See Figure IV)

Standard base course material. To provide a standard for comparison purposes, a set of specimens was molded from material meeting the specifications of an accepted base course[6] as shown on the gradation chart. (Figure I) Specimens were made up at moisture contents of 2%, 4%, 6% and 8%, three specimens being molded for each moisture content. These specimens were tested immediately after moulding.

Untreated unacceptable soil. To measure the performance of the untreated soil, a set of specimens was molded

[6] Specification for granular base course, Underwood, McLellan & Associates Ltd.

at moisture contents corresponding to those of the standard specimens, three specimens at each, 2%, 4%, 6% and 8% moisture content. These specimens were also tested immediately after molding.

Three additional specimens of both materials above were also prepared at optimum moisture for absorption tests.

Portland cement-treated material. Specimens of the test material were molded as described previously, after mixing with varying quantities of standard Portland cement. Three samples were prepared at each cement content, 2%, 3%, 4% and 5%. The specimens were immediately extruded from the molds with a jacking device. They were then sealed in aluminum foil and dipped in melted paraffin to prevent loss of moisture, and placed in a moist curing room for seven days. The moisture content at molding was optimum moisture, which would, in the field, permit maximum compaction. Sealing the specimens would correspond to priming of the base course in construction. The seven day curing period for these and other specimens was chosen as the maximum time reasonably permissible in construction before paving operations would impose loads as great as the highway design loads on the prepared base course. The procedure for preparing and curing the cement-soil specimens was in

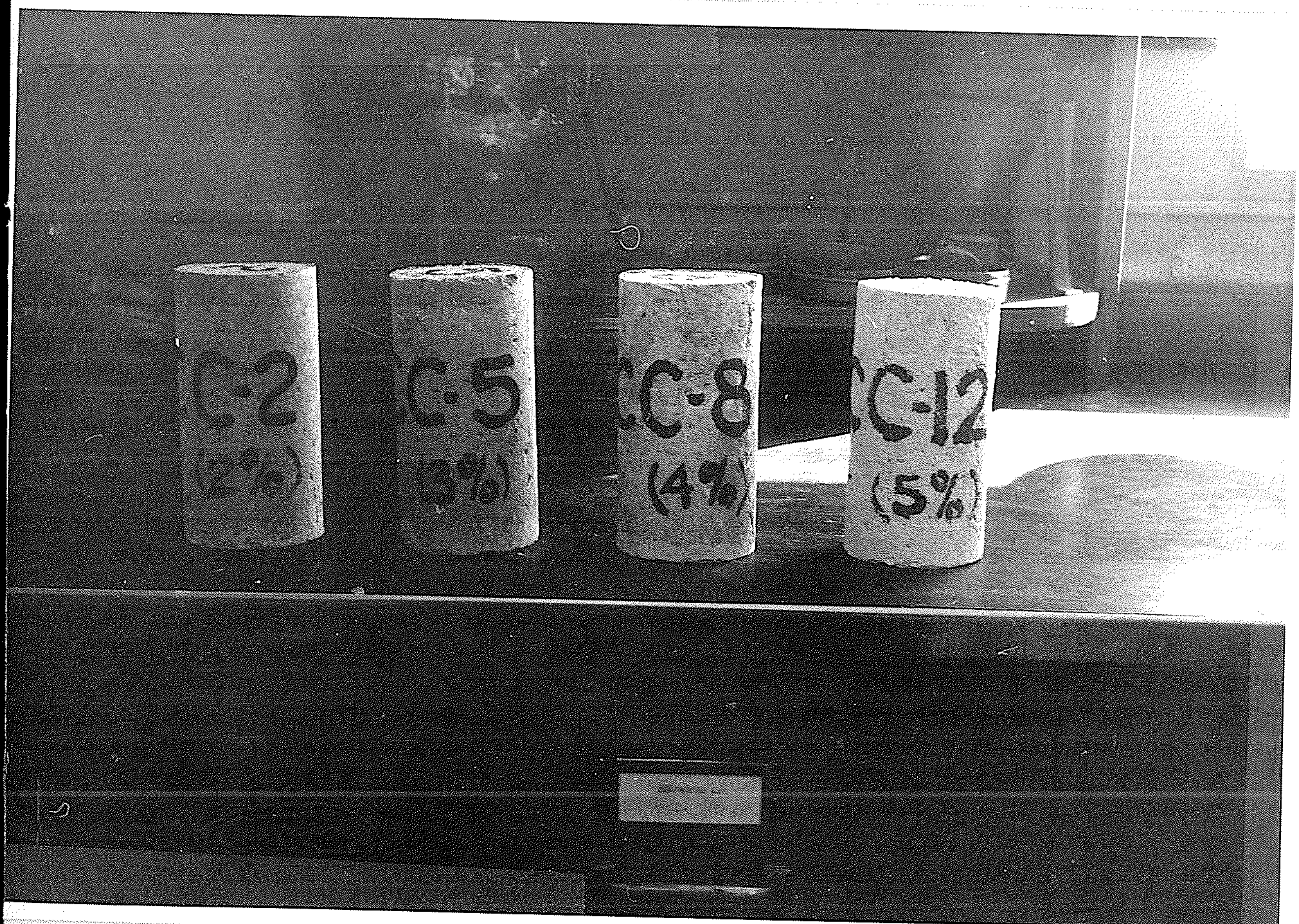

Figure IV Moulded Test Specimens of Calcium Chloride Treated Silty Gravel general accordance with the suggested A.S.T.M. method,[7] After curing, the specimens were air-dried overnight and then dried in an oven at 140°F to remove all moisture. The bottom end was then capped with filter paper to prevent loss of material, and the specimens enclosed in a rubber sleeve, which remained in place for triaxial testing. They were placed in a tank, resting om brass screens to permit free passage of water, and the tank was filled with water to the top of the specimens as illustrated in Figure IX. This permitted flow of water into the specimens, from the bottom only, due to capillarity and gravity flow. The rubber sleeve served two purposes. First, it helf the sample intact, and secondly it prevented passage of water through the sides of the specimen. Material in place in a base course would not lose or gain moisture laterally as it would be at a moisture content very close to that of the adjacent material in the base course. The treatment of the specimens in the water bath was designed to simulate field conditions with water-filled ditches.

After the specimens attained constant weight as determined by periodic checks, they were subjected to triaxial compressions tests as described later. The results

[7] Earl J. Felt and Melvin S. Abrams, "Suggested Method of Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory," Procedures for Testing Soils (Philadelphia: The American Society for Testing Material, 1958)

of the check weighings were plotted to form curves describing the rate of water absorption. These curves are included in the test result section.

<u>Asphalt-treated material</u>. Asphalt treated specimens were made in sets of three at asphalt contents of 2%, 3%, 4% and 5%. Before moulding, the samples were air-dried for 48 hours to permit good bond of asphalt and gravel material as the asphalt used was SS-1 emulsion. It was found that best mixing was possible using about double the optimum moisture content for the untreated soil, and that after air-drying, compaction was most easily obtained with only about one half of one percent moisture. As these conditions would be possible in the field, they were used in the preparation of the test specimens. The 48 hour air-drying period was considered the maximum permissible time in actual construction practice due to the danger of saturation by rainfall on the spread material before compaction. After drying, the specimens were moulded and subjected to the absorption treatment previously described. They were then tested in triaxial compression.

<u>Lime-treated material</u>. Specimens of material treated with hydrated lime were prepared exactly as those treated with Portland cement, with identical contents of additive, in this case lime. They were cured and partially saturated

Figure V Calcium Chloride-Treated Specimen After Drying in the same manner as the cement-treated samples.

Calcium chloride treated specimens. These were prepared in sets of three with calcium chloride contents of 2%, 3%, 4% and 5%. They were prepared and treated exactly as were the lime and Portland cement samples. Seven days curing was again permitted before testing, and absorption of water as before. One specimen is illustrated in Figure V.

III TEST PROCEDURES

Compaction tests. Standard Proctor compaction tests (A.S.T.M. Designation D - 698 - 58T) were performed on the standard acceptable base course material and on the unsuitable soil. These tests gave information on the maximum density and optimum moisture content for preparation of the triaxial test specimens. Figures X and XI.

Triaxial compression tests. Triaxial compression tests were performed on all samples of treated and untreated materials prepared as described previously. The samples were tested still encased in the rubber sleeves installed for water absorption. Lateral confining pressures were obtained by the application of compressed air and measured accurately by the use of a mercury manometer connected in parallel to the air supply system. A sensitive pressure regulator

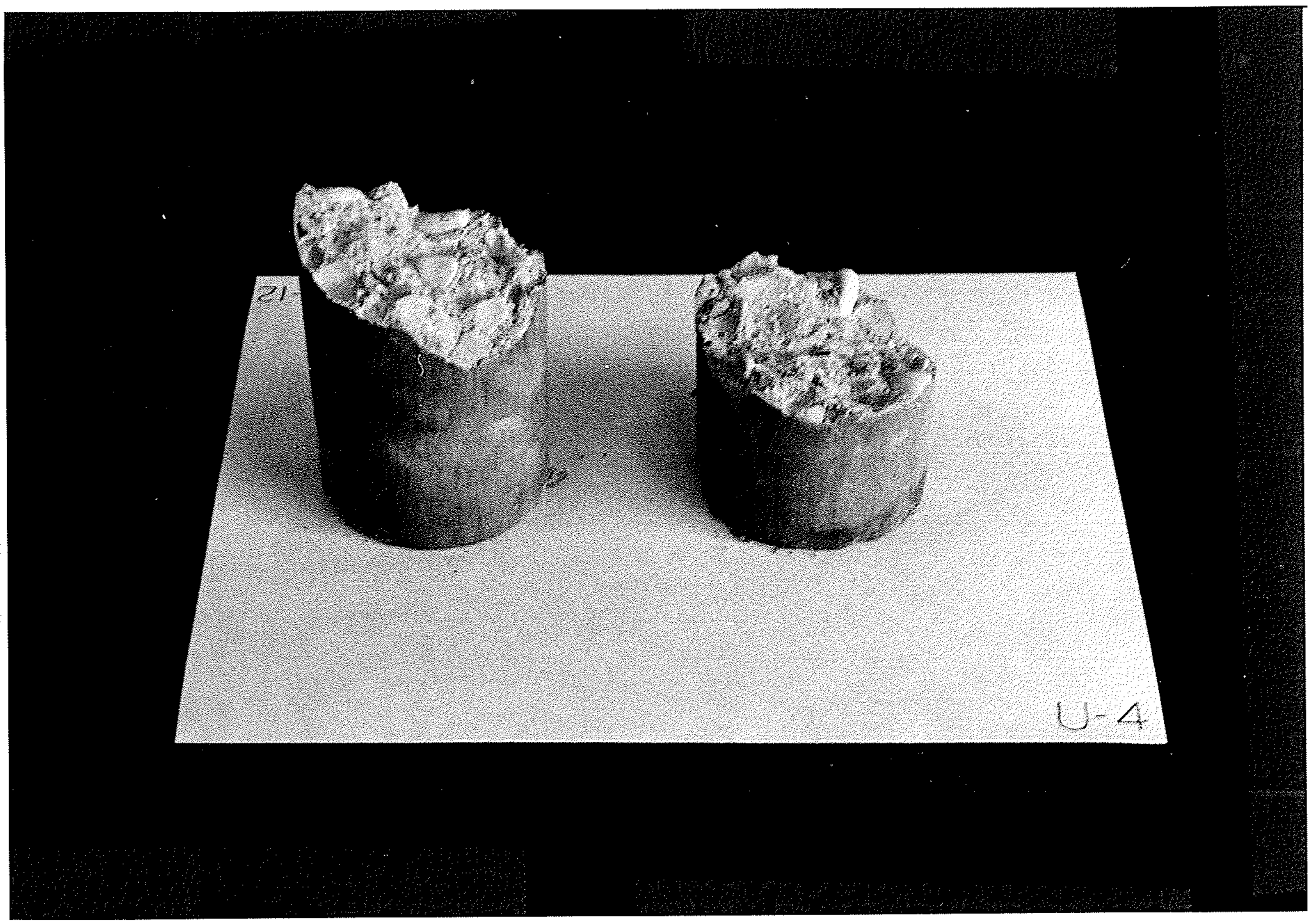

Figure VI Test Specimen after Triaxial Test permitted fine control of the pressure. These precautions were necessary because of the low lateral pressures used, namely, two, five and eight p.s.i. The low lateral pressures were used to keep confinement in the range existing in base courses in a typical road pavement system. Vertical loads were applied hydraulically in such a manner that a uniform vertical strain rate was maintained. The rate of strain used was 0.05 inches per minute, in accordance with recommended practice.[8]

While the tests were essentially "undrained" because of the rapid rate of loading, the stop-cock for drainage of the specimen was left open, permitting partial drainage. This was done because movement of water in a base course would be possible except under conditions of complete saturation. In this manner pore pressures in the test specimen were kept from fully developing as they would in a completely undrained test. Figure VI shows a specimen of untreated silty gravel after failure in a triaxial compression test.

Water absorption tests. To compare the treated and untreated materials for relative rates of absorption and maximum amounts of absorption, specimens of the untreated

[8]T. William Lambe, Soil Testing for Engineers, (New York, N. Y. : John Wiley and Sons Inc., 1951)

standard and unacceptable material were prepared. These were dried and placed in the water bath exactly as were the treated materials as described previously, and periodic weighings were made until they had reached constant weight. The results were plotted and the curves are included in the test results section. (Figures XII to XVI)

Moisture content determinations were made on samples derived from the bottom, enter and top of all specimens to determine the nature of moisture distribution resulting from the water bath treatment.

Classification tests. The portion of the test material passing the no. 40 sieve was tested by use of the standard Atterberg Limit tests and wet mechanical analysis to determine the nature of the fine portion of the material and thus more accurately describe it. The results of these tests are summarized on the gradation chart. (Figure VII)

FIGURE VII MECHANICAL ANALYSIS OF GRAVEL TEST MATERIALS

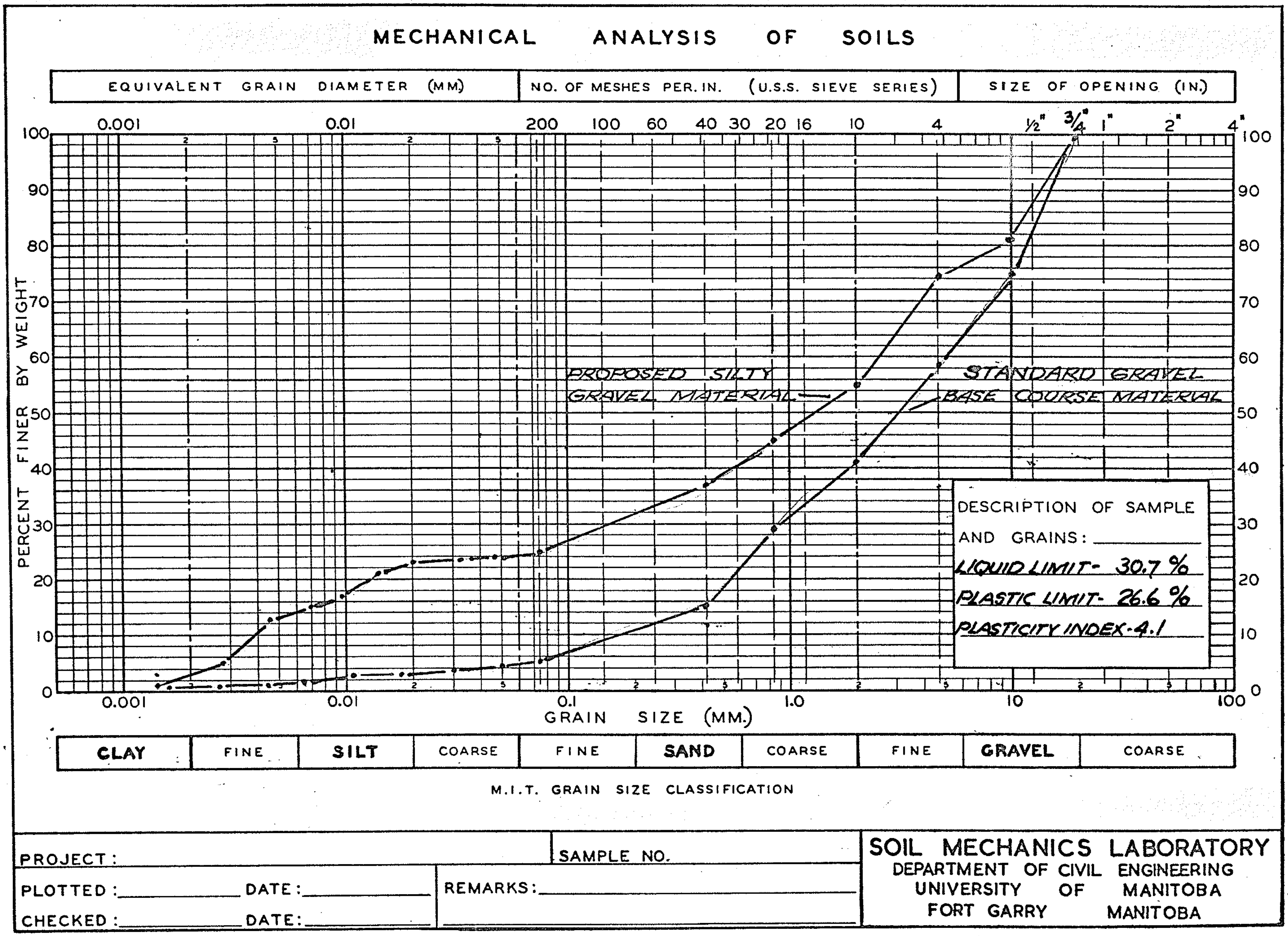

Figure VIII Lime-treated Specimens prepared for Absorption Test

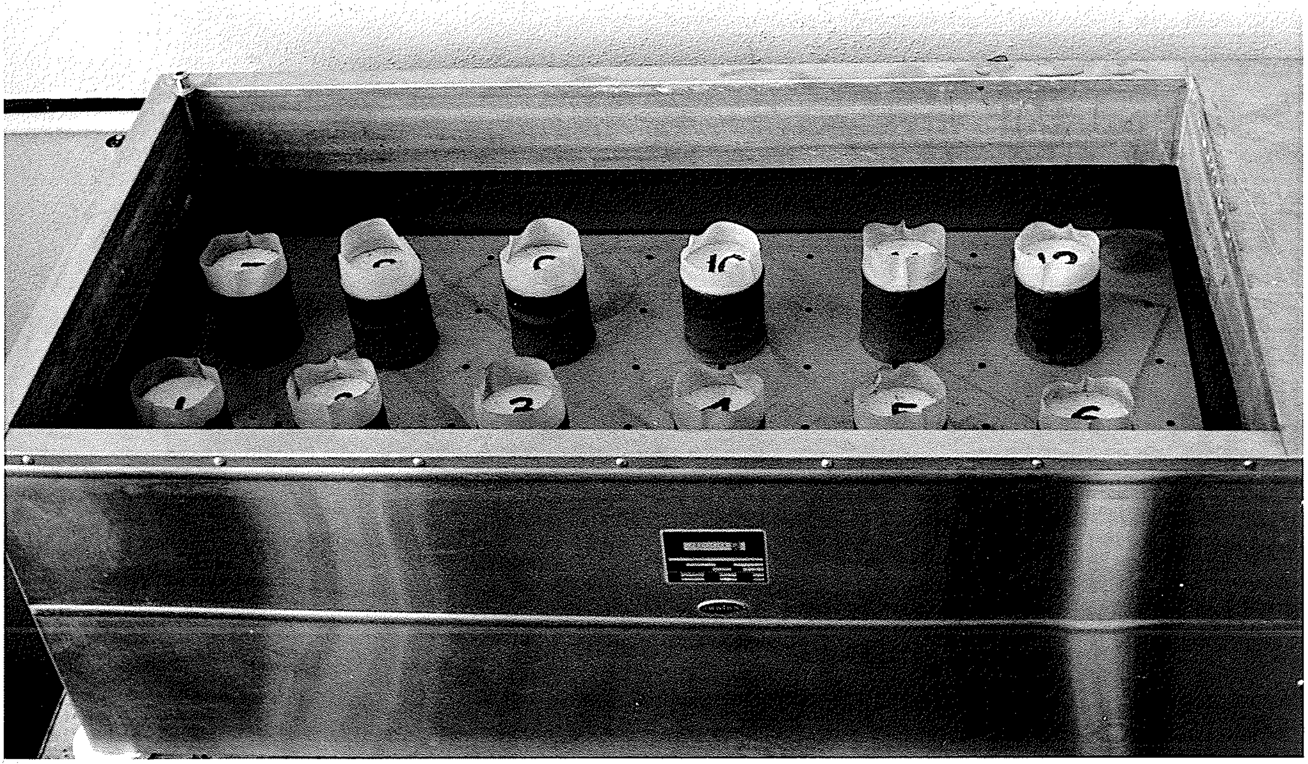

Figure IX Test Specimens in Water Bath

CHAPTER III

TEST RESULTS

I PROCTOR COMPACTION TESTS

The curves showing unit weight and moisture content are presented in Figures X and XI. Optimum moisture content for the standard base course was found to be 7.2%, and maximum dry unit weight, at this moisture content, 141.5 pounds per cubic foot. For the untreated silty gravel, optimum moisture content was determined to be 7.2%, and maximum dry unit weight 136.0 pounds per cubic foot.

The figures for dry unit weight were converted to 1285 grams per specimen of one-fiftieth cubic foot for the standard base material, and 1232 grams per specimen for the untreated silty gravel, to permit preparation of specimens with dry unit weight corresponding to maximum Proctor compaction.

