25 March 1938

NRL Report No. M-1435

FR-1435

NAVY DEPARTMENT

BUREAU OF ENGINEERING

Report

on

Synthetic Bonded Steel Molding Sands.

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D.C.

Number of Pages: Text - 9 Tables - 4 Plates - 17

Authorization: BuEng. ltr. QP/Castings (6-19-Ds) of 13 July 1928.

Date of Test: 1 November 1937 to 1 March 1938.

Prepared by:

R. E. Morey, Contract Employee,
Sand Technologist.

Reviewed by:

C. W. Briggs, Metallurgist.

R. H. Canfield, Senior Physicist, Superintendent,
Division of Physical Metallurgy.

Approved by:

H. M. Cooley, Captain, USN, Director.

Distribution:
BuEng. (5)
BuC&R (5)

ejh

ABSTRACT

From a simple sand mix consisting of washed silica sand, bentonite and water it is possible to prepare synthetic green sands, synthetic dry sands, and air dried sands with excellent properties. The synthetic dry sand is prepared by merely oven drying the green sand. The addition of organic binders to green sand is also studied.

Table of Contents

Subject	Page
Abstract	
Authorization	1
Statement of Problem	1
Known Facts Bearing on the Problem	1
Methods Used in Testing	2
Test Results	
Green Sand	3
Dry Sand	5
Air Dried Sands	6
Cereal Binders in Synthetic Green Sands	8
Summary	9
Recommendations	9

Appendices

Distribution and Fineness Number of Washed Silica Sand	Table 1
Comparison of Hand Mixed and Mulled Sand-Bentonite-Moisture Mixes	2
Strengths of Binders in Synthetic Green Sand	3
Mold Hardness Produced by Various Binders in Green Sand	4
The Effect of Bentonite on the Properties of Silica Sand	Plate 1
The Effect of Moisture Content on the Properties of Silica Sand 4.5% Bentonite	2
The Effect of Moisture Content on the Properties of Silica Sand 2% Bentonite	3
The Effect of Moisture Content on the Properties of Silica Sand 3% Bentonite	4
The Effect of Moisture Content on the Properties of Silica Sand 7% Bentonite	5
The Effect of Moisture Content on the Properties of Silica Sand 10% Bentonite	6
Green Compression Strength of Synthetic Sand as a Junction of Moisture and Bentonite	7
Green Compression Strength of Synthetic Sand as a Junction of Moisture and Bentonite	8
The Effect of Moisture Content on the Properties of Silica Sand 4% Bentonite	9
Green Compressive Strength of Synthetic Sand as a Junction of Moisture Content	10
The Effect of Moisture on Dry Compression	11
The Effect of Moisture on Dry Compression	12

Table of Contents (Continued)

Composite Curves of Dry and Green Compression Strengths of Synthetic Sand .... Plate 13
Mold Hardness Obtained with Various Percentages of Moisture 14
Minimum Air Drying Time to Obtain Mold Hardness 15
Mold Hardness Obtained with Various Binders 16
The Effect of Substituting Organic Binder for Bentonite. 17

AUTHORIZATION

1. The studies in steel casting research were originally authorized by Bureau of Engineering letter QP/Castings (6-19-Ds) of 13 July 1928.

STATEMENT OF PROBLEM

2. The object of this report is to present information on the preparation of green and dry molding sands for the production of steel castings.

KNOWN FACTS BEARING ON THE PROBLEM

3. There are many kinds and varieties of steel molding sands being used by the industry today. The foundries operated by the Navy also use many varieties. These sands may be either natural bonded sands, semi-bonded sands, synthetic bonded sands, or mixtures of graded sands of any one of these. It may be seen that innumerable variations can thus be obtained. In one case it is known that there are six steel molding sands in a shop, which in turn are prepared into 15 different mixes.

4. It is not necessary to have a variety of sands in order to produce a large number of sand mixes. For example, one grade of silica sand could easily be made up into a large number of synthetic sand mixes if it were so desired, and such a condition has been observed in commercial practice.

5. If the number of sands could be reduced and the mixes simplified, greater care could be devoted to them with the result that a more scientific control would be maintained.

6. It is now fully appreciated by everyone connected with the manufacturing of castings that sand conditions may be responsible for a large proportion of defective castings. This realization has brought about the extensive use of sand control equipment in the foundry, such as sand reclaimers, mullers and the like. When sand is moved, reclaimed, milled, rebonded and transported back to the molding floor on a large scale plan, it is extremely difficult and economically unfeasible to have a number of sand mixes, each one requiring special attention. It is much more convenient to be able to shake out all sands at one place and maintain one backing sand that would have somewhat near the properties of the facing sand.

7. It would be extremely advantageous in a shop where both methods of molding are used if simplification could be carried to the point that both synthetic green sand and synthetic dry sand molds could be made from approximately the same sand mix.

8. The most simplified sand mix would consist of silica sand, water and a single bonding material. The question that now arises is -

would this simplified mix be the proper sand for dry sand practice as well as for green sand practice? Of course, there is the possibility that it may not fulfill the requirements of either process.

9. In a study of commercial sand mixtures for both the green and dry sand practice it has been noticed that there are numerous additions of cereal type binders to the mix. In some cases there are as many as three different types; that is, sugar products, cereal products, and resinous by-products that are incorporated in the mixture in addition to the clay.

10. The question has been asked on numerous occasions as to just what mold properties were benefited by the addition of the cereal type binders. The answers have been quite varied and seldom agree. After a compilation of these opinions, it was found that in the case of green sands the cereal type binders were believed to increase the compression strength and the shear strength; that they did not reduce the permeability or sintering point, and that they were responsible for castings with a much improved surface appearance. These remarkable conditions were thought, in some cases, to be contrary to what would normally be expected.

11. It was therefore plain that further experimentation was needed on the subject of the cereal type binders. Thus the objects of the work undertaken were:

(1) To prepare a simplified synthetic green sand.

(2) To prepare a simplified synthetic dry sand.

(3) To study the properties of green sands when various cereal type binders were incorporated in the mix.

METHODS USED IN TESTING

12. All sand testing methods used in this investigation are in accordance with the standards and tentative standards of the American Foundrymen's Association, as set forth in the March 1931 edition of Testing and Grading of Foundry Sands.

13. The sand used throughout most of the investigation was a washed silica sand with an A.F.A. grain fineness number of 63.2. The distribution of this sand is tabulated in Table 1.

14. Bentonite (90 per cent through 200 mesh) was used as the bonding material. All mixes are given in per cent by weight using the tempered sand as being equivalent to 100 per cent. The sand, as soon as it was mixed, was placed in moisture tight glass jars and allowed to temper for 24 hours before proceeding with the tests. In the preliminary test work it was found that there was very little change in the sand properties after tempering three hours, when bentonite is used as the sole binder. The longer time was selected as equilibrium conditions were thus assured.

15. Unfortunately, the Laboratory is not equipped with a laboratory muller so it was necessary to mix the sands, bond, and water by hand. This mixing and kneading was given careful attention. In order to establish a relation between the laboratory mixing and large scale mulling conditions, several different mixes were prepared with the only variable being the mixing or the mulling. An example of comparison of the variations that may exist is shown in Table 2. It will be observed that the differences obtained are small in nature.

16. The Dietert Mold Hardness Tester was used in determining the hardness of the test specimens.

TEST RESULTS

Green Sand

17. Starting out with the washed silica sand of an A.F.A. grain fineness number of 63.2 and a moisture content of 4 per cent, different percentages of bentonite were added varying from 1 to 10 per cent. The mixes were tested for permeability, green compression strength, and green shear strength. The values obtained are set forth in Plate 1. The permeability stays fairly constant over a wide variation in bentonite content. The compression strength increases as the bentonite content increases, and this is also true of the shear strength, but not to the same degree.

18. Continual work with these sands showed that the best molding conditions were obtained when the sand had a green compressive strength of from 4 to 6 pounds per square inch. Figure 1 shows that this condition can be attained by bentonite additions of 3.5 to 5.5 per cent when a moisture content of 4 per cent is used.

19. The moisture content, however, has a very important effect on the strength of a sand-bentonite-water mixture. Plate 2 portrays the properties that may be obtained by varying the water content from 1 to 10 per cent when the bentonite content remains fixed at 4.5 per cent. It may be seen that the moisture content has a marked effect on the green compression strength.

20. In the case of moisture ranging from 5 to 10 per cent, however, the compression strength is nearly constant. Above 10 per cent, the strength gradually decreases. On decreasing the moisture below 5 per cent, the green compression strength increases rapidly until it reaches a maximum. At this point, however, the sand is too dry to handle readily.

21. The optimum moisture content of a sand has been described in various ways. It has been referred to as the water content at which the loose apparent density of the sand is at a minimum[1]. In some cases

(1) H. Dietert, "The Control of Hardness and Other Mold Properties," Trans. A.F.A. 1932, p. 70.

it has been spoken of as the water content at which the best mechanical properties may be obtained. Since there appears to be some doubt as to just what the proper definition may be, it is considered to be, in this work, as the water content at which the apparent density of rammed sand is at a minimum. This was done by recording the weight of the standard A.F.A. permeability specimen exactly two inches in height as shown by the limits gauge on the rammer after the usual three rams. Since the volume is constant, the weight of the specimen can be plotted directly or it may be plotted as an apparent density by dividing the sand weight in grams by 103.0 cc, which is the volume of the specimen.

22. On Plate 2 is plotted the weight of the sand bonded with 4.5 per cent bentonite and with varying moisture content. A very interesting observation is that the minimum point comes at the point of maximum permeability. Since this condition was found to be true in other cases (Figures 3, 4, 5, and 6), it may be considered as a convenience that the optimum moisture content is represented by the point of maximum permeability.

23. The permeability curve as illustrated in Plate 2 reaches a maximum of 163 at 2.1 per cent moisture. With a further increase of moisture, the permeability decreases.

24. Additional curves (Plates 3, 4, 5, and 6) have been constructed from the results obtained by studying 2, 3, 7, and 10 per cent bentonite mixtures with varying moisture contents. These graphs, along with that of Plate 2, present a fairly complete picture of the silica-bentonite-moisture series of a synthetically bonded washed and graded silica sand of 63.2 fineness number.

25. From this series of graphs the green compression strength curves are plotted on one composite graph (Plate 7). Additional curves for compression strength may be plotted by interpolation of the experimental data, as is illustrated in Plate 8. The optimum moisture content curve has also been plotted on Plates 7 and 8 from the experimental data.

26. Synthetic bonded green sands consisting of bentonite-moisture-silica sand should be mixed with a higher moisture content than that recorded by the optimum moisture content curve in order to counteract the drying out tendency that takes place after mixing or mulling. For this reason, an additional curve is shown and called the "green sand moisture content." This curve should be used as a basis for the moisture addition when using a similar sand distribution.

27. The composite green compression strength chart (Plate 8) can be used in preparing a green sand with any desired green compression strength, by merely deciding upon some value of green compression strength and by drawing a horizontal line to the "green sand moisture curve." The bentonite content may then be obtained by interpolation from the two nearest strength curves and the moisture content may be read on the horizontal scale. It should, of course, be mentioned again that the

curves will refer only to the particular sand studied. However, charts of this nature can be constructed by any foundry with the usual sand testing equipment.

28. In order that the differences in sand properties may be observed, resulting from a change in sands, a study was made of washed silica sand of an A.F.A. grain fineness of 52.9. The sieve distribution of this sand is shown in Table 1.

29. A series of graphs showing the effects of increasing bentonite on the permeability and green compression strength were prepared, similar to that of Plate 9. A comparison of Plates 2 and 9 will show the changes which developed in the sand properties by decreasing the grain fineness number. The permeability increases and the green compression strength decreases in going from a No. 63 to a No. 53 sand.

30. Plate 10 is a composite graph constructed similar to that of Plate 8. In general, it may be said that the smaller grain size exhibits the greatest green compression strength for the same moisture content and bentonite content. Also, the curves have a slightly different trend and the optimum moisture curve is more curved in the finer sand.

