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SUBJECT TO REVISION

Louisiana Highway Research

TYPICAL MOISTURE DENSITY CURVES

Louisiana Department of Highways - Research Unit

TYPICAL MOISTURE - DENSITY CURVES

by

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Research Report No. 16

Interim Report No. 3

Research Project No. 61-11S

Conducted by
LOUISIANA DEPARTMENT OF HIGHWAYS
Research Unit
in Cooperation with
U.S. Department of Commerce
BUREAU OF PUBLIC ROADS

May 1965

SYNOPSIS

This report is concerned with the development of a family of compaction curves covering most untreated soils used for highway construction in Louisiana.

The soils which were investigated in formulating the family of curves are from all sections of the State and encompass a wide variety of soils that are commonly used for highway construction.

The combined family of compaction curves is satisfactory for use with almost all untreated soils from sand to heavy clay. An adequate laboratory check should be made at the beginning of each project to insure that the soils to be used on the project do fit the family of curves. The curves are for use with material passing the #4 screen.

This family of curves results in a considerable saving of time with little, if any, loss in accuracy.

This family of curves, with proper laboratory precautions to assure that the soils will fit the family, will be used for raw soil compaction control on all Louisiana projects.

ACKNOWLEDGEMENTS

This study was initiated in 1962 under the general supervision of Mr. A. S Kemahlioglu then the Soils Research Engineer. Later it was continued under the supervision of Mr. Harry L. Roland, Soils Research Geologist. The development of the curves was accomplished largely through their efforts.

USE OF TYPICAL MOISTURE - DENSITY CURVES

INTRODUCTION

One of the many problems associated with compaction control on any construction project is the time consuming task of obtaining maximum density and optimum moisture content of soils both in the laboratory and in the field. In addition to the time element, there seems to be a relatively large operator variance in performing this particular aspect of materials control.

In order to eliminate most of the time consuming work and to obtain results which are somewhat more uniform in character, the Soils Research Unit of the Louisiana Department of Highways undertook the task of developing a family of curves from which maximum density and optimum moisture content could be obtained by determining only one point on a curve for a given soil.

The primary family of curves (Figure 1) was developed and submitted to the field in February, 1963. This curve was developed by plotting approximately 1,000 moisture-density curves taken from the files.

A supplemental family of curves designed to cover those materials which would not fit the original family was developed in the same general manner. (Figure 2) However, two basic causes have deterred checking the accuracy of the family for these materials, namely: (1) comparatively few of these curves are encountered and (2) there is a transition zone where it is extremely difficult to classify the material so as to decide which family to use. (Figure 4)

The soils which fit into this supplemental category are generally somewhat granular in nature, however, there appears to be no practicable field method of distinguishing the materials in this category by soil type from those which fit the main family of curves.

SCOPE

This research program was instigated in an attempt to eliminate some of the time consuming work of obtaining maximum density and optimum moisture content of Louisiana soils in the laboratory and in the field.

The investigation was set up to encompass two phases: (1) an evaluation of the available data to produce a set of typical moisture-density curves, and (2) laboratory and field checks of the developed set of curves.

This report, in effect, is a final report on the untreated soils portion of this research project, however, the checking process shall be continued for an indefinite period. An investigation is being made as to the feasibility of using this family of curves for lime treated soils. The results of this investigation will be given in a separate report.

MATERIALS TESTED AND TEST PROCEDURES USED

All types of soils from every Highway District in the State are well represented due to the process of random selection. The method of compaction used in this study was LDH-TR 418-61 (Method A) which, it must be emphasized, calls for using only that fraction of material passing the No. 4 sieve.

The procedure used to develop the Family of Curves was as follows:

Approximately 1,000 moisture-density curves were randomly selected from the files and plotted with wet density as the ordinate and moisture content (per cent of dry weight) as the abscissa. The optimum moisture contents and maximum wet densities were then tabulated for each two pound increment of density. The densities within these increments were then averaged and those values for these increments that were not within plus or minus 10 per cent of the mean were discarded and the remainder reaveraged for maximum density and optimum moisture content. In addition, the densities were averaged at each of several moisture contents to determine an average slope for each curve.

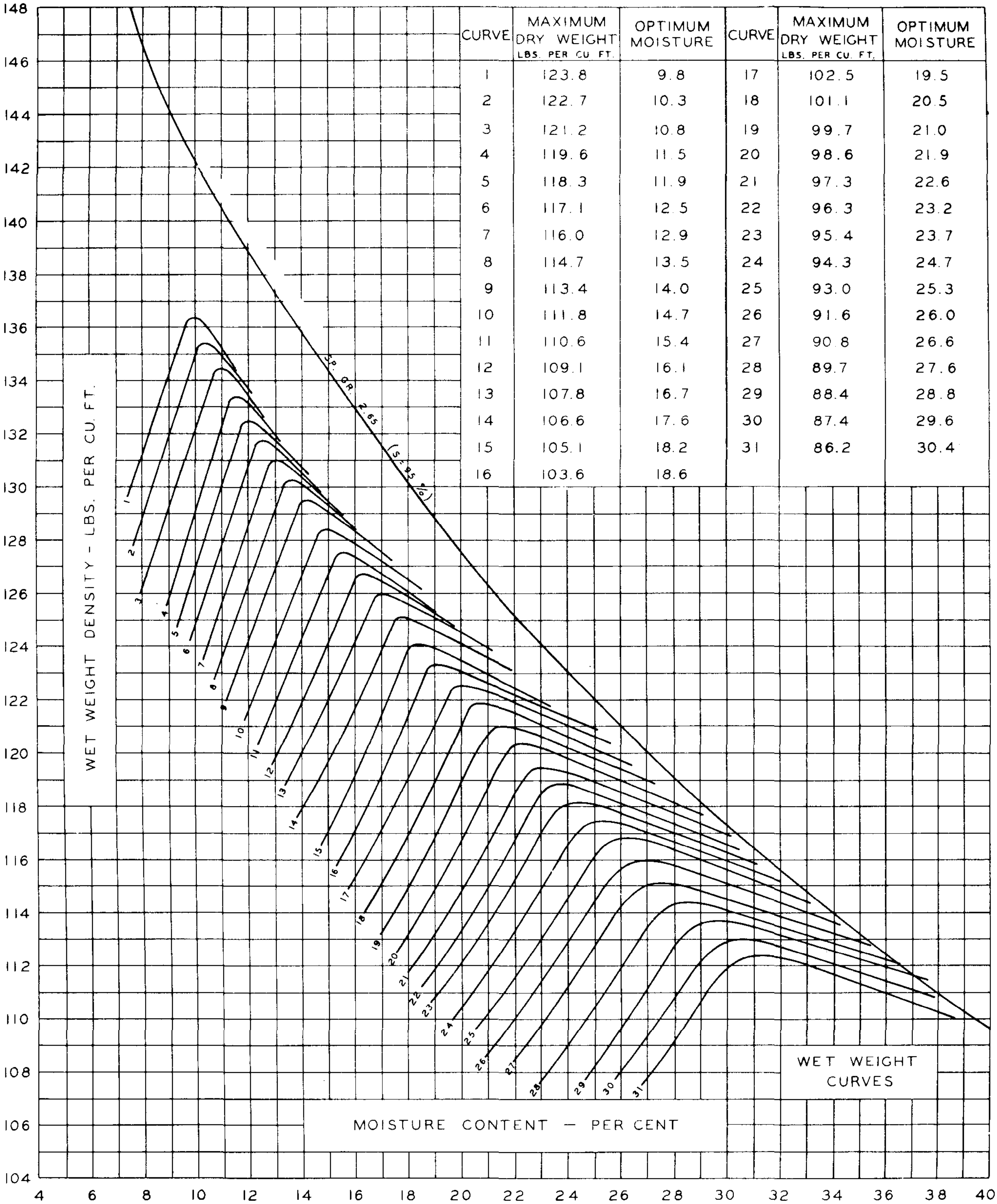
After developing a rather rough set of curves 100 curves were selected at random from the files and checked against the Family for accuracy. It was noted at this point that a minor adjustment was needed to improve its precision.

After this adjustment, another 100 curves were selected at random and plotted. This produced a seemingly satisfactory degree of accuracy (Figure 1). The family of curves was then distributed to the central and district laboratories with instructions to check each normally run curve against the family of curves to determine the applicability of the family to the soils being used in these areas. This check was made by picking a point from the curve that was being run which was near optimum moisture and plotting on the family of curves. The maximum densities and optimum moistures obtained by the two methods were then compared. After this comparison process was instituted it was felt that the family of curves should be expanded to include those materials with low density and high optimum moisture content which were prevalent in some areas. This expanded

NOT TO BE USED FOR SANDS

Figure 1

January 1963

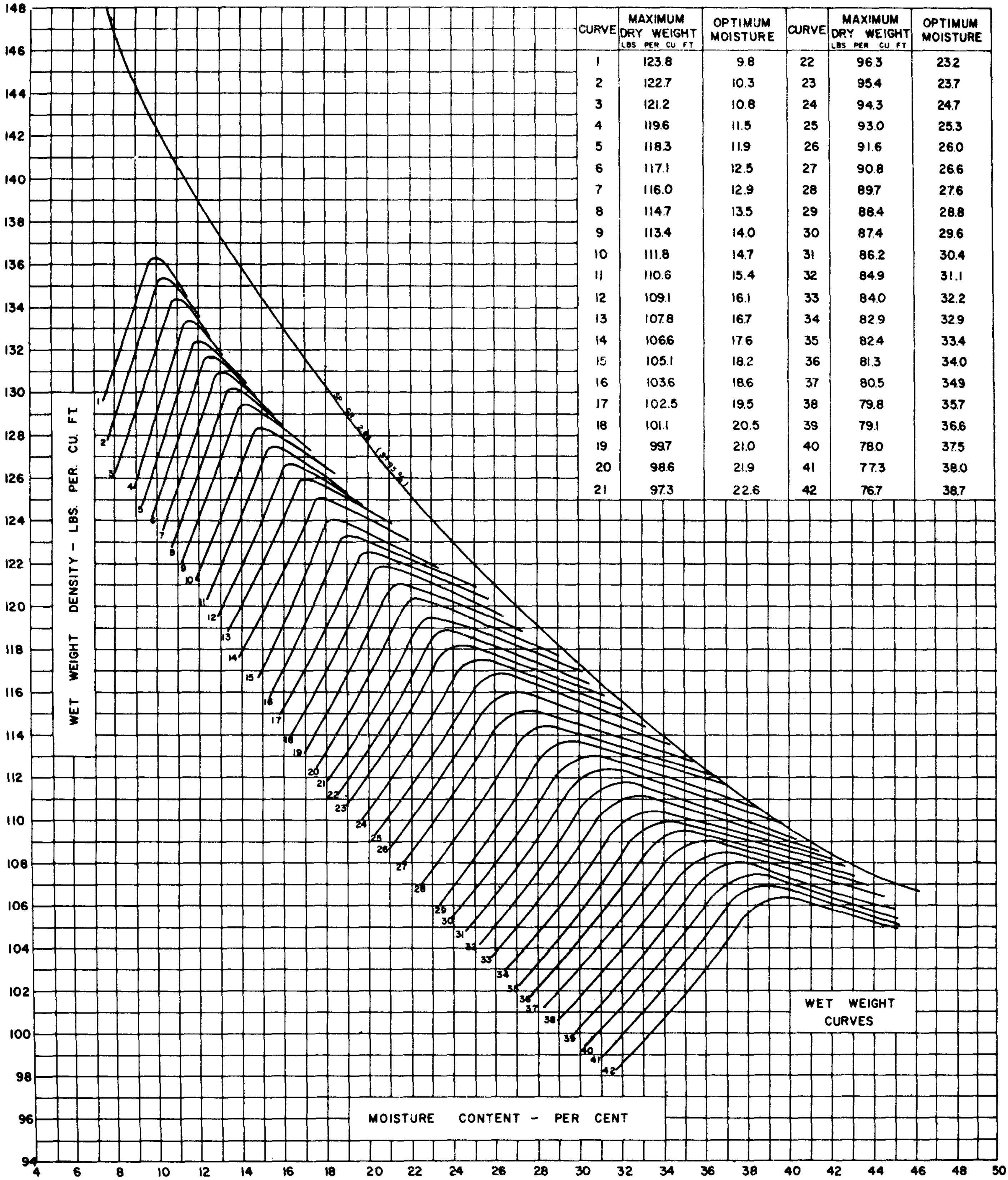


CURVE	MAXIMUM DRY WEIGHT LBS. PER CU. FT.	OPTIMUM MOISTURE	CURVE	MAXIMUM DRY WEIGHT LBS. PER CU. FT.	OPTIMUM MOISTURE
1	123.8	9.8	17	102.5	19.5
2	122.7	10.3	18	101.1	20.5
3	121.2	10.8	19	99.7	21.0
4	119.6	11.5	20	98.6	21.9
5	118.3	11.9	21	97.3	22.6
6	117.1	12.5	22	96.3	23.2
7	116.0	12.9	23	95.4	23.7
8	114.7	13.5	24	94.3	24.7
9	113.4	14.0	25	93.0	25.3
10	111.8	14.7	26	91.6	26.0
11	110.6	15.4	27	90.8	26.6
12	109.1	16.1	28	89.7	27.6
13	107.8	16.7	29	88.4	28.8
14	106.6	17.6	30	87.4	29.6
15	105.1	18.2	31	86.2	30.4
16	103.6	18.6			

TYPICAL MOISTURE - DENSITY CURVES

Method of Compaction: LDH Designation: TR 418-61 (Method A) - Maximum Size Aggregate: Minus 4 Material Only