II ABSORPTION TESTS

The rate of absorption of water by the immersed specimens is shown graphically in Figures XII to XVI. For the purpose of illustrating the effect of additives on the rate and amount of absorption, the graphs for additive-

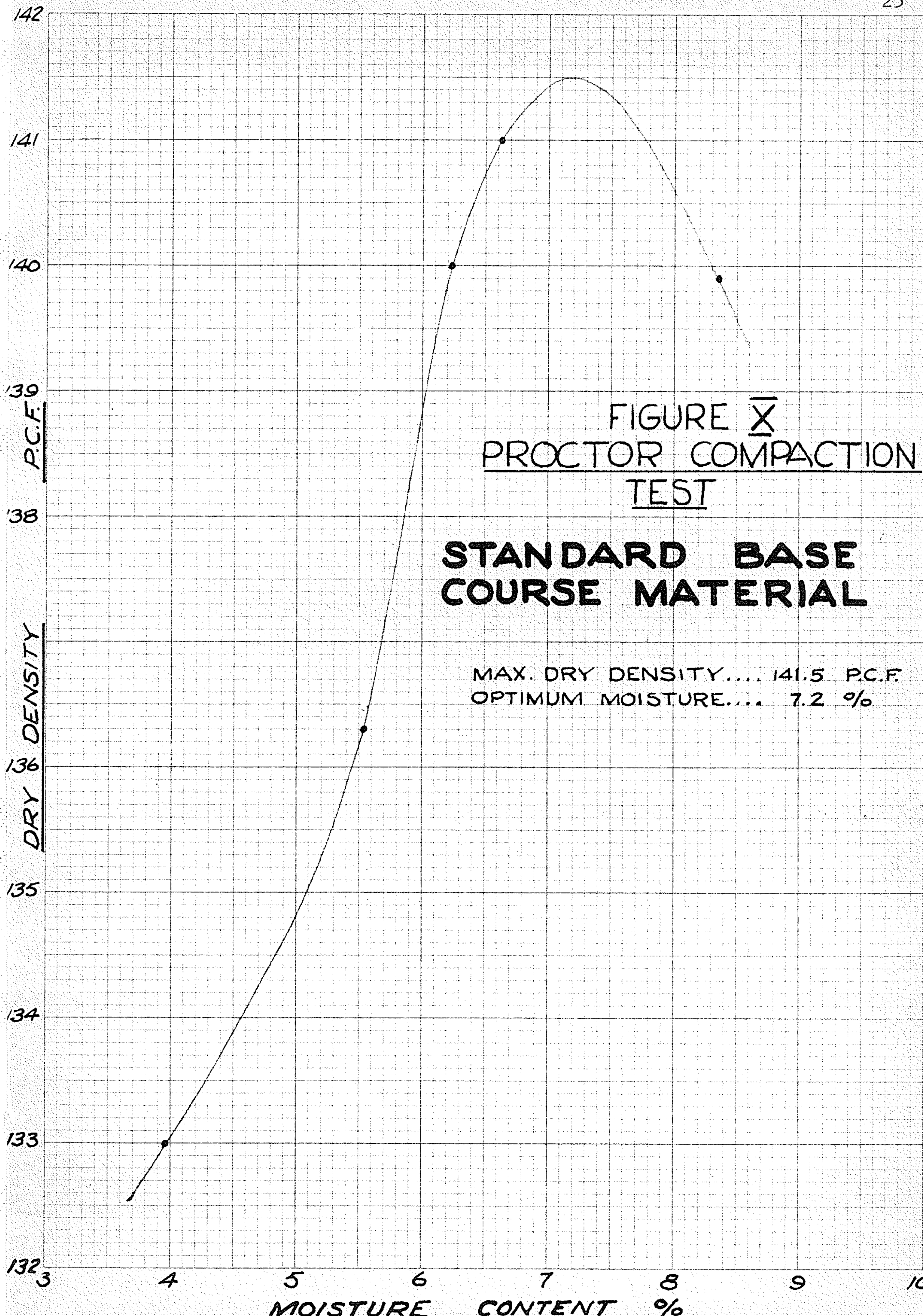
FIGURE X̄
PROCTOR COMPACTION TEST
STANDARD BASE COURSE MATERIAL
MAX. DRY DENSITY.... 141.5 P.C.F.
OPTIMUM MOISTURE.... 7.2 %
DRY DENSITY P.C.F.
MOISTURE CONTENT %
142
141
140
139
138
136
135
134
133
132
3
4
5
6
7
8
9
10

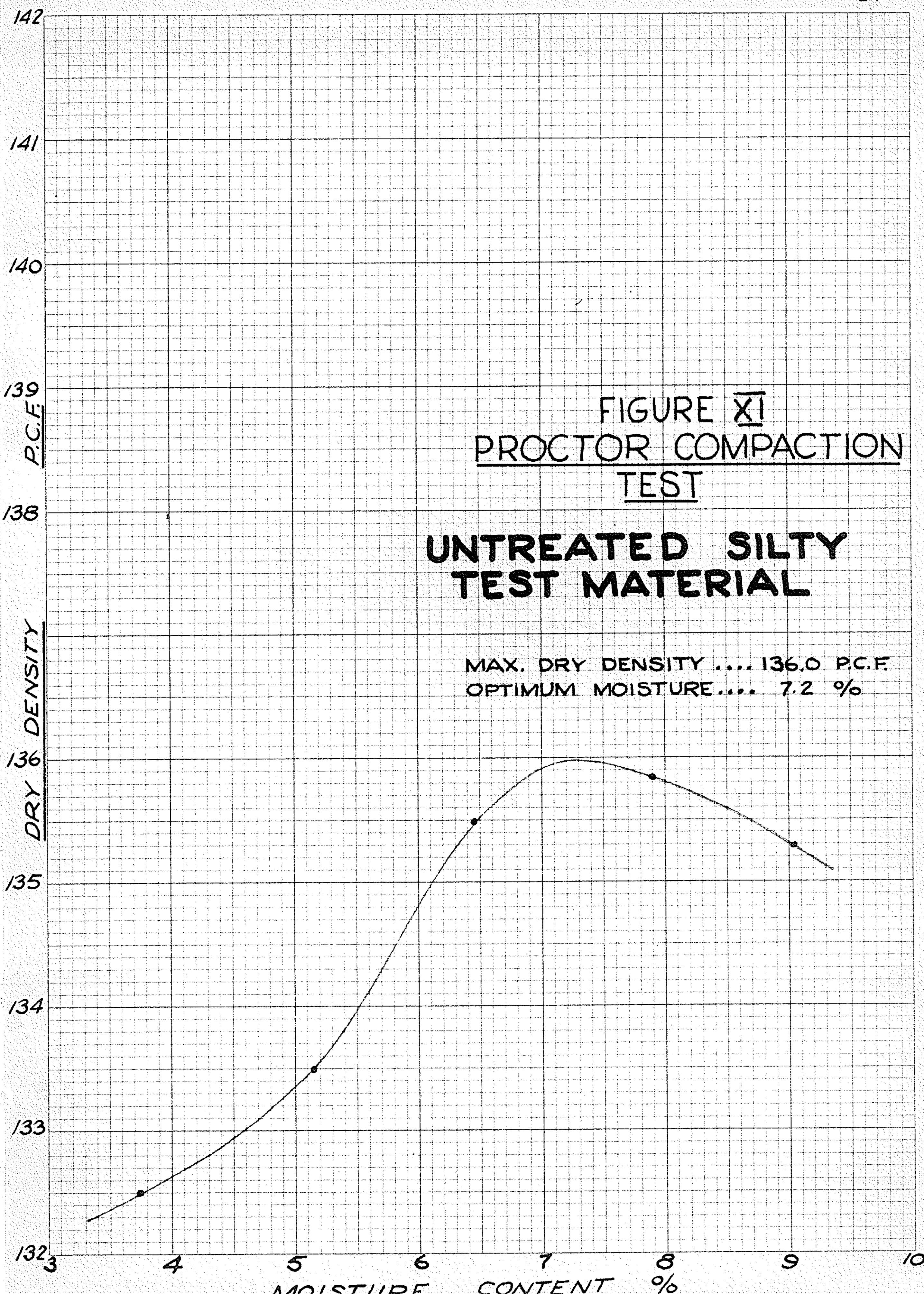
FIGURE XI
PROCTOR COMPACTION TEST
UNTREATED SILTY TEST MATERIAL
MAX. DRY DENSITY .... 136.0 P.C.F.
OPTIMUM MOISTURE .... 7.2 %
DRY DENSITY P.C.F.
142
141
140
139
138
136
135
134
133
132
3
4
5
6
7
8
9
10
MOISTURE CONTENT %

treated materials include the curve for untreated silty gravel.

The specimens ceased absorbing water before the end of the forty-eight hour test period in all cases except where calcium chloride was added to the material. Maximum moisture content reached for each material is shown in table I.

TABLE I

MOISTURE ABSORBED IN ABSORPTION TESTS

Material	Final Moisture content
Standard base gravel	6.65%
Untreated silty gravel	8.75%
Silty gravel, 2% cement	6.11%
Silty gravel, 3% cement	6.06%
Silty gravel, 4% cement	6.02%
Silty gravel, 5% cement	5.90%
Silty gravel, 2% lime	7.33%
Silty gravel, 3% lime	7.35%
Silty gravel, 4% lime	7.47%
Silty gravel, 5% lime	7.60%
Silty gravel, 2% asphalt	1.22%
Silty gravel, 3% asphalt	0.98%
Silty gravel, 4% asphalt	0.90%
Silty gravel, 5% asphalt	0.83%
Silty gravel, 2% calcium chloride	7.35%
Silty gravel, 3% calcium chloride	6.35%
Silty gravel, 4% calcium chloride	4.58%
Silty gravel, 5% calcium chloride	4.27%

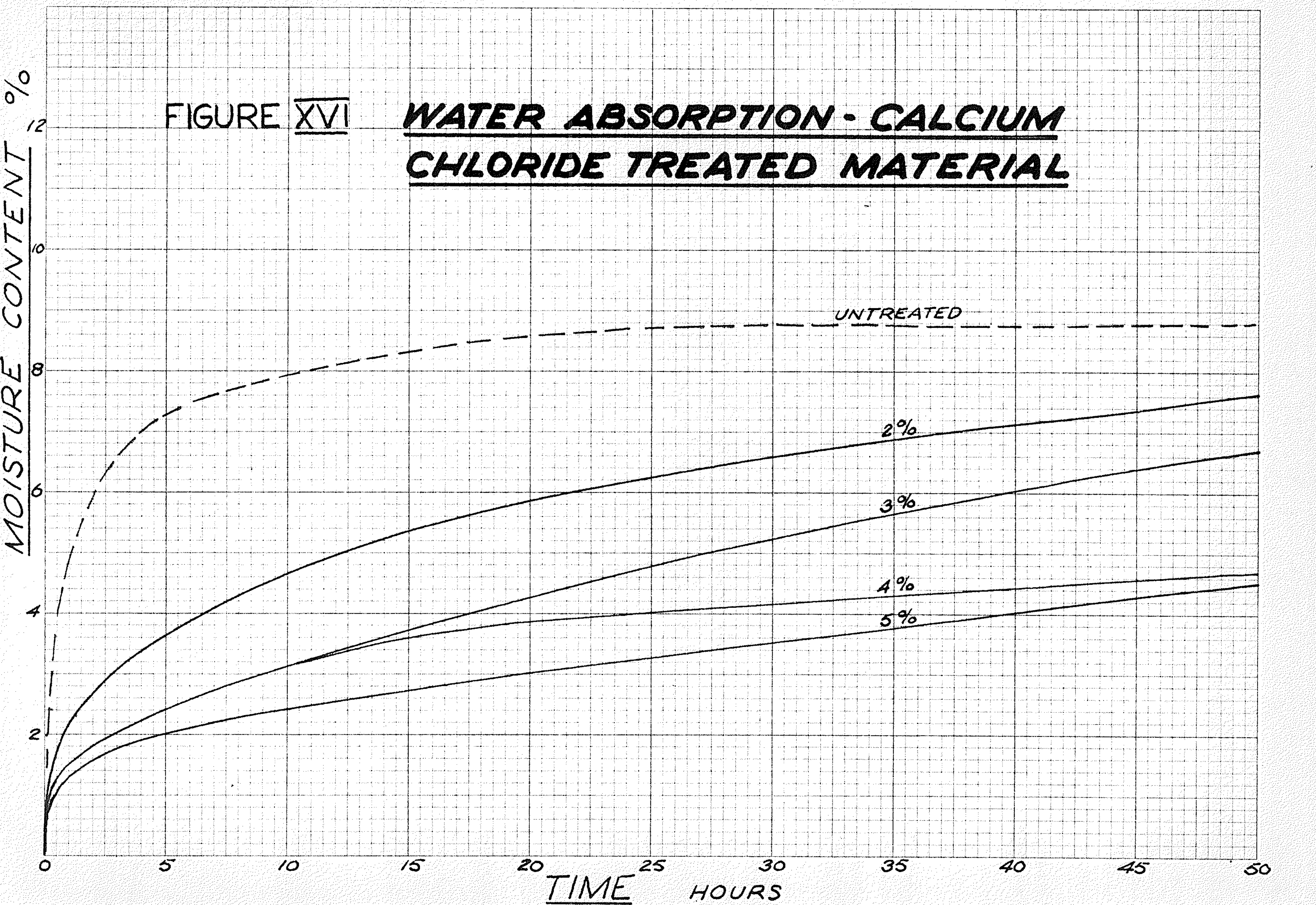
FIGURE XVI
WATER ABSORPTION - CALCIUM CHLORIDE TREATED MATERIAL
MOISTURE CONTENT %
TIME HOURS
UNTREATED
2%
3%
4%
5%
0
2
4
6
8
10
12
5
10
15
20
25
30
35
40
45
50

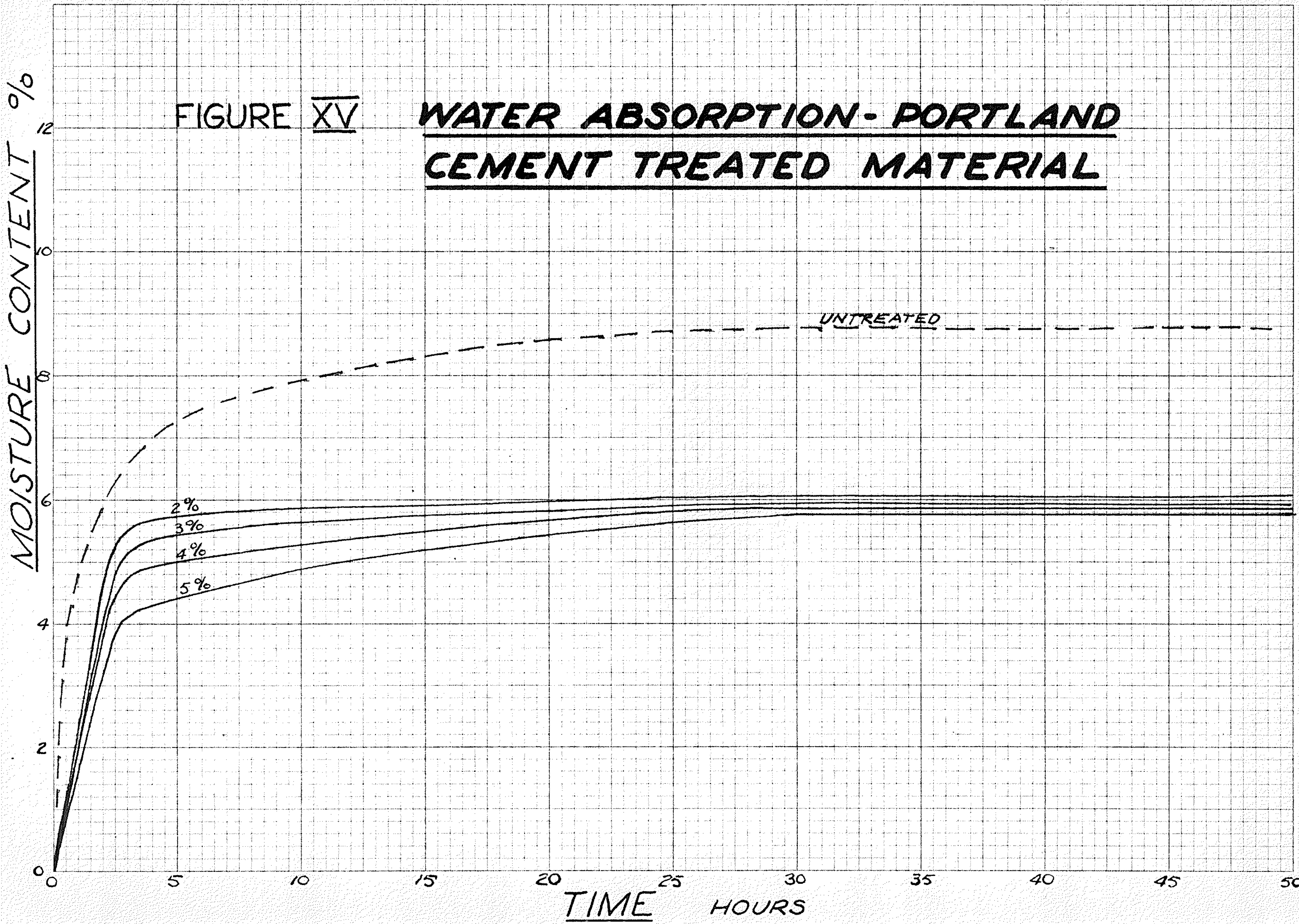
FIGURE XV WATER ABSORPTION - PORTLAND CEMENT TREATED MATERIAL
MOISTURE CONTENT %
UNTREATED
2%
3%
4%
5%
0
2
4
6
8
10
12
0
5
10
15
20
25
30
35
40
45
50
TIME HOURS

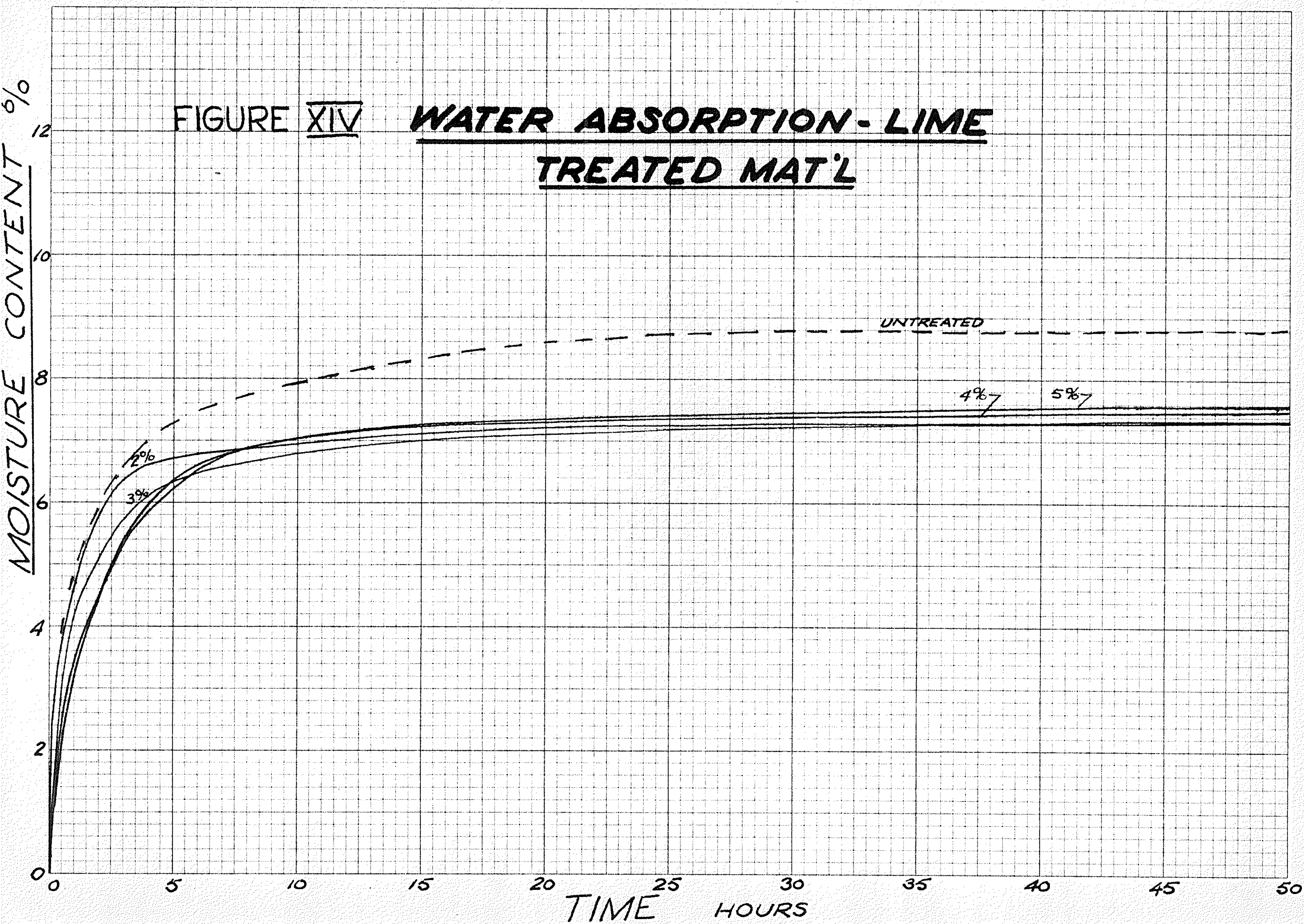

FIGURE XIV WATER ABSORPTION - LIME TREATED MAT'L
MOISTURE CONTENT %
12
10
8
6
4
2
0
UNTREATED
4%
5%
2%
3%
0
5
10
15
20
25
30
35
40
45
50
TIME HOURS

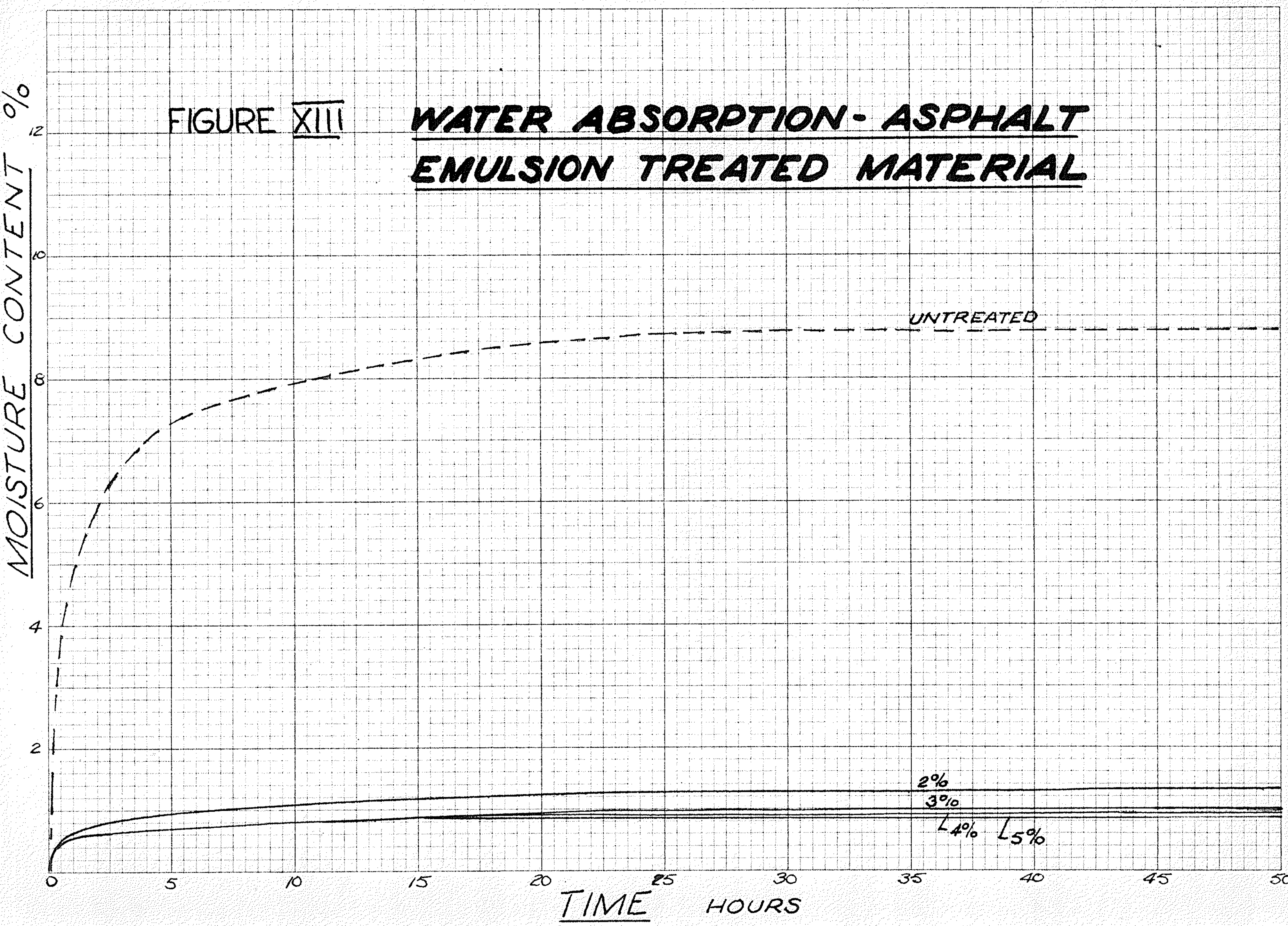
FIGURE XIII
WATER ABSORPTION - ASPHALT EMULSION TREATED MATERIAL
MOISTURE CONTENT %
TIME HOURS
UNTREATED
2%
3%
4%
5%
0
2
4
6
8
10
12
0
5
10
15
20
25
30
35
40
45
50

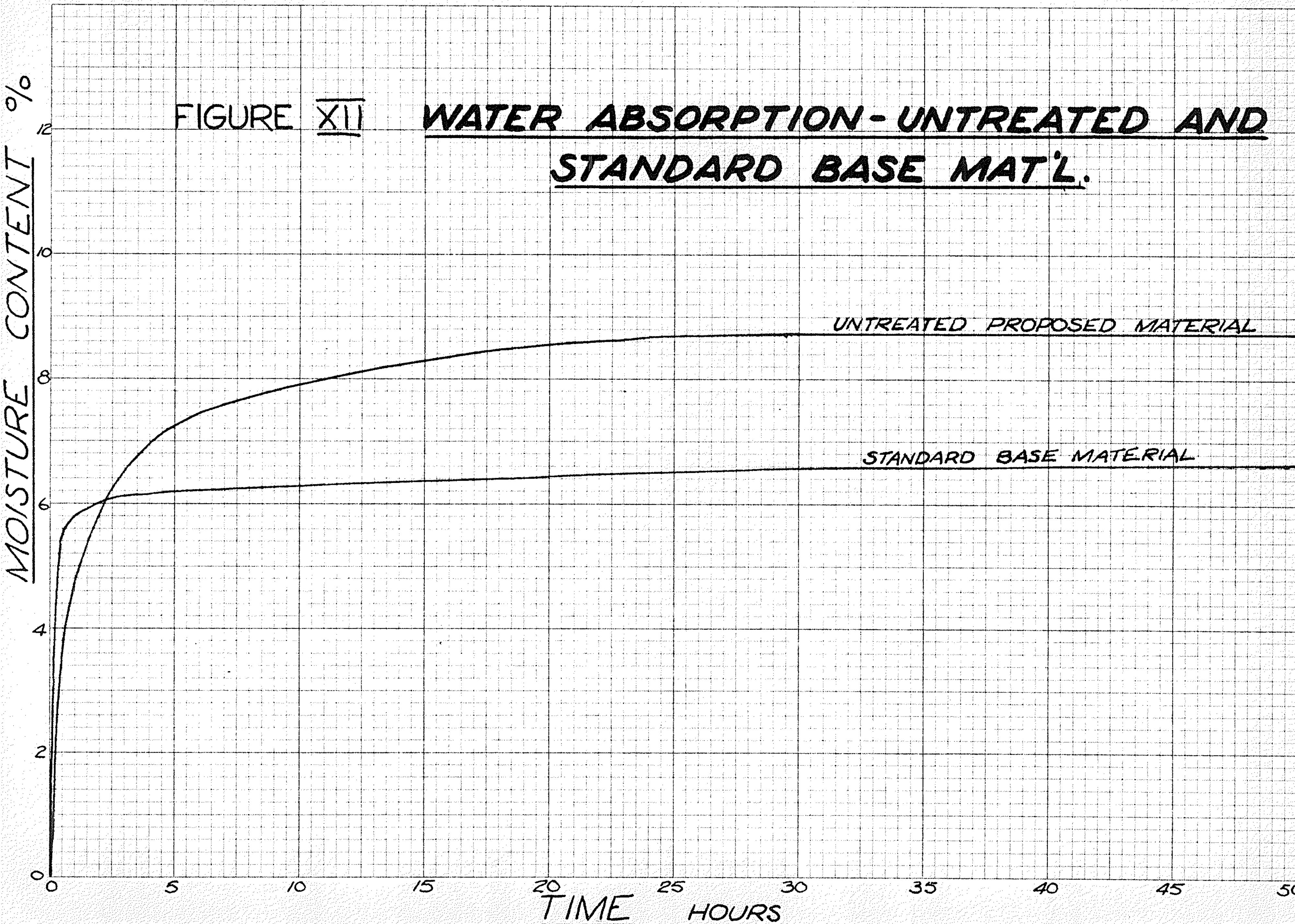

FIGURE XII WATER ABSORPTION - UNTREATED AND STANDARD BASE MAT'L.
UNTREATED PROPOSED MATERIAL
STANDARD BASE MATERIAL
MOISTURE CONTENT %
TIME HOURS
0
2
4
6
8
10
12
5
10
15
20
25
30
35
40
45
50

III TRIAXIAL COMPRESSION TESTS

The test data and calculations for the triaxial compression tests have been filed in the soil testing laboratory at the University of Manitoba.