31. It may be seen from the above data that practically any type of green sand necessary may be obtained by varying the fineness of the washed silica sand or the contents of bentonite or water. Also wide variations may be obtained in compression strength and permeability of a sand, by making variations in the bentonite content or the moisture content.

32. Only on Plate 1 was data plotted to show the green shear strength. It was found that in general, when using the washed silica sand-bentonite-water mixtures, the green shear strength is approximately 30 per cent of the green compression strength.

Dry Sand

33. It was planned to study the dry sand properties of the green sand mixtures so that if it were found desirable to use the dry sand practice, it could be accomplished without changing to a different sand or mix.

34. In this study, the washed silica sand having a fineness number of 63.2 was used, with bentonite as a bonding material. The sands mixtures were oven dried at 400 degrees F. The bentonite contents selected for study were 4 and 8 per cent with 3, 6, 9, and 12 per cent moisture. The results obtained are plotted on Plates 11 and 12. Values obtained in the green condition are also plotted for comparison. It may be readily seen that the dry strength increases with increase in water content, while maintaining the bentonite content constant. From

the dry compression strength curves it was determined that with

	4% Bentonite	8% Bentonite
50 pounds per square inch will be produced by	1.83% H_2O	2.92% H_2O
100 pounds per square inch will be produced by	5.92% H_2O	4.57% H_2O
150 pounds per square inch will be produced by	8.65% H_2O	6.20% H_2O
200 pounds per square inch will be produced by	11.40% H_2O	7.77% H_2O

These strength-moisture relations were plotted on the graph of Plate 8, so that the fundamental relationship between dry compression strength, green compression strength, moisture and bentonite could be illustrated. It is interesting to note that in mixtures with less than 3 per cent water, an increase in bentonite will not only decrease the dry compression strength, but increase the green compression strength.

35. From Plate 13 it may be seen that a dry sand of any desired property may be obtained. The dry strength desired should be decided upon first. It is evident that several percentages of bentonite will produce the desired dry compression strength, but some point on the dry compression strength line should be selected where the bentonite, moisture, and green strength have suitable values. By this it is meant that the bentonite content should not be too high or the mix will be sticky and expensive; the water content should not be too high or the mix will be low in flowability and green strength, and will take a long time to dry; also, the green compression strength should be such that the sand is workable in the green state.

36. It is believed, however, from the above data, that a suitable dry sand can be produced from the synthetic green sand that is in use by increasing the moisture content when the sand is being mulled. Thus a simplified procedure has been established for the preparation of dry sand molds by the use of a simplified synthetic green sand.

Air Dried Sands

37. The drying of green sand molds in air is a method of production that is used somewhat extensively, although the properties of air dried mold are not so well known. Air drying may in many cases be substituted for oven drying and produce even better results, providing it is not necessary to obtain the high strengths that are associated with dry sand molds. Air drying takes from one to four hours, while oven drying usually takes three to twelve hours.

38. In both dry sand molds and air dried sand molds, the moisture at the mold face is very low when the molds are poured, so there is practically no steam generated for perhaps the first two minutes. By the time the heat penetrates far enough into the mold to produce steam, the initial skin formation of the metal(1) will be sufficient to resist

(1) C. Briggs and R. Gezelius, "Studies in Solidification and Contraction in Steel Castings III - The Rate of Skin Formation," Trans. A.F.A., Feb. 1936, p. 274.

the back pressure of the steam, providing the mold has some reasonable measure of permeability.

39. Resistance to contraction, of course, is not as great in air dried molds as in oven dried molds. Also, it is much easier to remove and clean castings from air dried molds.

40. When properly made, air dried molds have a smooth hard surface, free from checks and cracks. When the molds are closed they will fit tightly and prevent the occurrence of fins, which are so common in oven dried molds.

41. The rate of air drying depends upon the time, temperature, humidity, air circulation, moisture content, permeability, size of the mold, and fineness of the sand. Of these variables, the drying time and the moisture content are the most effective in controlling the mold surface.

42. In Plate 14 the results are shown of mold hardness tests made on four mixtures of synthetic sands containing 4 per cent bentonite and 2, 4, 6, and 8 per cent water. The sand containing 2 per cent moisture was much too dry to develop a good hardness on air drying. In regard to the 4, 6, and 8 per cent moisture content, it may be seen that the higher the moisture content, the slower is the development of the mold hardness, but that eventually (2 to 5 days) a higher ultimate hardness is obtained. Thus if fast air drying is necessary, the 4 per cent moisture mix should be the one adopted, whereas if the molds will remain open for more than a day or two, the higher moisture contents may prove the most satisfactory.

43. From the data of Plate 14, the curves of Plate 15 were constructed. This graph shows the time and moisture content necessary to obtain a given hardness when a washed silica sand of a fineness number of 63.2 was used, bonded with 4 per cent bentonite. It will be observed that for any given hardness there is a minimum time in which it may be produced, and a definite moisture content which must be used. These combinations locate the moisture content line.

44. Very often other materials are mixed with the sand to speed up the drying process. In Plate 16 there is shown the effect of substituting 1 per cent of organic binder for 1 per cent of bentonite. The moisture content was maintained at 4 per cent. The addition of the cereal type binders produced greater hardnesses and produced these hardnesses sooner than was obtained in the straight bentonite mix.

45. The value of these organic binders is somewhat doubtful, for in the first place air dried molds usually stay open for three or four hours and in many cases longer; thus the increase of 3 to 5 points in hardness that can be obtained by using the organic binders may be of actually little commercial value. It is difficult to prove this point, as the writer knows of no test that correlates mold hardness with

its ability to resist erosion or spalling by the action of the molten metal. Some preliminary experiments have been performed at this Laboratory which show that cereal binders do produce large quantities of gas when brought in contact with molten metal; thus sands must be considerably more permeable to prevent pinhole porosity.

46. The green compression strength of sands containing cereal binders is reduced, and the presence of the organic binders makes the sand sticky, allowing it to adhere to the patterns so that the mold surface is not as smooth as when bentonite is used alone.

47. It is thus felt that it is not necessary to complicate the green sand mix by the addition of cereal binders to increase the mold hardness of air-dried sand molds.

Cereal Binders in Synthetic Green Sands.

48. It has been stated previously that a large number of commercial green sand mixes contain one or more of the cereal type binders in addition to clay or bentonite. There also appears to be some doubt as to the result of their effect on the properties of green sand. This latter point was studied in regard to an A.F.A. No. 63.2 fineness washed silica sand.

49. Cereal type binders fall into three classes: cereal or sugar by-products, the resinous or lignone by-products, and the drying oils. Representative binders of all these classes were studied.

50. In an effort to ascertain the actual properties imparted to a synthetic green sand by these materials, batches were mixed containing 4 per cent of the various binders with 3 per cent water and washed silica sand of fineness No. 63. These mixes were tested for green permeability, green compression strength, and green shear strength. The results obtained from testing are set forth in Table 3. It is interesting to note that the green strength of bentonite far exceeds that of any other binder. In the permeability test the bentonite is exceeded only by Mogul. The strength of Mogul, however, was so low that it fell to pieces before it could be tested for compression strength. Bentonite may be said to have the highest permeability of any workable binder tested.

51. In order to ascertain if there were any advantages in combining the binders with bentonite, several mixes were made of various binders with bentonite at a moisture content of 3 per cent. These results are illustrated in Plate 17. On the left ordinate is plotted the strength of the 4 per cent bentonite mix without additional binders. The right ordinate shows the green compressive strength of the various binders without bentonite. The dotted line is the green compressive strength resulting from sand-bentonite-3 per cent water mixes in which bentonite varied from 0 per cent to 4 per cent.

52. In every case the green compression strength decreases as the organic binders are substituted partially or wholly for bentonite.

In the case of the resinous or soluble binders, the strength of the bentonite and organic binder combined is even less than the strength of the bentonite portion of the binder would produce by itself. This means that the soluble organic binder not only does not produce any green strength, but it actually decreases the strength that the bentonite would produce.

53. It has been previously stated that organic binders do not improve the mold surface. In most cases, because of their slightly sticky characteristics, they adhere to the pattern.

54. Four mixes were tested for green sand mold hardness (Table 4). Sand bonded with bentonite had in all cases the greater hardness. The substitution of 1 per cent of Bindex, a soluble binder, for 1 per cent of bentonite reduced the mold hardness 50 per cent.

55. The above results tend to indicate that the organic binders have little, if any, beneficial effect upon the properties of synthetic green sand. As a class, they do not increase the green permeability, green compression and shear strengths, or green mold hardness; neither do they improve the workability of the sand or surface finish of the mold. Therefore, it appears that their presence in a green synthetic sand mix is not necessary, for they only complicate the mix.

SUMMARY

56. From a simple sand mix consisting of washed silica sand, bentonite and water, it is possible to prepare synthetic green sands, synthetic dry sands and air dried sands with excellent properties. The synthetic dry sand is prepared by merely oven drying the green sand.

RECOMMENDATIONS

57. It is recommended that the steel foundries operated by the Navy consider the possible adoption of synthetic sands of the simplified sand-bentonite-water mix.

Table 1

Distribution and Fineness Number of
Washed Silica Sand.

Sieve No. U.S. Standard	Per Cent	Retained
6	0	0
12	0	0
20	0.04	0.30
30	0.26	0.94
40	2.72	3.90
50	12.50	14.74
70	38.44	54.90
100	31.78	23.32
140	11.54	1.40
200	2.22	0.10
270	0.30	0.02
Pan	0.22	0.04
A.F.A. Grain Fineness Number	63.2	52.9

Table 2

Comparison of Hand Mixed and Mulled
Sand-Bentonite-Moisture Mixes.

Mixing Method	Moisture	Bentonite	Permeability No.	Green Compression Lbs./Sq.In.
Hand(1)	4.0%	5.0%	122	5.52
Mulled(2)	4.1%	5.0%	106	5.65

(1) Sand and bentonite mixed dry and water added. Mixed by rubbing between palms of hands for five minutes. Tempered 24 hours and tested.

(2) Mixed dry for 30 seconds. Water added and mulled for five minutes and tested.

Table 3

Strengths of Binders in
Synthetic Green Sand.