Not to be used for granular materials — *Figure 1A* — *Revised June 1963*



CURVE	MAXIMUM DRY WEIGHT LBS PER CU FT	OPTIMUM MOISTURE	CURVE	MAXIMUM DRY WEIGHT LBS PER CU FT	OPTIMUM MOISTURE
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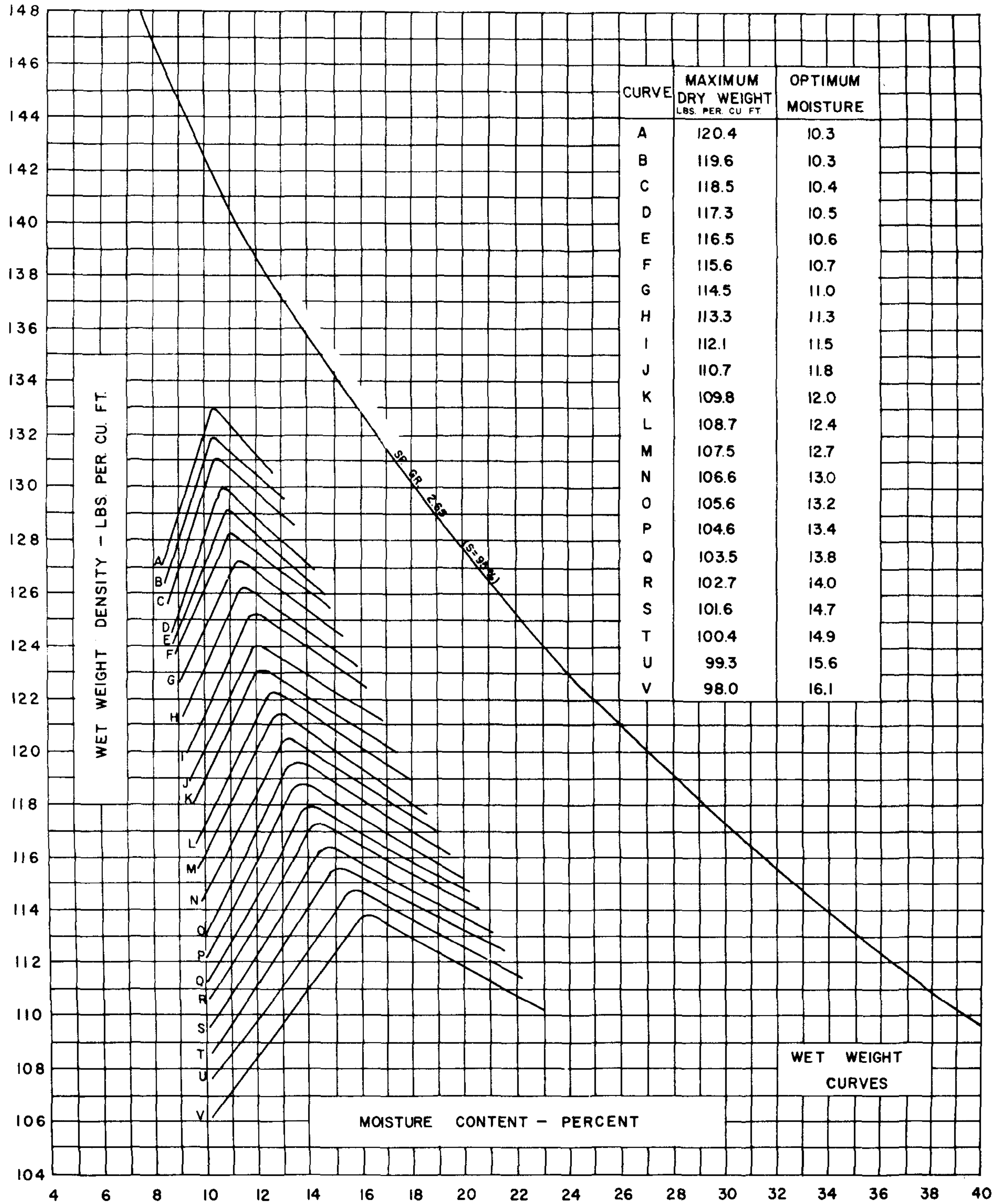
10	111.8	14.7	31	86.2	30.4
11	110.6	15.4	32	84.9	31.1
12	109.1	16.1	33	84.0	32.2
13	107.8	16.7	34	82.9	32.9
14	106.6	17.6	35	82.4	33.4
15	105.1	18.2	36	81.3	34.0
16	103.6	18.6	37	80.5	34.9
17	102.5	19.5	38	79.8	35.7
18	101.1	20.5	39	79.1	36.6
19	99.7	21.0	40	78.0	37.5
20	98.6	21.9	41	77.3	38.0
21	97.3	22.6	42	76.7	38.7

TYPICAL MOISTURE - DENSITY CURVES

Method of compaction: LDH Designation: TR 418-61 (Method A) - Maximum Size Aggregate: Minus 4 Material Only

To be used for granular materials *Figure 2* *June 1963*



CURVE	MAXIMUM DRY WEIGHT LBS. PER CU. FT.	OPTIMUM MOISTURE
A	120.4	10.3
B	119.6	10.3
C	118.5	10.4
D	117.3	10.5
E	116.5	10.6
F	115.6	10.7
G	114.5	11.0
H	113.3	11.3
I	112.1	11.5
J	110.7	11.8
K	109.8	12.0
L	108.7	12.4
M	107.5	12.7
N	106.6	13.0
O	105.6	13.2
P	104.6	13.4
Q	103.5	13.8
R	102.7	14.0
S	101.6	14.7
T	100.4	14.9
U	99.3	15.6
V	98.0	16.1

TYPICAL MOISTURE - DENSITY CURVES

Method of Compaction: IDH Designation: TR 418-61 (Method A) - Maximum Size Aggregate: Minus 4 Material Only

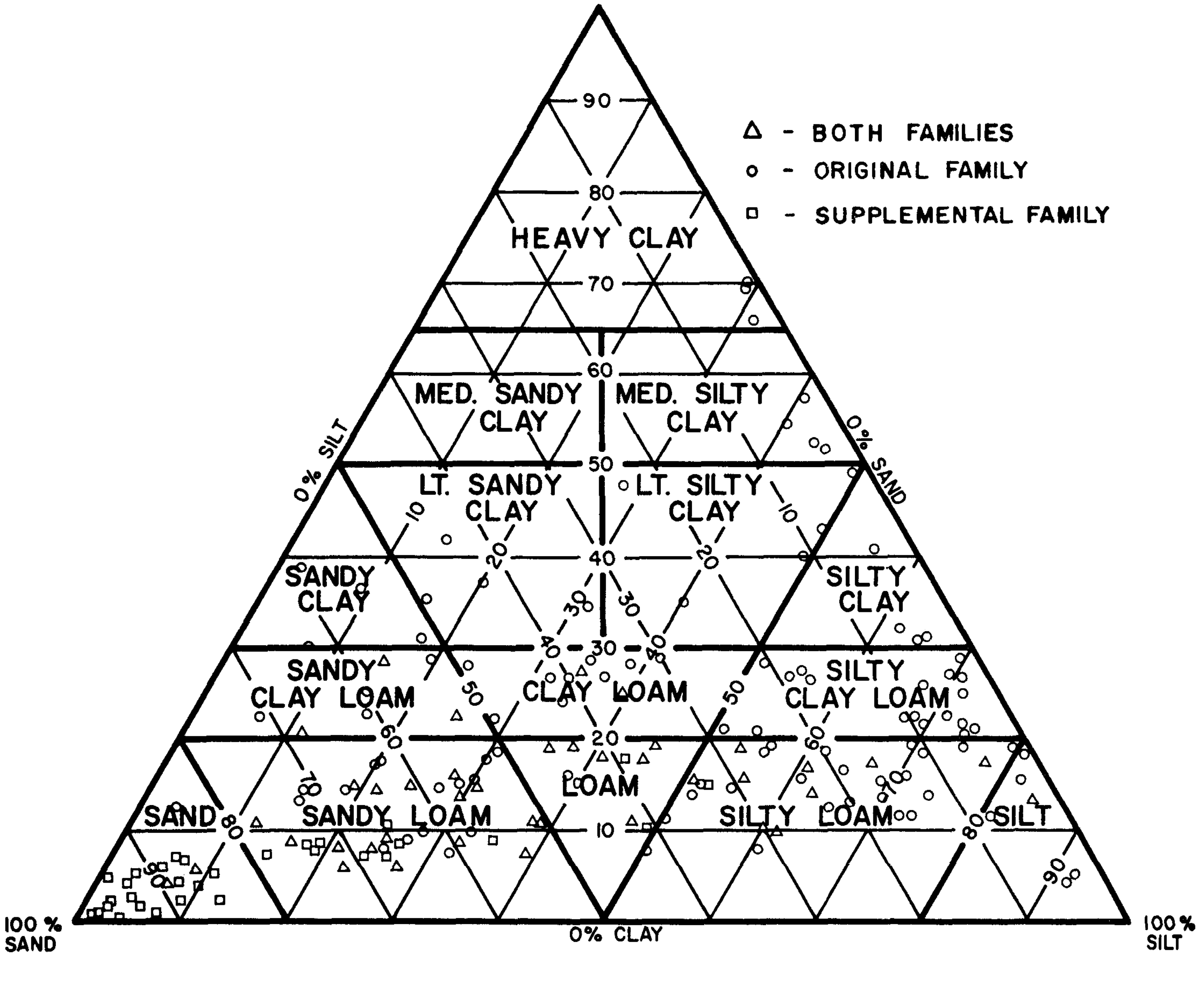


Figure 3 - Graphical illustration of the Classification of Soils that fit both families, the Original Family (Figure 1A) and the Supplemental Family (Figure 2).

family is shown in Figure 1A.

In the development of the curves of Figures 1 and 1A, it was noted that many sandy materials, (that is materials in the sand or sandy loam classifications) did not fit these series of curves (Figures 1 and 1A). These materials showed optimum moistures considerably less that those shown in Figures 1 and 1A for the same density. In order to attempt to include these materials a supplemental family of curves was prepared (Figure 2). Approximately 100 curves were used to develop the family as shown in Figure 2. It should be noted at this point that although most of the soils which fit this supplemental family of Figure 2 are sandy soils, all sandy soils do not fit the supplemental family. (Figure 3) Many sandy soils satisfactorily fit the major family of curves shown in Figure 1A. A total of 1618 curves have been checked with 1560 of these most nearly coinciding with the family of curves shown in Figure 1A, and 58 most nearly coinciding with the supplemental family of curves shown in Figure 2. The following is a summary of the accuracy check information:

FAMILY OF CURVES SHOWN IN FIGURE 1A

	Maximum Dry Density % within			Optimum Moisture Content % within		
No. Samples	±2 lbs.	±3 lbs.	3+lbs.	±1%	±2%	2+%
1560	93% (1456)	98% (1534)	2% (26)	76% (1183)	95% (1485)	5% (75)

% of curves within ±2 pounds density and ±1% opt. moisture = 75% (1163)
±2 ±2% = 92% (1435)
±3 ±2% = 95% (1476)

FAMILY OF CURVES SHOWN IN FIGURE 2

	Maximum Dry Density % within			Optimum Moisture Content % within		
No. Samples	±2 lbs.	±3 lbs.	3+ lbs.	±1%	±2%	2+%
58	97% (56)	97% (56)	3% (2)	74% (43)	100% (58)	0 (0)

% of curves within ±2 pounds density and ±1% opt. moisture = 83% (48)
±2 ±2% = 97% (56)
±3 ±2% = 97% (56)

FAMILY OF CURVES OF FIGURES 1A & 2 COMBINED

No. Samples	Maximum Dry Density % within ±2 lbs.	±3 lbs.	3^+lbs.	Optimum Moisture Content % within ±1%	±2%	2^+%
1618	93% (1512)	98% (1590)	2% (28)	76% (1226)	95% (1543)	5% (75)

% of curves within ±2 pounds density and ±1% opt. moisture = 75% (1211)
±2 ±2% = 92% (1491)
±3 ±2% = 95% (1532)

The percentage of curves fitting each family is as shown below:

Family	No.	Per Cent
Figure 1A	1476	92
Figure 2	56	3
Neither	86	5

DISCUSSION OF RESULTS

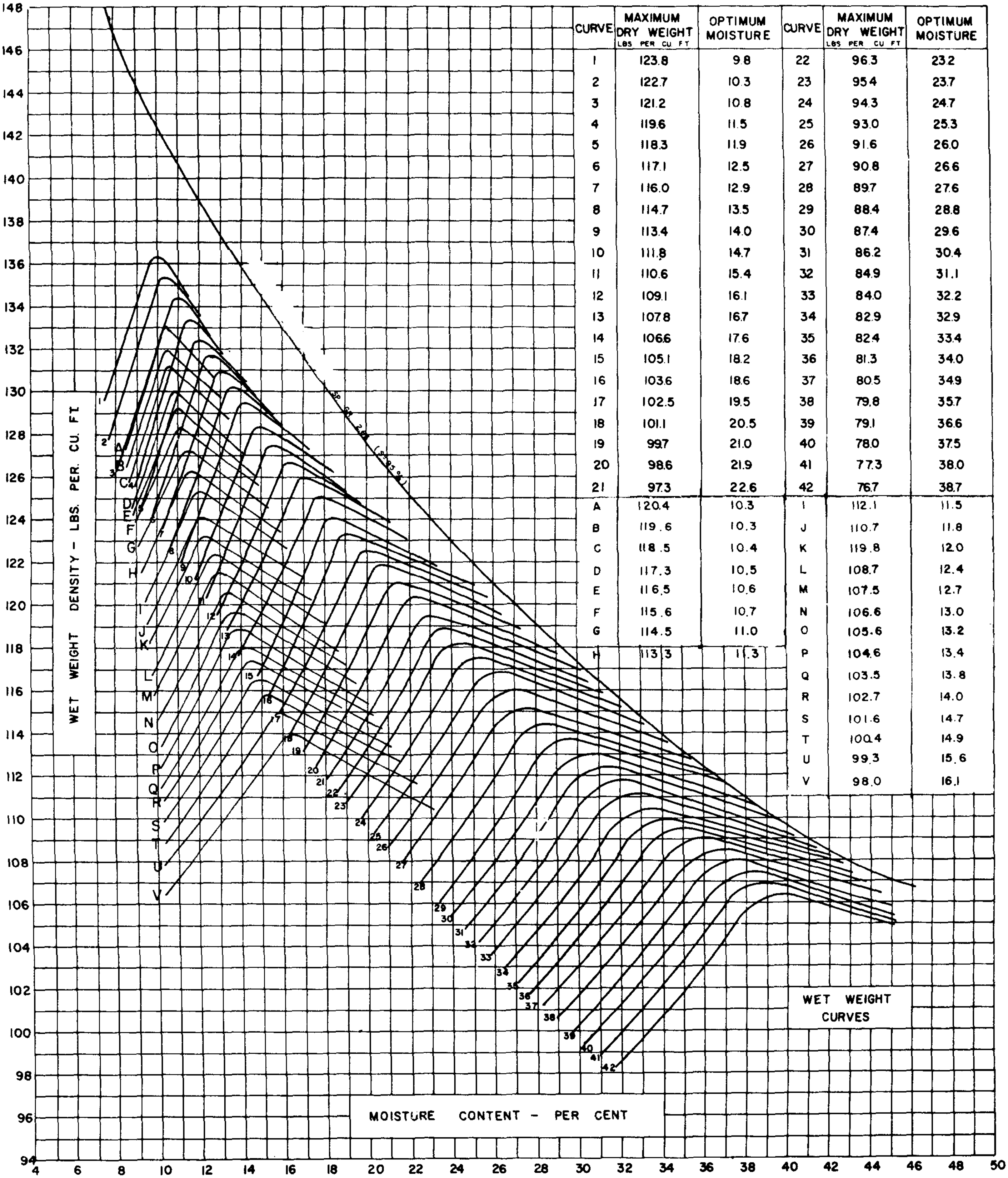
For the purposes of this study it is considered that any curve that is within 2% optimum moisture and 3 lbs. dry weight density of the optimum moisture and maximum density of the appropriate curve from the family of curves is a "hit," that is, it may be considered to be identical with the curve from the family without appreciable error. This is considered to be true for the following reasons:

1. Our experience with running curves indicates that duplicate curves run in a normal laboratory manner may quite often deviate from each other by this amount.

2. Assuming a perfectly run laboratory curve it is probable that deviations from this curve to the above mentioned extent would not be appreciably detrimental to the roadway.