Sample calculations are included in the appendix and Mohr's rupture envelopes are shown in Figures XVII to XXXIX.

Summary test values are presented in tables II to VII following.

TABLE II

TRIAXIAL TEST RESULTS, STANDARD BASE COURSE

Moisture content percent	Cohesion p.s.i.	Angle of internal friction degrees
2.0	2	63.3
4.0	4	51.8
6.0	4	30.8
8.0	2	30.8

TABLE III

TRIAXIAL TEST RESULTS, UNTREATED SILTY GRAVEL

Moisture content percent	Cohesion p.s.i.	Angle of internal friction degrees
2.0	8.0	48.3
4.0	9.0	37.0
6.0	4.7	30.5
8.0	2.9	24.3

TABLE IV

TRIAXIAL TEST RESULTS, ASPHALT TREATED MATERIAL (SILTY GRAVEL)

Asphalt content percent	Cohesion p.s.i.	Angle of internal friction degrees
2	8.5	44.5
3	18.0	46.0
4	20.0	51.0
5	12.0	53.0

TABLE V

TRIAXIAL TEST RESULTS, LIME TREATED MATERIAL (SILTY GRAVEL)

Lime content percent	Cohesion p.s.i.	Angle of internal friction degrees
2	11	47.0
3	13	48.0
4	15	50.1
5	38	25.5

TABLE VI

TRIAXIAL TEST RESULTS, PORTLAND CEMENT TREATED MATERIAL (SILTY GRAVEL)

Cement content percent	Cohesion p.s.i.	Angle of internal friction degrees
2	30	59.8
3	67	51.6
4	232	11.0
5	300	8.8

TABLE VII

TRIAXIAL TEST RESULTS, CALCIUM CHLORIDE TREATED MATERIAL (SILTY GRAVEL)

Calcium chloride content percent	Cohesion p.s.i.	Angle of internal friction degrees
2	1.0	8.8
3	1.0	35.2
4	1.0	25.0
5	no test	

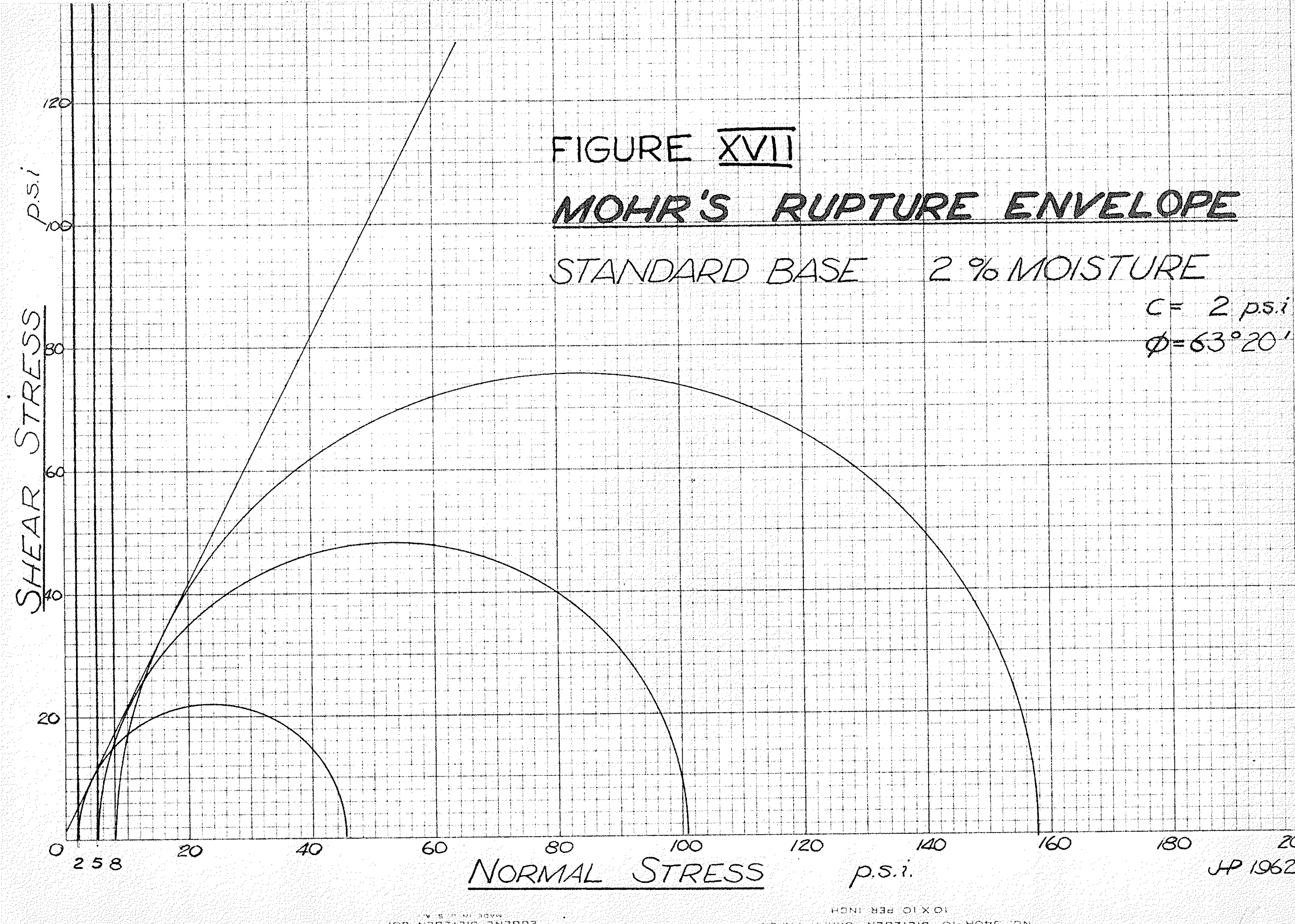
FIGURE XVII
MOHR'S RUPTURE ENVELOPE
STANDARD BASE 2 % MOISTURE
C = 2 p.s.i
φ = 63°20'
SHEAR STRESS p.s.i
NORMAL STRESS p.s.i.
0
2 5 8
20
40
60
80
100
120
140
160
180
200
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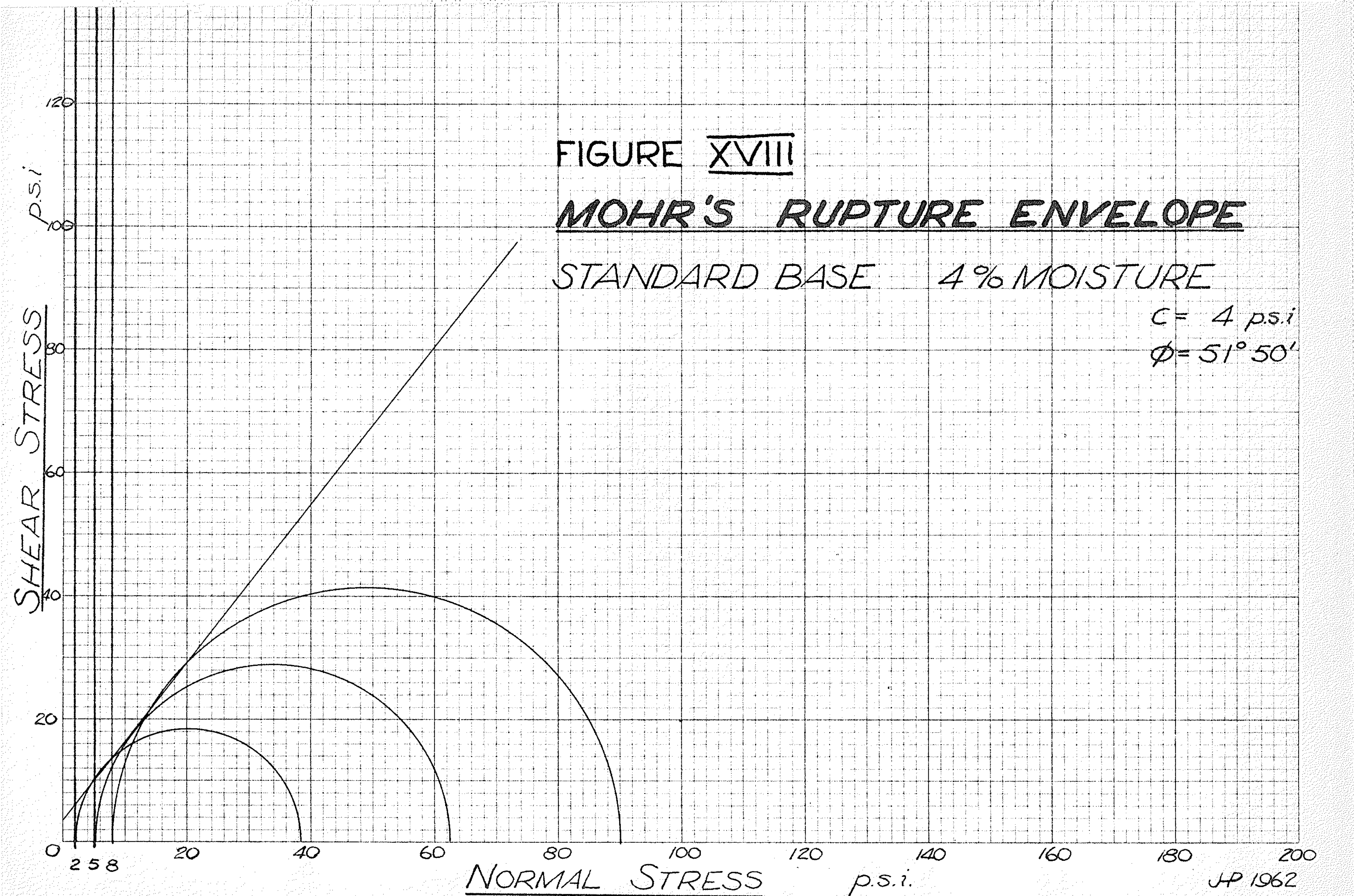

FIGURE XVIII
MOHR'S RUPTURE ENVELOPE
STANDARD BASE 4% MOISTURE
C = 4 p.s.i
φ = 51° 50'
SHEAR STRESS p.s.i
NORMAL STRESS p.s.i.
0
2 5 8
20
40
60
80
100
120
140
160
180
200
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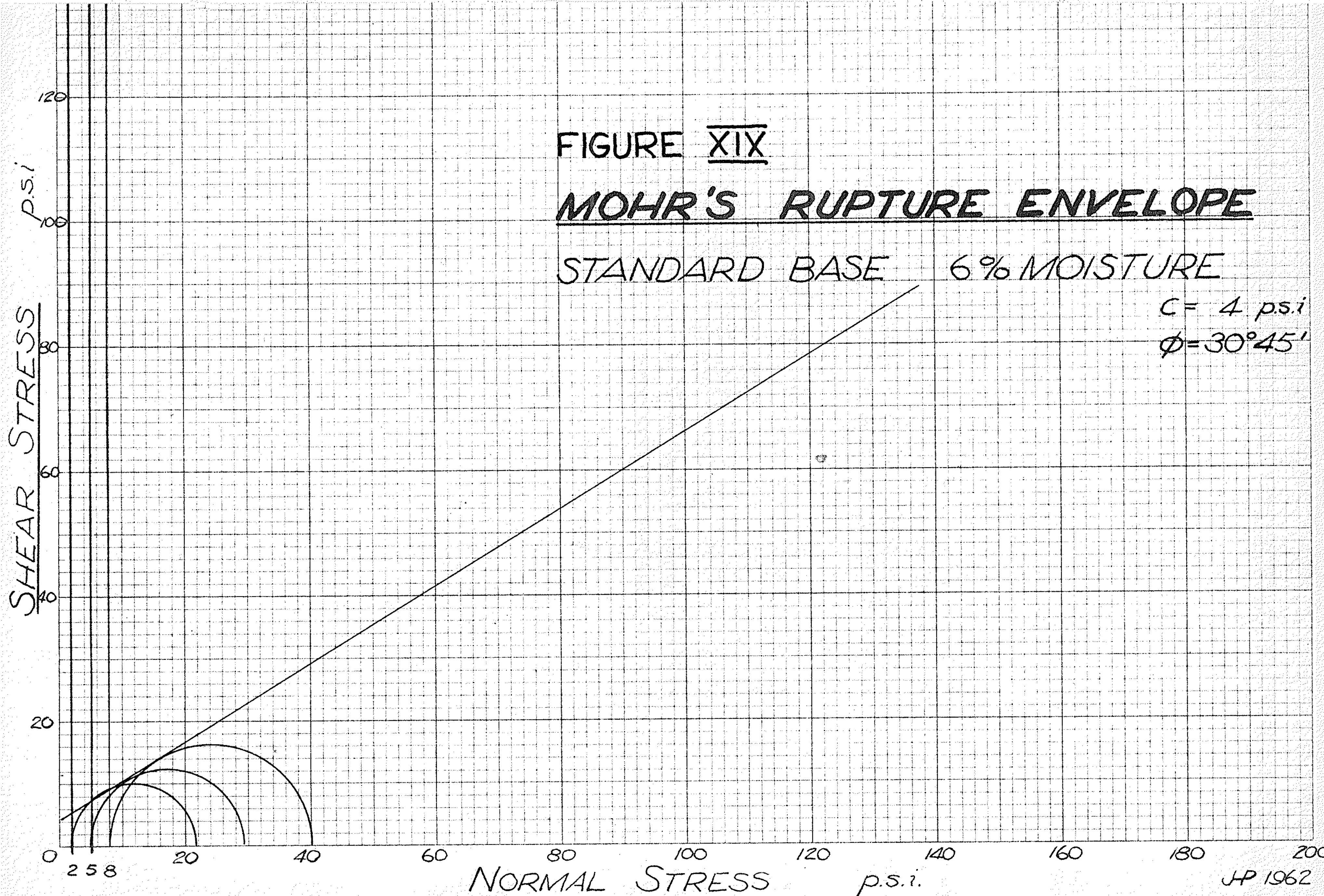
FIGURE XIX
MOHR'S RUPTURE ENVELOPE
STANDARD BASE 6 % MOISTURE
C = 4 p.s.i
φ = 30°45'
SHEAR STRESS p.s.i
120
100
80
60
40
20
0
2 5 8
20
40
60
80
100
120
140
160
180
200
NORMAL STRESS p.s.i.
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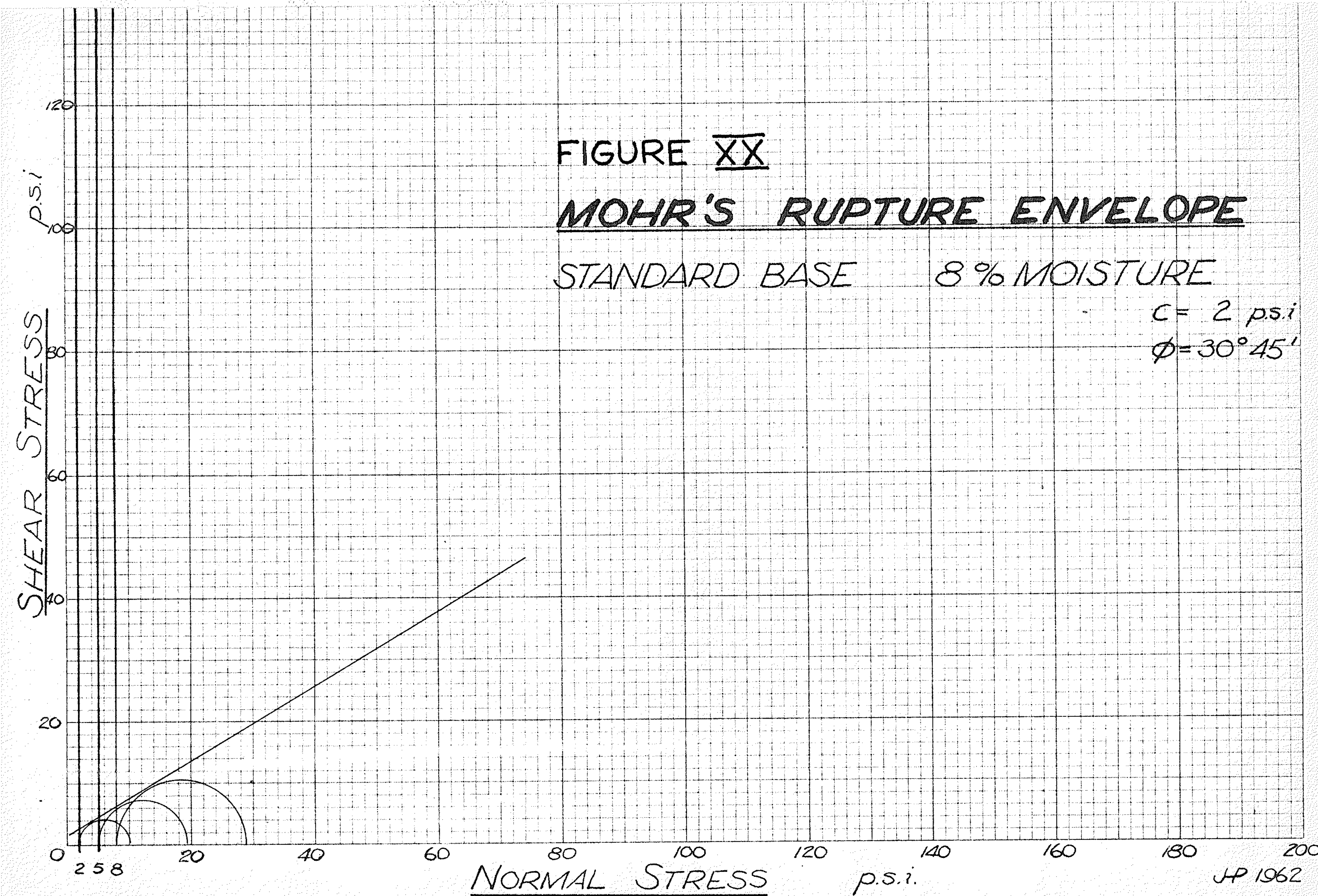
FIGURE XX
MOHR'S RUPTURE ENVELOPE
STANDARD BASE 8 % MOISTURE
C = 2 p.s.i
Φ = 30° 45'
SHEAR STRESS p.s.i
20
40
60
80
100
120
0
2 5 8
20
40
60
80
100
120
140
160
180
200
NORMAL STRESS p.s.i.
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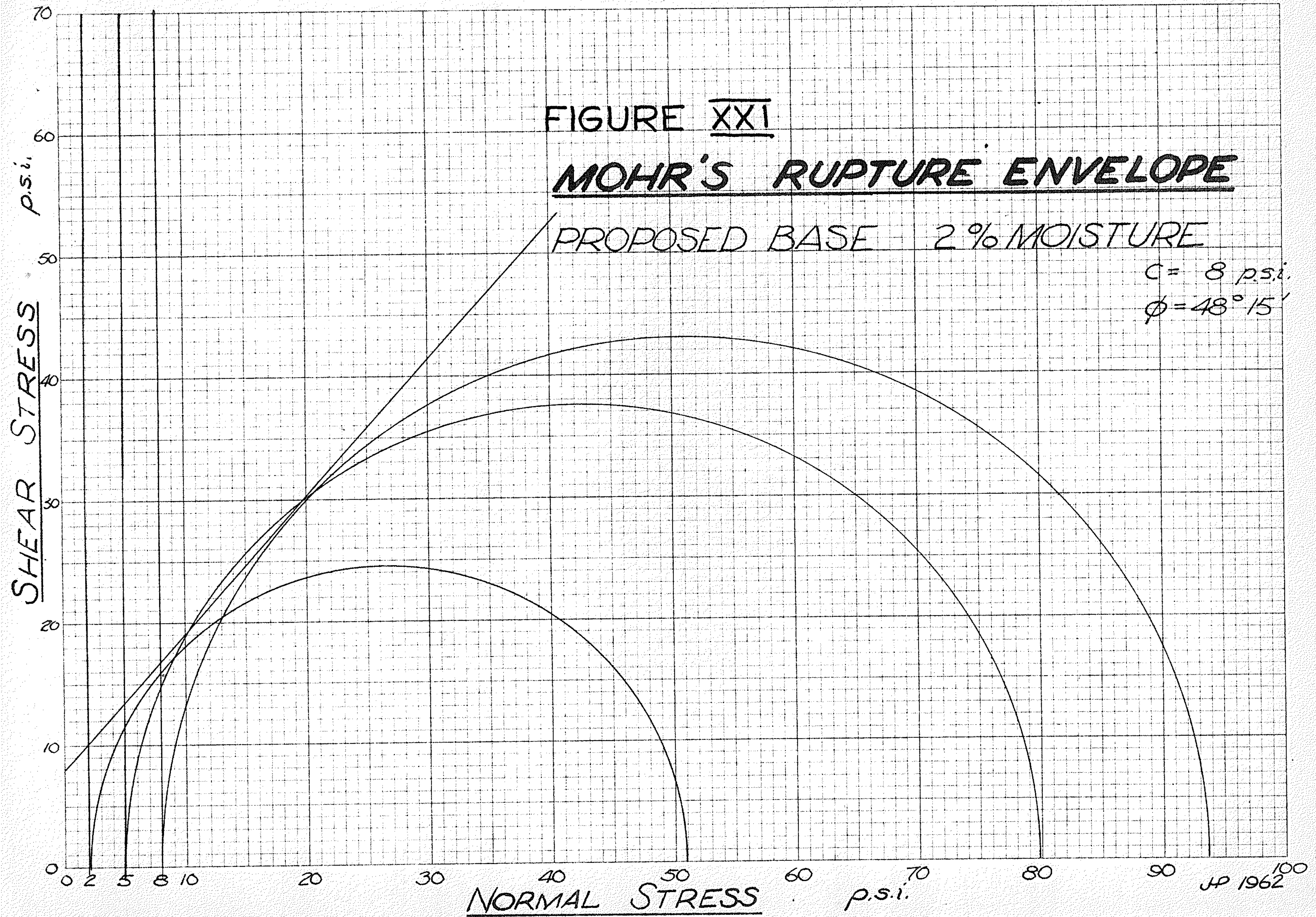
FIGURE XXI
MOHR'S RUPTURE ENVELOPE
PROPOSED BASE 2% MOISTURE
C = 8 p.s.i.
φ = 48° 15'
SHEAR STRESS p.s.i.
NORMAL STRESS p.s.i.
0
10
20
30
40
50
60
70
0 2 5 8 10 20 30 40 50 60 70 80 90 100
JP 1962