Binder	Green Permeability	Green Compression	Green Shear
Bentonite	128	4.67	1.29
Dextrin	90	2.50	0.80
Truline	91	1.78	0.62
Kordek	95	0.90	0.35
Liquid Bindex	127	0.71	0.31
Glutrin	121	0.65	0.30
Bindex	114	0.64	0.28
Goulac	126	0.61	0.28
Mogul	185	Very low	Very low
Core oil	85	0.33	Very low
Linseed	67	0.22	Very low

Binder 4%

Water 3%

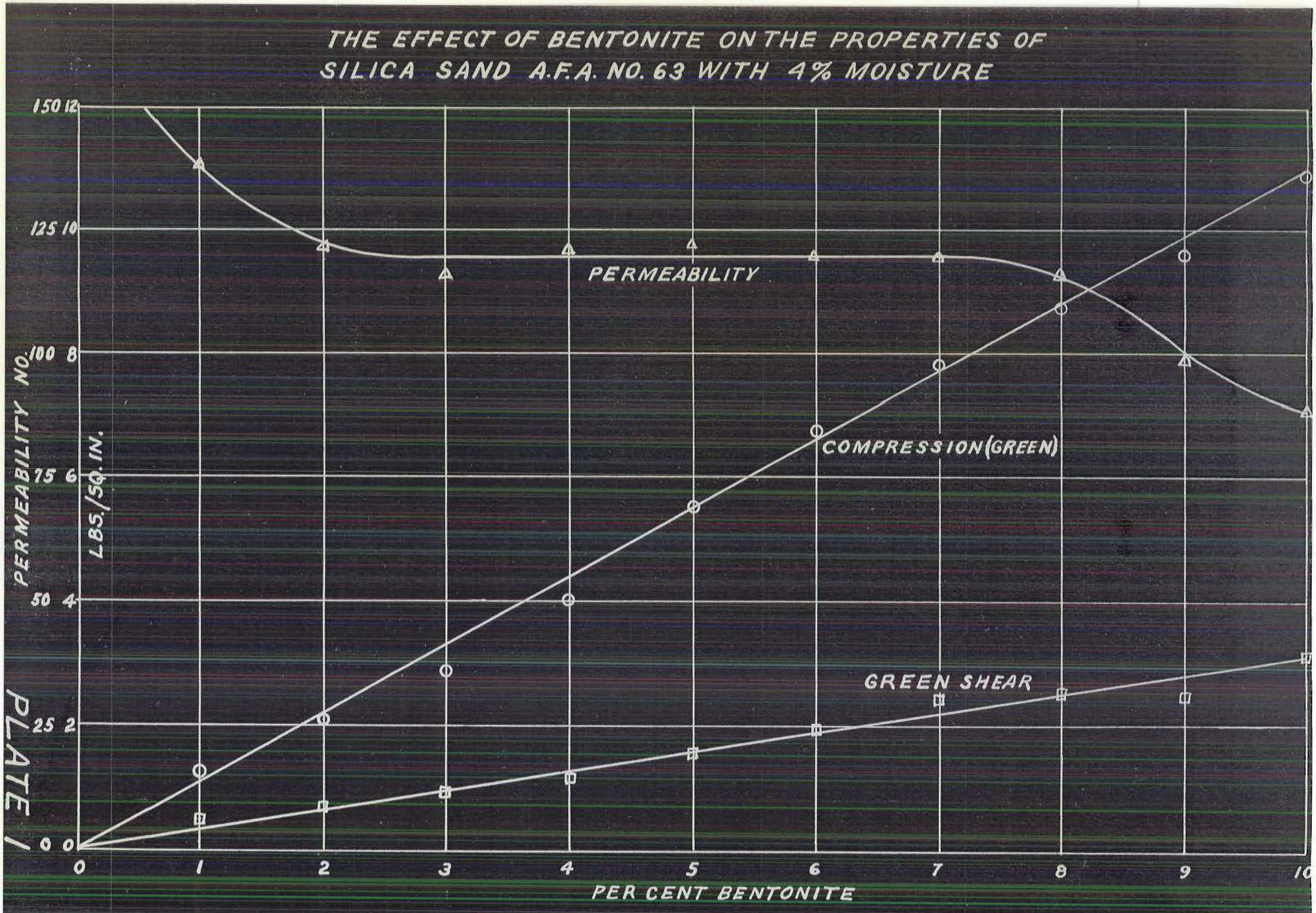
Silica sand (fineness 63.2)

Table 4

Mold Hardness Produced by Various
Binders in Green Sand.

Bentonite	Other Binder	Water	Mold Hardness
4%	None	3%	61.3
3%	Dextrin 1%	3%	60.9
3%	Kordek 1%	3%	60.7
3%	Bindex 1%	3%	30.8

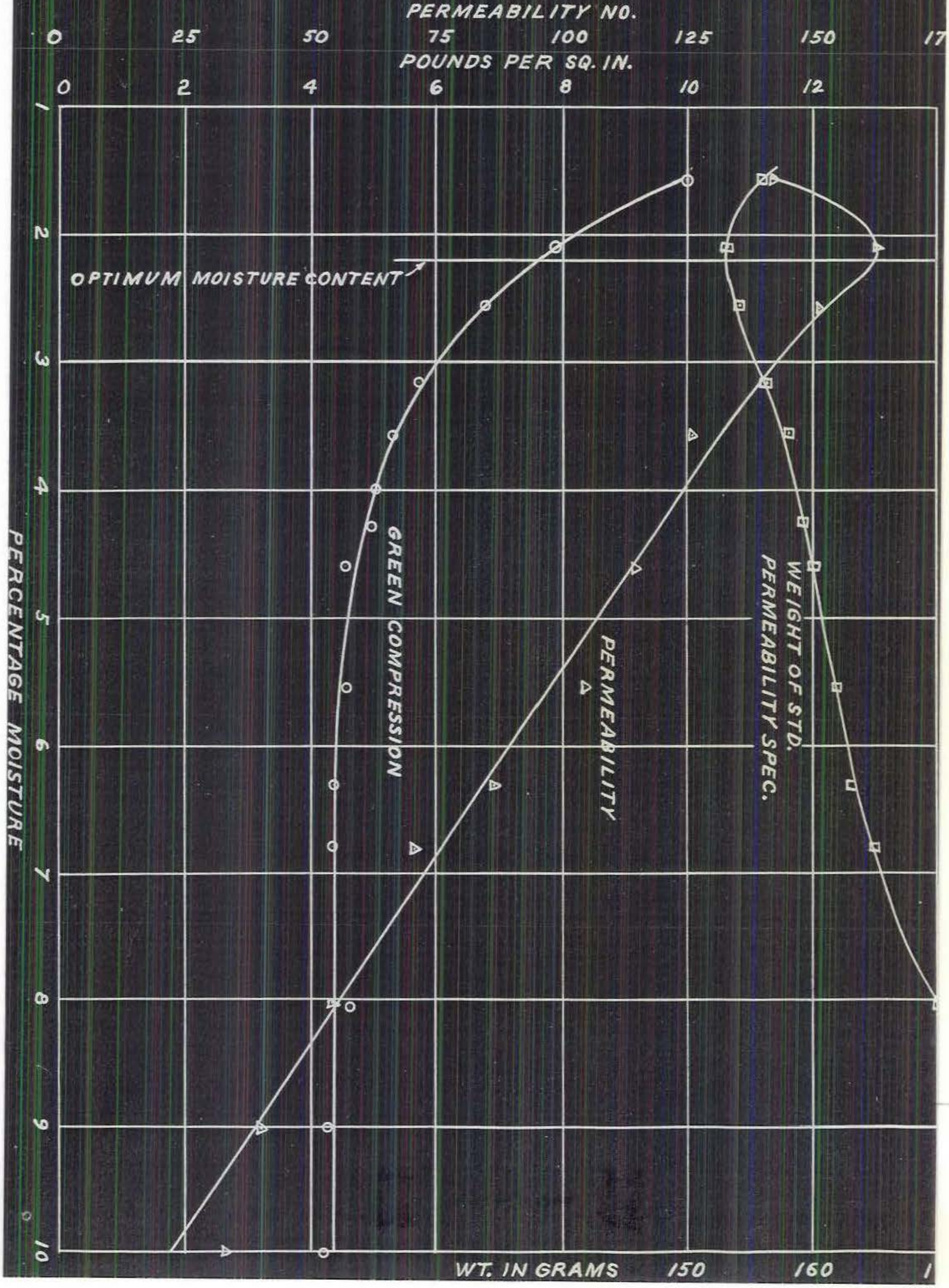
Silica sand, fineness 63.2.



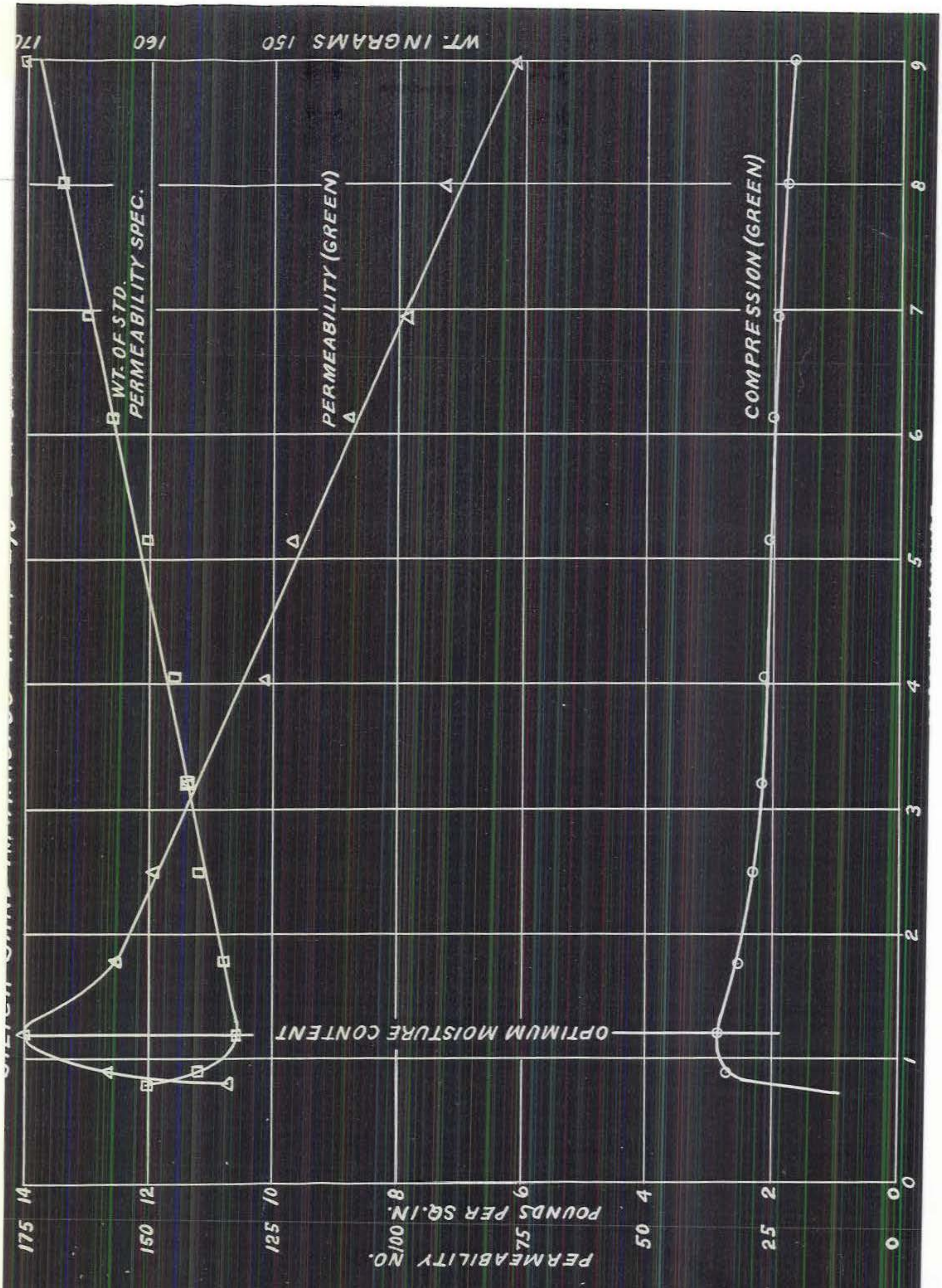
THE EFFECT OF BENTONITE ON THE PROPERTIES OF
SILICA SAND A.F.A. NO. 63 WITH 4% MOISTURE
PERMEABILITY NO.
LBS./SQ. IN.
150 12
125 10
100 8
75 6
50 4
25 2
0 0
PERMEABILITY
COMPRESSION (GREEN)
GREEN SHEAR
0
1
2
3
4
5
6
7
8
9
10
PER CENT BENTONITE

PLATE I

PLATE 2



PERMEABILITY NO.
0 25 50 75 100 125 150 17
POUNDS PER SQ. IN.
0 2 4 6 8 10 12
OPTIMUM MOISTURE CONTENT
GREEN COMPRESSION
PERMEABILITY
WEIGHT OF STD. PERMEABILITY SPEC.
PERCENTAGE MOISTURE
1 2 3 4 5 6 7 8 9 10
WT. IN GRAMS 150 160 1



WT. IN GRAMS
150
160
170
WT. OF STD.
PERMEABILITY SPEC.
PERMEABILITY (GREEN)
COMPRESSION (GREEN)
OPTIMUM MOISTURE CONTENT
POUNDS PER SQ. IN.
PERMEABILITY NO.
0 25 50 75 100 125 150 175
0 2 4 6 8 10 12 14
0 1 2 3 4 5 6 7 8 9