An analysis of Figure 4 reveals that there is a definite overlapping of the curves of Figure 1A and Figure 2 in the area of higher wet densities. That is, the optimum moistures and maximum densities of the supplemental family of curves

Figure 4



CURVE	MAXIMUM DRY WEIGHT LBS PER CU FT	OPTIMUM MOISTURE	CURVE	MAXIMUM DRY WEIGHT LBS PER CU FT	OPTIMUM MOISTURE
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2	122.7	10.3	23	95.4	23.7
3	121.2	10.8	24	94.3	24.7
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5	118.3	11.9	26	91.6	26.0
6	117.1	12.5	27	90.8	26.6
7	116.0	12.9	28	89.7	27.6
8	114.7	13.5	29	88.4	28.8
9	113.4	14.0	30	87.4	29.6
10	111.8	14.7	31	86.2	30.4
11	110.6	15.4	32	84.9	31.1
12	109.1	16.1	33	84.0	32.2
13	107.8	16.7	34	82.9	32.9
14	106.6	17.6	35	82.4	33.4
15	105.1	18.2	36	81.3	34.0
16	103.6	18.6	37	80.5	34.9
17	102.5	19.5	38	79.8	35.7
18	101.1	20.5	39	79.1	36.6
19	99.7	21.0	40	78.0	37.5
20	98.6	21.9	41	77.3	38.0
21	97.3	22.6	42	76.7	38.7
A	120.4	10.3	I	112.1	11.5
B	119.6	10.3	J	110.7	11.8
C	118.5	10.4	K	119.8	12.0
D	117.3	10.5	L	108.7	12.4
E	116.5	10.6	M	107.5	12.7
F	115.6	10.7	N	106.6	13.0
G	114.5	11.0	O	105.6	13.2
H	113.3	11.3	P	104.6	13.4
			Q	103.5	13.8
			R	102.7	14.0
			S	101.6	14.7
			T	100.4	14.9
			U	99.3	15.6
			V	98.0	16.1

TYPICAL MOISTURE - DENSITY CURVES

Family of Figure 1A shown in black - Family of Figure 2 shown in red.

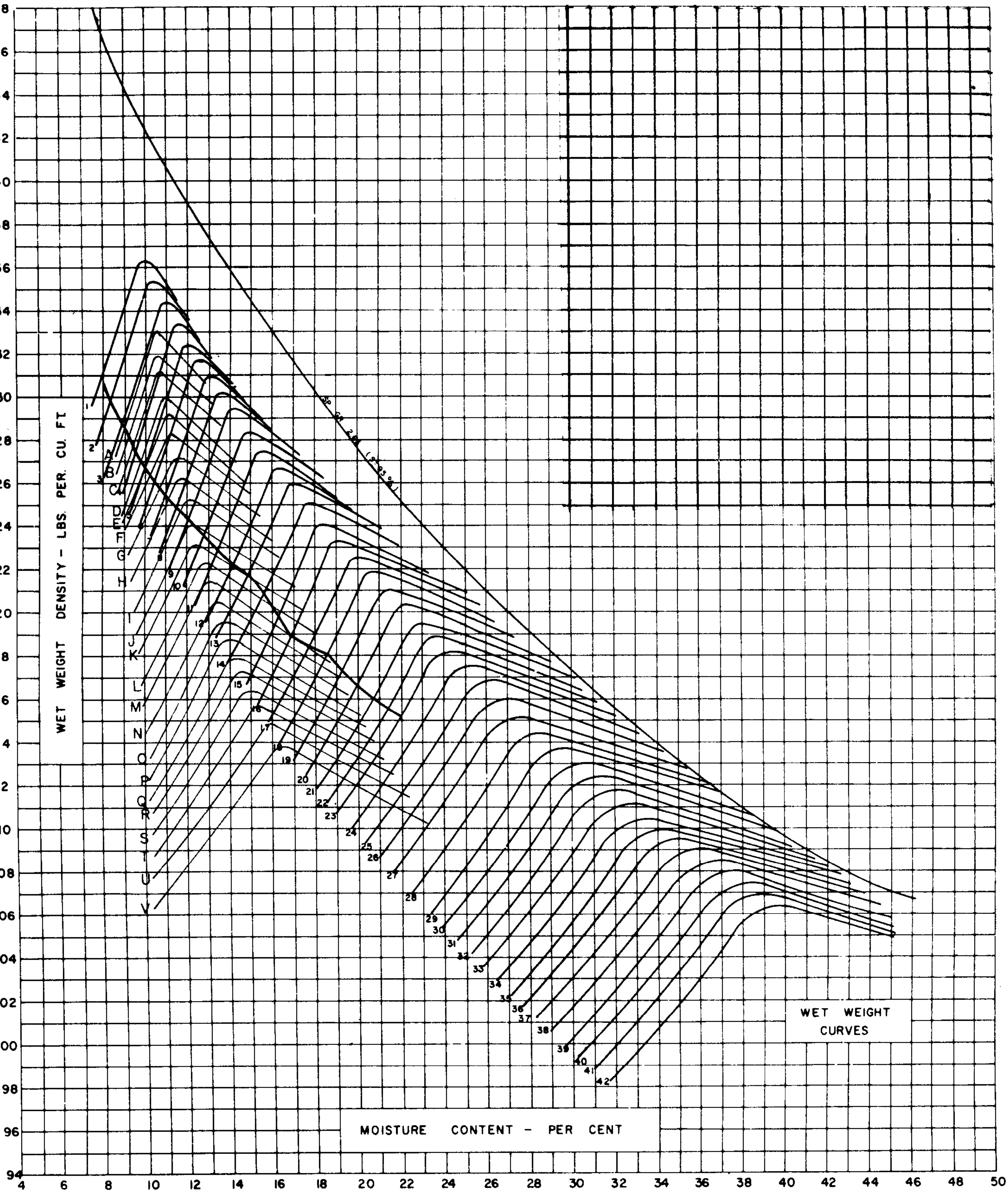
are within the allowable tolerance of 2% moisture and 3 lbs. density of those of the curves of the major family in that area.

Figure 5 shows a line drawn at 2% from optimum moisture on the dry side in the higher density range of the major family of curves. Curves A through I of the supplemental family of curves have peaks that are to the right of the 2% moisture line on the major family. Since the peaks of these curves are generally within the area that would be considered as "hits" on the major family of curves these supplemental curves can be eliminated. It is felt that the confusion caused by trying to determine which family of curves should be used in this area would be extremely large and that only a false accuracy would be achieved.

Figure 6 shows a combination of the two families of curves with curves A through I of the supplemental family eliminated and new letter designations assigned to the remainder of this family. In addition to the two per cent dry side line for the major family a line is drawn at two per cent on the wet side from the supplemental family and curves. It is recommended, and is specified in the procedure for use of the family of curves, that the proctor point run in the field be slightly on the dry side of optimum. With this stipulation the only area of probable confusion of the curves as shown in Figure 6 is that area between the 2% wet side line and the peaks of the supplemental family of curves. In this area (Area 1) it is possible that whether the material is slightly on the wet side of optimum or a good deal on the dry side of optimum may not be readily discernable. Since moisture changes are more easily detected on the wet side of optimum than on the dry side, beyond about 2% on the wet side (Area 2), a determination that the material is on the wet side of optimum should be easily made. This should be especially so since the materials of the supplemental family tend to be granular in nature and some water loss from the proctor mold will often be noticed at moisture contents wetter than optimum. For points falling to the left of area one it should be relatively easy to ascertain whether the proctor at the point molded is very near to optimum or several percentage points therefrom. It should also be noted that the portion of Area 1 where confusion of curves might be expected is relatively small since the distance from the peak of the major family of curves increases rapidly in this area and with a little experience a determination as to whether the material is slightly wet or quite dry can be made except in the higher density portion of this area.

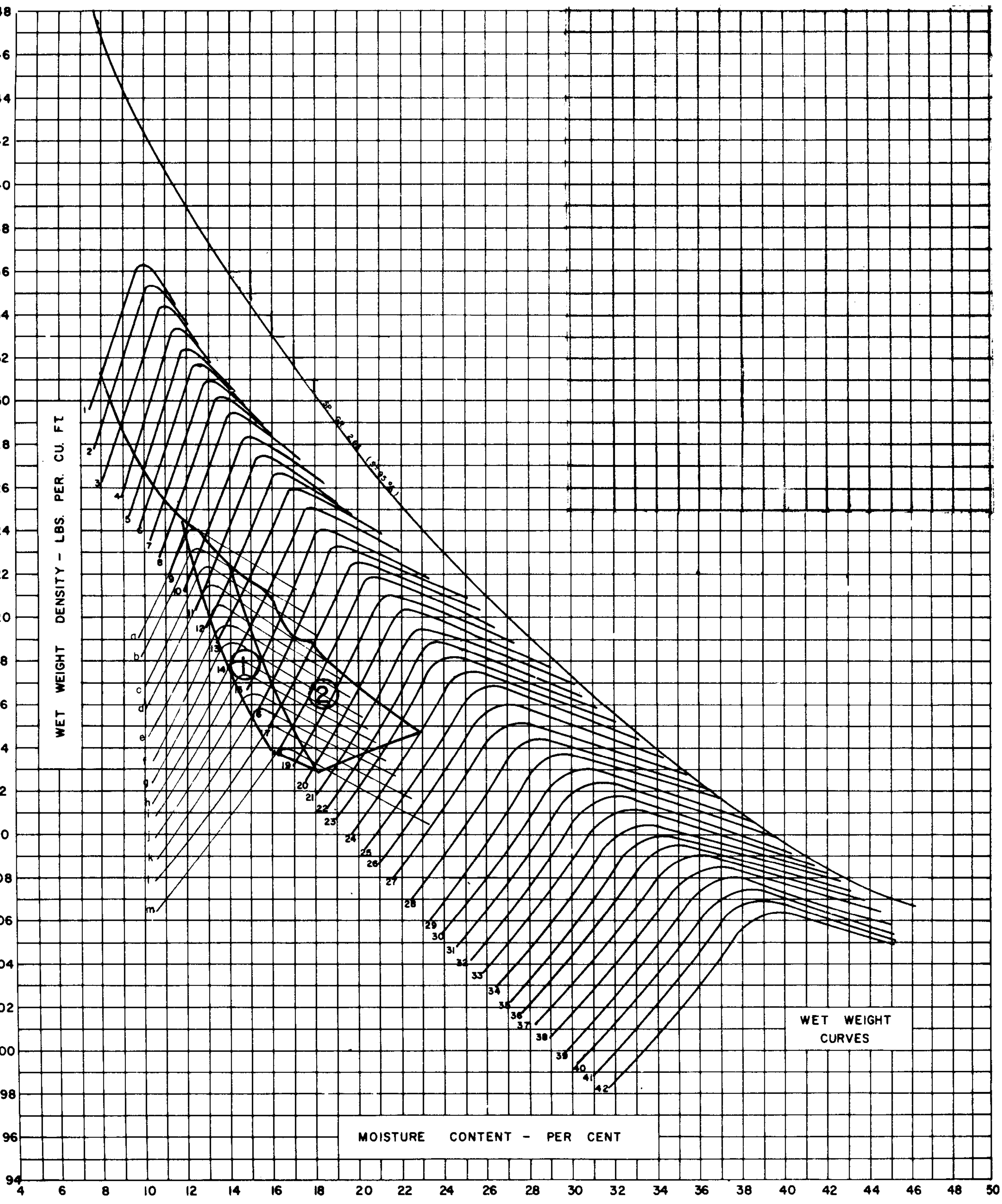
Figure 7 shows the final family of curves which is to be submitted to the field for construction use. It includes all of the major family of curves and that portion of the supplemental family which was shown in Figure 6. The area of doubt shown in Figure 6 (Area 1) is shaded and the revised procedure for use of the family curves requires that for all points falling within this area an

Figure 5



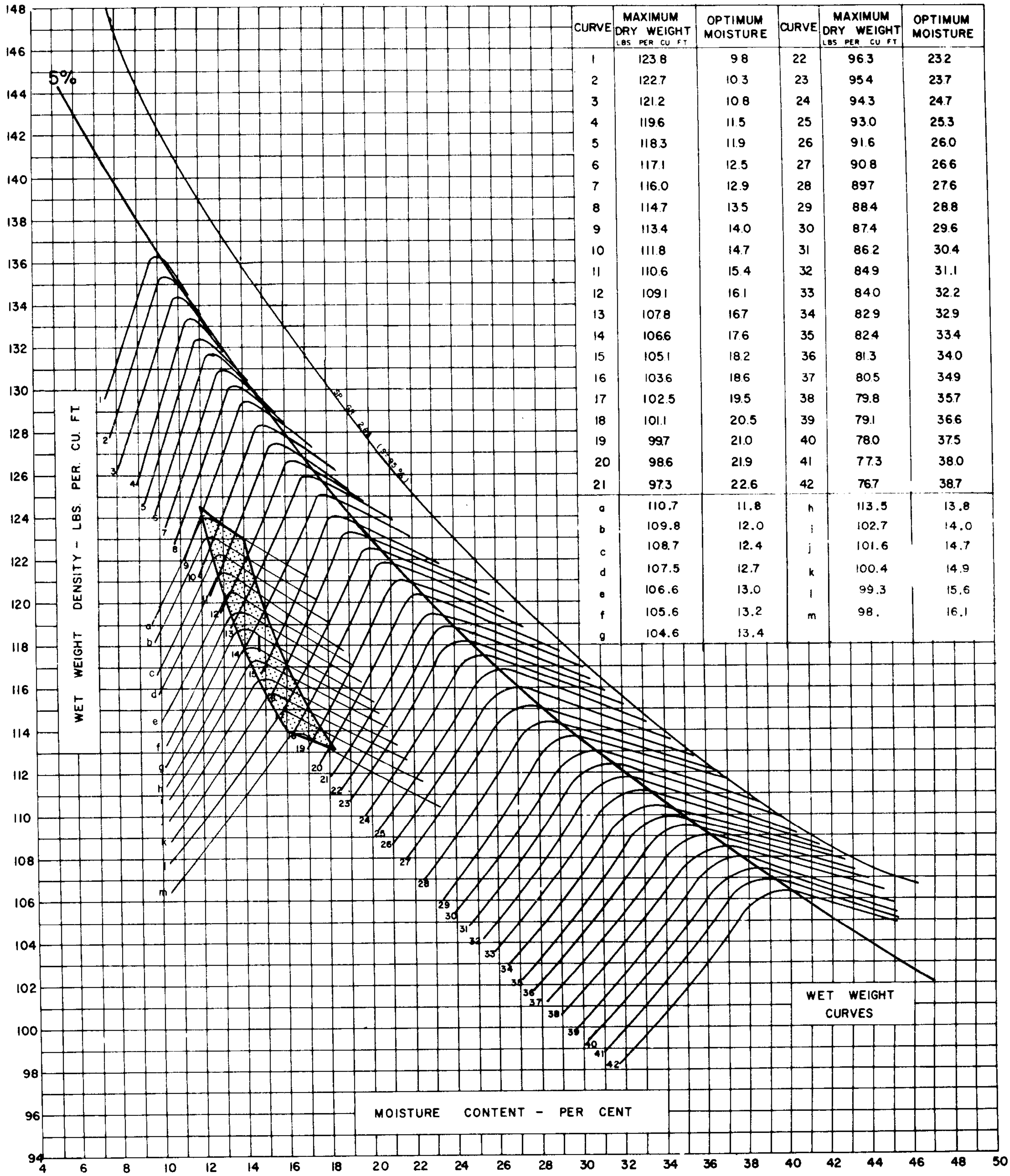
TYPICAL MOISTURE - DENSITY CURVES

Figure 6



TYPICAL MOISTURE - DENSITY CURVES

Figure 7



CURVE	MAXIMUM DRY WEIGHT LBS PER CU FT	OPTIMUM MOISTURE	CURVE	MAXIMUM DRY WEIGHT LBS PER CU FT	OPTIMUM MOISTURE
1	123.8	9.8	22	96.3	23.2
2	122.7	10.3	23	95.4	23.7
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5	118.3	11.9	26	91.6	26.0
6	117.1	12.5	27	90.8	26.6
7	116.0	12.9	28	897	27.6
8	114.7	13.5	29	88.4	28.8
9	113.4	14.0	30	87.4	29.6
10	111.8	14.7	31	86.2	30.4
11	110.6	15.4	32	84.9	31.1
12	109.1	16.1	33	84.0	32.2
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14	106.6	17.6	35	82.4	33.4
15	105.1	18.2	36	81.3	34.0
16	103.6	18.6	37	80.5	349
17	102.5	19.5	38	79.8	35.7
18	101.1	20.5	39	79.1	36.6
19	99.7	21.0	40	78.0	37.5
20	98.6	21.9	41	77.3	38.0
21	97.3	22.6	42	76.7	38.7
a	110.7	11.8	h	113.5	13.8
b	109.8	12.0	i	102.7	14.0
c	108.7	12.4	j	101.6	14.7
d	107.5	12.7	k	100.4	14.9
e	106.6	13.0	l	99.3	15.6
f	105.6	13.2	m	98.	16.1
g	104.6	13.4			

TYPICAL MOISTURE - DENSITY CURVES

Method of Compaction LDH TR: 418 Maximum size aggregate - Minus #4 material only additional point be run after the addition of water to the soil. This point should adequately determine which curve should be used.