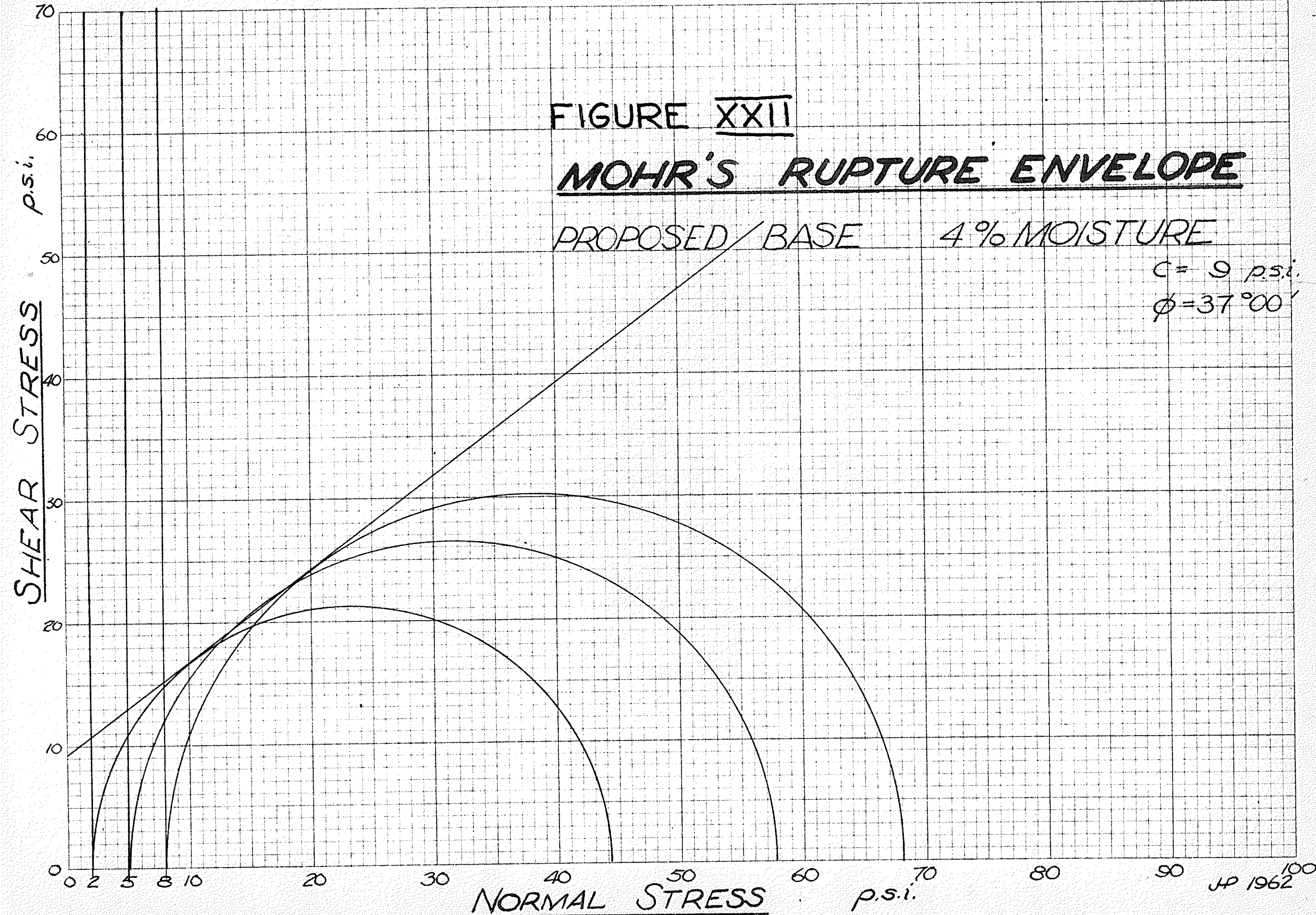
FIGURE XXII
MOHR'S RUPTURE ENVELOPE
PROPOSED BASE 4% MOISTURE
C = 9 p.s.i.
φ = 37°00'
SHEAR STRESS p.s.i.
NORMAL STRESS p.s.i.
0
10
20
30
40
50
60
70
0 2 5 8 10
20
30
40
50
60
70
80
90
100
JP 1962

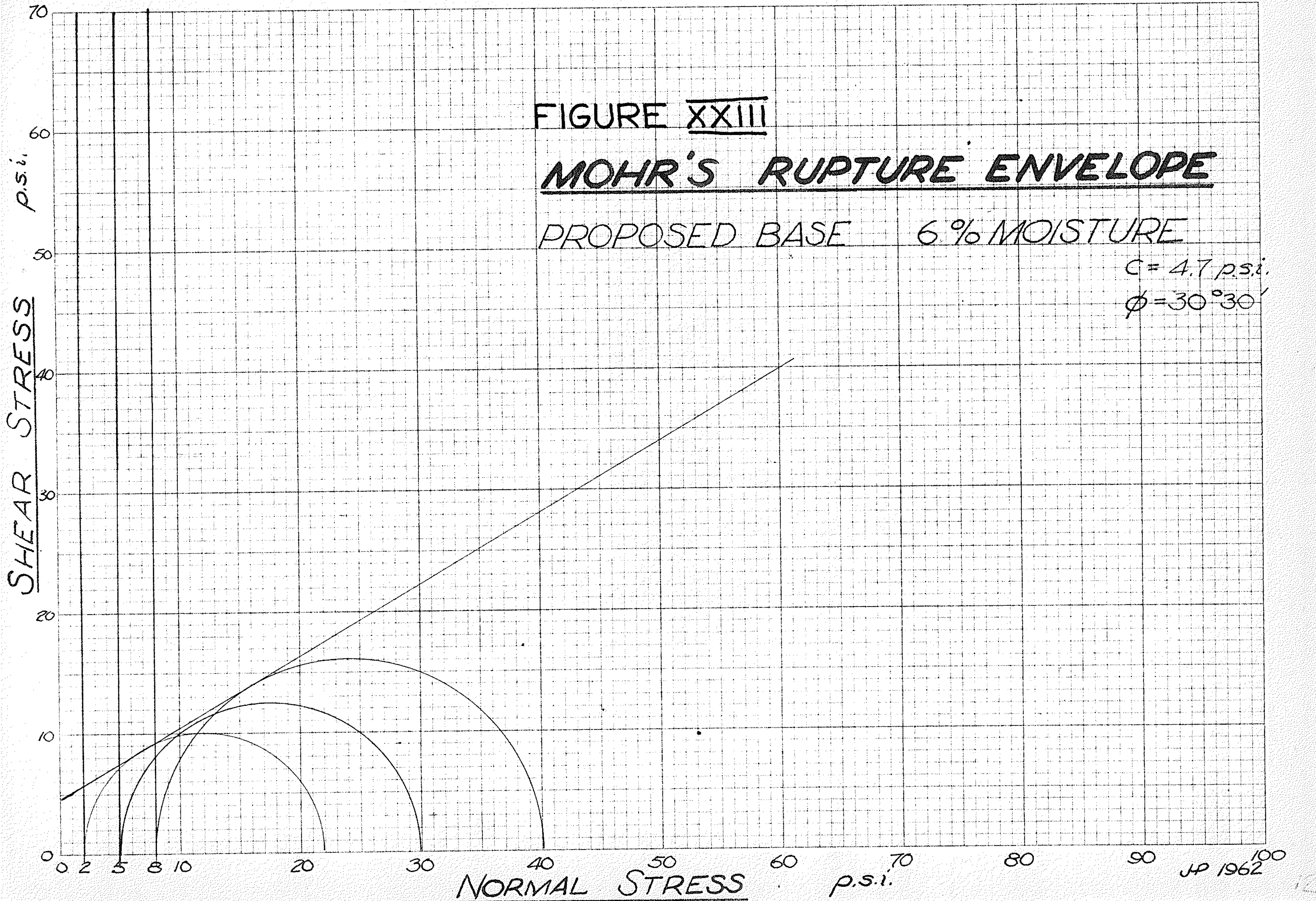

FIGURE XXIII
MOHR'S RUPTURE ENVELOPE
PROPOSED BASE 6 % MOISTURE
C = 4.7 p.s.i.
ϕ = 30°30'
SHEAR STRESS p.s.i.
70
60
50
40
30
20
10
0
0 2 5 8 10 20 30 40 50 60 70 80 90 100
NORMAL STRESS p.s.i.
JP 1962

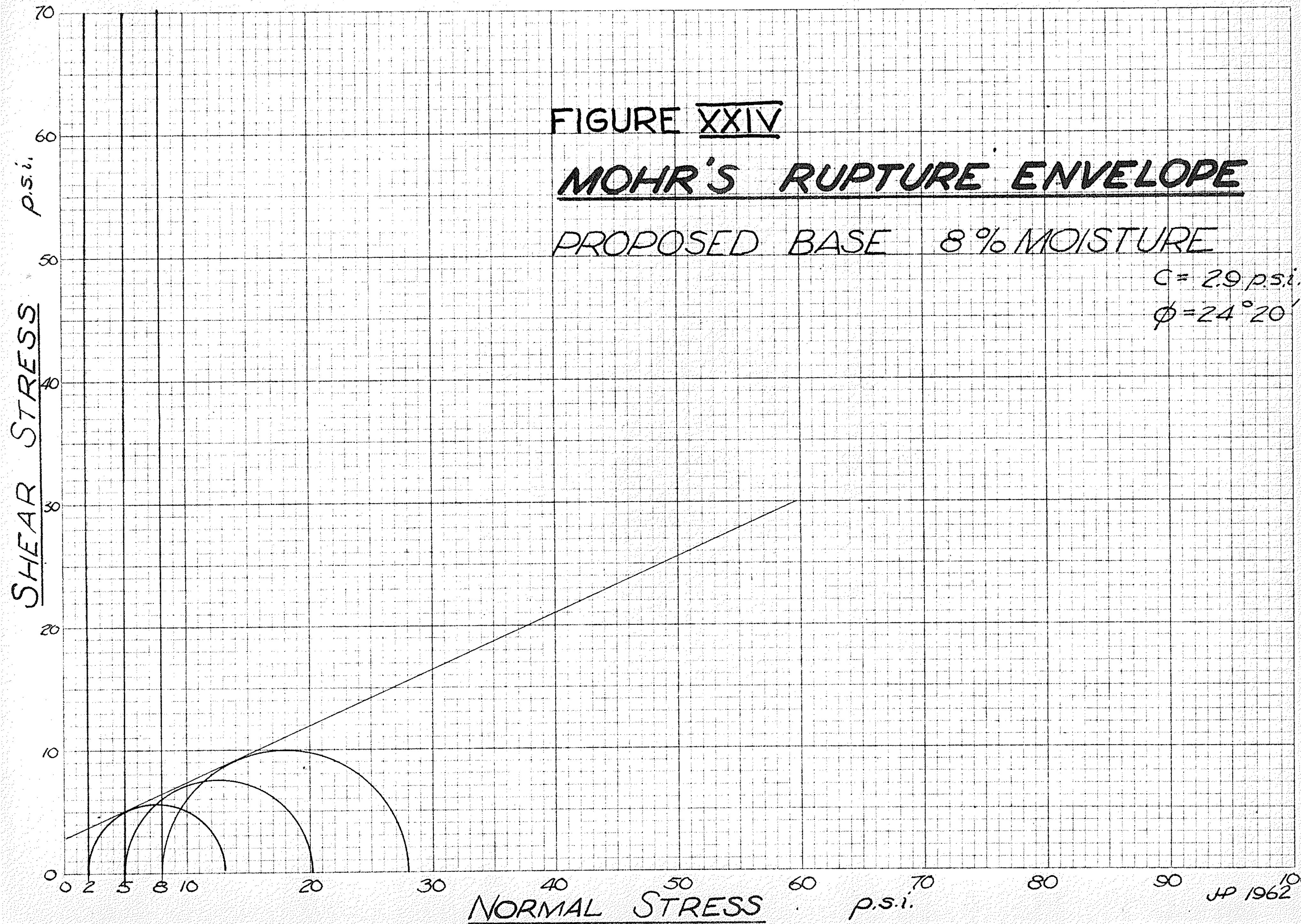
FIGURE XXIV
MOHR'S RUPTURE ENVELOPE
PROPOSED BASE 8% MOISTURE
C = 2.9 p.s.i.
φ = 24°20'
SHEAR STRESS p.s.i.
NORMAL STRESS p.s.i.
0 10 20 30 40 50 60 70
0 2 5 8 10 20 30 40 50 60 70 80 90 100
JP 1962

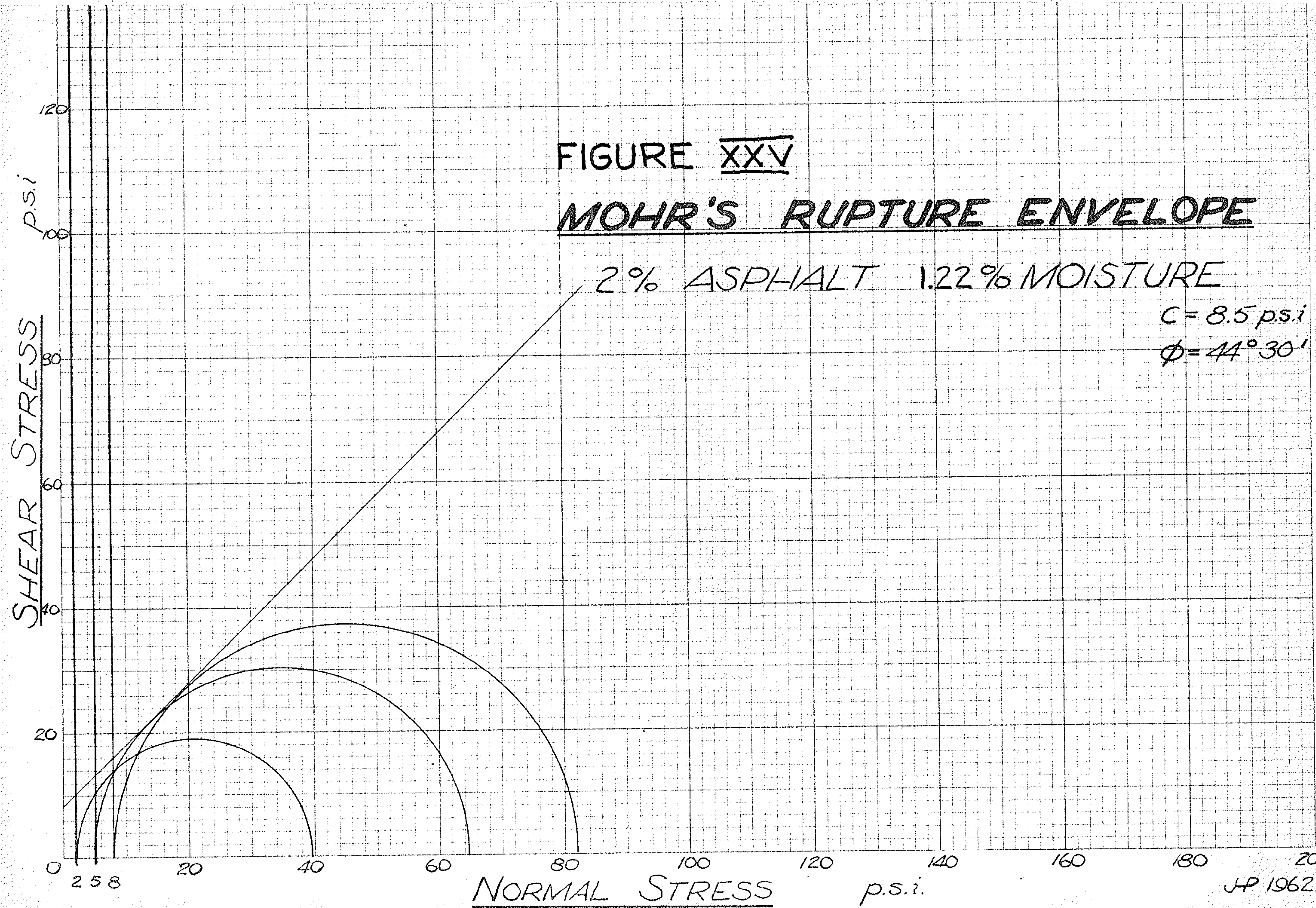
FIGURE XXV
MOHR'S RUPTURE ENVELOPE
2% ASPHALT 1.22% MOISTURE
C = 8.5 p.s.i
φ = 44° 30'
SHEAR STRESS p.s.i
NORMAL STRESS p.s.i.
0
20
40
60
80
100
120
140
160
180
200
2 5 8
JP 1962

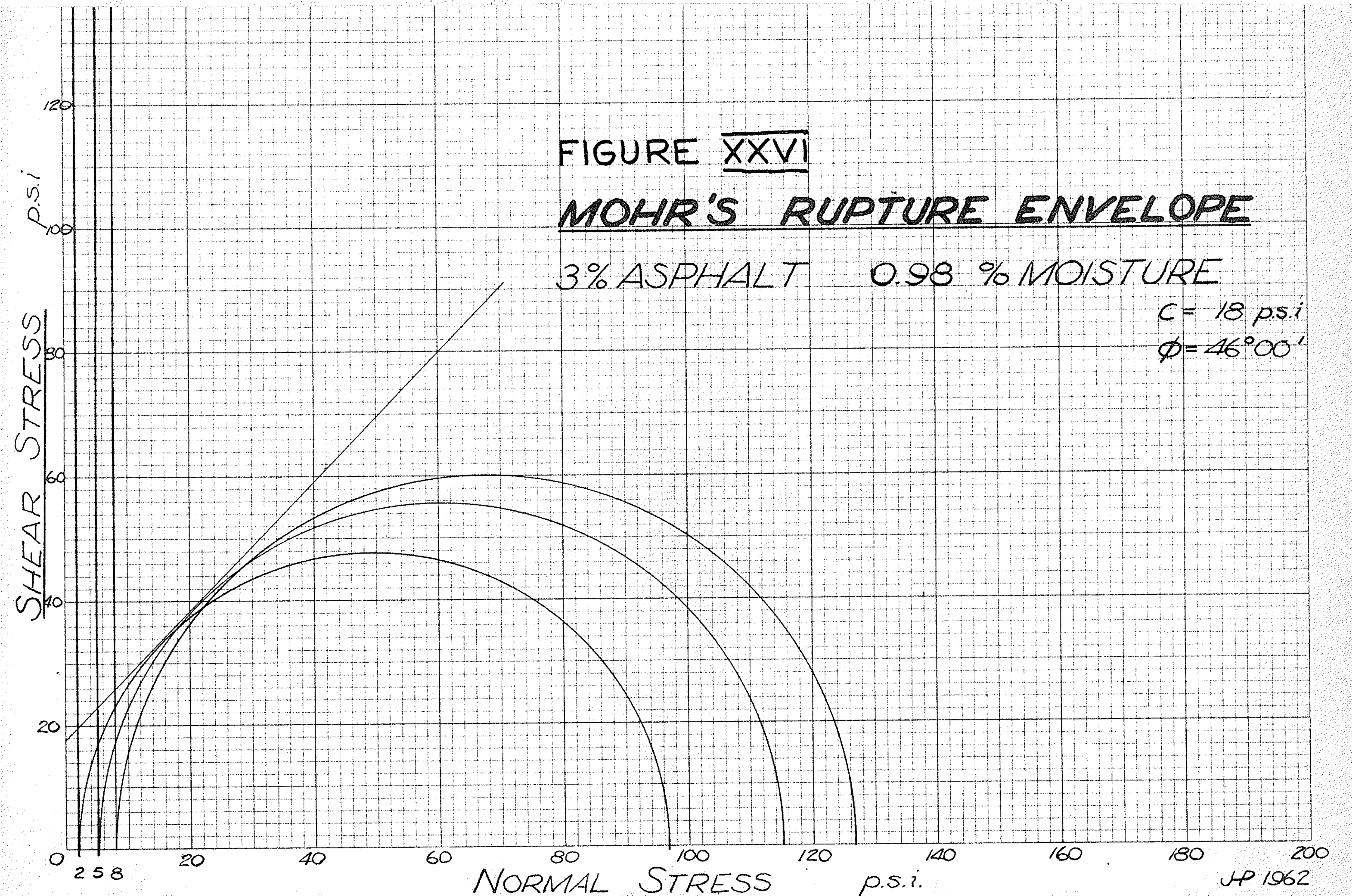
FIGURE XXVI
MOHR'S RUPTURE ENVELOPE
3% ASPHALT 0.98 % MOISTURE
C = 18 p.s.i
φ = 46°00'
SHEAR STRESS p.s.i
120
100
80
60
40
20
0
2 5 8
20
40
60
80
100
120
140
160
180
200
NORMAL STRESS p.s.i.
J-P 1962

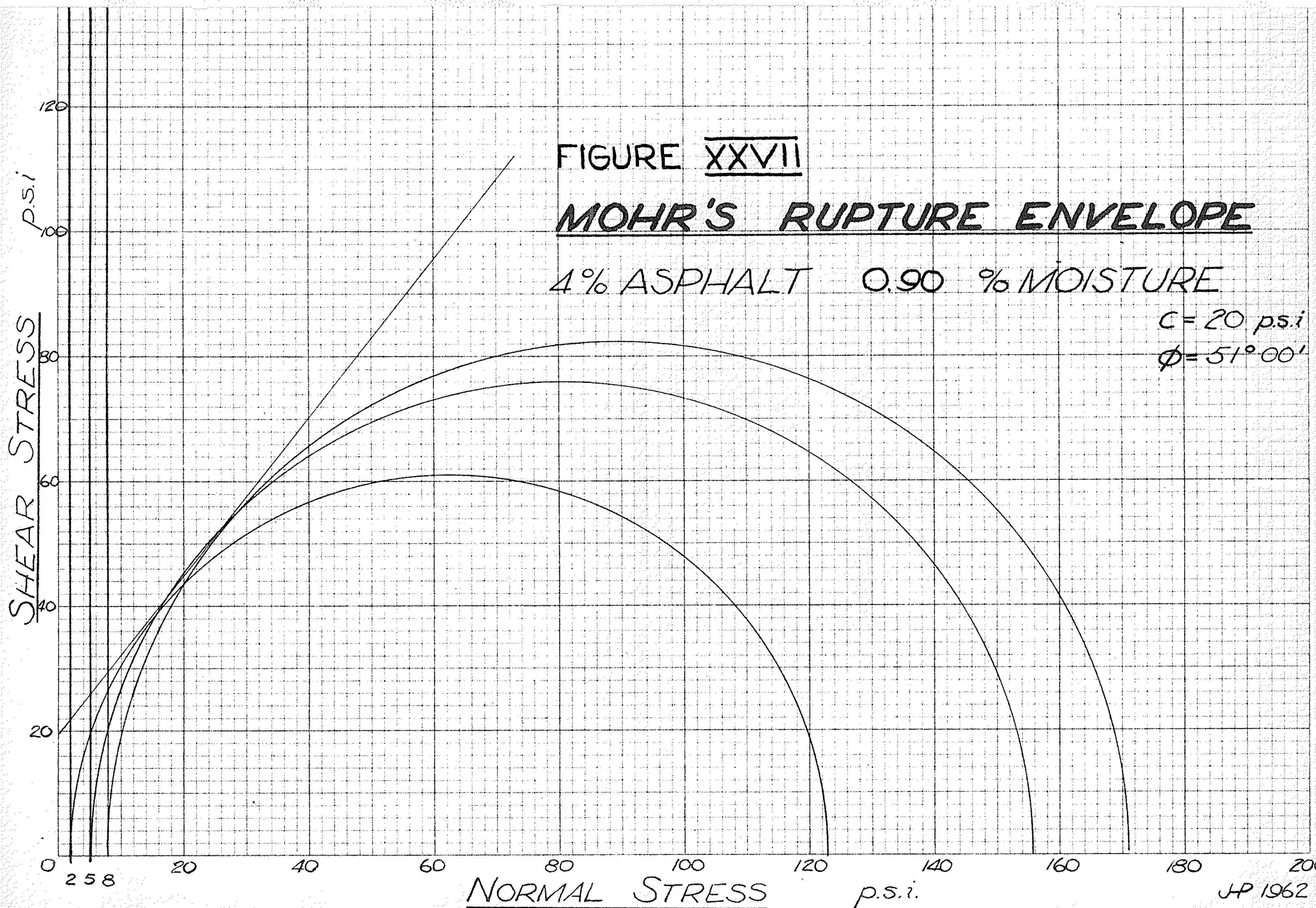
FIGURE XXVII
MOHR'S RUPTURE ENVELOPE
4% ASPHALT 0.90 % MOISTURE
C = 20 p.s.i
Φ = 51° 00'
SHEAR STRESS p.s.i
120
100
80
60
40
20
0
2 5 8
20
40
60
80
100
120
140
160
180
200
NORMAL STRESS p.s.i.
J-P 1962