PLATE 3

THE EFFECT OF MOISTURE CONTENT ON THE PROPERTIES
OF SILICA SAND A.F.A. NO.63 WITH 3% BENTONITE

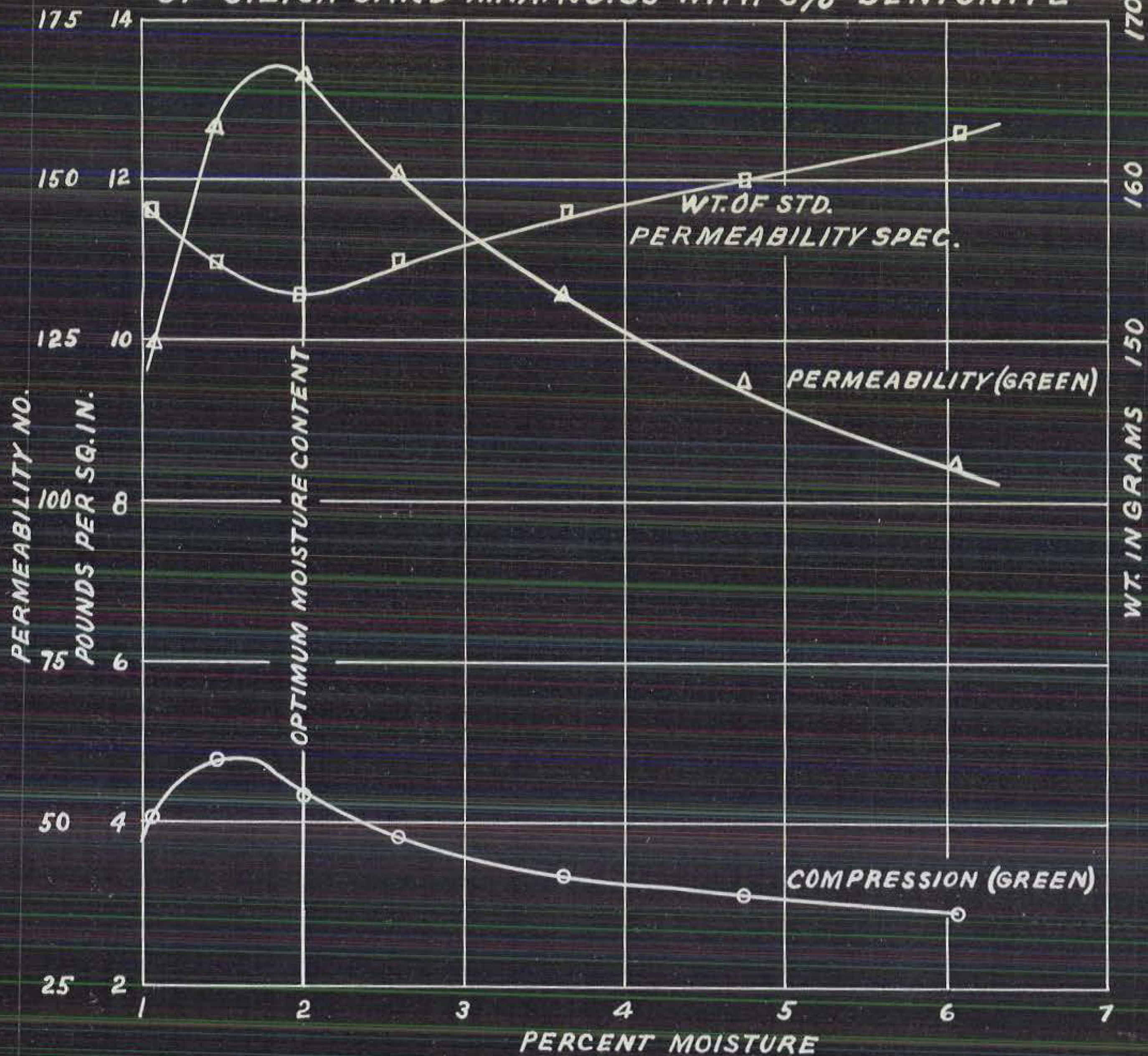


PLATE 4

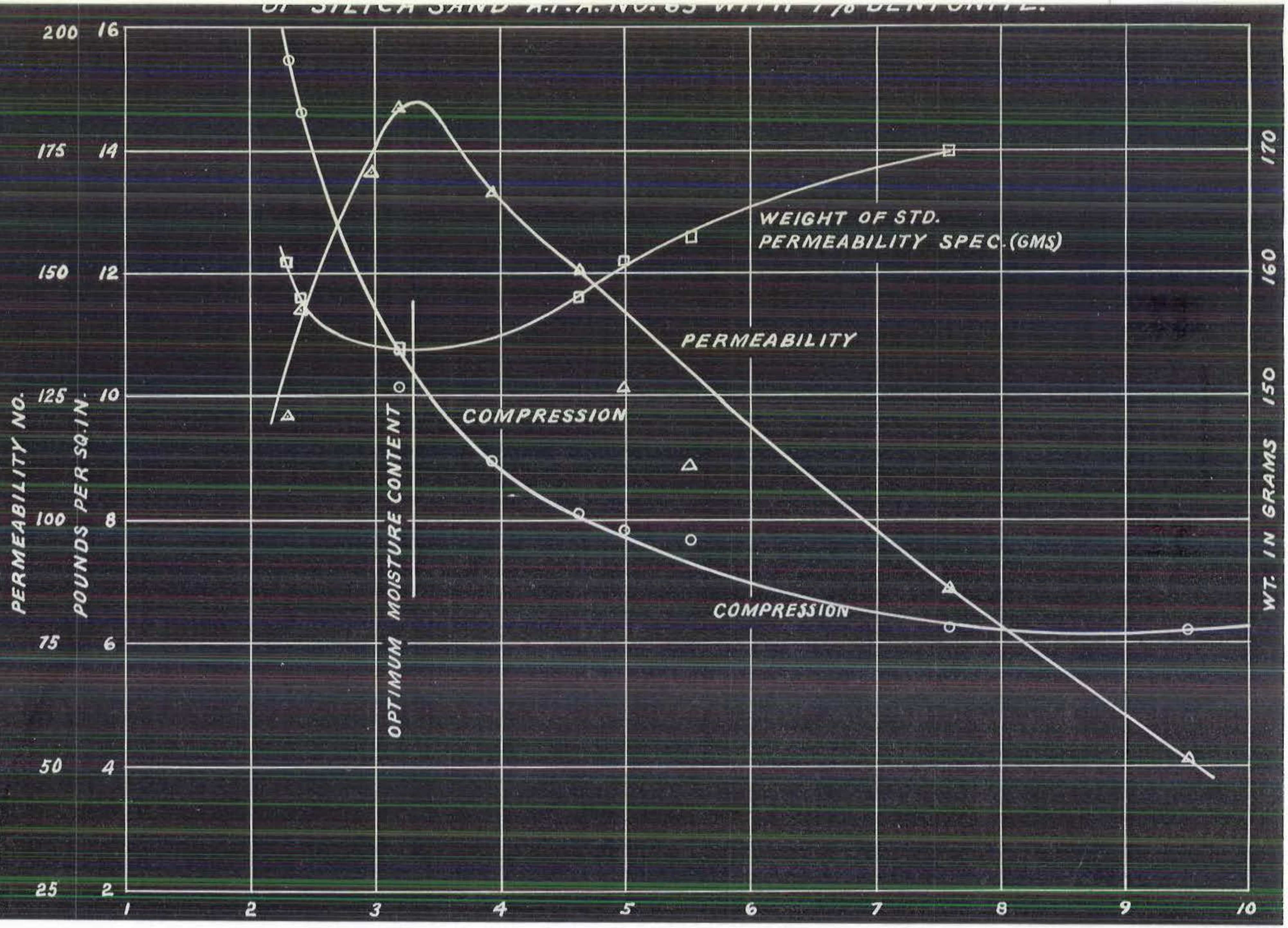

WEIGHT OF STD.
PERMEABILITY SPEC. (GMS)
PERMEABILITY
COMPRESSION
COMPRESSION
OPTIMUM MOISTURE CONTENT
PERMEABILITY NO.
POUNDS PER SQ. IN.
WT. IN GRAMS
200 175 150 125 100 75 50 25
16 14 12 10 8 6 4 2
170 160 150
1 2 3 4 5 6 7 8 9 10

PLATE 5

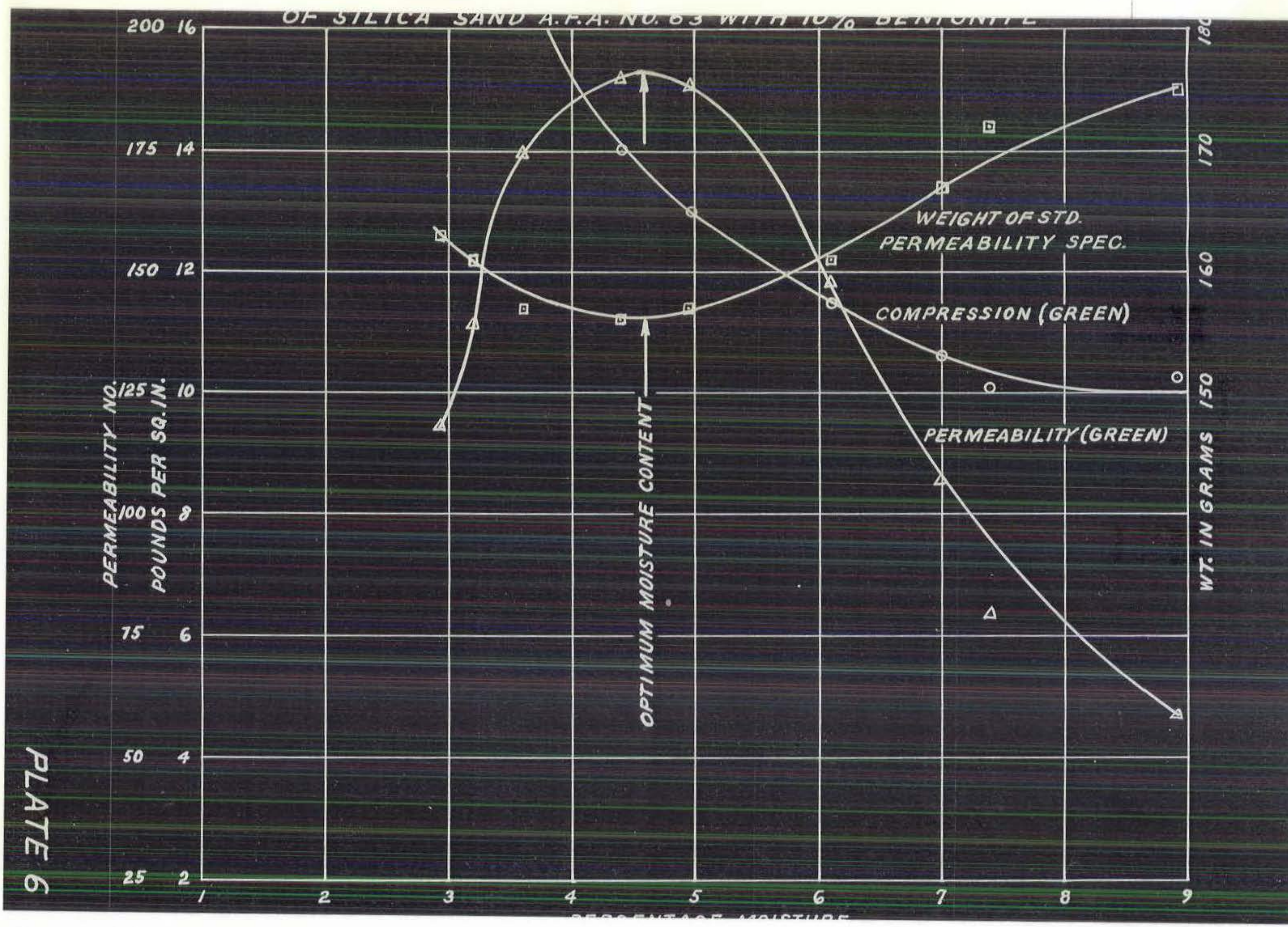

OF SILICA SAND A.F.A. NO. 63 WITH 10% BENTONITE
200 16
175 14
150 12
125 10
100 8
75 6
50 4
25 2
PERMEABILITY NO.
POUNDS PER SQ. IN.
1 2 3 4 5 6 7 8 9
180 170 160 150
WT. IN GRAMS
WEIGHT OF STD.
PERMEABILITY SPEC.
COMPRESSION (GREEN)
PERMEABILITY (GREEN)
OPTIMUM MOISTURE CONTENT