Figure 8 shows the final family of curves (Figure 7) with the 0, 5, and 10% air voids lines and the 95% saturation line shown. Air voids as shown are a percentage of the total volume of the sample and the per cent saturation is, of course, based on the per cent of total voids filled with water. It is interesting to note that the 5% air voids line follows very closely the peak of the curves in the major family. The fact that the line of maximum density is also very nearly a line of consistent voids gives rise to interesting possibilities for compaction control based on voids control. The soils of the supplemental portion of the family, however, do not seem to bear a direct ratio to the per cent voids. Since the 5% voids line is so nearly coincidental with the peaks of the curves of the major family and since field proctor points on the dry side of optimum are desired; this line is shown on the final family of curves and the revised procedure for use of the family of curves requires that proctor points fall to the left of this line. In general, if points are molded which fall to the right of this line, a new point will be run at a lower moisture content. However, an exception must be made for those soils having high clay contents and relatively flat curves. which cannot be readily dried and handled in the field due to creation of a cloddy condition which gives rise to large voids in the proctor. Proctors for these soils will be molded as near to optimum as is practicable.

CONCLUSIONS

1. A family of curves for use with raw soils has been developed.

2. This family of curves has proved practical for field use.

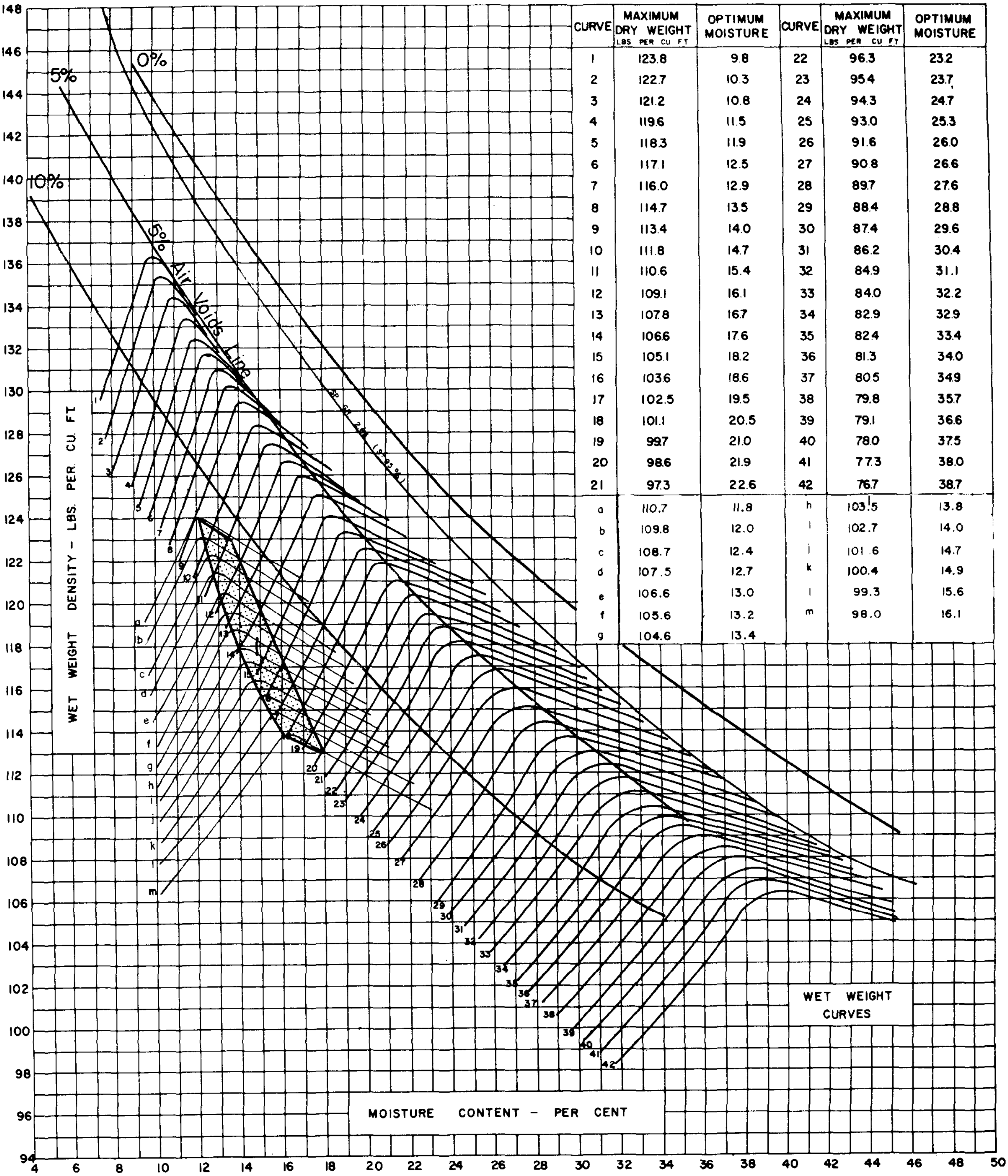
3. Considerable confusion of field personnel has been eliminated by the simplified process of the family of curves.

4. Approximately 95% of the laboratory curves checked fit the family of curves.

5. Field results using the family of curves have been satisfactory. It is probable that greater accurracy in picking optimum moisture and maximum density is obtained using the family of curves and there is a considerable saving of time.

6. This family of curves, with proper laboratory precautions to assure that the soils will fit the family, will be used for raw soil compaction control on all Louisiana projects.

Figure 8



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9	113.4	14.0	30	87.4	29.6
10	111.8	14.7	31	86.2	30.4
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d	107.5	12.7	k	100.4	14.9
e	106.6	13.0	l	99.3	15.6
f	105.6	13.2	m	98.0	16.1
g	104.6	13.4			

TYPICAL MOISTURE - DENSITY CURVES

Showing 0, 5 & 10% air voids line and 95% saturation line.

APPENDIX

Tentative Method of Determination of

MOISTURE-DENSITY RELATIONSHIP USING FAMILY OF CURVES

LDH Designation: TR 415-64

Scope

1. This method of test is intended to determine the relationship between the moisture content of soils and resulting densities (oven-dry weight per cu. ft.) utilizing the family of moisture-density curves (Fig. 7), when the soil is compacted as specified herein. It is intended to be used as an accurate short cut procedure for LDH Designation: TR 418 and TR 401, and is to be used with the minus No. 4 material of soils only.

Apparatus

2. The apparatus shall consist of the following:

(a) Mold. - A cylindrical metal mold having a capacity of 1/30 cu. ft. (0.0333 cu. ft.) with an internal diameter of 4.0 inches (± 0.005 in) and a height of 4.584 ± 0.005 inches, which has a detachable collar approximately 2 1/2 inches in height. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base plate. Molds shall be replaced if the diameter is more than 4.01 inches or the height is less than 4.50 inches on any side.

(b) Compactive device. - A metal rammer having a 2.00 ±0.01 inch diameter circular face or a segment of a 2-inch radius circle with an equivalent area and weighing 5.50 ± 0.50 lb. The rammer shall be equipped with an arrangement to control the height of drop to 12.0 ± 0.1 inches.

(c) Straightedge - A steel straightedge

(d) Balances - A balance or scale of 25 lb. capacity sensitive to 0.01 lb. (or equivalent metric balance), and a 500 gram capacity balance sensitive to 0.1 gram.

(e) Drying Apparatus - A thermostatically controlled drying oven capable of maintaining temperatures of 100° C ± 5° C (230°±9°F) for drying moisture samples. A hot plate or an approved Speedy Moisture Device may be used for moisture determinations in the field.

(f) Sieve - A number 4 sieve conforming to the requirements of the Standard Specifications for Sieves for Testing Purposes (AASHO Designation: M 92).

(g) Mixing Tools - Miscellaneous tools such as mixing pan, spoon, trowel, spatula, etc. or a suitable mechanical device for mixing thoroughly the sample of soil with water.

(h) Graduated Cylinder (250 cc) - For measuring water to be added to sample. (For Central Laboratory and Dist. Labs.)

Sample

3. (a) A representative sample of soil weighing approximately 6 lbs. (or 2724 grams) shall be taken for each one-point Proctor.

Procedure

4. (a) The 6 lb. sample shall be thoroughly mixed with sufficient water to bring the sample to slightly less than its optimum moisture content.

A compacted specimen shall then be formed by compacting the thoroughly mixed soil in the mold (with collar attached) in three equal layers to give a total compacted depth of about 5 inches; each layer being compacted by 25 blows of the rammer dropping free from a height of 12 inches or 12 inches above the approximate elevation of each finally compacted layer when a stationary mounted type of rammer is used. During compaction the mold shall rest on a uniform, rigid foundation. The blows shall be uniformly distributed over the surface of the layer being compacted. After the specimen has been compacted, the collar shall be removed from the mold and the compacted soil carefully trimmed even with the top of the cylinder by means of a straightedge.

(b) The mold containing the compacted soil specimen shall be weighed. This weight minus the weight of the mold shall then be multiplied by 30 and the result recorded as the wet weight per cubic foot of compacted soil.

(c) The base plate shall be detached and the specimen removed from the mold. A representative sample shall be taken from a location near the center of the specimen.

(d) For moisture content determination in the field a 200 gram sample shall be secured as described in "c", weighed immediately and dried to a constant weight by use of a hot plate.

(e) An approved speedy moisture device may be used to determine the moisture content in the field.

(f) For moisture content determination in the Central or District Laboratories not less than a 100 gram sample shall be secured as in "c". This sample shall be weighed immediately and dried in an oven at 110° ± 5° C (230° F ± 9° F) to a constant weight.

Calculations

5. The water content of the soil as compacted shall be calculated as follows:

$$W = \frac{(W_1 - W_2) \times 100}{W_2}$$

where:

W = Moisture content in percent based on weight of oven-dry soil.

W_1 = Weight of wet soil.

W_2 = Weight of oven-dry soil.

Moisture-Density Relationship as Determined From the Family of Typical Moisture-Density Curves

6. The calculations in section 4(b) and in section 5 shall be made to determine the wet density in lbs/cu. ft. and the corresponding water content. These determine a point which may now be plotted on the Family of Curves and extrapolated to arrive at a maximum wet weight and optimum moisture content. When this point falls between two family curves, a minor interpolation is necessary. The maximum dry density in lbs/cu. ft. and the corresponding per cent optimum moisture is then read from the chart or interpolated from the chart (Table 1).

Precautions

7. (a) Any point falling to the left of Area 1 applies to the supplemental (a-m) portion of the family. Any point falling in area one should be repeated using fresh soil at a higher moisture content. If the density value for this point decreases the point previously run may be used to pick a curve from the (a-m) portion of the family. If the density value for the second point rises the proper curve may be selected from the major (1-42) portion of the family using this point.

(b) The maximum wet density and optimum moisture point should be on the dry side of the curve at or near optimum as it is difficult to interpolate between curves for friable soils when on the wet side of the peak.

(c) When the moisture density values of a compacted material are plotted and found to be to the right of the 5.0% air voids curve, the test should be repeated using a lower moisture content. An exception to this rule must be made for those soils having high clay contents and relatively flat curves. These soil cannot readily be dried to optimum in the field due to the creation of a cloddy condition which will cause voids in the proctor. Proctors for these materials should be made as near to optimum as practicable. When the moisture density value of a compacted material is plotted and found to be to the right of the 95% saturation line the test should be repeated using a new sample.

In the event the result obtained on the 'check' is found to be similar to the original, a complete curve shall be run on the soil in question using LDH Designation : TR 418.