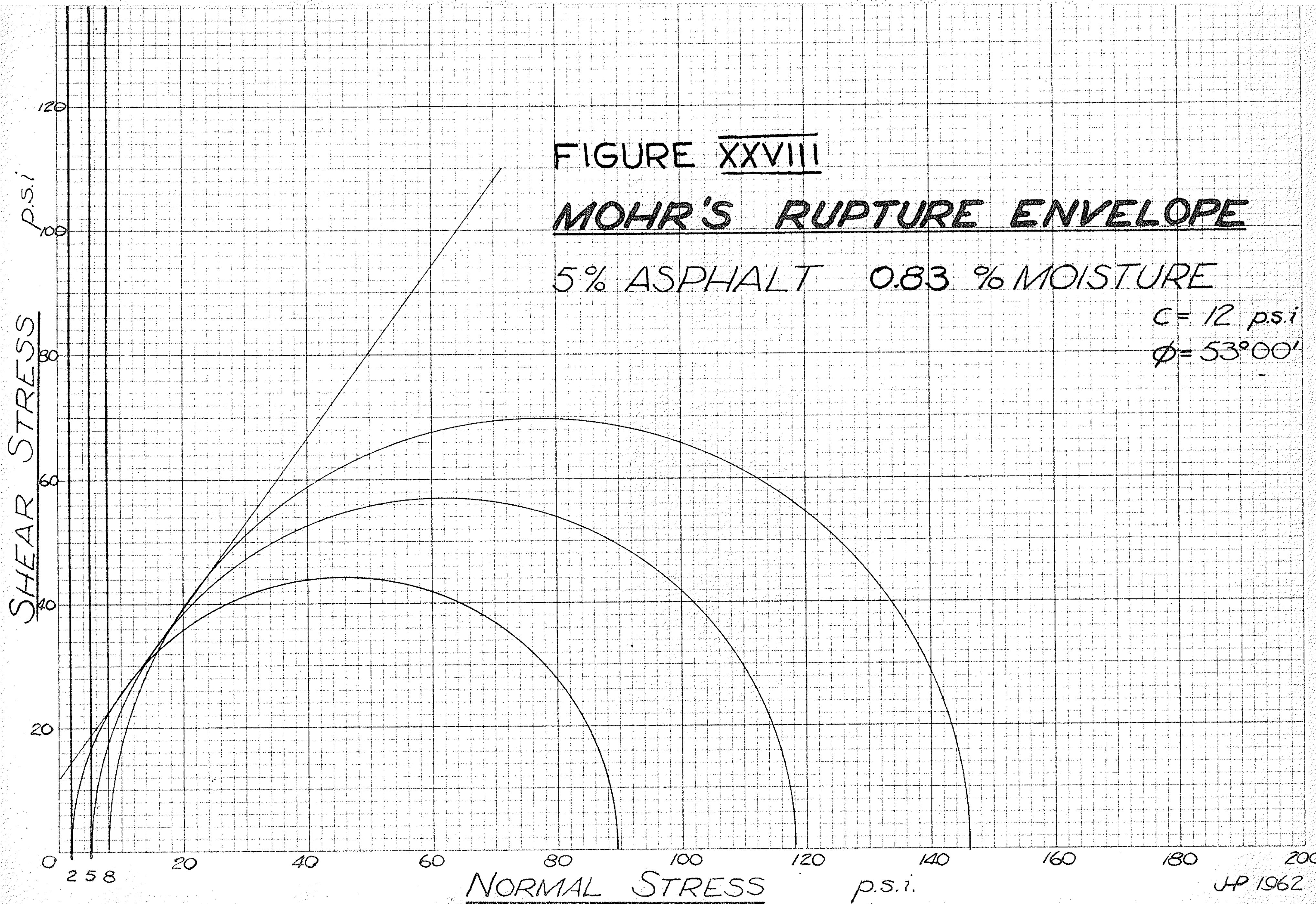
FIGURE XXVIII
MOHR'S RUPTURE ENVELOPE
5% ASPHALT 0.83 % MOISTURE
C = 12 p.s.i
Φ = 53°00'
SHEAR STRESS p.s.i
NORMAL STRESS p.s.i.
0 2 5 8 20 40 60 80 100 120 140 160 180 200
20 40 60 80 100 120
J-P 1962

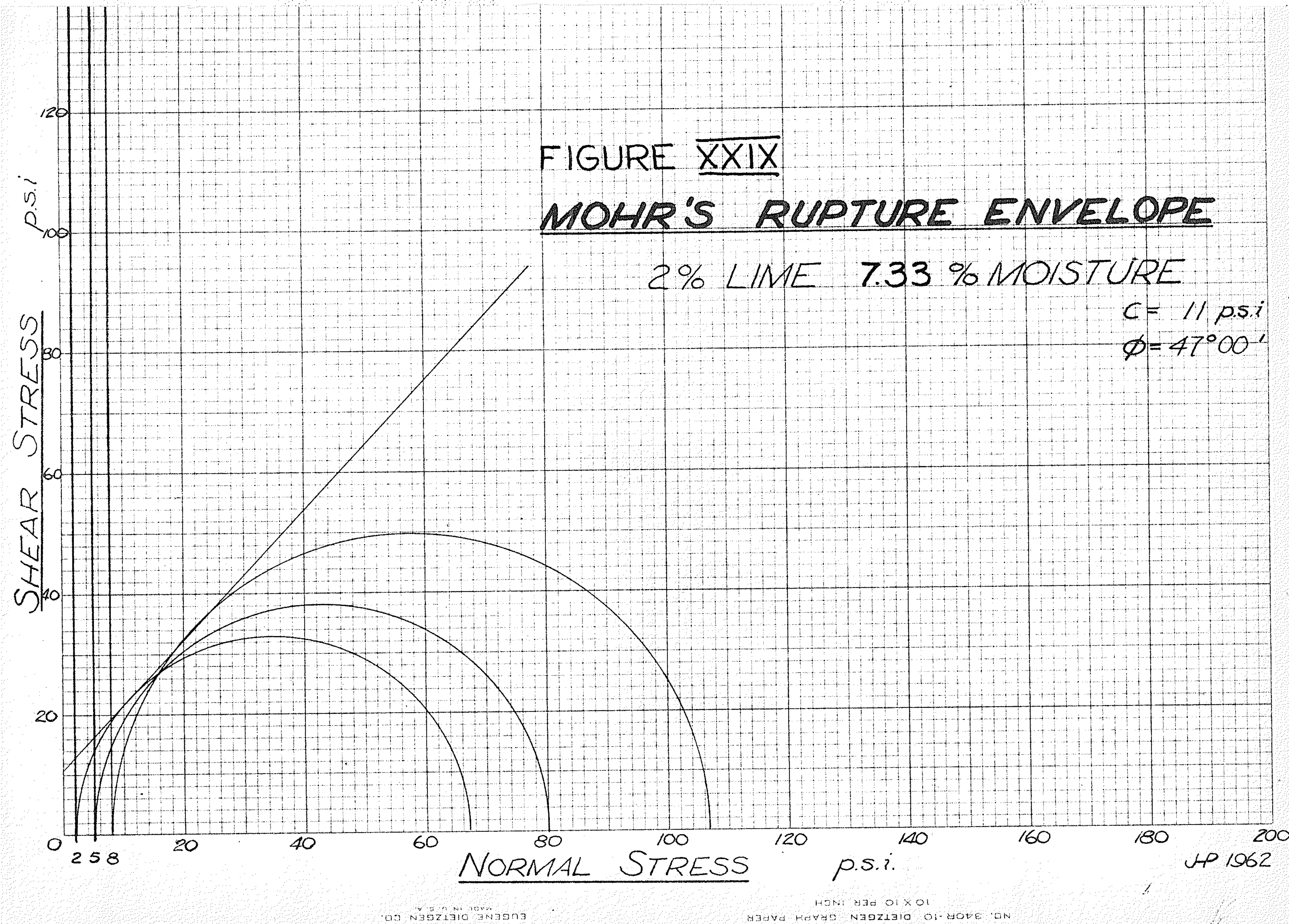

FIGURE XXIX
MOHR'S RUPTURE ENVELOPE
2% LIME 7.33 % MOISTURE
C = 11 p.s.i
φ = 47°00'
SHEAR STRESS p.s.i
NORMAL STRESS p.s.i
0
2 5 8
20
40
60
80
100
120
140
160
180
200
J-P 1962
NO. 340R-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.

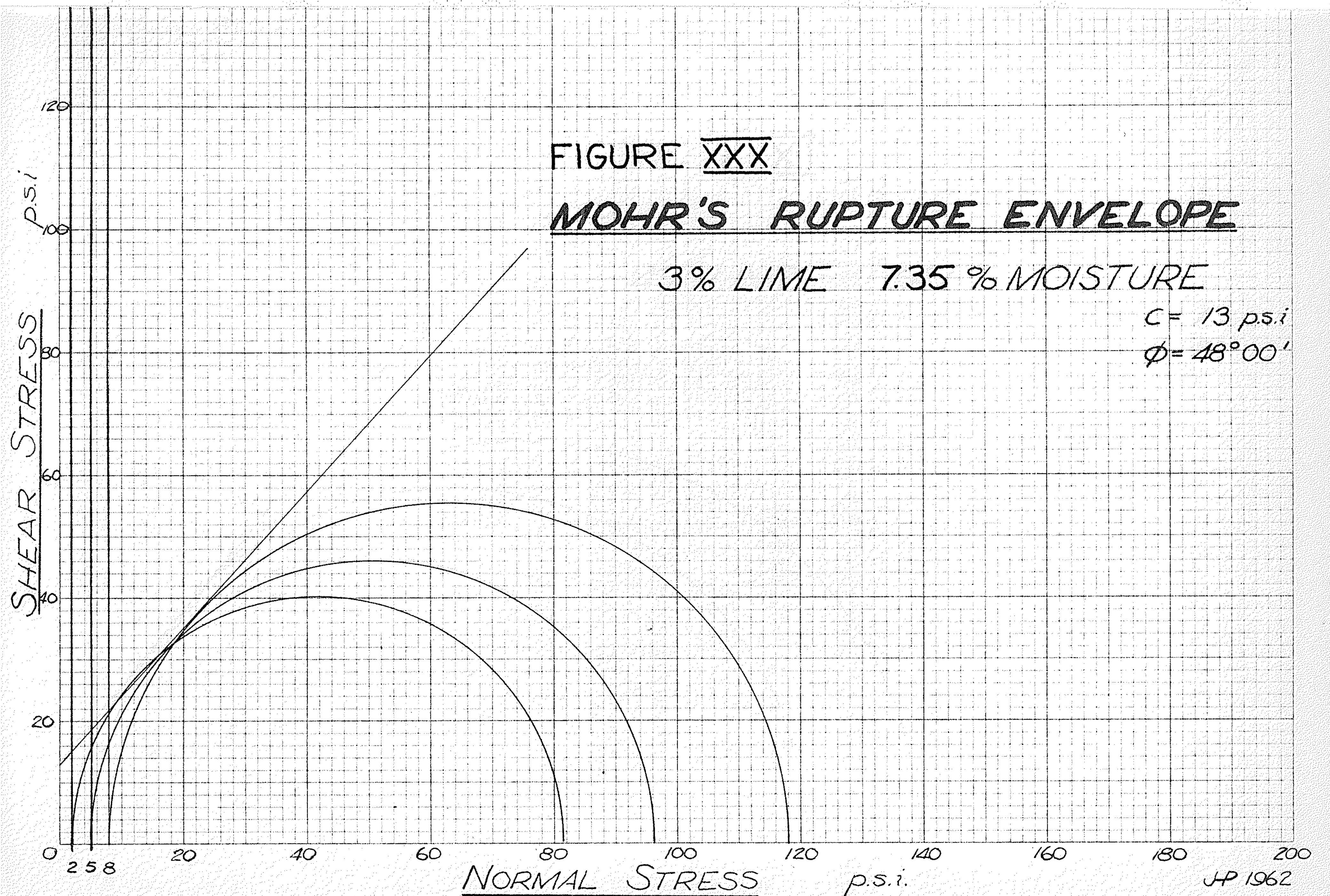
FIGURE XXX
MOHR'S RUPTURE ENVELOPE
3% LIME 7.35 % MOISTURE
C= 13 p.s.i
φ= 48°00'
SHEAR STRESS p.s.i
120
100
80
60
40
20
0
2 5 8
20
40
60
80
100
120
140
160
180
200
NORMAL STRESS p.s.i.
J-P 1962

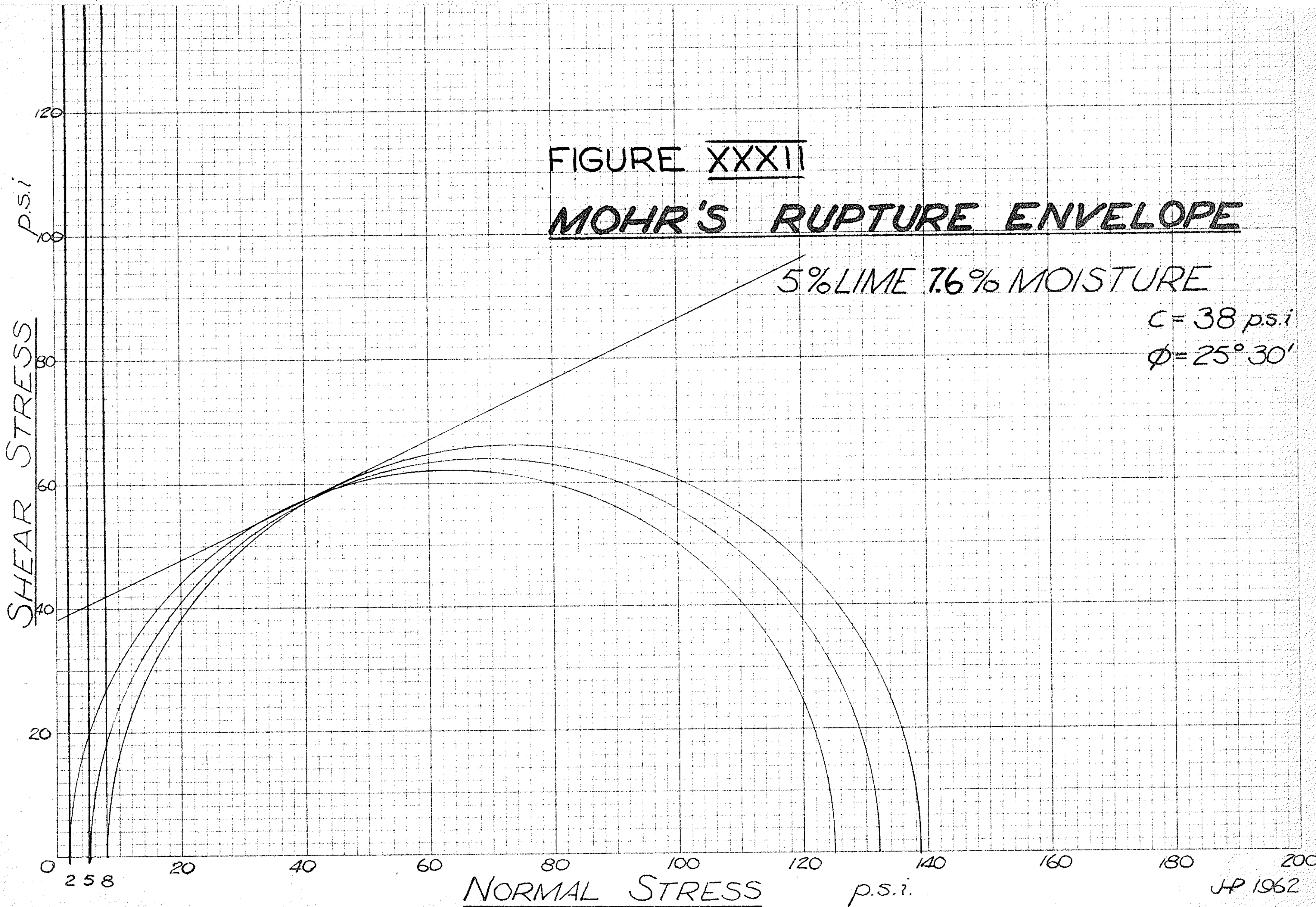

FIGURE XXXII
MOHR'S RUPTURE ENVELOPE
5% LIME 7.6% MOISTURE
C = 38 p.s.i
ϕ = 25° 30'
SHEAR STRESS p.s.i
120
100
80
60
40
20
0
2 5 8
20
40
60
80
100
120
140
160
180
200
NORMAL STRESS p.s.i.
J.P 1962

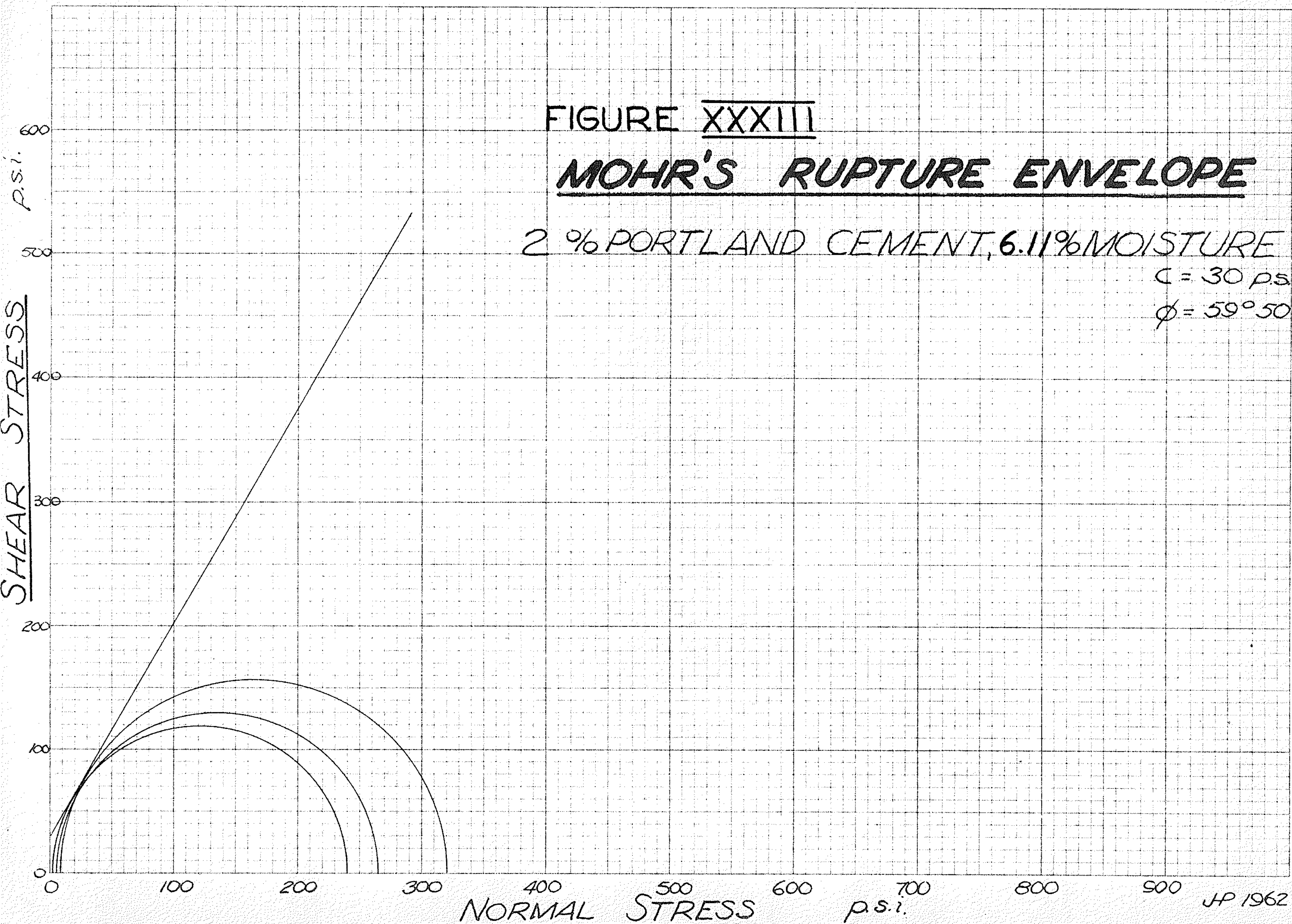

FIGURE XXXIII
MOHR'S RUPTURE ENVELOPE
2 % PORTLAND CEMENT, 6.11% MOISTURE
C = 30 p.s.i.
ϕ = 59°50'
SHEAR STRESS p.s.i.
0
100
200
300
400
500
600
0
100
200
300
400
500
600
700
800
900
NORMAL STRESS p.s.i.
JP 1962

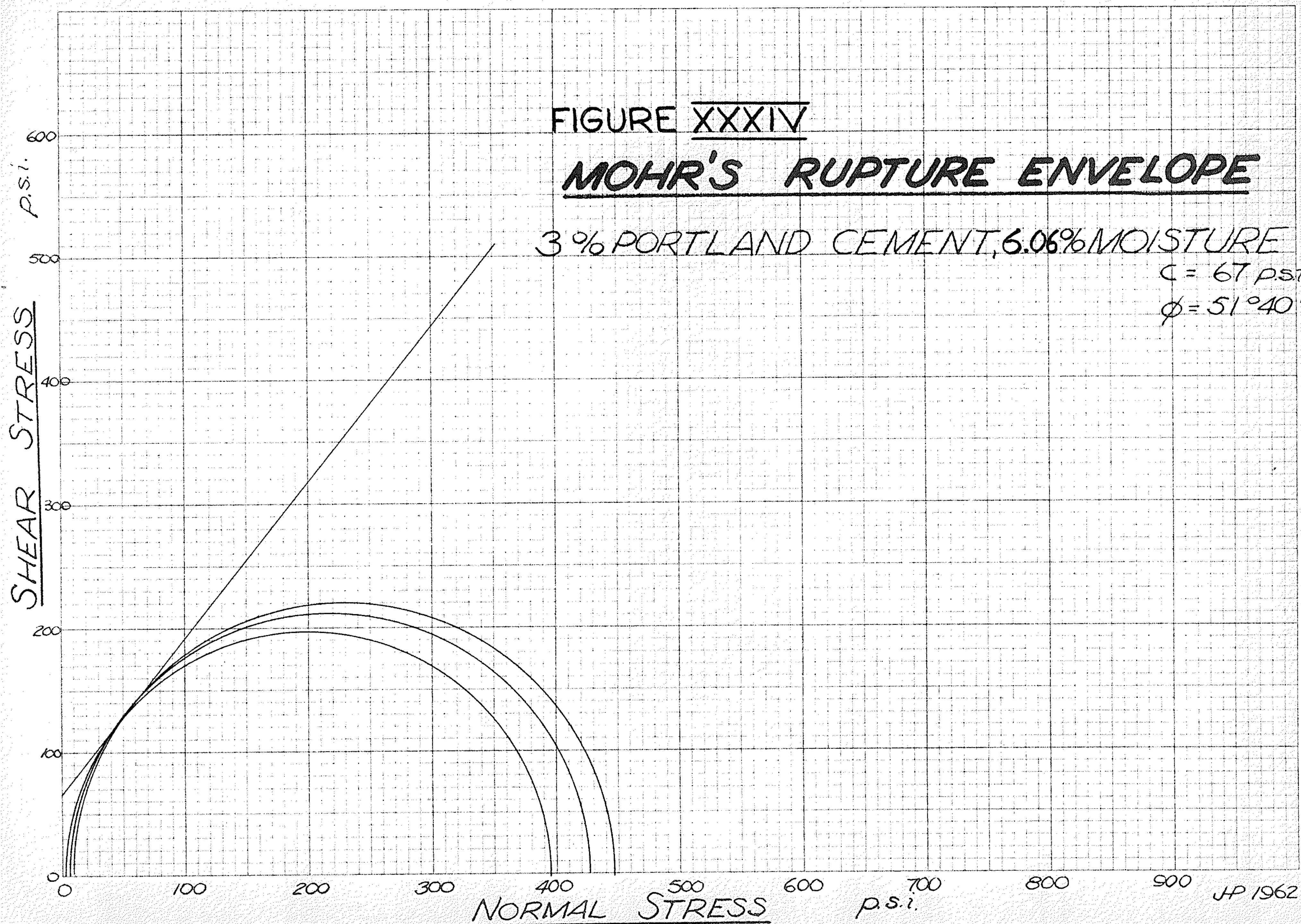
FIGURE XXXIV
MOHR'S RUPTURE ENVELOPE
3% PORTLAND CEMENT, 6.06% MOISTURE
C = 67 p.s.i.
φ = 51°40'
SHEAR STRESS p.s.i.
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
NORMAL STRESS p.s.i.
JP 1962