PLATE 6

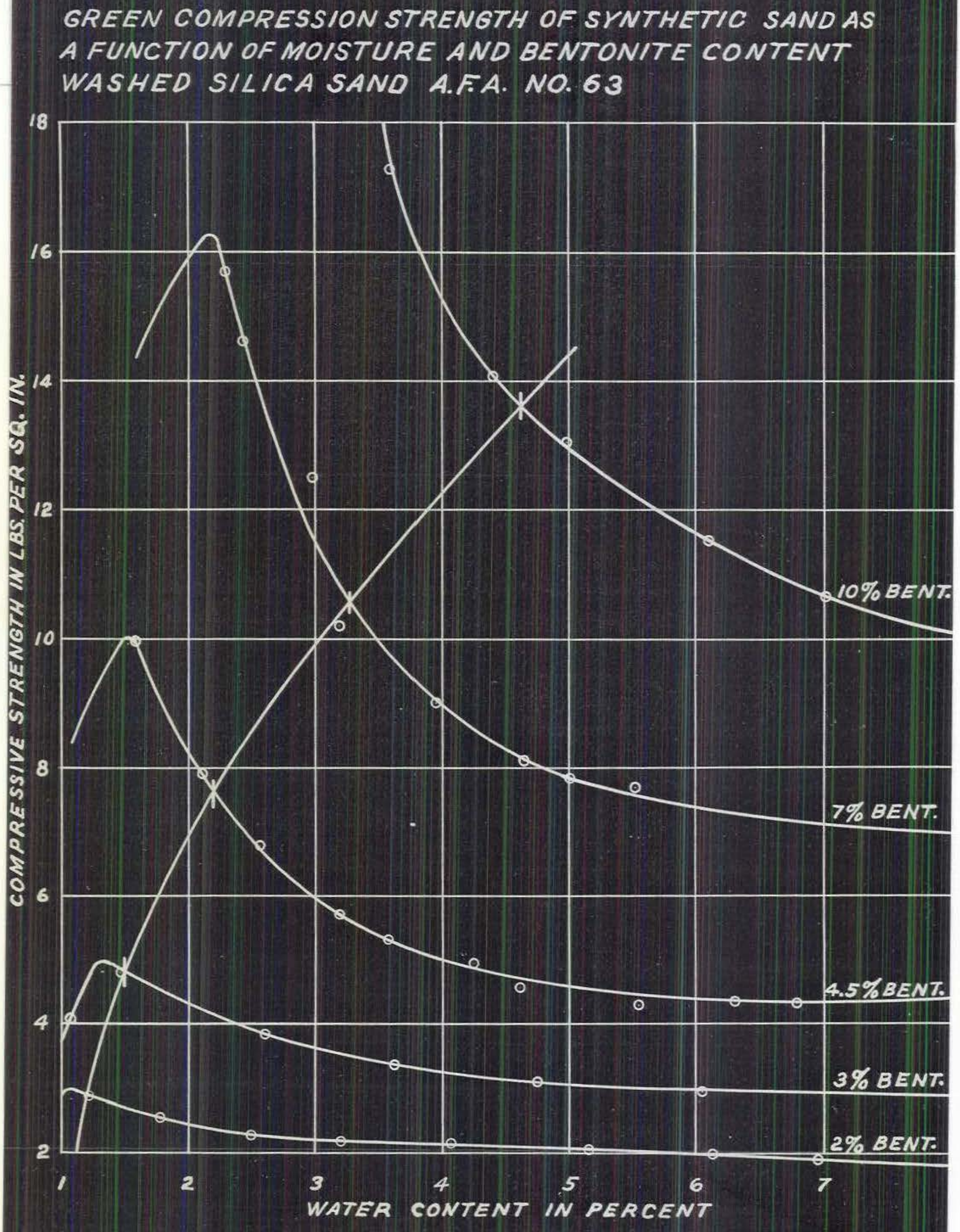

GREEN COMPRESSION STRENGTH OF SYNTHETIC SAND AS A FUNCTION OF MOISTURE AND BENTONITE CONTENT WASHED SILICA SAND A.F.A. NO. 63
COMPRESSIVE STRENGTH IN LBS. PER SQ. IN.
18
16
14
12
10
8
6
4
2
1
2
3
4
5
6
7
WATER CONTENT IN PERCENT
10% BENT.
7% BENT.
4.5% BENT.
3% BENT.
2% BENT.

PLATE 7

GREEN COMPRESSIVE STRENGTH OF SYNTHETIC SAND AS A FUNCTION OF MOISTURE AND BENTONITE CONTENT WASHED SILICA SAND A.F.A. NO. 63