Example:

Suppose after running a one point density the results are: wet density = 118.0 lbs/cu. ft., moisture content = 18.0%. By plotting this point on the Family of Curves and extrapolating to the peak, it shows a point which is approximately 1/2 way between curves 17 and 18. From the chart the dry density for 17 = 102.5 at 19.5% moisture content and 18 = 101.1 at 20.5% moisture content. By interpolation:

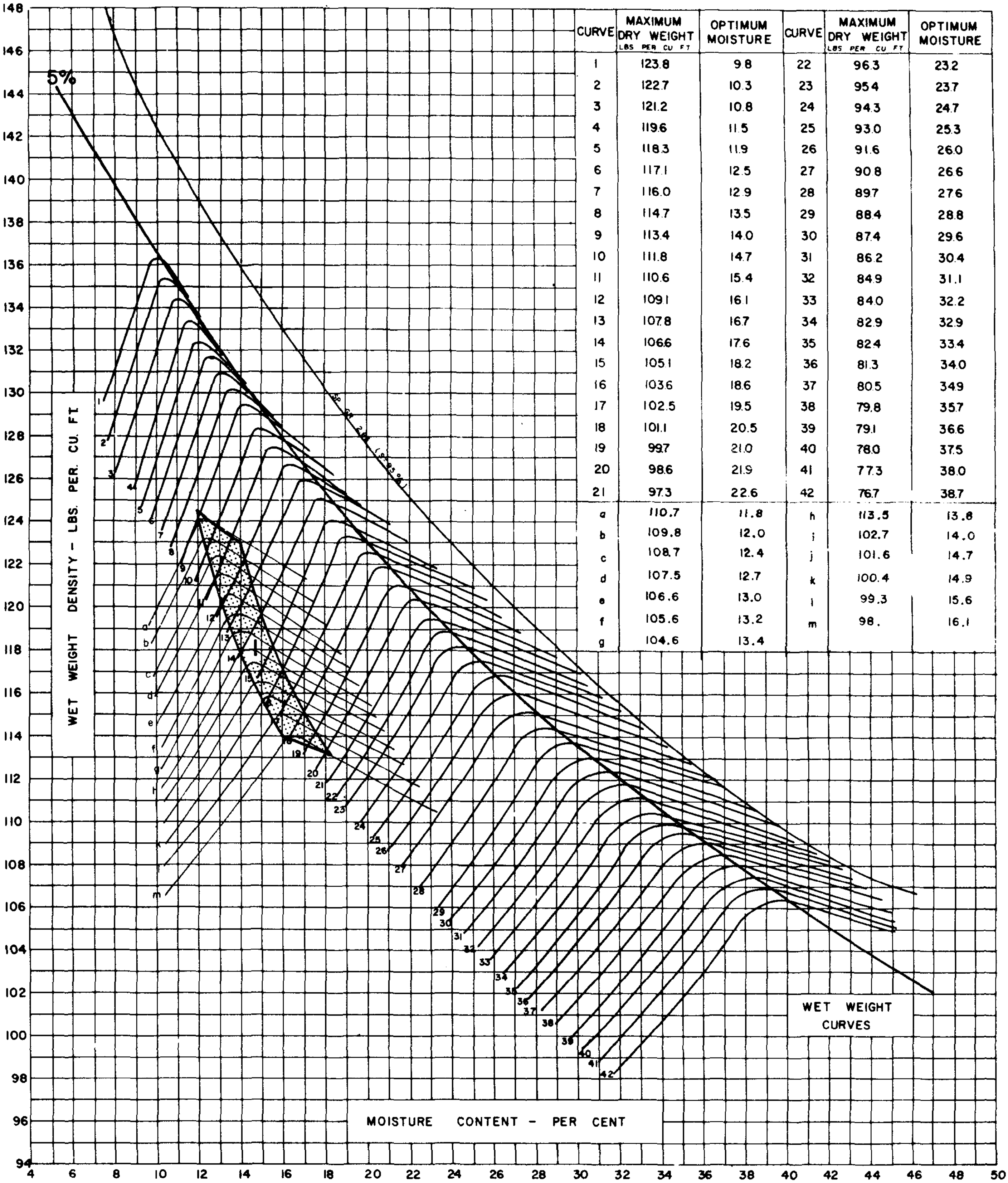
102.5 - 101.1 = 1.4 x .50 = 0.7 lbs/cu. ft. difference in density and;

20.5% - 19.5% = 1.0% x .50 = 0.5% difference in moisture content, thus;

102.5 - 0.7 = 101.8 or 101.1 + 0.7 = 101.8 lbs/cu. ft. and 20.5 - 0.5 = 20% or 19.5 + 0.5 = 20% moisture content, therefore;

maximum dry density = 101.8 lbs/cu. ft.
optimum moisture = 20%

Figure 7



CURVE	MAXIMUM DRY WEIGHT LBS PER CU FT	OPTIMUM MOISTURE	CURVE	MAXIMUM DRY WEIGHT LBS PER CU FT	OPTIMUM MOISTURE
1	123.8	9.8	22	96.3	23.2
2	122.7	10.3	23	95.4	23.7
3	121.2	10.8	24	94.3	24.7
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5	118.3	11.9	26	91.6	26.0
6	117.1	12.5	27	90.8	26.6
7	116.0	12.9	28	89.7	27.6
8	114.7	13.5	29	88.4	28.8
9	113.4	14.0	30	87.4	29.6
10	111.8	14.7	31	86.2	30.4
11	110.6	15.4	32	84.9	31.1
12	109.1	16.1	33	84.0	32.2
13	107.8	16.7	34	82.9	32.9
14	106.6	17.6	35	82.4	33.4
15	105.1	18.2	36	81.3	34.0
16	103.6	18.6	37	80.5	34.9
17	102.5	19.5	38	79.8	35.7
18	101.1	20.5	39	79.1	36.6
19	99.7	21.0	40	78.0	37.5
20	98.6	21.9	41	77.3	38.0
21	97.3	22.6	42	76.7	38.7
a	110.7	11.8	h	113.5	13.8
b	109.8	12.0	i	102.7	14.0
c	108.7	12.4	j	101.6	14.7
d	107.5	12.7	k	100.4	14.9
e	106.6	13.0	l	99.3	15.6
f	105.6	13.2	m	98.	16.1
g	104.6	13.4			

TYPICAL MOISTURE - DENSITY CURVES

Method of Compaction LDH TR: 418 Maximum size aggregate - Minus #4 material only

RESEARCH PUBLICATIONS

1. Concrete Pavement Research. H. L. Lehmann and C. M. Watson, Part I (1956), Part II (1958).

2. Use of Self-Propelled Pneumatic-Tired Rollers in Bituminous Construction and Recommended Procedures. A Special Report, 1958.

3. Use of Explanded Clay Aggregate in Bituminous Construction. H. L. Lehmann and Verdi Adam, 1959.

4. Application of Marshall Method in Hot Mix Design. Verdi Adam, 1959.

5. Effect of Viscosity in Bituminous Construction. Verdi Adam, 1961.

6. Slab Breaking and Seating on Wet Subgrades with Pneumatic Roller. J. W. Lyon, Jr., January 1963.

7. Lightweight Aggregate Abrasion Study. Hollis B. Rushing, Research Project No. 61-7C, February 1963.

8. Texas Triaxial R-Value Correlation. Harry L. Roland, Jr., Research Project No. 61-1S, March 1963.

9. Asphaltic Concrete Pavement Survey. S. C. Shah, Research Project No. 61-1B, April 1963.

10. Compaction of Asphaltic Concrete Pavement with High Intensity Pneumatic Roller. Part I. Verdi Adam, S. C. Shah and P. J. Arena, Jr., Research Project No. 61-7B, July 1963.

11. A Rapid Method of Soil Cement Design. Harry L. Roland, Jr., Ali S. Kemahlioglu, Research Project No. 61-8S, March 1964.

12. Correlation of the Manual Compaction Manner with Mechanical Hammers for the Marshall Method of Design for Asphaltic Concrete. P. J. Arena, Jr. Research Project No. 63-1B, September 1964.

13. Nuclear Method for Determining Soil Moisture and Density. Harry L. Roland, Jr., Research Project No. 62-1S, November 1964.

14. Service Temperature Study for Asphaltic Concrete. P. J. Arena, Jr. Research Project No. 61-3B, October 1964.

15. Quality Control Analysis. S. C. Shah, Research Project No. 63-1G, November, 1964.

16. Typical Moisture-Density Curves. C. M. Higgins, Research Project No. 61-11S, May 1965.

Louisiana
DEPARTMENT OF HIGHWAYS
P. O. BOX 4245, CAPITOL STATION
BATON ROUGE, LA. 70804

IN REPLY PLEASE REFER TO
FILE NO.

September 13, 1965

TYPICAL MOISTURE-DENSITY CURVES
RESEARCH PROJECT NO. 61-11S
LOUISIANA HPR 1(3)

Materials Engineers
American Association of State
Highway Officials

Enclosed is a report entitled, TYPICAL MOISTURE-DENSITY CURVES.

This report is concerned with the development of a family of compaction curves covering most untreated soils used for highway construction in Louisiana This concept is being successfully used in routine construction control in Louisiana.

Any comments or suggestions concerning this report are invited.

Very truly yours,

Verdi Adam
Research & Development Engineer

VA:kll

Enclosure

Louisiana
DEPARTMENT OF HIGHWAYS
P. O. BOX 4245, CAPITOL STATION
BATON ROUGE, LA. 70804

IN REPLY PLEASE REFER TO
FILE NO.

September 13, 1965

TYPICAL MOISTURE-DENSITY CURVES
RESEARCH PROJECT NO. 61-11S
LOUISIANA HPR 1(3)

Mr. Lyman G. Youngs
Division Engineer
Bureau of Public Roads
3444 Convention Street
Baton Rouge, Louisiana

Dear Mr. Youngs:

Enclosed are 104 copies of the final report for the captioned project entitled, TYPICAL MOISTURE-DENSITY CURVES.

We have made arrangements to distribute this report to the Materials Engineers of the AASHO.

This report is concerned with the development of a family of compaction curves covering most untreated soils used for highway construction in Louisiana.

Very truly yours,

Verdi Adam
Research & Development Engineer

VA:kll
Enclosures
cc: Mr. E. J. James
Mr. T. W. Parish, Jr.
Mr. A. D. Jackson
Mr. Oren Baker
Mr. J. B. Carter
Section Heads - Engineering
Mr. C. W. Burns
All District Engineers
All District Lab. Engineers
All Project Engineers
Mr. D. D. McDuff
Mr. A. S. Kemahlioglu
Advisory Research Council
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Louisiana Highway Research

TYPICAL MOISTURE DENSITY CURVES

Louisiana Department of Highways - Research Unit

TYPICAL MOISTURE - DENSITY CURVES

by

C. M. HIGGINS
Soils Research Engineer

Research Report No. 16

Interim Report No. 3

Research Project No. 61-11S

Conducted by
LOUISIANA DEPARTMENT OF HIGHWAYS
Research Unit
in Cooperation with
U.S. Department of Commerce
BUREAU OF PUBLIC ROADS

May 1965

SYNOPSIS

This report is concerned with the development of a family of compaction curves covering most untreated soils used for highway construction in Louisiana.

The soils which were investigated in formulating the family of curves are from all sections of the State and encompass a wide variety of soils that are commonly used for highway construction.

The combined family of compaction curves is satisfactory for use with almost all untreated soils from sand to heavy clay. An adequate laboratory check should be made at the beginning of each project to insure that the soils to be used on the project do fit the family of curves. The curves are for use with material passing the #4 screen.

This family of curves results in a considerable saving of time with little, if any, loss in accuracy.

This family of curves, with proper laboratory precautions to assure that the soils will fit the family, will be used for raw soil compaction control on all Louisiana projects.

ACKNOWLEDGEMENTS

This study was initiated in 1962 under the general supervision of Mr. A. S Kemahlioglu then the Soils Research Engineer. Later it was continued under the supervision of Mr. Harry L. Roland, Soils Research Geologist. The development of the curves was accomplished largely through their efforts.

USE OF TYPICAL MOISTURE - DENSITY CURVES

INTRODUCTION

One of the many problems associated with compaction control on any construction project is the time consuming task of obtaining maximum density and optimum moisture content of soils both in the laboratory and in the field. In addition to the time element, there seems to be a relatively large operator variance in performing this particular aspect of materials control.

In order to eliminate most of the time consuming work and to obtain results which are somewhat more uniform in character, the Soils Research Unit of the Louisiana Department of Highways undertook the task of developing a family of curves from which maximum density and optimum moisture content could be obtained by determining only one point on a curve for a given soil.

The primary family of curves (Figure 1) was developed and submitted to the field in February, 1963. This curve was developed by plotting approximately 1,000 moisture-density curves taken from the files.

A supplemental family of curves designed to cover those materials which would not fit the original family was developed in the same general manner. (Figure 2) However, two basic causes have deterred checking the accuracy of the family for these materials, namely: (1) comparatively few of these curves are encountered and (2) there is a transition zone where it is extremely difficult to classify the material so as to decide which family to use. (Figure 4)

The soils which fit into this supplemental category are generally somewhat granular in nature, however, there appears to be no practicable field method of distinguishing the materials in this category by soil type from those which fit the main family of curves.

SCOPE

This research program was instigated in an attempt to eliminate some of the time consuming work of obtaining maximum density and optimum moisture content of Louisiana soils in the laboratory and in the field.

The investigation was set up to encompass two phases: (1) an evaluation of the available data to produce a set of typical moisture-density curves, and (2) laboratory and field checks of the developed set of curves.

This report, in effect, is a final report on the untreated soils portion of this research project, however, the checking process shall be continued for an indefinite period. An investigation is being made as to the feasibility of using this family of curves for lime treated soils. The results of this investigation will be given in a separate report.

MATERIALS TESTED AND TEST PROCEDURES USED

All types of soils from every Highway District in the State are well represented due to the process of random selection. The method of compaction used in this study was LDH-TR 418-61 (Method A) which, it must be emphasized, calls for using only that fraction of material passing the No. 4 sieve.

The procedure used to develop the Family of Curves was as follows:

Approximately 1,000 moisture-density curves were randomly selected from the files and plotted with wet density as the ordinate and moisture content (per cent of dry weight) as the abscissa. The optimum moisture contents and maximum wet densities were then tabulated for each two pound increment of density. The densities within these increments were then averaged and those values for these increments that were not within plus or minus 10 per cent of the mean were discarded and the remainder reaveraged for maximum density and optimum moisture content. In addition, the densities were averaged at each of several moisture contents to determine an average slope for each curve.

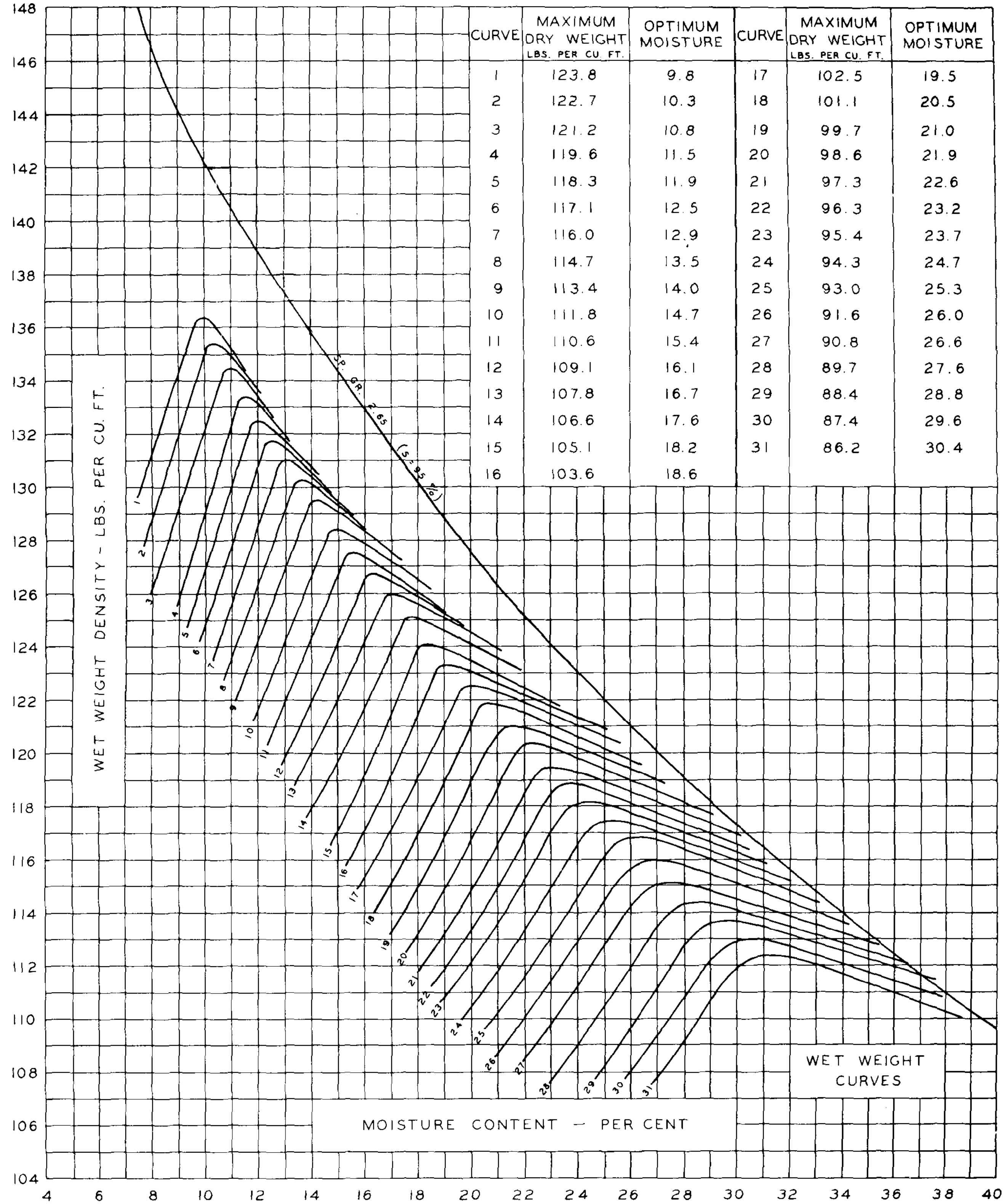
After developing a rather rough set of curves 100 curves were selected at random from the files and checked against the Family for accuracy. It was noted at this point that a minor adjustment was needed to improve its precision.