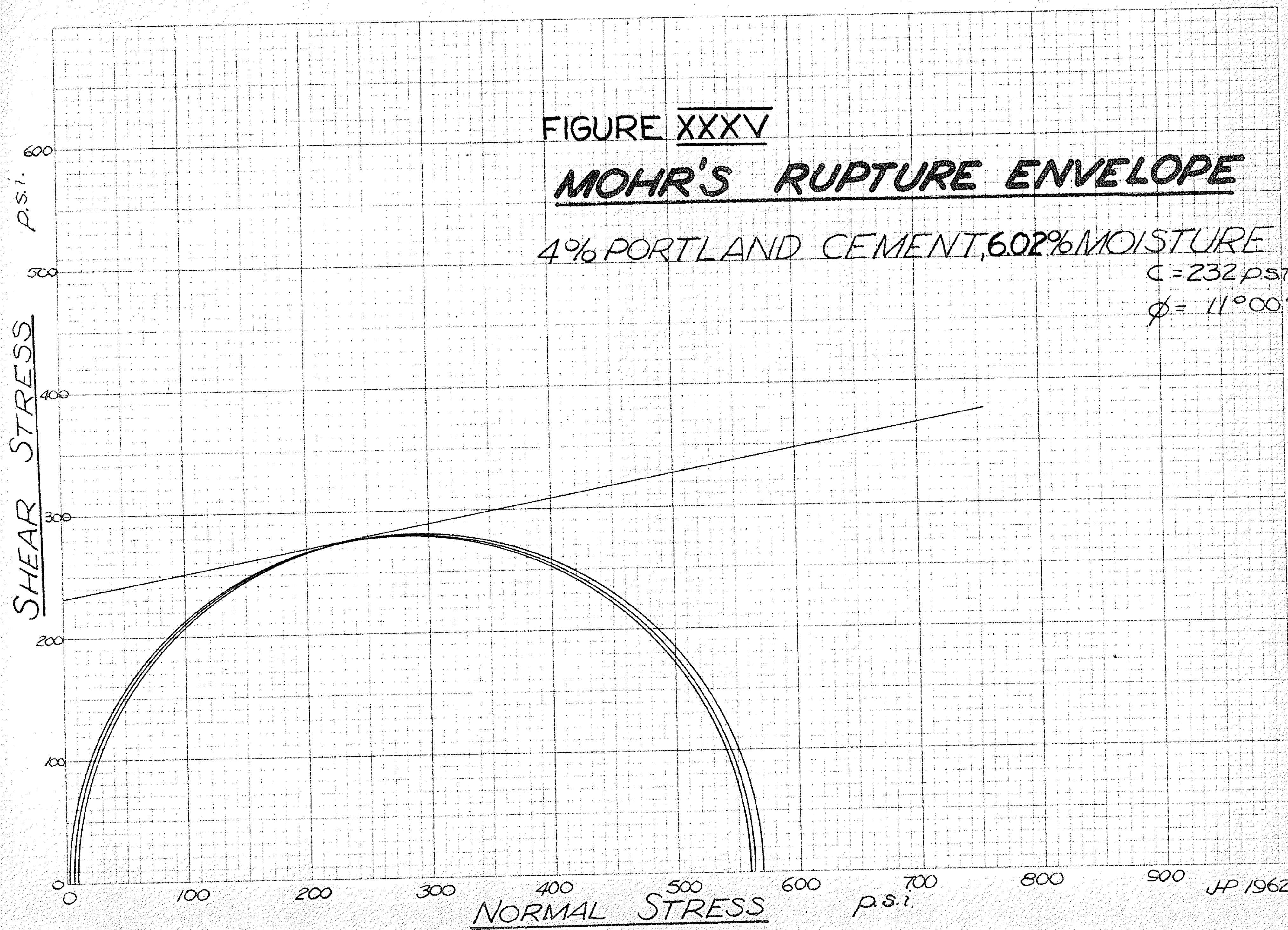

FIGURE XXXV
MOHR'S RUPTURE ENVELOPE
4% PORTLAND CEMENT, 6.02% MOISTURE
C = 232 p.s.i.
φ = 11°00'
SHEAR STRESS p.s.i.
NORMAL STRESS p.s.i.
0
100
200
300
400
500
600
700
800
900
JP 1962

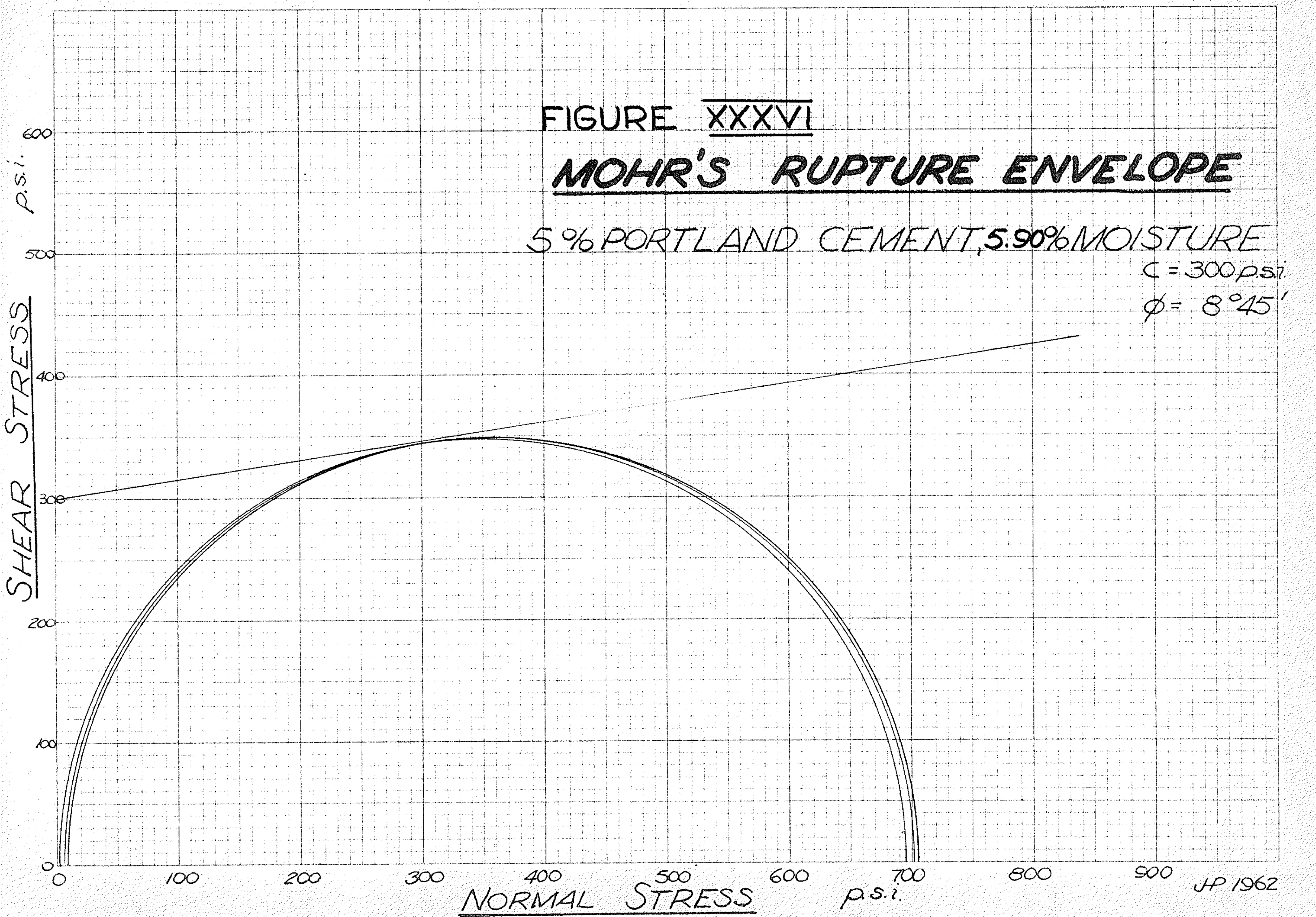
FIGURE XXXVI
MOHR'S RUPTURE ENVELOPE
5% PORTLAND CEMENT, 5.90% MOISTURE
C = 300 p.s.i.
φ = 8°45'
SHEAR STRESS p.s.i.
NORMAL STRESS p.s.i.
0
100
200
300
400
500
600
700
800
900
JP 1962

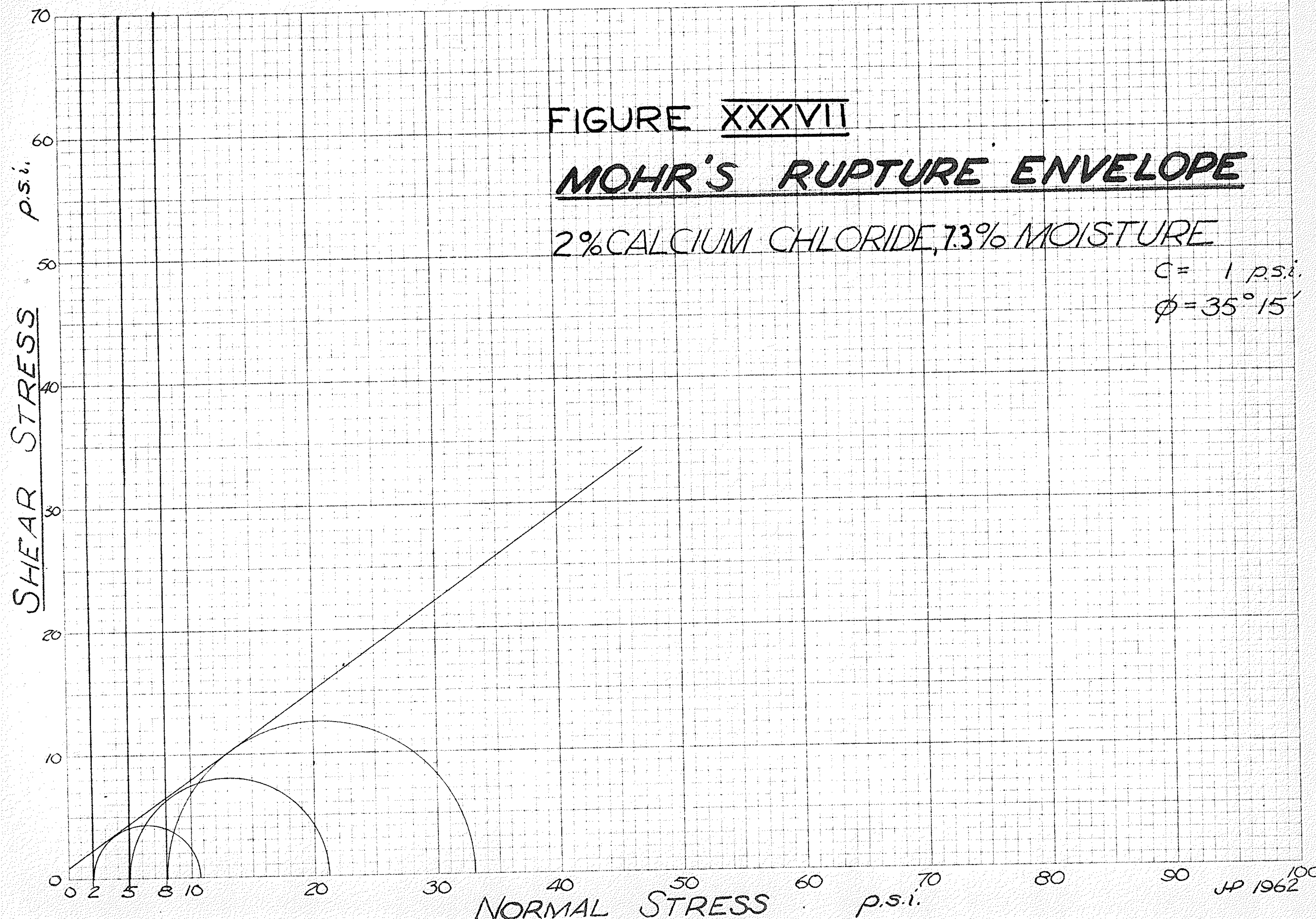

FIGURE XXXVII
MOHR'S RUPTURE ENVELOPE
2% CALCIUM CHLORIDE, 7.3% MOISTURE
C = 1 p.s.i.
φ = 35° 15'
SHEAR STRESS p.s.i.
NORMAL STRESS p.s.i.
0 10 20 30 40 50 60 70
0 2 5 8 10 20 30 40 50 60 70 80 90 100
J.P. 1962

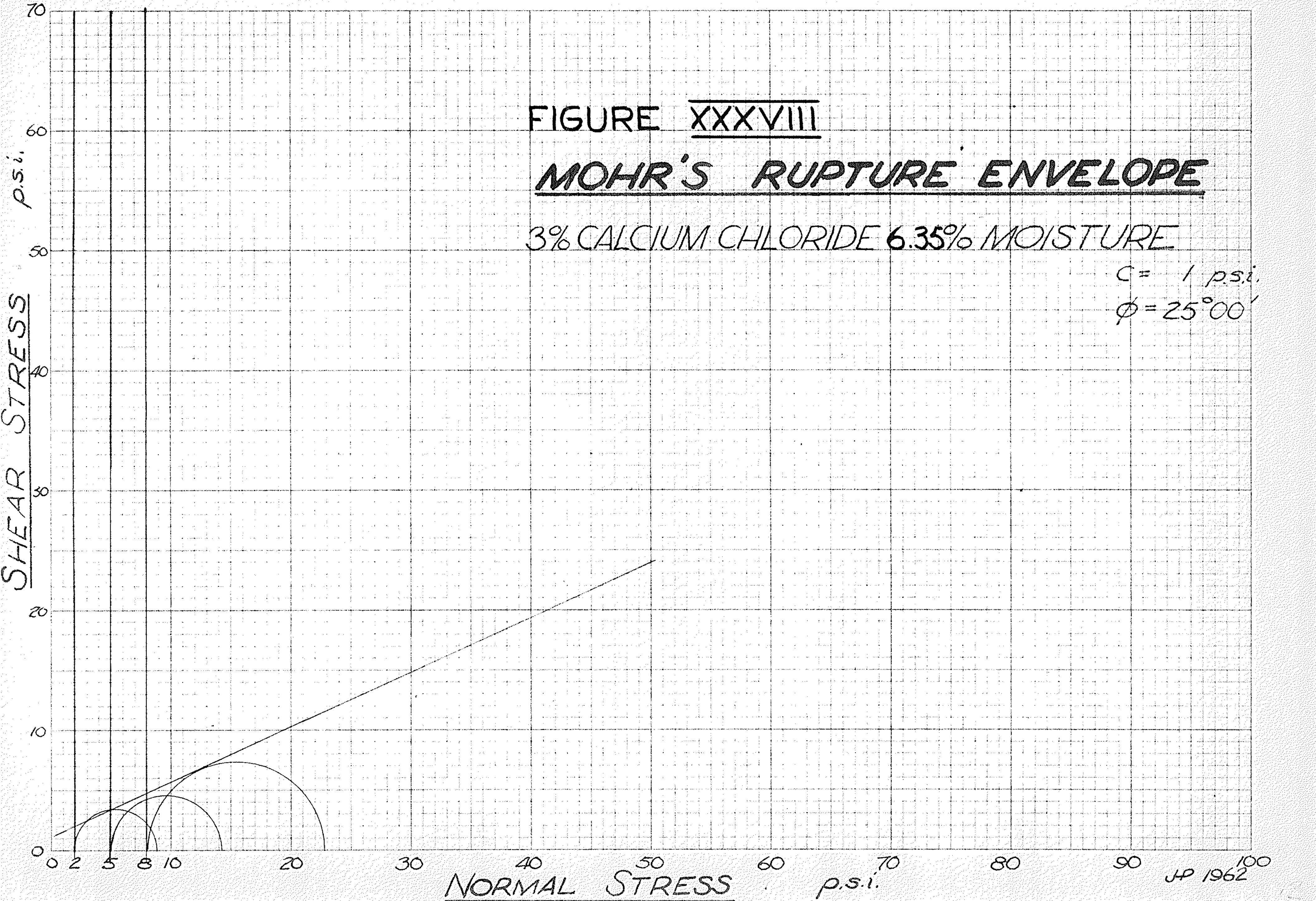

FIGURE XXXVIII
MOHR'S RUPTURE ENVELOPE
3% CALCIUM CHLORIDE 6.35% MOISTURE
C = 1 p.s.i.
φ = 25°00'
SHEAR STRESS p.s.i.
NORMAL STRESS p.s.i.
0
10
20
30
40
50
60
70
0
2
5
8
10
20
30
40
50
60
70
80
90
100
JP 1962

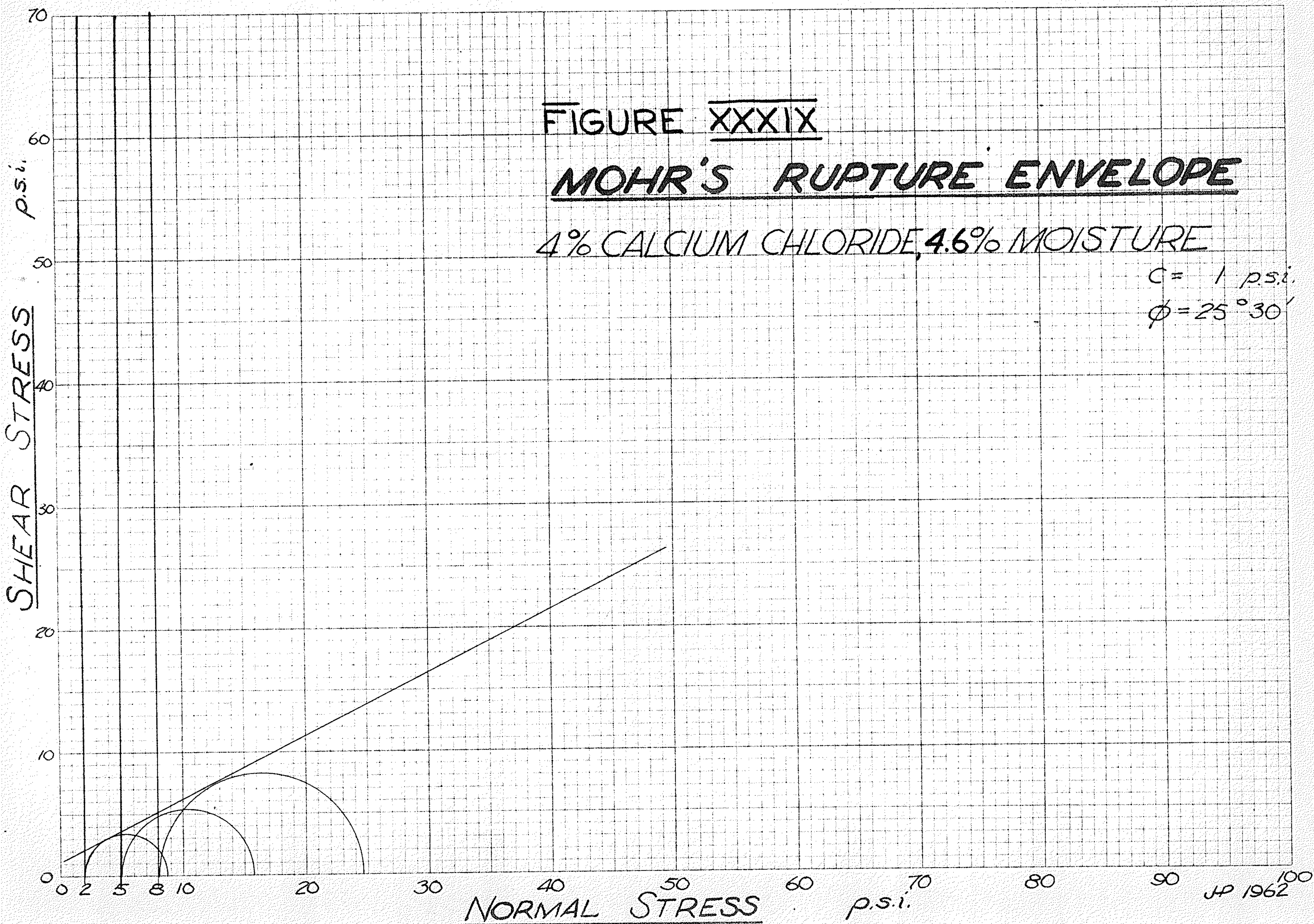
FIGURE XXXIX
MOHR'S RUPTURE ENVELOPE
4% CALCIUM CHLORIDE, 4.6% MOISTURE
C = 1 p.s.i.
ϕ = 25°30'
SHEAR STRESS p.s.i.
NORMAL STRESS p.s.i.
0 10 20 30 40 50 60 70
0 2 5 8 10 20 30 40 50 60 70 80 90 100
JP 1962

Figure XL Untreated Gravel Specimen After Triaxial Test
(Silty Gravel)