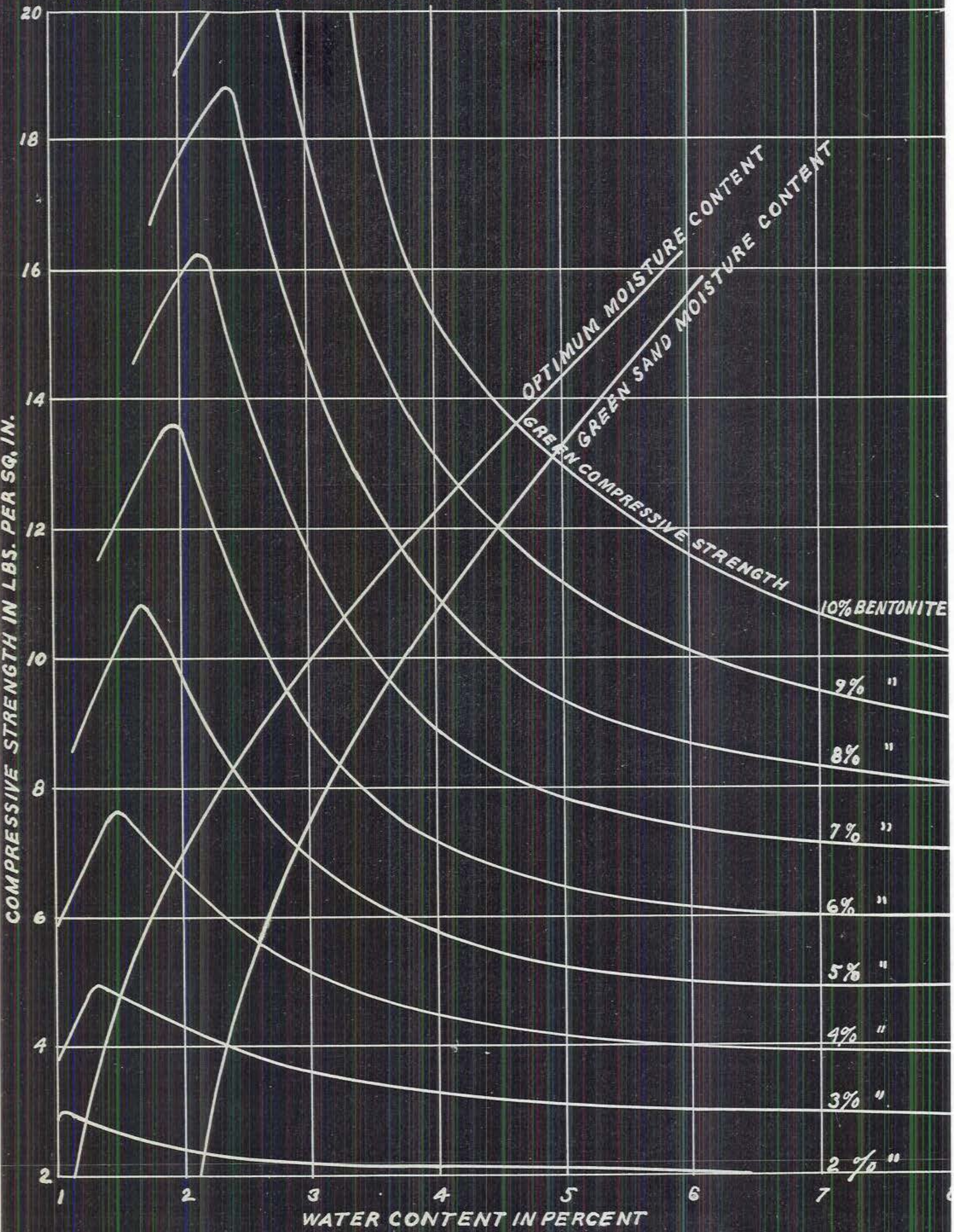


PLATE 8

THE EFFECT OF MOISTURE CONTENT ON THE PROPERTIES OF SILICA SAND A.F.A. NO. 53 WITH 4% BENTONITE

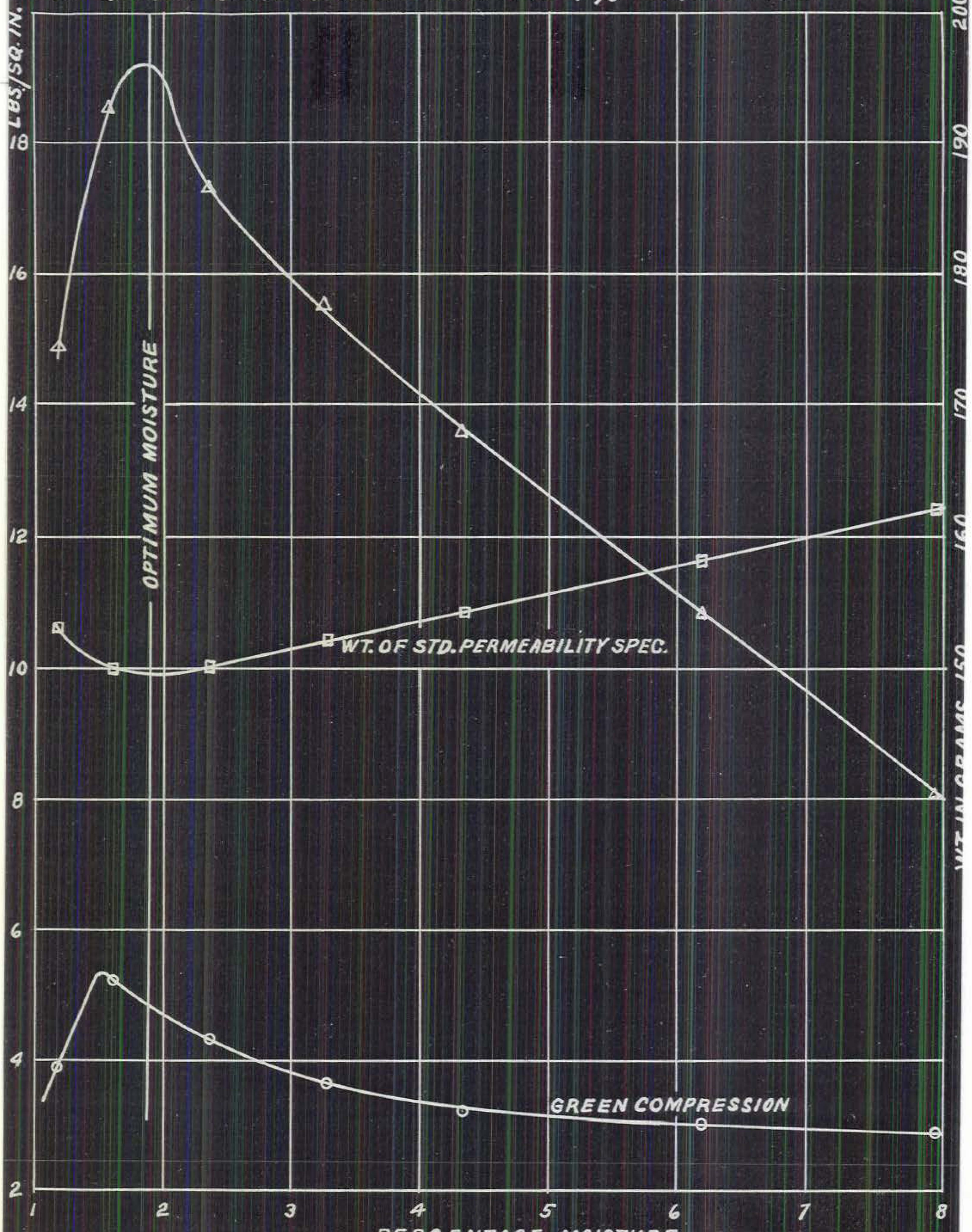


PLATE 9

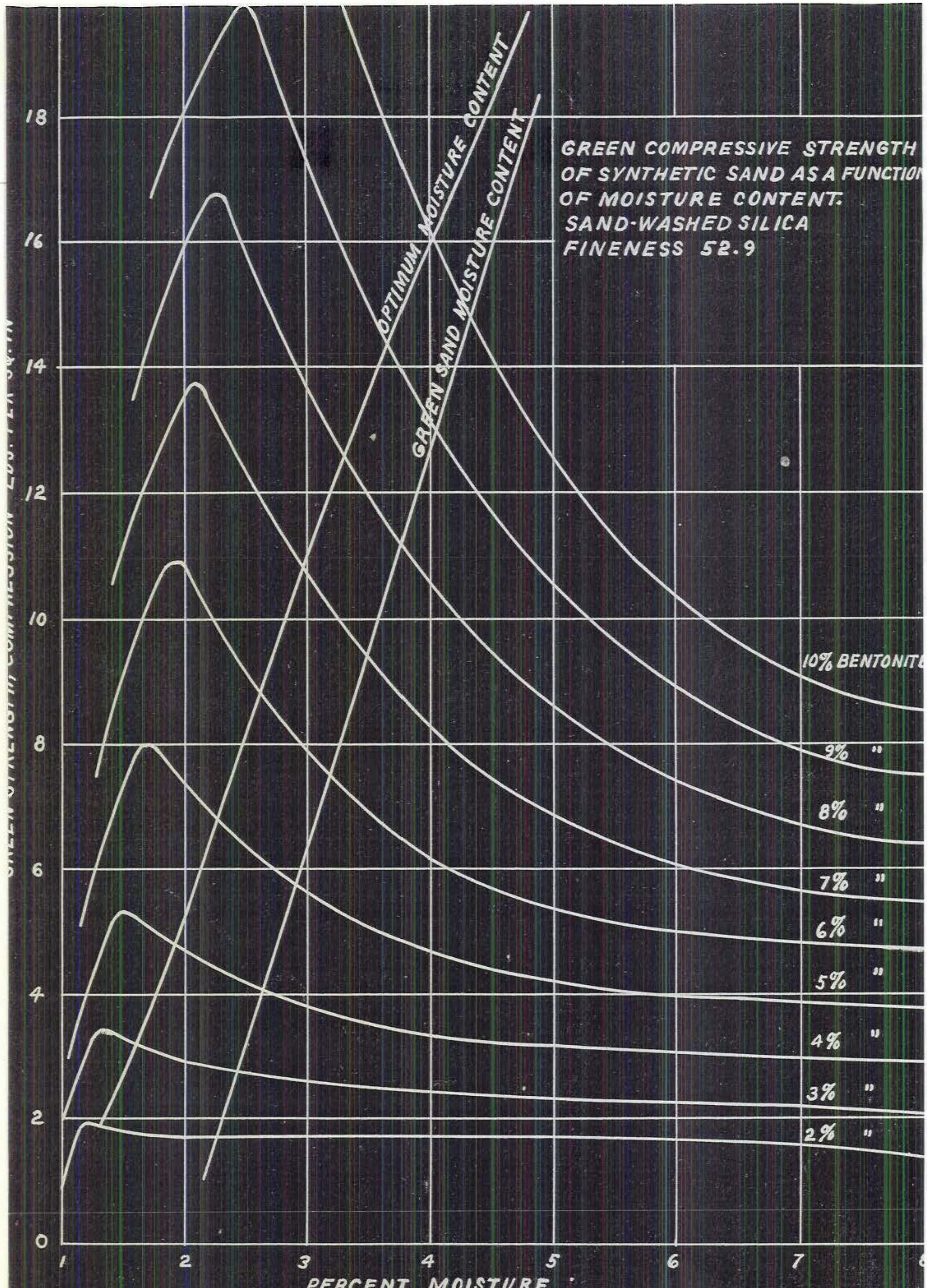

GREEN COMPRESSIVE STRENGTH
OF SYNTHETIC SAND AS A FUNCTION
OF MOISTURE CONTENT.
SAND-WASHED SILICA
FINENESS 52.9
OPTIMUM MOISTURE CONTENT
GREEN SAND MOISTURE CONTENT
10% BENTONITE
9% "
8% "
7% "
6% "
5% "
4% "
3% "
2% "
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
PERCENT MOISTURE

PLATE 10

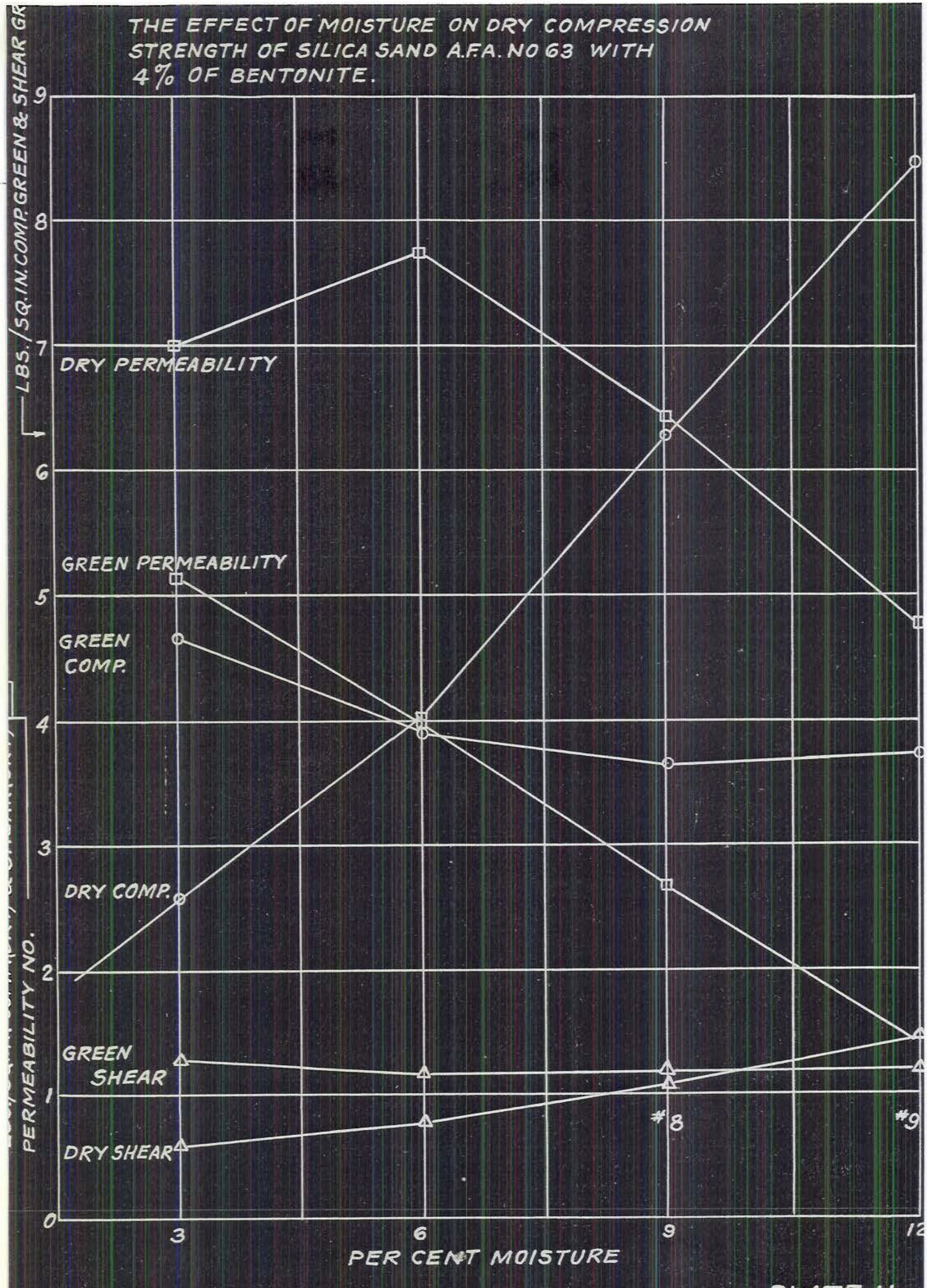
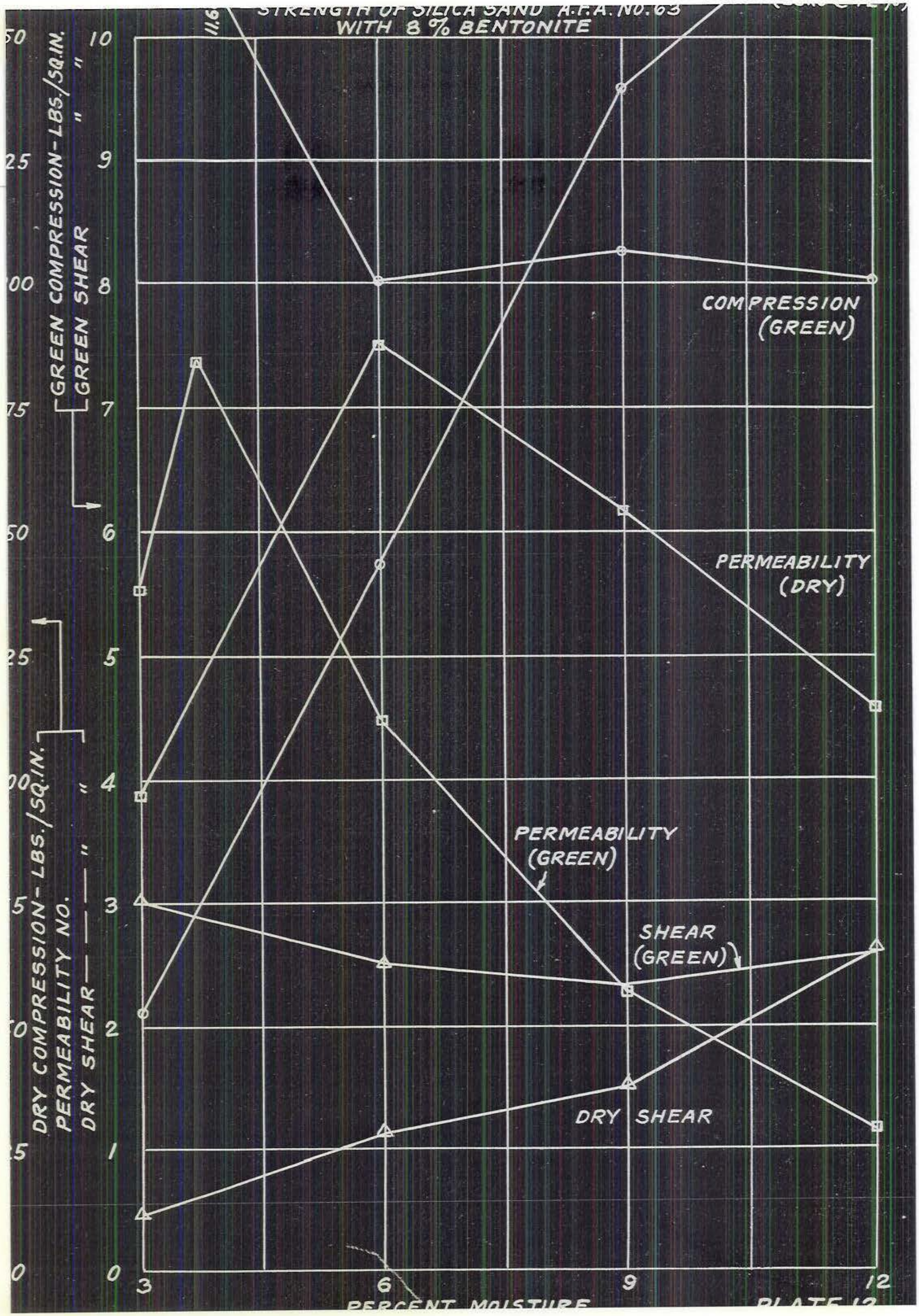