After this adjustment, another 100 curves were selected at random and plotted. This produced a seemingly satisfactory degree of accuracy (Figure 1). The family of curves was then distributed to the central and district laboratories with instructions to check each normally run curve against the family of curves to determine the applicability of the family to the soils being used in these areas. This check was made by picking a point from the curve that was being run which was near optimum moisture and plotting on the family of curves. The maximum densities and optimum moistures obtained by the two methods were then compared. After this comparison process was instituted it was felt that the family of curves should be expanded to include those materials with low density and high optimum moisture content which were prevalent in some areas. This expanded

NOT TO BE USED FOR SANDS

Figure 1

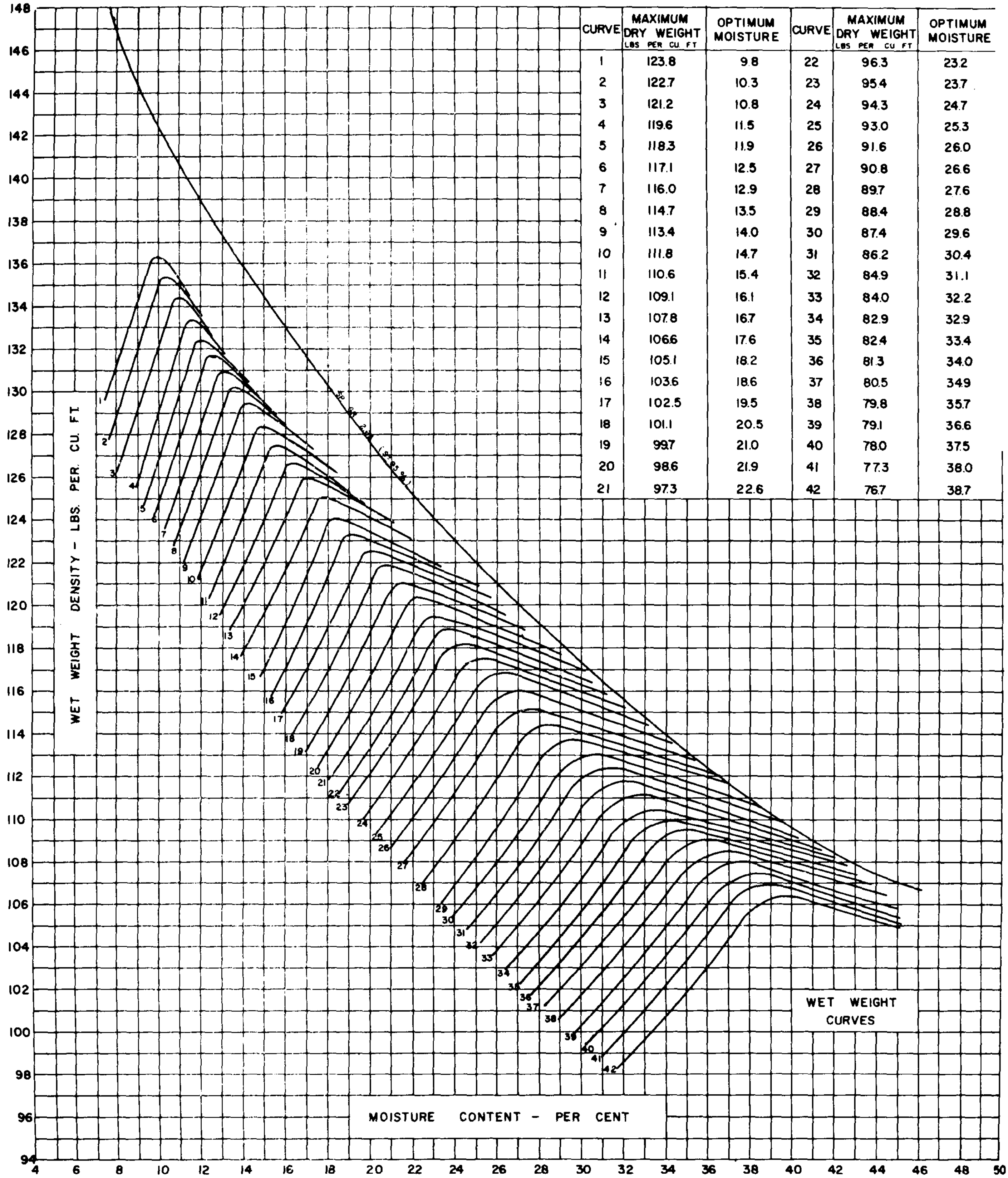
January 1963



CURVE	MAXIMUM DRY WEIGHT LBS. PER CU. FT.	OPTIMUM MOISTURE	CURVE	MAXIMUM DRY WEIGHT LBS. PER CU. FT.	OPTIMUM MOISTURE
1	123.8	9.8	17	102.5	19.5
2	122.7	10.3	18	101.1	20.5
3	121.2	10.8	19	99.7	21.0
4	119.6	11.5	20	98.6	21.9
5	118.3	11.9	21	97.3	22.6
6	117.1	12.5	22	96.3	23.2
7	116.0	12.9	23	95.4	23.7
8	114.7	13.5	24	94.3	24.7
9	113.4	14.0	25	93.0	25.3
10	111.8	14.7	26	91.6	26.0
11	110.6	15.4	27	90.8	26.6
12	109.1	16.1	28	89.7	27.6
13	107.8	16.7	29	88.4	28.8
14	106.6	17.6	30	87.4	29.6
15	105.1	18.2	31	86.2	30.4
16	103.6	18.6			

TYPICAL MOISTURE – DENSITY CURVES

Method of Compaction: LDH Designation: TR 418-61(Method A) Maximum Size Aggregate: Minus 4 Material Only



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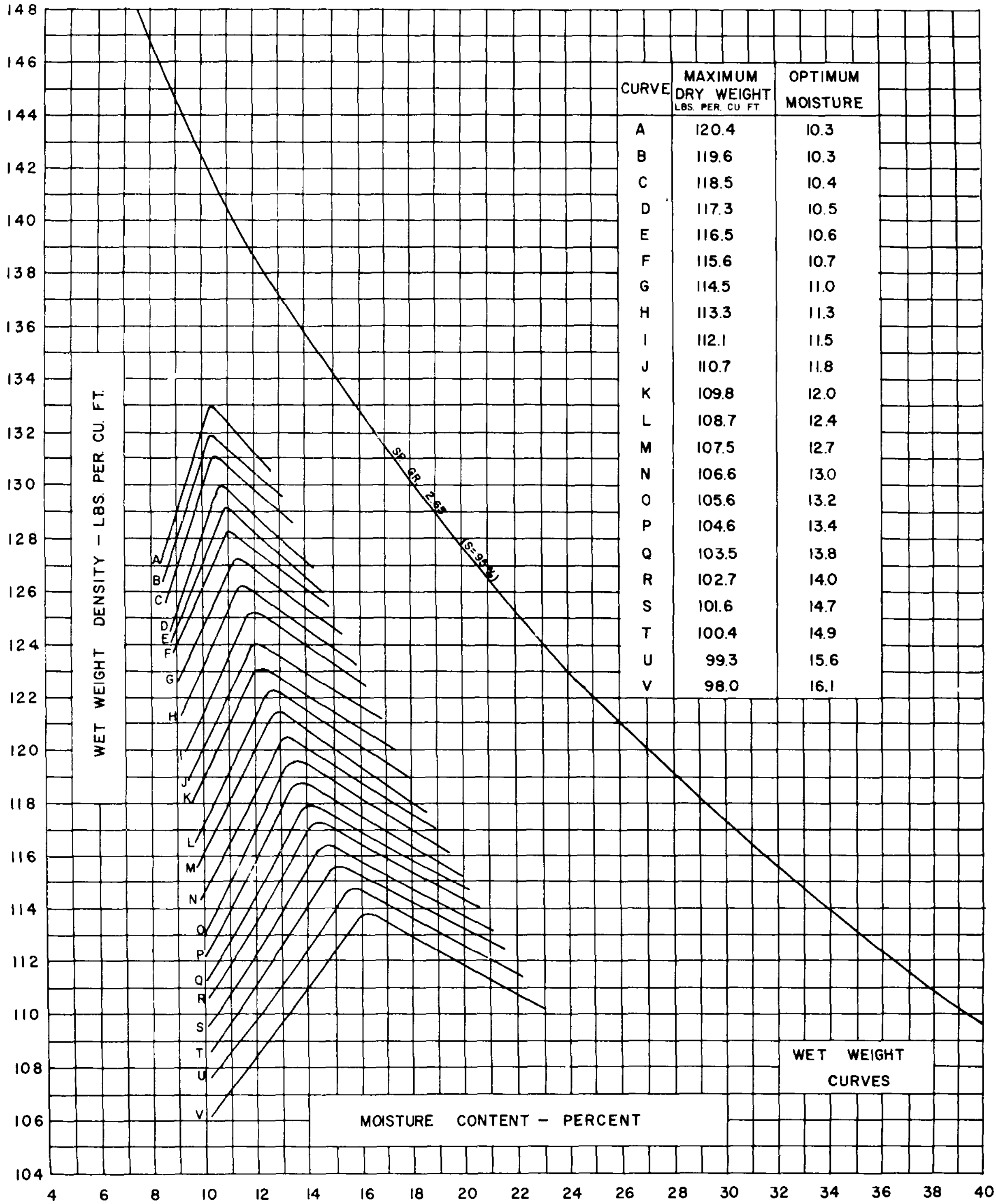
14	106.6	17.6	35	82.4	33.4
15	105.1	18.2	36	81.3	34.0
16	103.6	18.6	37	80.5	34.9
17	102.5	19.5	38	79.8	35.7
18	101.1	20.5	39	79.1	36.6
19	99.7	21.0	40	78.0	37.5
20	98.6	21.9	41	77.3	38.0
21	97.3	22.6	42	76.7	38.7

TYPICAL MOISTURE - DENSITY CURVES

Method of compaction: LDH Designation: TR 418-61 (Method A) - Maximum Size Aggregate: Minus 4 Material Only

Figure 2



CURVE	MAXIMUM DRY WEIGHT LBS. PER. CU. FT.	OPTIMUM MOISTURE
A	120.4	10.3
B	119.6	10.3
C	118.5	10.4
D	117.3	10.5
E	116.5	10.6
F	115.6	10.7
G	114.5	11.0
H	113.3	11.3
I	112.1	11.5
J	110.7	11.8
K	109.8	12.0
L	108.7	12.4
M	107.5	12.7
N	106.6	13.0
O	105.6	13.2
P	104.6	13.4
Q	103.5	13.8
R	102.7	14.0
S	101.6	14.7
T	100.4	14.9
U	99.3	15.6
V	98.0	16.1

TYPICAL MOISTURE – DENSITY CURVES

Method of Compaction: LDH Desig: TR 418-61 (Method A) Max. Size Agg: Minus 4 Material Only.

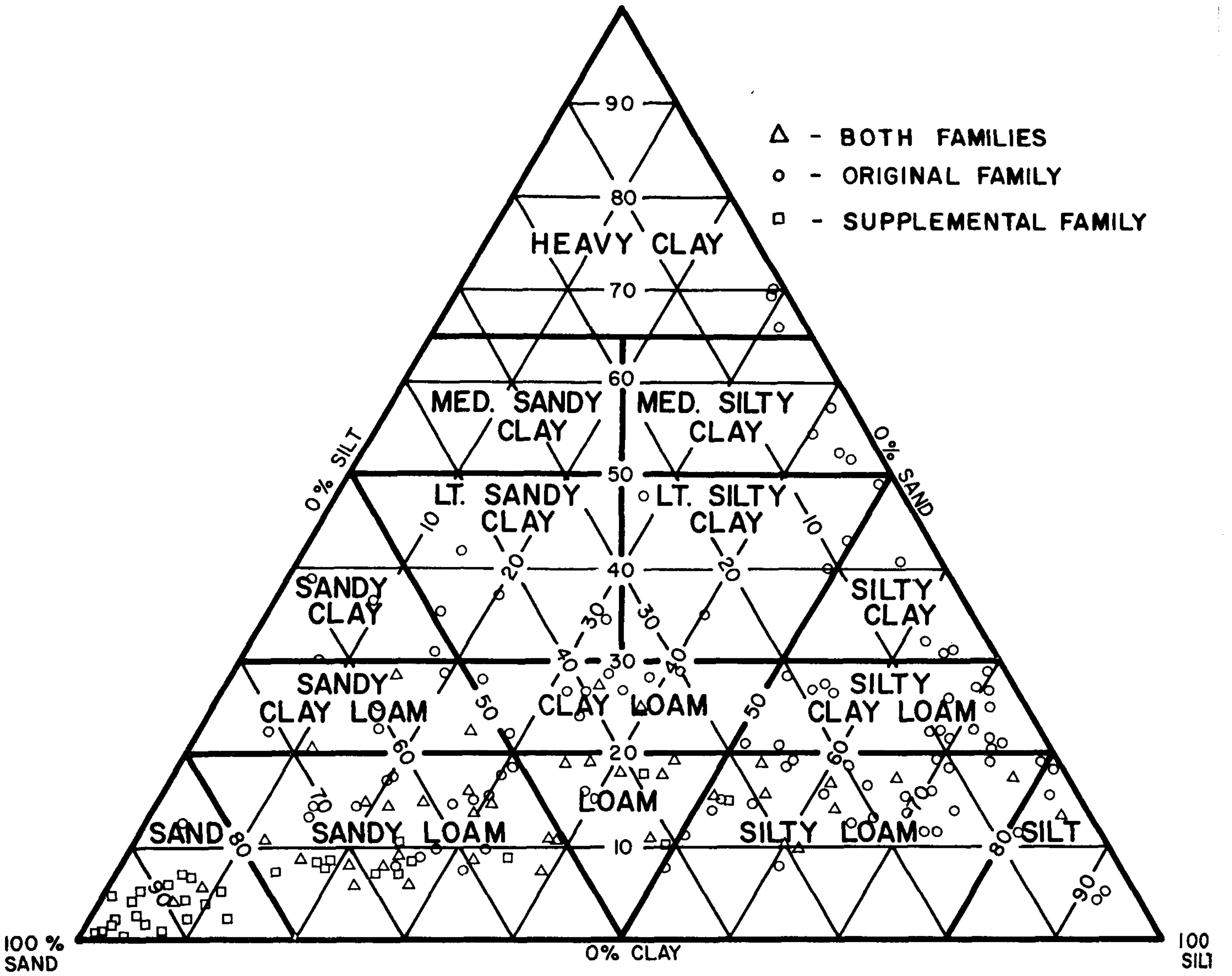


Figure 3 - Graphical illustration of the Classification of Soils that fit both families, the Original Family (Figure 1A) and the Supplemental Family (Figure 2).

family is shown in Figure 1A.