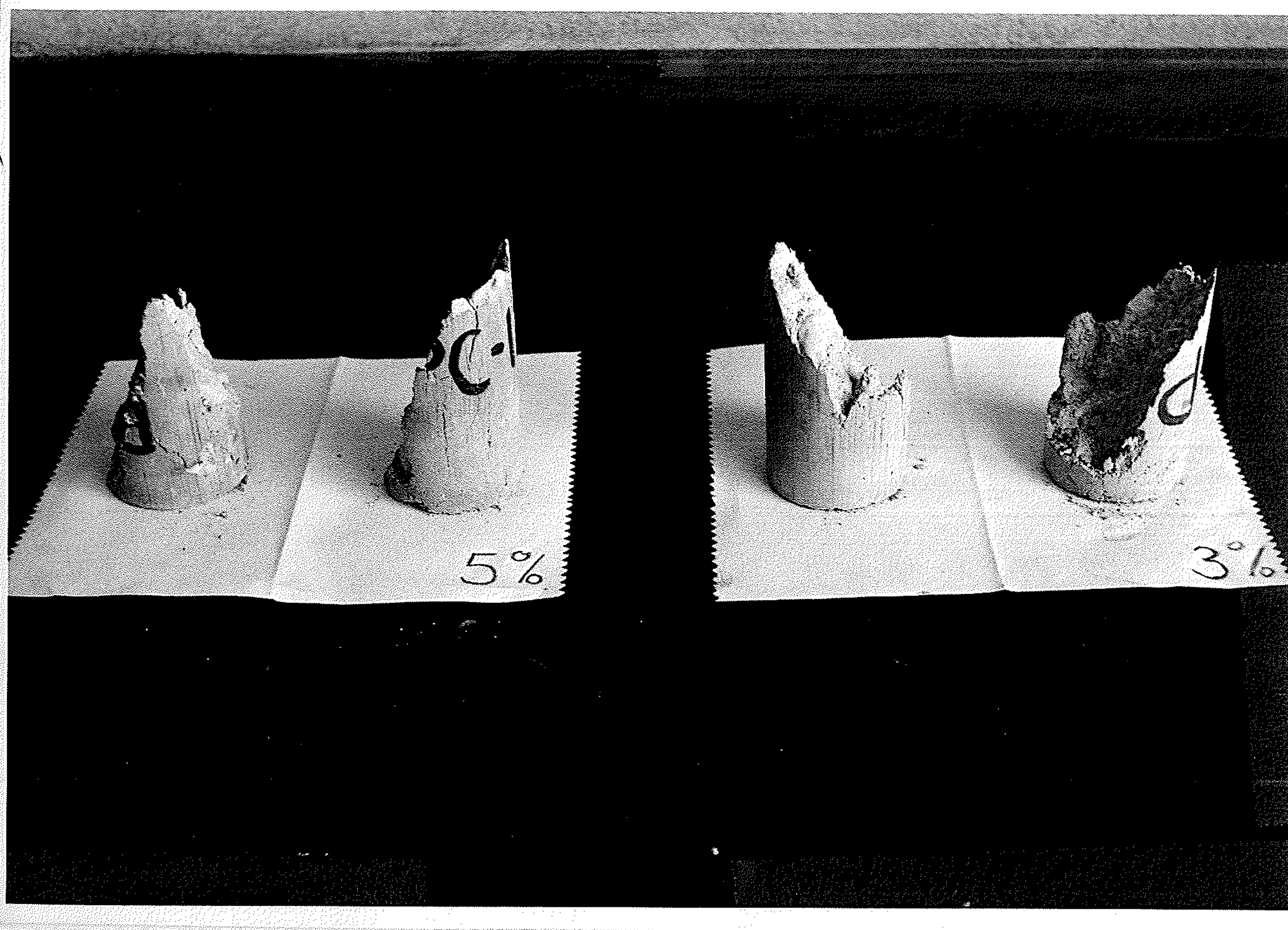

Figure XLI Portland Cement Specimens After Testing

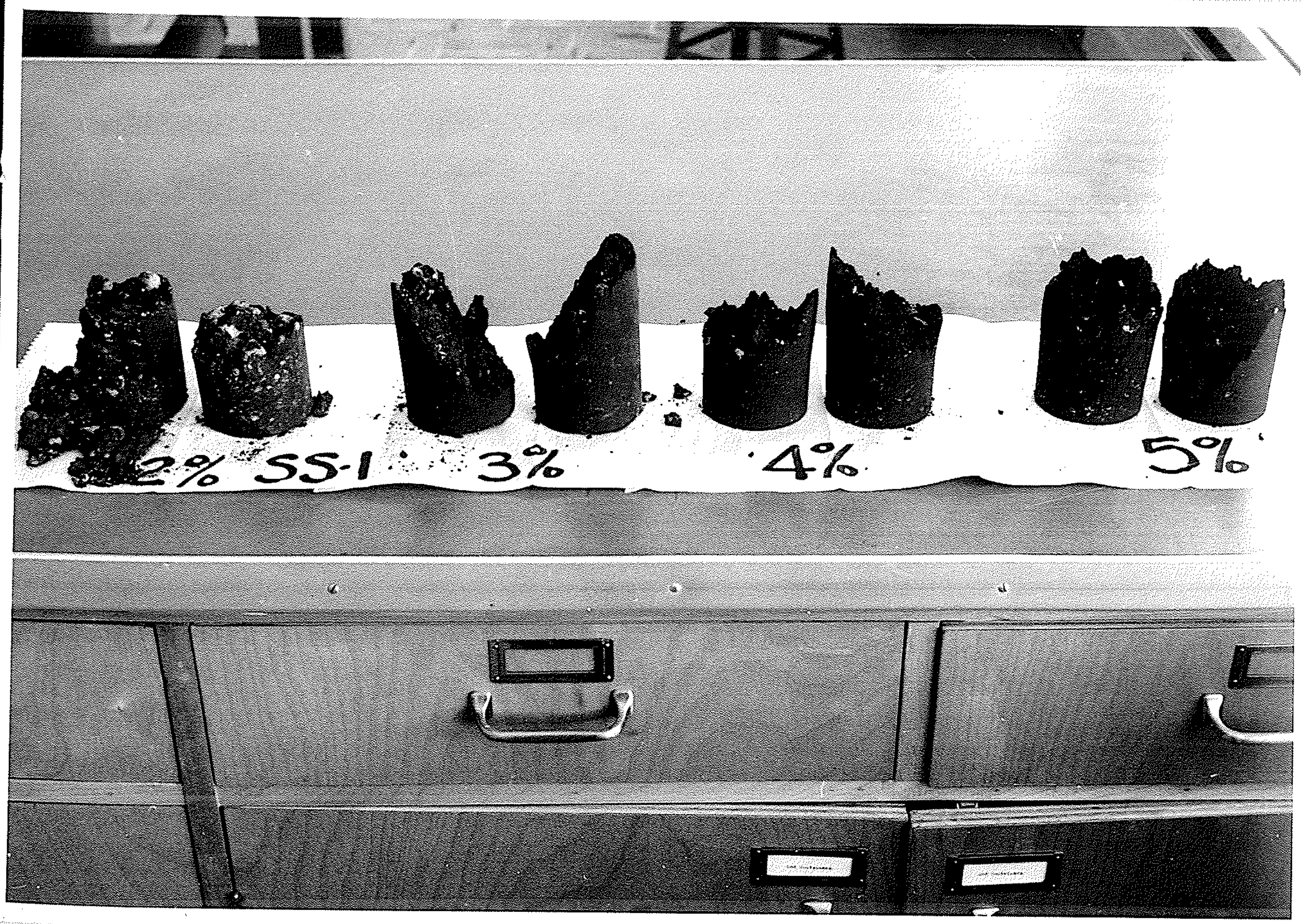

Figure XLII Asphalt-Treated Specimens After Testing

CHAPTER IV

DISCUSSION OF TEST RESULTS

I WATER ABSORPTION TESTS

The curves for the water absorption tests (Figures XII to XVI) show that the addition of any of the additives tested slowed the absorption rate. The total amount of water absorbed was also decreased except in the case of the calcium chloride treated material. The most marked alteration in absorption was evidenced by the asphalt treated material, where the addition of only two percent of asphalt decreased the total amount of water absorbed to less than one-seventh that of the untreated material.

Flow of water into the specimens was due to a combination of gravity flow caused by the head of water in the soaking tank, and capillarity. In most cases, moisture content tests taken at the top, centre and bottom of extra trial samples after soaking showed an even variation in water content from saturated, at the bottom, to moist at the top. In calcium chloride treated specimens, however, the water rose evenly with a definite plane, above which the material contained atmospheric moisture only, and below which a condition of saturation existed. It was concluded, therefor, that the addition of calcium chloride to the test material arrested capillary action almost completely. This property might be useful for treatment of frost-susceptible soils in which ice lenses are formed and grow as water is supplied to them through capillary action in the soil.

The moisture contents achieved by the method of soaking used here are comparable to moisture contents found in base courses about the province in the spring. A survey done by the Manitoba Highways Branch in 1952 and 1953[9] on highways around Brandon showed moisture contents varying from four to eight percent, the majority of tests indicating moisture between 6.5 and 7.5 percent. The greater moisture contents occurred with high content of fines in the base course material. These figures show agreement with the moisture contents achieved in the absorption tests by the standard base gravel and the untreated silty gravel.

It is felt, therefor, that the method devised for soaking the specimens is acceptable. An advantage over the method used by the Texas Highway Department, in which specimens are saturated under vacuum, is that the specimens can be weighed at intervals during soaking, and the actual rate of absorption thus studied. Trial specimens showed that no measurable effect on absorption was caused by interrupting soaking for periodic weighings. These

[9]Unpublished data, Manitoba Highways Branch

Auxiliary trial specimens also demonstrated good reproducibility of absorption data.

II TRIAXIAL COMPRESSION TESTS

The summary of results (Tables II to VII) and Mohr's Rupture Envelopes derived from the triaxial compression tests indicate that the addition of asphalt, Portland cement or lime to the silty gravel greatly improved the strength characteristics of the material. The addition of calcium chloride had the reverse effect, decreasing ultimate stress, cohesion and internal friction. Greatest ultimate stress values were obtained with Portland cement, with a peak value of 719.8 p.s.i. for five percent additive and eight p.s.i. confining pressure.

The effect of moisture content on the angle of internal friction is well demonstrated by the triaxial tests performed on the standard base gravel and untreated silty material with varying moisture contents (Figures XVII to XXV). As the moisture content was increased, the ultimate stress and angle of internal friction decreased.

The cohesion for both materials increased with the addition of some moisture and then decreased as surplus moisture was added. This is explained as an effect of the cementing action of the fines in the material, which would not be evident when the fines were too dry or too wet to provide shearing resistance as a plastic material.

The Mohr's Rupture Envelopes for two percent asphalt, two percent lime and two percent Portland cement treated material were superimposed on those for the standard base gravel and untreated silty gravel and are presented in Figure XLIV. The values of cohesion and angle of internal friction for the standard base and silty gravel materials were obtained by interpolating in tables II and III to determine the values at the moisture contents reached in the absorption tests. The lines representing the lower limits of "good base" and "fair base" material on the Texas Classification System[9] chart have also been added as a reference. It is seen that the addition of only two percent of the additives represented here vastly improved the strength characteristics of the silty gravel, with the greatest effect evidenced by the Portland cement treated material. It

[9] J. Rogers Martin and Hugh A. Wallace, "Design of the Flexible Pavement," Design and Construction of Asphalt Pavements (New York, N.Y.: McGraw Hill Book Co, Inc., 1958)

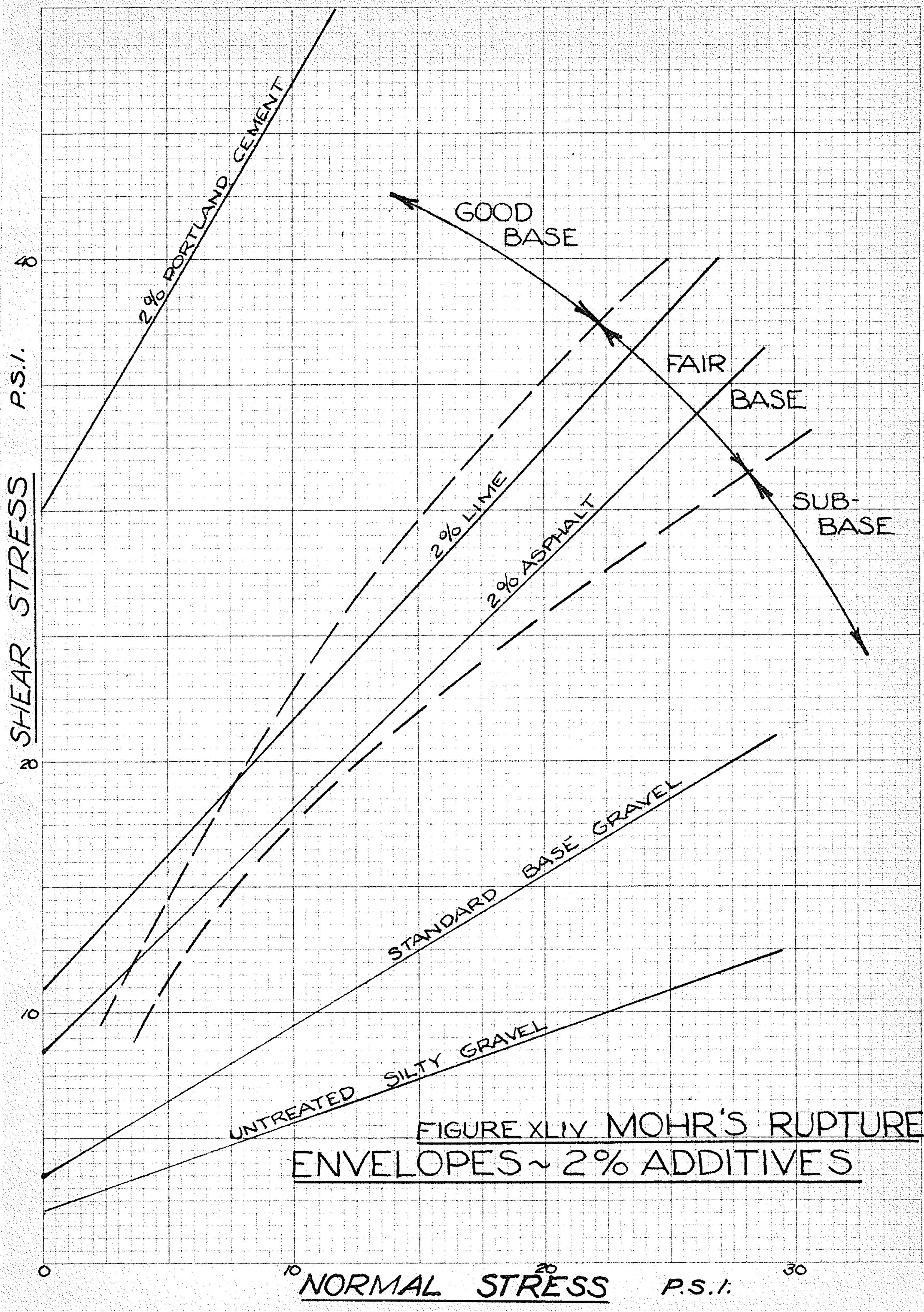

FIGURE XLIV MOHR'S RUPTURE ENVELOPES ~ 2% ADDITIVES is also seen that the standard base gravel, prepared to local specifications, falls below the limit of "fair base" material on the Texas classification chart at the moisture content reached in soaking as devised for this project. This could be taken as an indication of the reason for road failure so prevalent in this province every spring, when moisture contents reach the range used in these tests.

The envelopes for material treated with calcium chloride have not been considered because the calcium chloride detracted from the properties of the silty gravel. When five percent additive was used, the specimens were so plastic that triaxial testing was not possible, the specimens resembling jelly in consistency.

The addition of Portland cement increased the strength of the silty gravel to such an extent that the small changes in lateral pressure used were almost insignificant in comparison to the great ultimate stresses developed. This resulted in Mohr's diagrams for the tests which were almost superimposed one upon the other, especially with high contents of Portland cement, giving rise to some difficulty in accurately determining the rupture envelope graphically. However, the test results on specimens with high Portland cement content are not pertinent to the purpose of this project other than showing excessive strength and thereby excessive additive content.

Study of the test results for lime and Portland cement treated materials reveals an increase in cohesion and decrease in angle of internal friction when the additive content exceeded two percent Portland cement or four percent lime. This could be explained as a cementation effect, which would increase the shearing resistance and thereby the value obtained for cohesion from Mohr's Rupture diagrams.

The tests on untreated material clearly show the loss of stability which occurs with increase in moisture in a mechanically stabilized "clay-bound" base. This is responsible for the annual distress of many roads in the spring when conditions of high moisture are prevalent in this province. The action of some additives in decreasing this effect and thus ensuring ample strength at all times of the year would seem to be justification for their use even with good base course aggregates.

III ECONOMIC COMPARISON OF ADDITIVES

On the basis of the test results shown in Figure XLV, the silty gravel could be suitably stabilized with the addition of two percent Portland cement, three percent lime or three percent asphalt. The envelopes for these three treatments all satisfy the Texas classification requirement for "good base". An economic comparison of these three alternatives is presented in Table VIII, in which the cost of each alternate method is summarized. The basis of cost analysis is use of a road-mix method, where Portland cement or lime would be added by means of a stabilizing machine capable of effectively blending dry materials and asphalt added as a sprayed emulsion in a travel-plant mixer. The cost of a standard gravel base course material in place has been considered for comparison. The figures of $0.50 per cubic yard for silty gravel and $1.25 per cubic yard for standard base gravel are representative of pit prices in the Winnipeg area. A haul distance of ten miles has been arbitrarily chosen and a trucking rate of $0.07 per cubic yard per mile used as this is standard in the area. The cost of mixing additives is constant as the machinery and production rates are similar, so the difference in cost of base course in place is due mainly to the different costs and quantities of additives, although the cost of compacting asphalt treated material is slightly higher. Prices of additives are as quoted by local distributors. A base course nine inches thick is considered.

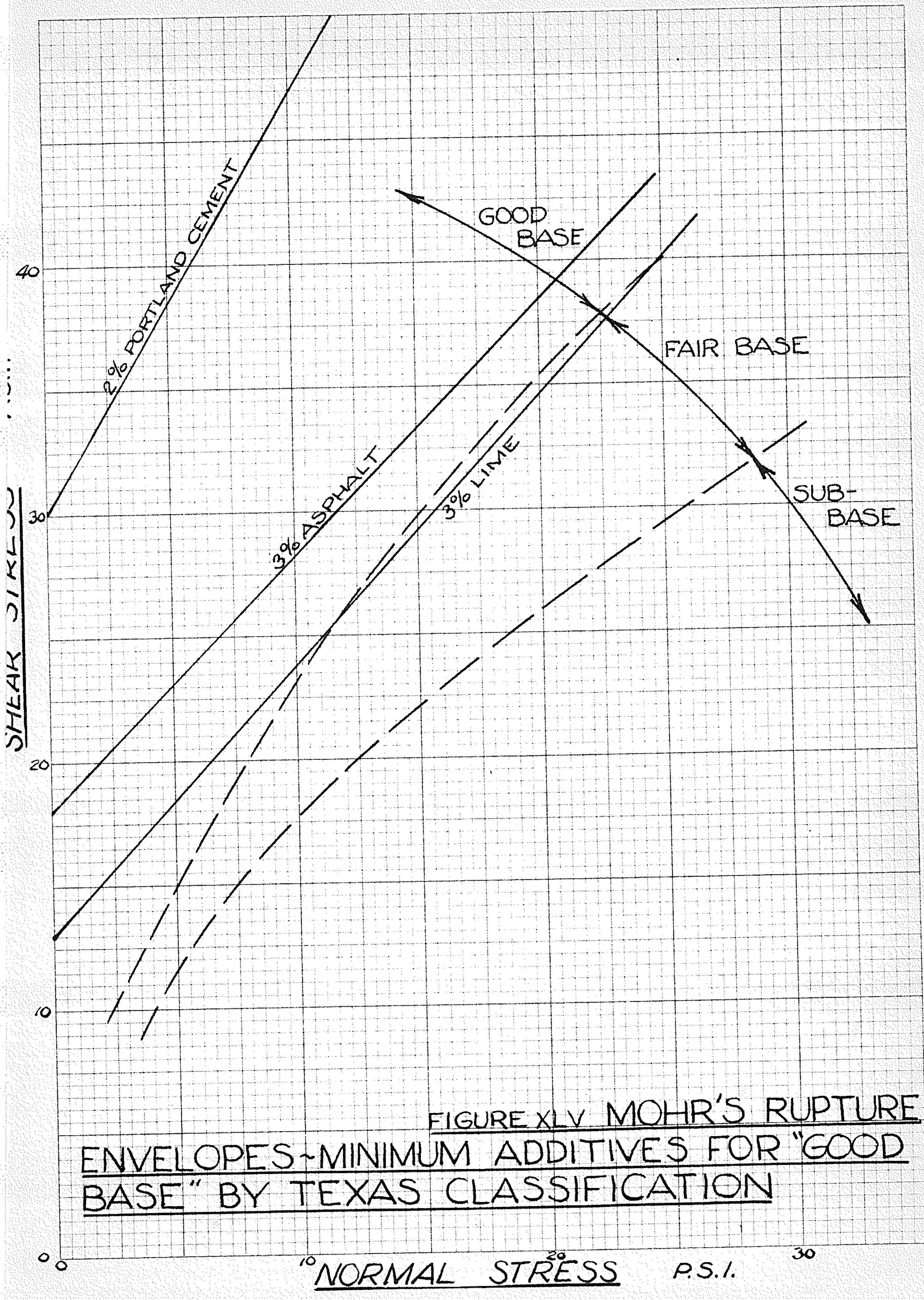

FIGURE XLV MOHR'S RUPTURE ENVELOPES ~ MINIMUM ADDITIVES FOR "GOOD BASE" BY TEXAS CLASSIFICATION

TABLE VIII

ECONOMIC COMPARISON OF ADDITIVES IN BASE CONSTRUCTION

Description of material	Cost of gravel material per square yard	Cost of additive per square yard	Cost of haul per square yard	Cost of compaction per square yard	Cost of mixing per square yard	Total Cost per square yard
Standard base	.41	--	.24	.06	--	0.71
3% asphalt	.16	.15	.24	.08	.24	0.87
3% lime	.16	.27	.24	.06	.24	0.97
2% Portland cement	.16	.20	.24	.06	.24	0.90

The total cost figures show that for the type of silty material considered, treatment with asphalt is the most economical method. The cost per square yard is only twenty-two percent higher than the cost of standard base course construction, or approximately ten percent higher on the whole pavement structure, subgrade, base course and pavement. In a case where good base gravel was seven miles further away than silty gravel, treating the silty gravel with three percent asphalt would be more economical than hauling in standard base material. In addition, superior strength under conditions of high moisture would be obtained.

The cost of stabilizing with two percent Portland cement is only slightly higher at ninety cents per square yard and would seem to preclude the use of three percent lime at a cost of ninety seven cents per square yard and lower strength.

CHAPTER V

SUMMARY AND CONCLUSIONS

I PROPERTIES AND ACTION OF ADDITIVES

The tests performed showed that the addition of lime, asphalt or Portland cement altered the strength of the silty test gravel favorably. These additives also decreased the rate of water absorption by altering the permeability of the treated material. The most noticeable decrease in permeability occurred when asphalt was added. The greatest strength was obtained by adding Portland cement, which additive required the least percentage content to improve the silty gravel to the point of acceptability.

Addition of calcium chloride to the test material resulted in no benefit to base course construction although it was noted to almost eliminate capillarity in the specimens formed.

It is, therefor, concluded that using the type of material studied, a good base course could be constructed if asphalt, lime or Portland cement were mixed into the gravel, and that this could be done economically. Further, it is concluded that such a stabilized base would perform better than a standard gravel base course under conditions of high moisture such as prevail in the spring of the year.

II EVALUATION OF TEST METHODS AND ERROR

The triaxial compression test as a means of comparing additives and designing mix proportions is considered a good method. It has been shown to reveal certain properties which would not be evident in an unconfined compression test method, specifically, the cementing action of lime and Portland cement and also of fines in a mechanically stabilized material. These show up as changes in the cohesion and angle of internal friction. In view of the success of the Texas Highway Department in corelating triaxial test results to field performance over a number of years, it would seem that the triaxial test method has much to offer in the field of highway base course construction.

Some difficulty was encountered in obtaining consistent results and a number of test series had to be repeated. It is felt that a larger specimen size would decrease the effect of individual stone particles and this is therefor recommended.

The method of soaking specimens which was devised for this project enabled study of absorption rates during soaking and it is felt that the distribution of moisture in the specimen closely approximates moisture conditions in the field.

The test method is subject to standard sources of error in weighing, reading triaxial compression dials for strain and stress and in plotting results for graphical solutions. However, any error in these processes would be evident in failure to obtain linear rupture envelopes unless they were consistent errors.

The greatest source of error would arise from any alteration in compaction effort required to achieve the density corresponding to maximum Proctor density for the untreated material. Some difficulty was noted in compacting asphalt treated specimens in that more blows with the ram hammer were required to compress the specimens to the required volume. In the case of the other additives, however, compaction effort required was almost identical to that required for untreated soil. This error could be eliminated by performing Proctor compaction tests on each type of additive-treated material, at each test content percentage, and determining the amount of material for each specimen in this way.

III SUMMARY OF WORK DONE AND SUGGESTIONS FOR FURTHER WORK

In this project, the effects of asphalt, Portland cement, lime and calcium chloride on strength and absorption properties of a silty gravel have been compared by means of the triaxial compression test. The method of test has been modified as required, especially in preparation of specimens, and a workable process evolved.

It has been shown that in the case of the material tested a good base course can be prepared by adding asphalt, lime or Portland cement to the otherwise unacceptable gravel and that this can be done economically.

Further work on the project would logically consist of field trials of the treated material and perhaps soaking and drying cycle tests on treated specimens.

Valuable information could be gained by repeating the test procedure on gravel materials unbalanced in gradation in manners different than the material tested. Examination of rejected gravel samples from projects about the province would probably reveal different problem types of material.