THE EFFECT OF MOISTURE ON DRY COMPRESSION STRENGTH OF SILICA SAND A.F.A. NO 63 WITH 4% OF BENTONITE.
LBS./SQ.IN. COMP. GREEN & SHEAR
PERMEABILITY NO.
DRY PERMEABILITY
GREEN PERMEABILITY
GREEN COMP.
DRY COMP.
GREEN SHEAR
DRY SHEAR
#8
#9
0
1
2
3
4
5
6
7
8
9
3
6
9
12
PER CENT MOISTURE

PLATE II



STRENGTH OF SILICA SAND A.F.A. NO. 63
WITH 8 % BENTONITE
11.6
GREEN COMPRESSION - LBS./SQ.IN.
GREEN SHEAR " "
DRY COMPRESSION - LBS./SQ.IN.
PERMEABILITY NO.
DRY SHEAR " "
COMPRESSION (GREEN)
PERMEABILITY (DRY)
PERMEABILITY (GREEN)
SHEAR (GREEN)
DRY SHEAR
0
1
2
3
4
5
6
7
8
9
10
3
6
9
12
PERCENT MOISTURE

PLATE 12

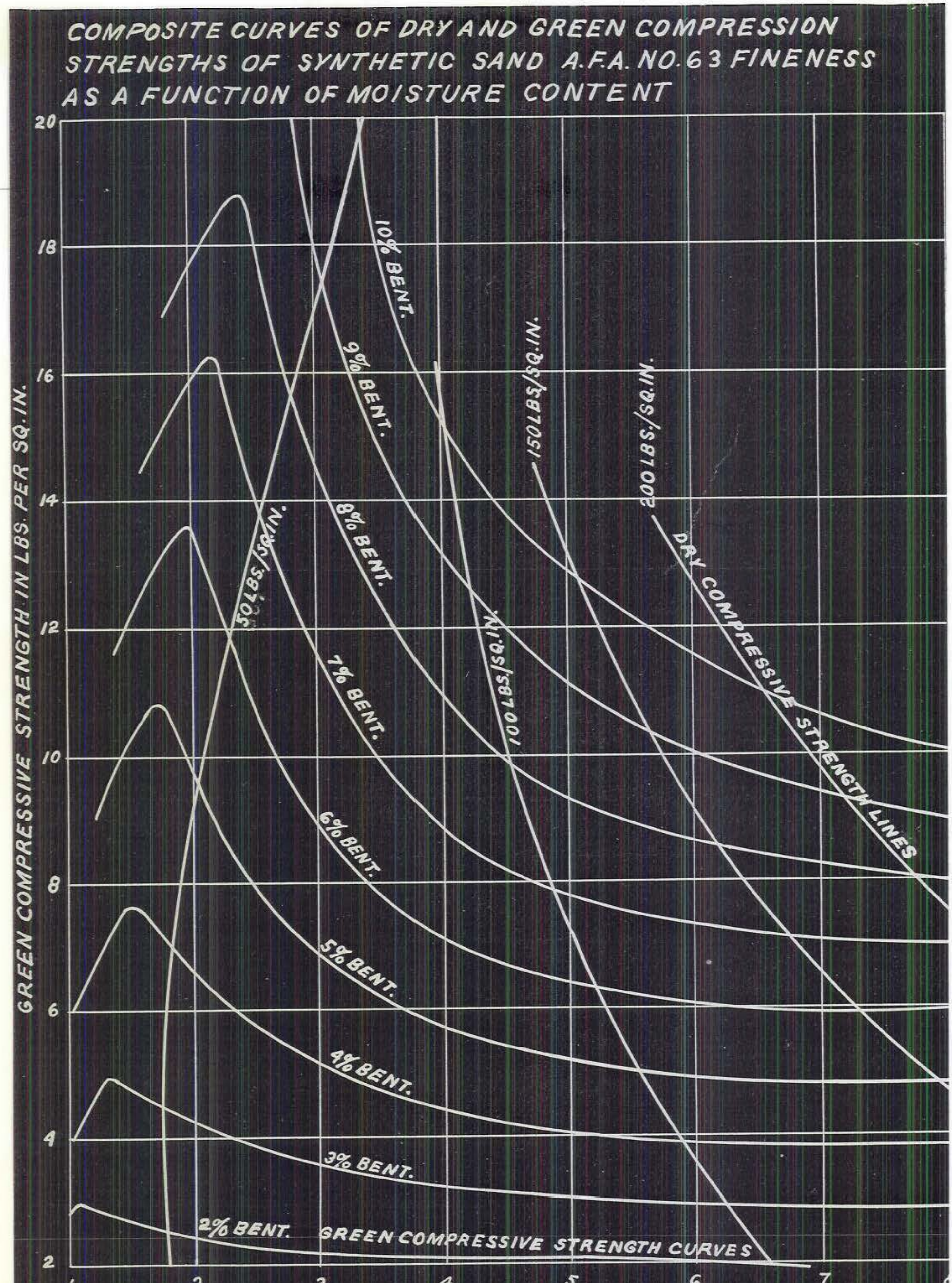

COMPOSITE CURVES OF DRY AND GREEN COMPRESSION STRENGTHS OF SYNTHETIC SAND A.F.A. NO. 63 FINENESS AS A FUNCTION OF MOISTURE CONTENT
GREEN COMPRESSIVE STRENGTH IN LBS. PER SQ. IN.
WATER CONTENT IN PERCENT
20
18
16
14
12
10
8
6
4
2
1
2
3
4
5
6
7
10% BENT.
9% BENT.
8% BENT.
7% BENT.
6% BENT.
5% BENT.
4% BENT.
3% BENT.
2% BENT.
50 LBS./SQ.IN.
100 LBS./SQ.IN.
150 LBS./SQ.IN.
200 LBS./SQ.IN.
DRY COMPRESSIVE STRENGTH LINES
GREEN COMPRESSIVE STRENGTH CURVES

PLATE 13

MOLD HARDNESS OBTAINED WITH VARIOUS PERCENTAGES OF MOISTURE. SILICA SAND A.F.A. NO. 63 FINENESS BONDED WITH 4 % BENTONITE.

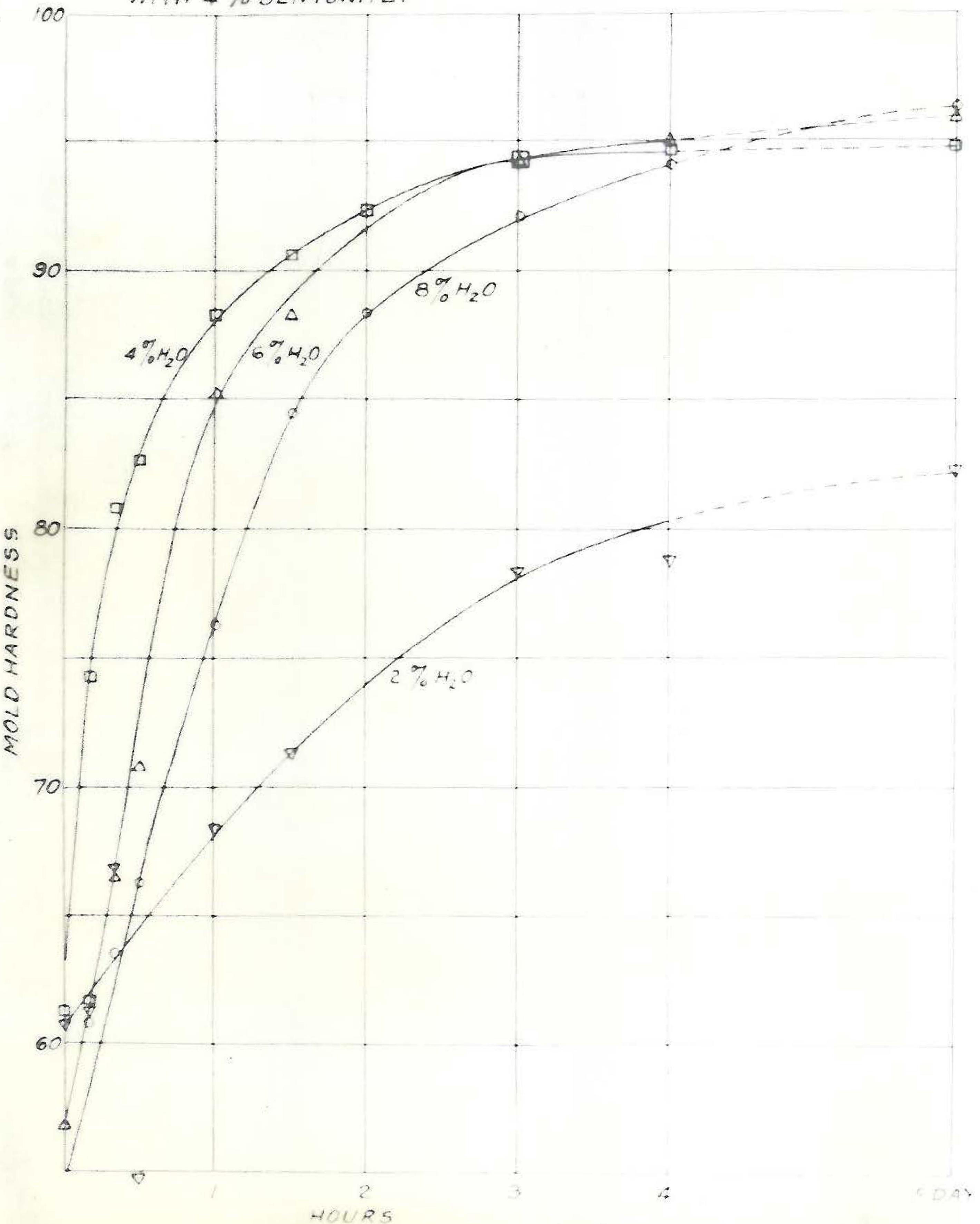


PLATE 14

MINIMUM AIR DRYING TIME TO OBTAIN MOLD HARDNESS

SILICA SAND A.F.A. NO 63 FINENESS BONDED WITH 4% BENTONITE

1. SELECT DESIRED HARDNESS
2. DRAW A VERTICAL LINE FROM INTERSECTION OF HARDNESS LINE AND MOISTURE CONTENT LINE TO FIND MINIMUM DRYING TIME
3. DRAW HORIZONTAL LINE FROM SAME POINT TO FIND MOISTURE CONTENT NECESSARY