In the development of the curves of Figures 1 and 1A, it was noted that many sandy materials, (that is materials in the sand or sandy loam classifications) did not fit these series of curves (Figures 1 and 1A). These materials showed optimum moistures considerably less that those shown in Figures 1 and 1A for the same density. In order to attempt to include these materials a supplemental family of curves was prepared (Figure 2). Approximately 100 curves were used to develop the family as shown in Figure 2. It should be noted at this point that although most of the soils which fit this supplemental family of Figure 2 are sandy soils, all sandy soils do not fit the supplemental family. (Figure 3) Many sandy soils satisfactorily fit the major family of curves shown in Figure 1A. A total of 1618 curves have been checked with 1560 of these most nearly coinciding with the family of curves shown in Figure 1A, and 58 most nearly coinciding with the supplemental family of curves shown in Figure 2. The following is a summary of the accuracy check information:

FAMILY OF CURVES SHOWN IN FIGURE 1A

	Maximum Dry Density % within			Optimum Moisture Content % within		
No. Samples	±2 lbs.	±3 lbs.	3^+lbs.	±1%	±2%	2^+%
1560	93% (1456)	98% (1534)	2% (26)	76% (1183)	95% (1485)	5% (75)

% of curves within ±2 pounds density and ±1% opt. moisture = 75% (1163)
±2 ±2% = 92% (1435)
±3 ±2% = 95% (1476)

FAMILY OF CURVES SHOWN IN FIGURE 2

	Maximum Dry Density % within			Optimum Moisture Content % within		
No. Samples	±2 lbs.	±3 lbs.	3^+lbs.	±1%	±2%	2^+%
58	97% (56)	97% (56)	3% (2)	74% (43)	100% (58)	0 (0)

% of curves within ±2 pounds density and ±1% opt. moisture = 83% (48)
±2 ±2% = 97% (56)
±3 ±2% = 97% (56)

FAMILY OF CURVES OF FIGURES 1A & 2 COMBINED

	Maximum Dry Density			Optimum Moisture Conte		
	% within			% within		
No. Samples	±2 lbs.	±3 lbs.	3^+lbs.	±1%	±2%	2
1618	93% (1512)	98% (1590)	2% (28)	76% (1226)	95% (1543)	59 (75

% of curves within ±2 pounds density and ±1% opt. moisture = 75% (1211)
±2 ±2% = 92% (1491)
±3 ±2% = 95% (1532)

The percentage of curves fitting each family is as shown below:

Family	No.	Per Cent
Figure 1A	1476	92
Figure 2	56	3
Neither	86	5

DISCUSSION OF RESULTS

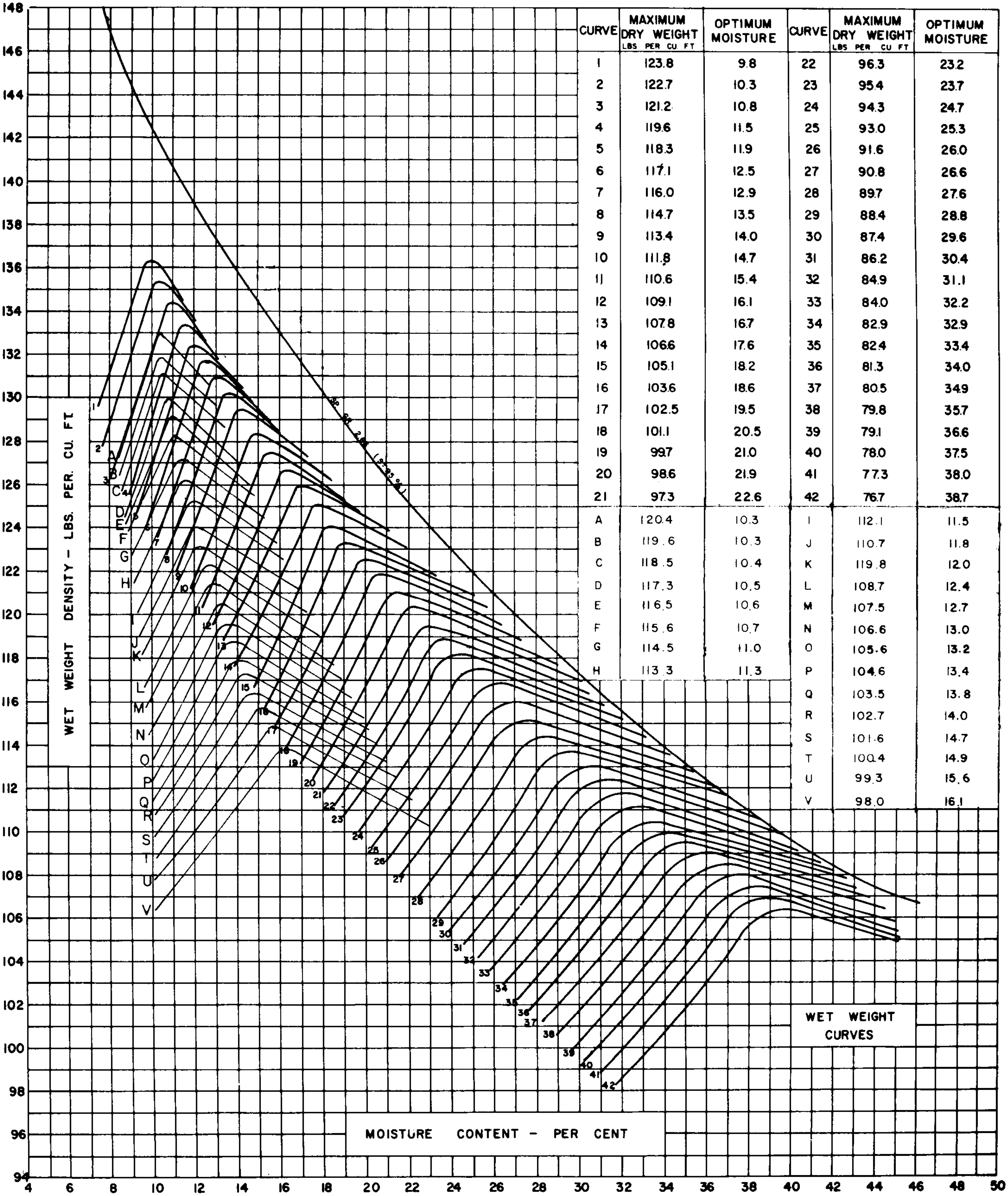
For the purposes of this study it is considered that any curve that is within 2% optimum moisture and 3 lbs. dry weight density of the optimum moisture and maximum density of the appropriate curve from the family of curves is a "hit, that is, it may be considered to be identical with the curve from the family without appreciable error. This is considered to be true for the following reasons:

1. Our experience with running curves indicates that duplicate curves run in a normal laboratory manner may quite often deviate from each other by this amount.

2. Assuming a perfectly run laboratory curve it is probable that deviation from this curve to the above mentioned extent would not be appreciably detrimental to the roadway.

An analysis of Figure 4 reveals that there is a definite overlapping of the curve of Figure 1A and Figure 2 in the area of higher wet densities. That is, the optimum moistures and maximum densities of the supplemental family of curve

Figure 4



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9	113.4	14.0	30	87.4	29.6
10	111.8	14.7	31	86.2	30.4
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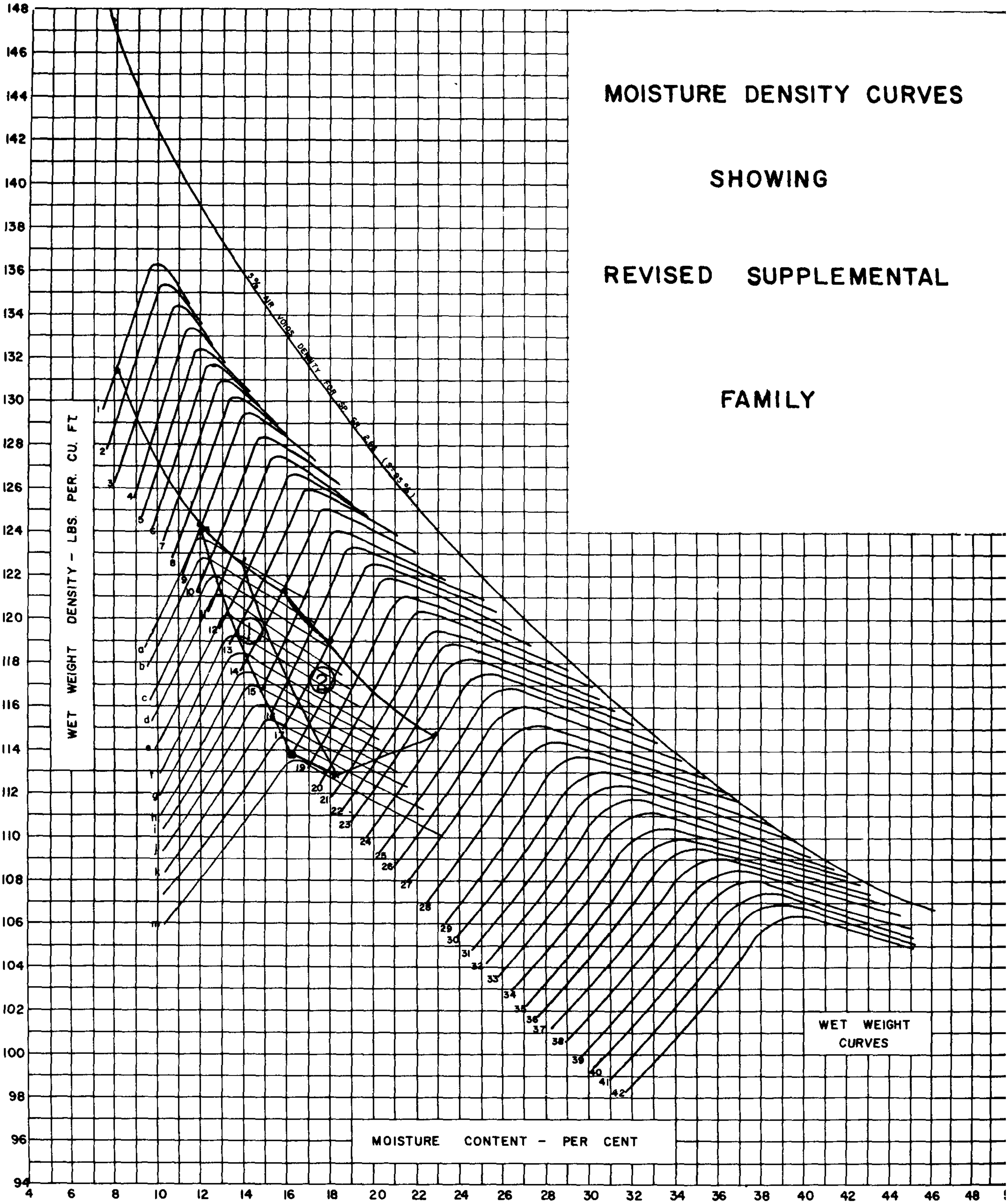
15	105.1	18.2	36	81.3	34.0
16	103.6	18.6	37	80.5	34.9
17	102.5	19.5	38	79.8	35.7
18	101.1	20.5	39	79.1	36.6
19	99.7	21.0	40	78.0	37.5
20	98.6	21.9	41	77.3	38.0
21	97.3	22.6	42	76.7	38.7
A	120.4	10.3	I	112.1	11.5
B	119.6	10.3	J	110.7	11.8
C	118.5	10.4	K	119.8	12.0
D	117.3	10.5	L	108.7	12.4
E	116.5	10.6	M	107.5	12.7
F	115.6	10.7	N	106.6	13.0
G	114.5	11.0	O	105.6	13.2
H	113.3	11.3	P	104.6	13.4
			Q	103.5	13.8
			R	102.7	14.0
			S	101.6	14.7
			T	100.4	14.9
			U	99.3	15.6
			V	98.0	16.1

TYPICAL MOISTURE - DENSITY CURVES

Family of Figure 1A shown in black - Family of Figure 2 shown in red.

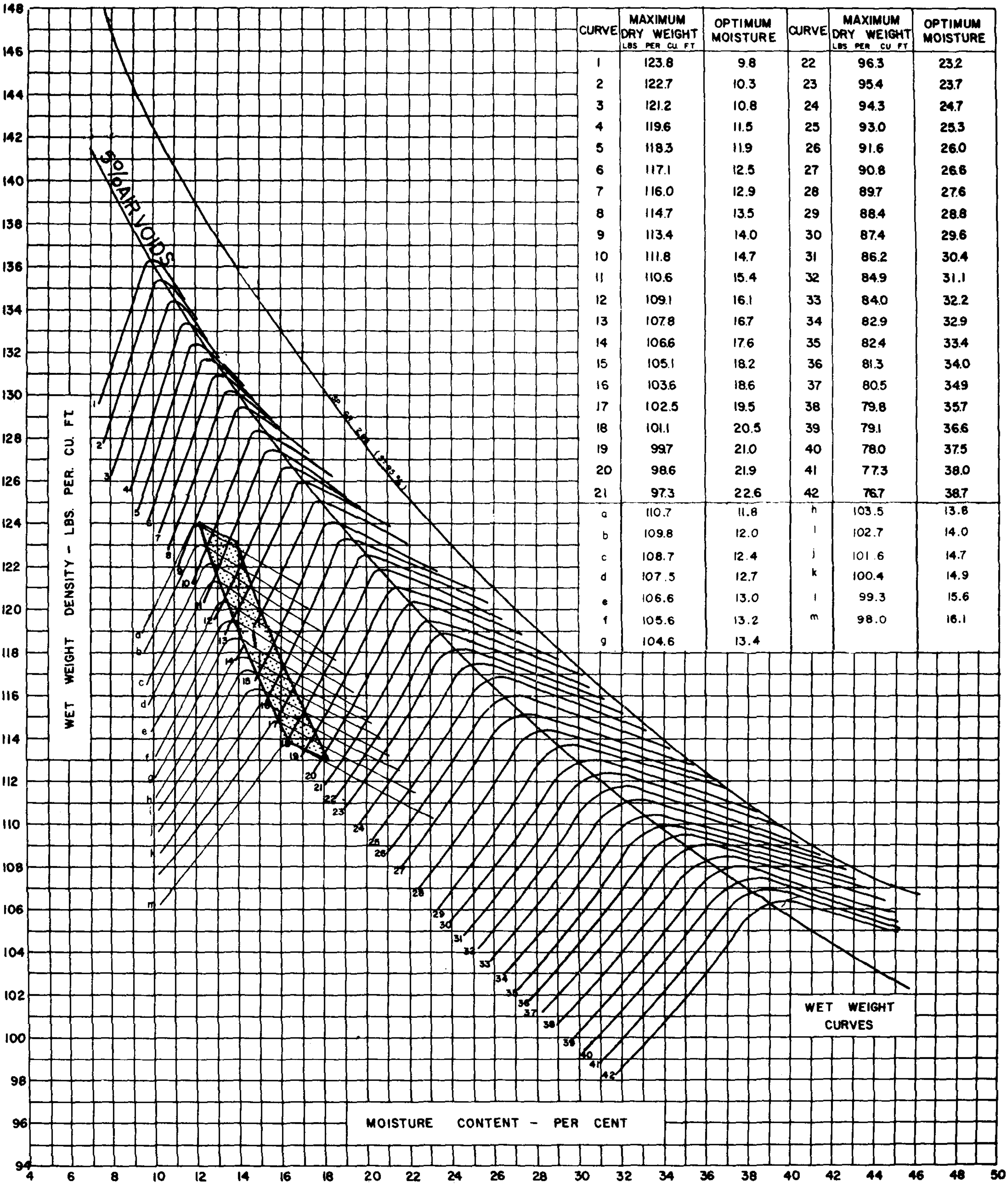
Figure 6



TYPICAL MOISTURE - DENSITY CURVES

Family of Figure 1A shown in black - Family of Figure 2 shown in red.