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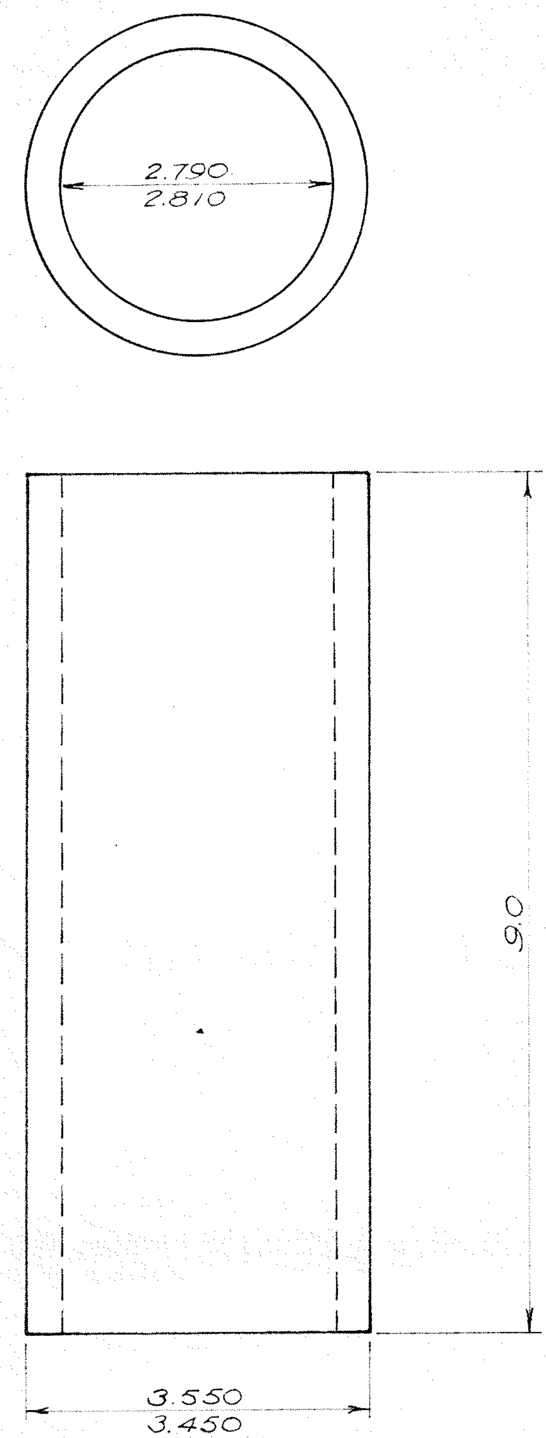
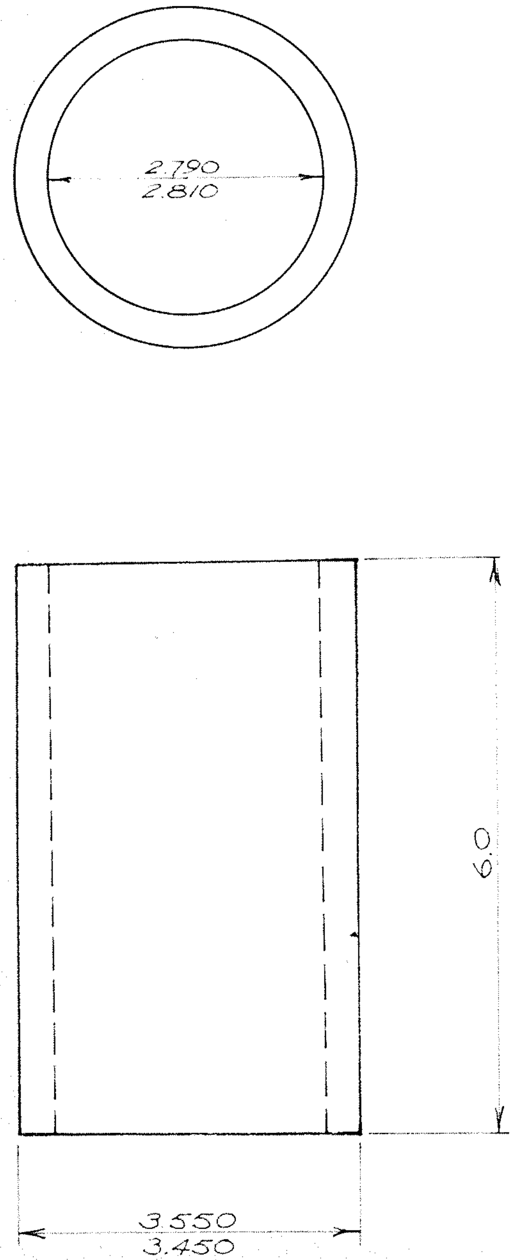


SPECIMEN MOLD - 4 Req'd.

(SCALE: HALF SIZE)

Machine from $3\frac{1}{2}''$ nom. diam. welded steel pipe, double extra strong (ASA)
Stamp on mold no's. 1 to 4. Finish all over.
Pipe mat'l. dimensions: I.D. - 2.728"
O.D. - 4.000"

JP-1960

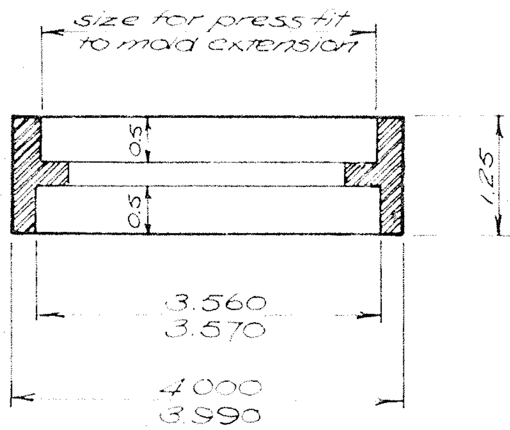


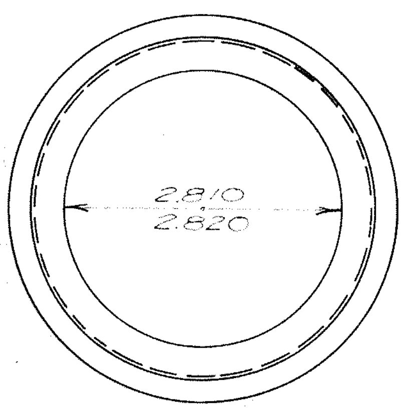
MOLD EXTENSION - 1 Req'd.

(SCALE: HALF SIZE)

Machine from $3\frac{1}{2}$" nom. diameter welded steel pipe, double extra strong (ASA)
Finish all over.

JP-1960



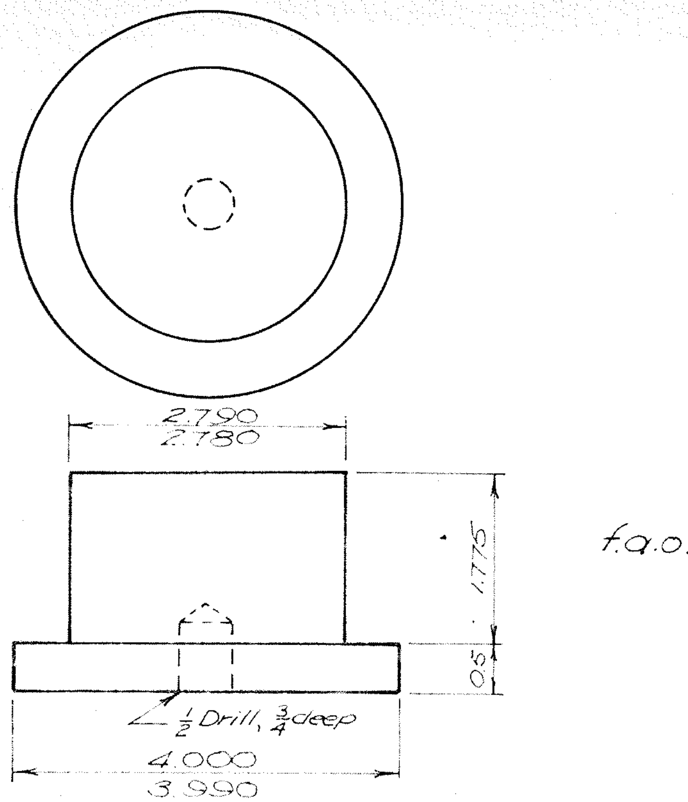


COLLAR - 1 Req'd.

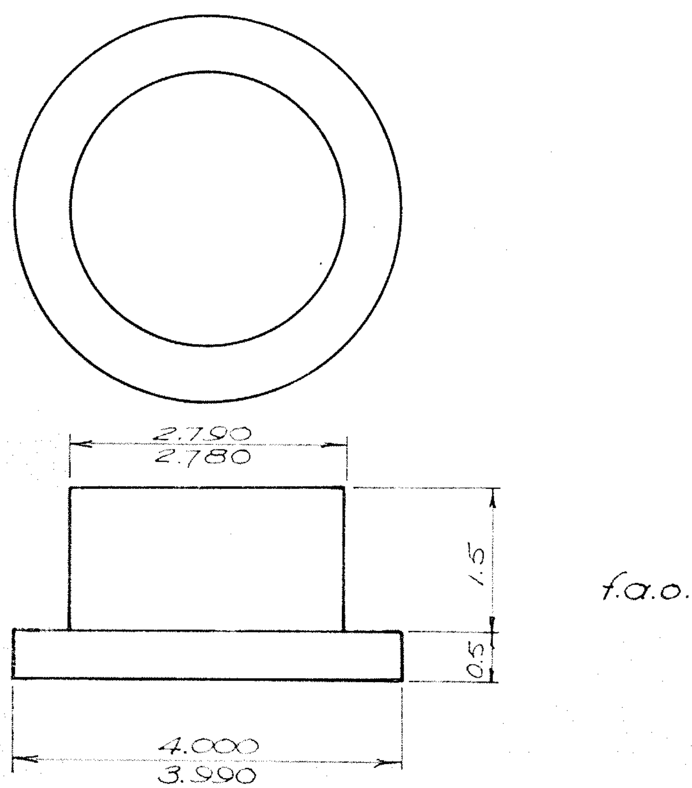
(SCALE: HALF SIZE)

Machine from $3\frac{1}{2}$" nom. diam. welded steel pipe, double extra strong (ASA)
Finish all over. Press onto mold extension.

JP-1960

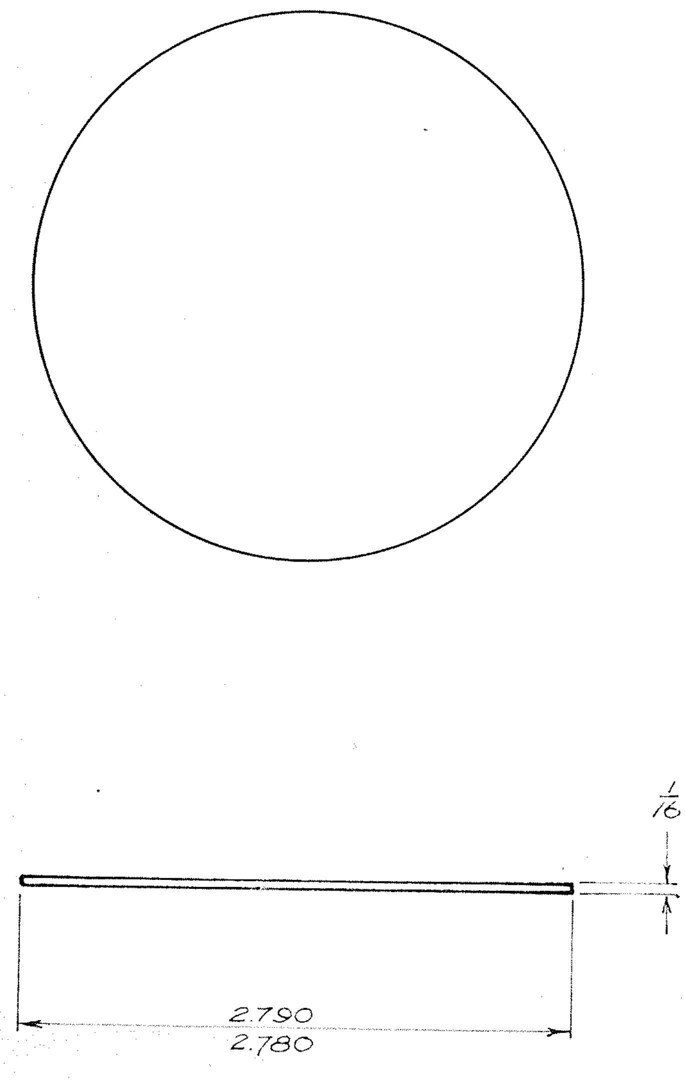


TOP PISTON - 1 Req'd. (Stl.)



BOTTOM PISTON - 1 Req'd. (Stl.)

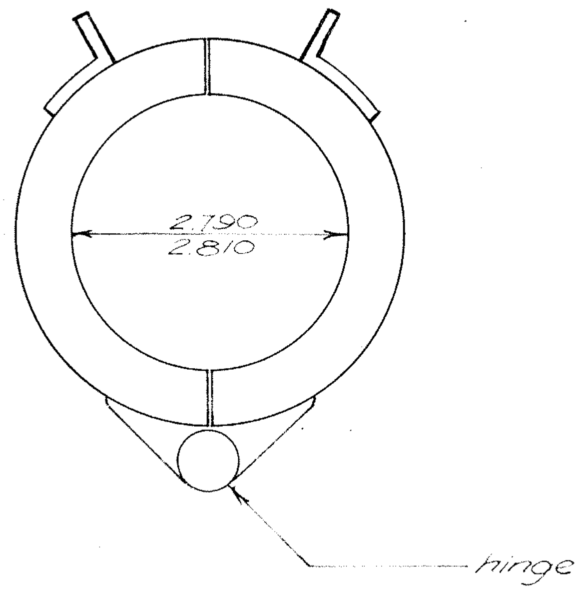
JP-1960

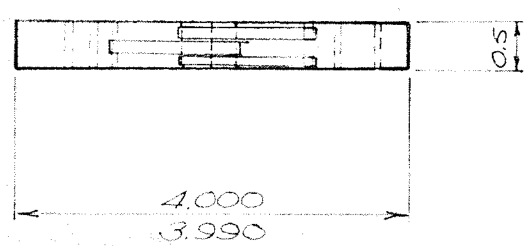


SEPARATING DISK - 8 Req'd.

(SCALE: FULL SIZE)

Machine from aluminum sheet stock



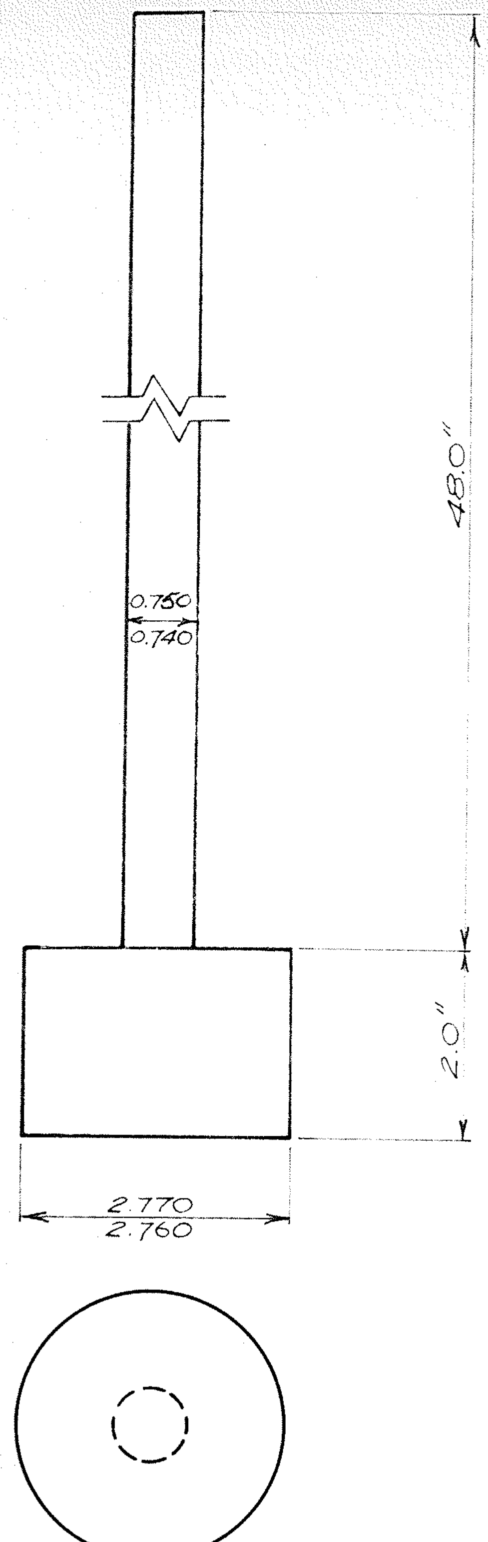


SPACER CLIP - 1 Req'd.

(SCALE: HALF SIZE)

Machine from $3\frac{1}{2}$" nom. diam. welded steel pipe, double extra strong (ASA)
Finish all over.

JP-1960

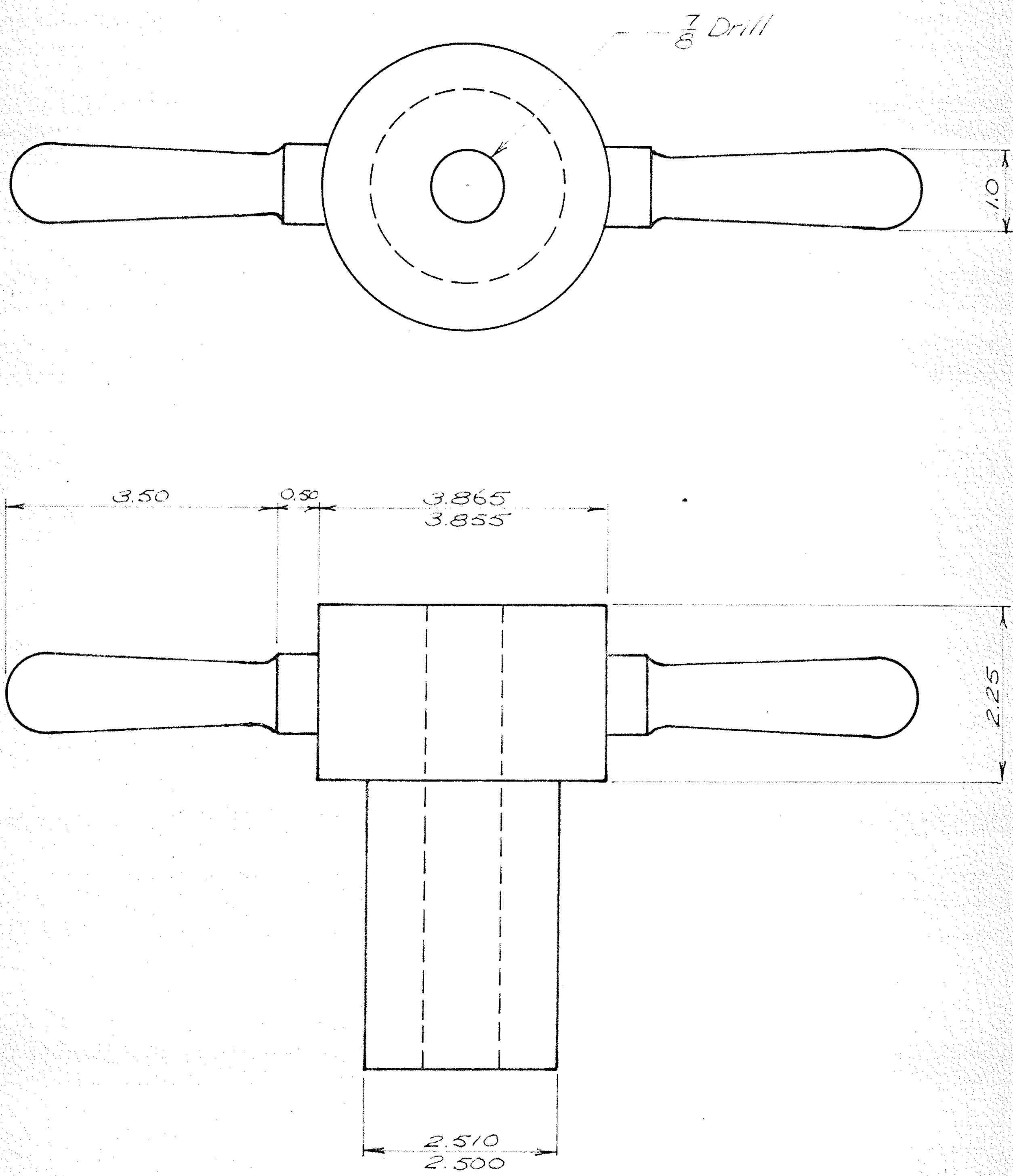


COMPACTION RAM - 1 Req'd. (St'l.)

(SCALE : HALF SIZE)

Groove shaft $\frac{1}{32}$" deep, 18" from top. Finish all over. Groove all round.

JP-1960

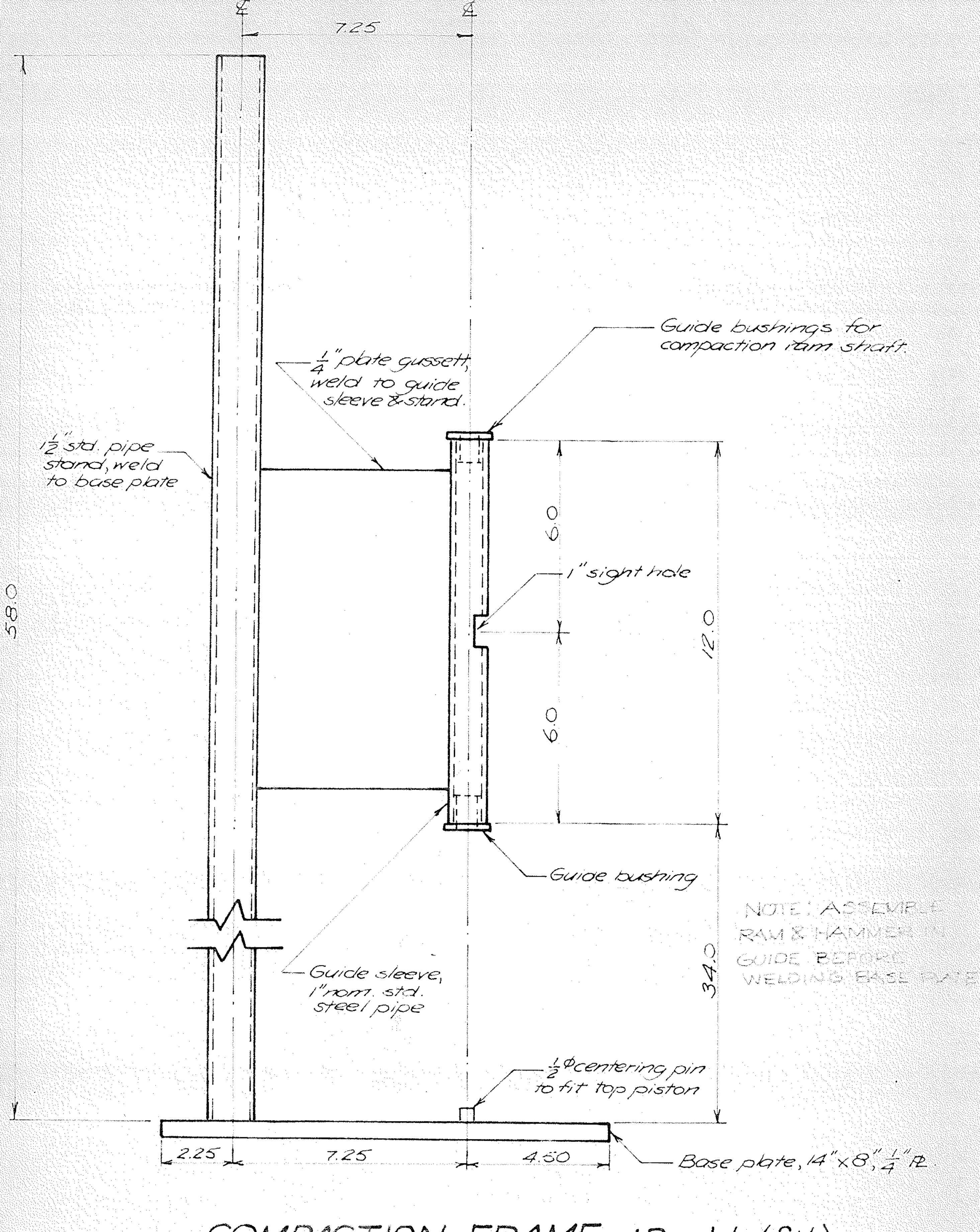


HAMMER - 1 Req'd. (Stl.)

(SCALE: HALF SIZE)

Finish all over.

JP-1960



COMPACTION FRAME - 1 Req'd. (Stl.)

(SCALE - QUARTER SIZE)

Grind welds to good appearance. Grey enamel all over except centering pin.

JP- 1960