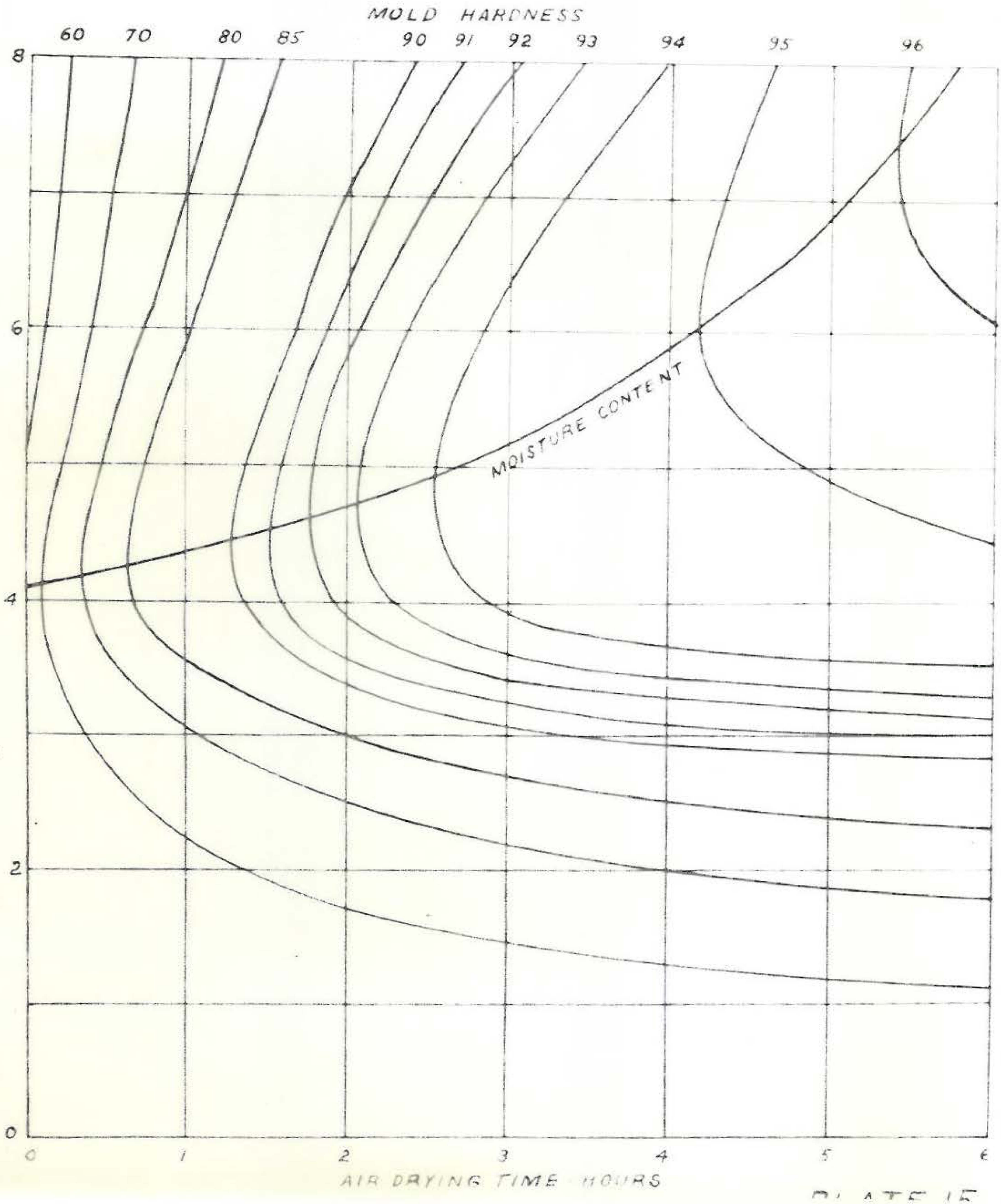
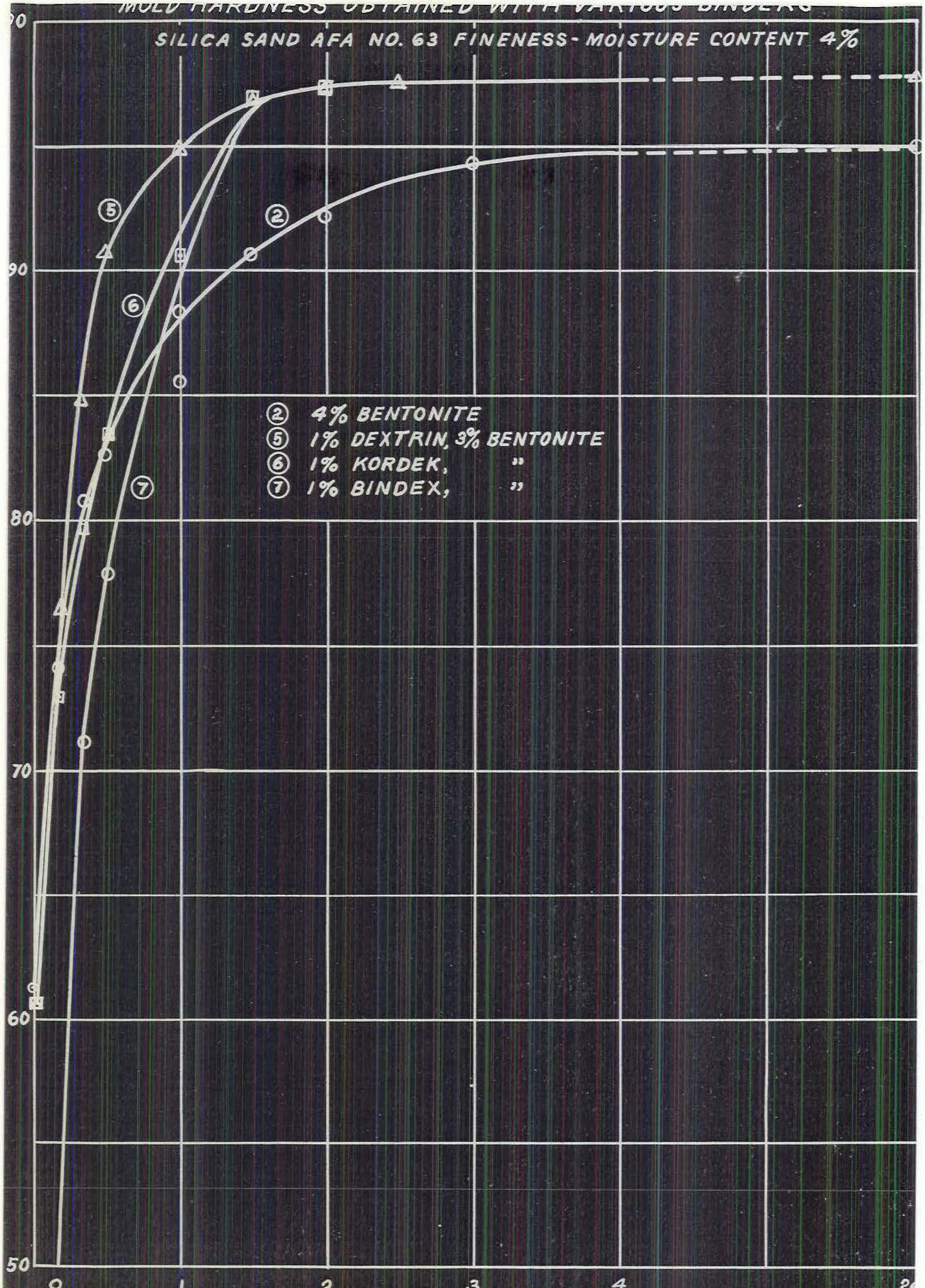
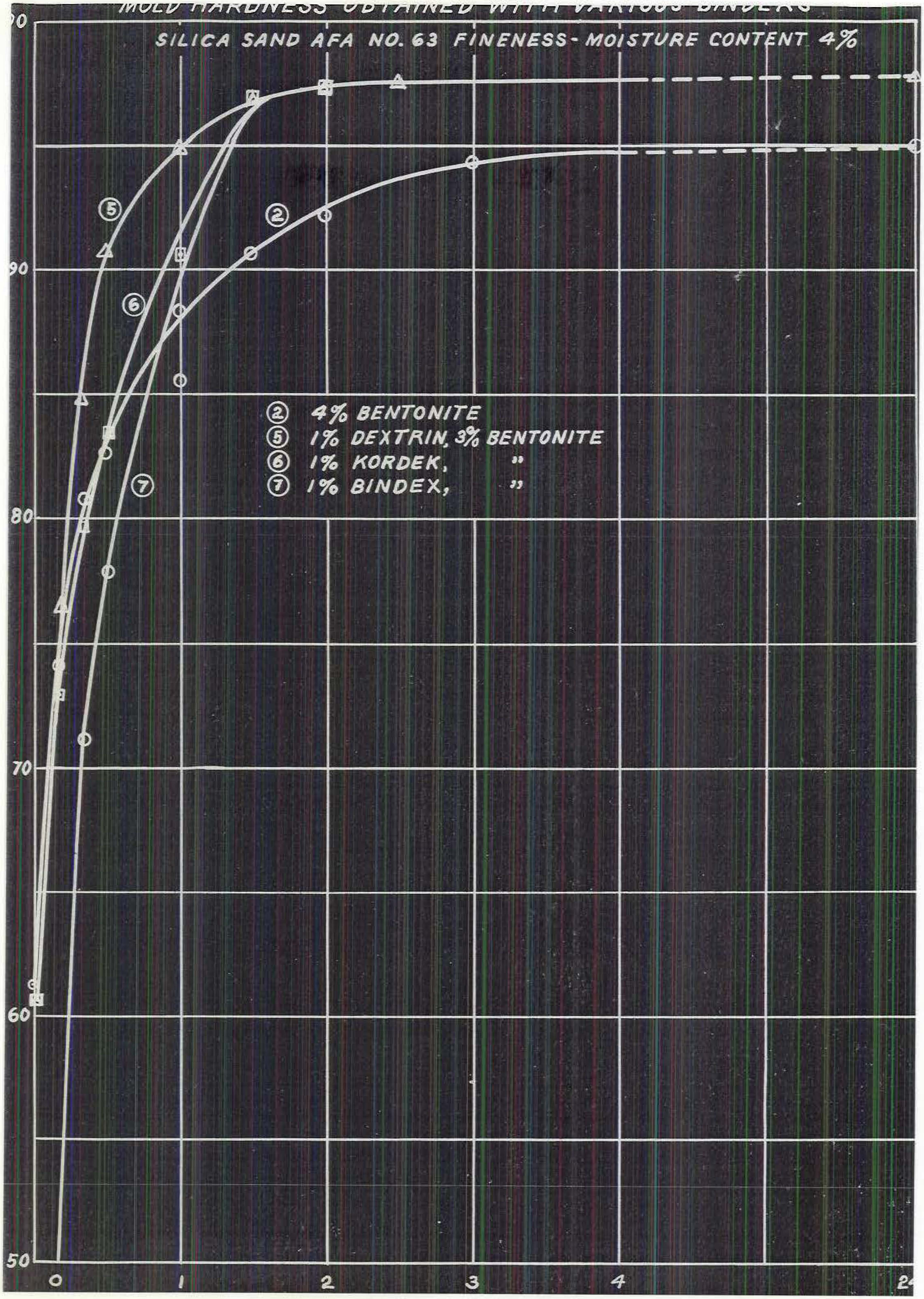


PLATE 15



SILICA SAND AFA NO. 63 FINENESS - MOISTURE CONTENT 4%
② 4% BENTONITE
⑤ 1% DEXTRIN, 3% BENTONITE
⑥ 1% KORDEK, "
⑦ 1% BINDEX, "
⑤
⑥
⑦
②
90
80
70
60
50
0
1
2
3
4
24


MOLD HARDNESS OBTAINED WITH VARIOUS BINDERS
SILICA SAND AFA NO. 63 FINENESS - MOISTURE CONTENT 4%
② 4% BENTONITE
⑤ 1% DEXTRIN, 3% BENTONITE
⑥ 1% KORDEK, "
⑦ 1% BINDEX, "
②
⑤
⑥
⑦
90
80
70
60
50
0
1
2
3
4
24