Figure 7



CURVE	MAXIMUM DRY WEIGHT LBS PER CU FT	OPTIMUM MOISTURE	CURVE	MAXIMUM DRY WEIGHT LBS PER CU FT	OPTIMUM MOISTURE
1	123.8	9.8	22	96.3	23.2
2	122.7	10.3	23	95.4	23.7
3	121.2	10.8	24	94.3	24.7
4	119.6	11.5	25	93.0	25.3
5	118.3	11.9	26	91.6	26.0
6	117.1	12.5	27	90.8	26.6
7	116.0	12.9	28	89.7	27.6
8	114.7	13.5	29	88.4	28.8
9	113.4	14.0	30	87.4	29.6
10	111.8	14.7	31	86.2	30.4
11	110.6	15.4	32	84.9	31.1
12	109.1	16.1	33	84.0	32.2
13	107.8	16.7	34	82.9	32.9
14	106.6	17.6	35	82.4	33.4
15	105.1	18.2	36	81.3	34.0
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21	97.3	22.6	42	76.7	38.7
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b	109.8	12.0	i	102.7	14.0
c	108.7	12.4	j	101.6	14.7
d	107.5	12.7	k	100.4	14.9
e	106.6	13.0	l	99.3	15.6
f	105.6	13.2	m	98.0	16.1
g	104.6	13.4			

TYPICAL MOISTURE - DENSITY CURVES

Method of Compaction LDH TR: 418 Maximum size aggregate - Minus #4 material only.

additional point be run after the addition of water to the soil. This point should adequately determine which curve should be used.

Figure 8 shows the final family of curves (Figure 7) with the 0, 5, and 10% air voids lines and the 95% saturation line shown. Air voids as shown are a percentage of the total volume of the sample and the per cent saturation is, of course, based on the per cent of total voids filled with water. It is interesting to note that the 5% air voids line follows very closely the peak of the curves in the major family. The fact that the line of maximum density is also very nearly a line of consistent voids gives rise to interesting possibilities for compaction control based on voids control. The soils of the supplemental portion of the family, however, do not seem to bear a direct ratio to the per cent voids. Since the 5% voids line is so nearly coincidental with the peaks of the curves of the major family and since field proctor points on the dry side of optimum are desired; this line is shown on the final family of curves and the revised procedure for use of the family of curves requires that proctor points fall to the left of this line. In general, if points are molded which fall to the right of this line, a new point will be run at a lower moisture content. However, an exception must be made for those soils having high clay contents and relatively flat curves which cannot be readily dried and handled in the field due to creation of a cloddy condition which gives rise to large voids in the proctor. Proctors for these soils will be molded as near to optimum as is practicable.

CONCLUSIONS

1. A family of curves for use with raw soils has been developed.

2. This family of curves has proved practical for field use.

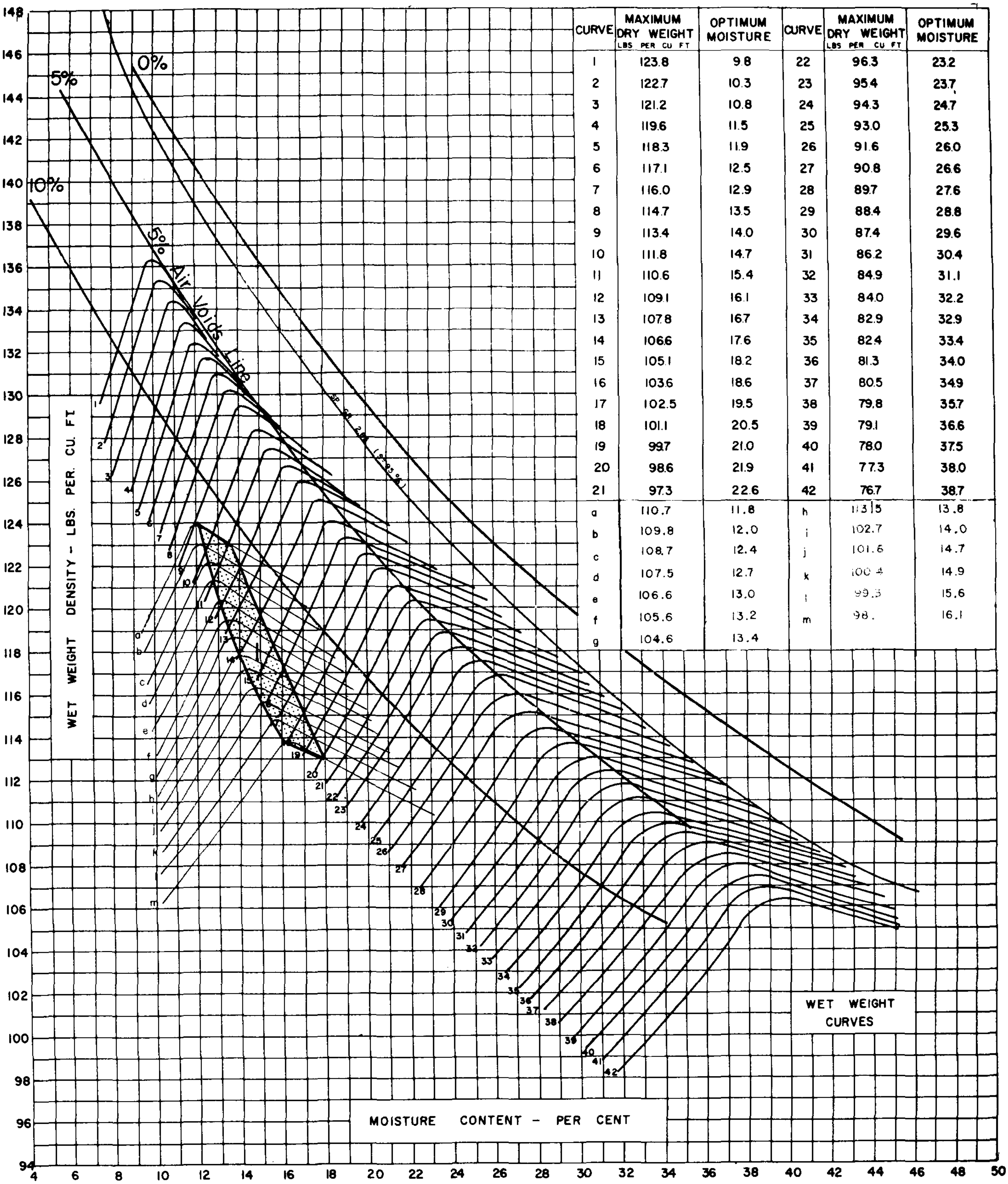
3. Considerable confusion of field personnel has been eliminated by the simplified process of the family of curves.

4. Approximately 95% of the laboratory curves checked fit the family of curves.

5. Field results using the family of curves have been satisfactory. It is probable that greater accurracy in picking optimum moisture and maximum density is obtained using the family of curves and there is a considerable saving of time.

6. This family of curves, with proper laboratory precautions to assure that the soils will fit the family, will be used for raw soil compaction control on all Louisiana projects.

Figure 8



CURVE	MAXIMUM DRY WEIGHT LBS PER CU FT	OPTIMUM MOISTURE	CURVE	MAXIMUM DRY WEIGHT LBS PER CU FT	OPTIMUM MOISTURE
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11	110.6	15.4	32	84.9	31.1
12	109.1	16.1	33	84.0	32.2
13	107.8	16.7	34	82.9	32.9
14	106.6	17.6	35	82.4	33.4
15	105.1	18.2	36	81.3	34.0
16	103.6	18.6	37	80.5	34.9
17	102.5	19.5	38	79.8	35.7
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19	99.7	21.0	40	78.0	37.5
20	98.6	21.9	41	77.3	38.0
21	97.3	22.6	42	76.7	38.7
a	110.7	11.8	h	113 5	13.8
b	109.8	12.0	i	102.7	14.0
c	108.7	12.4	j	101.6	14.7
d	107.5	12.7	k	100.4	14.9
e	106.6	13.0	l	99.3	15.6
f	105.6	13.2	m	98.	16.1
g	104.6	13.4			

TYPICAL MOISTURE - DENSITY CURVES

Showing 0, 5 & 10% air voids line and 95% saturation line .

APPENDIX

Tentative Method of Determination of

MOISTURE-DENSITY RELATIONSHIP USING FAMILY OF CURVES

LDH Designation: TR 415-64

Scope

1. This method of test is intended to determine the relationship between the moisture content of soils and resulting densities (oven-dry weight per cu. ft.) utilizing the family of moisture-density curves (Fig. 7), when the soil is compacted as specified herein. It is intended to be used as an accurate short cut procedure for LDH Designation: TR 418 and TR 401, and is to be used with the minus No. 4 material of soils only.

Apparatus

2. The apparatus shall consist of the following:

(a) Mold. - A cylindrical metal mold having a capacity of 1/30 cu. ft. (0.0333 cu. ft.) with an internal diameter of 4.0 inches (± 0.005 in) and a height of 4.584 ± 0.005 inches, which has a detachable collar approximately 2 1/2 inches in height. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base plate. Molds shall be replaced if the diameter is more than 4.01 inches or the height is less than 4.50 inches on any side.

(b) Compactive device. - A metal rammer having a 2.00 ±0.01 inch diameter circular face or a segment of a 2-inch radius circle with an equivalent area and weighing 5.50 ± 0.50 lb. The rammer shall be equipped with an arrangement to control the height of drop to 12.0 ± 0.1 inches.

(c) Straightedge - A steel straightedge

(d) Balances - A balance or scale of 25 lb. capacity sensitive to 0.01 lb. (or equivalent metric balance), and a 500 gram capacity balance sensitive to 0.1 gram.

(e) Drying Apparatus - A thermostatically controlled drying oven capable of maintaining temperatures of 100° C ± 5° C • (230°±9°F) for drying moisture samples. A hot plate or an approved Speedy Moisture Device may be used for moisture determinations in the field.

(f) Sieve - A number 4 sieve conforming to the requirements of the Standard Specifications for Sieves for Testing Purposes (AASHO Designation: M 92).

(g) Mixing Tools - Miscellaneous tools such as mixing, pan, spoon, trowel, spatula, etc. or a suitable mechanical device for mixing thoroughly the sample of soil with water.

(h) Graduated Cylinder (250 cc) - For measuring water to be added to sample. (For Central Laboratory and Dist. Labs.)

Sample

3. (a) A representative sample of soil weighing approximately 6 lbs. (or 2724 grams) shall be taken for each one-point Proctor.

Procedure

4. (a) The 6 lb. sample shall be thoroughly mixed with sufficient water to bring the sample to slightly less than its optimum moisture content.

A compacted specimen shall then be formed by compacting the thoroughly mixed soil in the mold (with collar attached) in three equal layers to give a total compacted depth of about 5 inches; each layer being compacted by 25 blows of the rammer dropping free from a height of 12 inches or 12 inches above the approximate elevation of each finally compacted layer when a stationary mounted type of rammer is used. During compaction the mold shall rest on a uniform, rigid foundation. The blows shall be uniformly distributed over the surface of the layer being compacted. After the specimen has been compacted, the collar shall be removed from the mold and the compacted soil carefully trimmed even with the top of the cylinder by means of a straightedge.

(b) The mold containing the compacted soil specimen shall be weighed. This weight minus the weight of the mold shall then be multiplied by 30 and the result recorded as the wet weight per cubic foot of compacted soil.

(c) The base plate shall be detached and the specimen removed from the mold. A representative sample shall be taken from a location near the center of the specimen.

(d) For moisture content determination in the field a 200 gram sample shall be secured as described in "c", weighed immediately and dried to a constant weight by use of a hot plate.

(e) An approved speedy moisture device may be used to determine the moisture content in the field.

(f) For moisture content determination in the Central or District Laboratories not less than a 100 gram sample shall be secured as in "c". This sample shall be weighed immediately and dried in an oven at 110° ± 5° C (230° F ± 9° F) to a constant weight.

Calculations

5. The water content of the soil as compacted shall be calculated as follows:

$$W = \frac{(W_1 - W_2) \times 100}{W_2}$$

where:

W = Moisture content in percent based on weight of oven-dry soil.

W_1 = Weight of wet soil.

W_2 = Weight of oven-dry soil.

Moisture-Density Relationship as Determined From the Family of Typical Moisture-Density Curves

6. The calculations in section 4(b) and in section 5 shall be made to determine the wet density in lbs/cu. ft. and the corresponding water content. These determine a point which may now be plotted on the Family of Curves and extrapolated to arrive at a maximum wet weight and optimum moisture content. When this point falls between two family curves, a minor interpolation is necessary. The maximum dry density in lbs/cu. ft. and the corresponding per cent optimum moisture is then read from the chart or interpolated from the chart (Figure 7).

Precautions

7. (a) Any point falling to the left of Area 1 applies to the supplemental (a-m) portion of the family. Any point falling in area one should be repeated using fresh soil at a higher moisture content. If the density value for this point decreases the point previously run may be used to pick a curve from the (a-m) portion of the family. If the density value for the second point rises the proper curve may be selected from the major (1-42) portion of the family using this point.

(b) The maximum wet density and optimum moisture point should be on the dry side of the curve at or near optimum as it is difficult to interpolate between curves for friable soils when on the wet side of the peak.

(c) When the moisture density values of a compacted material are plotted and found to be to the right of the 5.0% air voids curve, the test should be repeated using a lower moisture content. An exception to this rule must be made for those soils having high clay contents and relatively flat curves. These soils cannot readily be dried to optimum in the field due to the creation of a cloddy condition which will cause voids in the proctor. Proctors for these materials should be made as near to optimum as practicable. When the moisture density value of a compacted material is plotted and found to be to the right of the 95% saturation line the test should be repeated using a new sample.

In the event the result obtained on the 'check' is found to be similar to the original, a complete curve shall be run on the soil in question using LDH Designation : TR 418.

Example:

Suppose after running a one point density the results are: wet density = 118.0 lbs/cu. ft., moisture content = 18.0%. By plotting this point on the Family of Curves and extrapolating to the peak, it shows a point which is approximately 1/2 way between curves 17 and 18. From the chart the dry density for 17 = 102.5 at 19.5% moisture content and 18 = 101.1 at 20.5% moisture content. By interpolation:

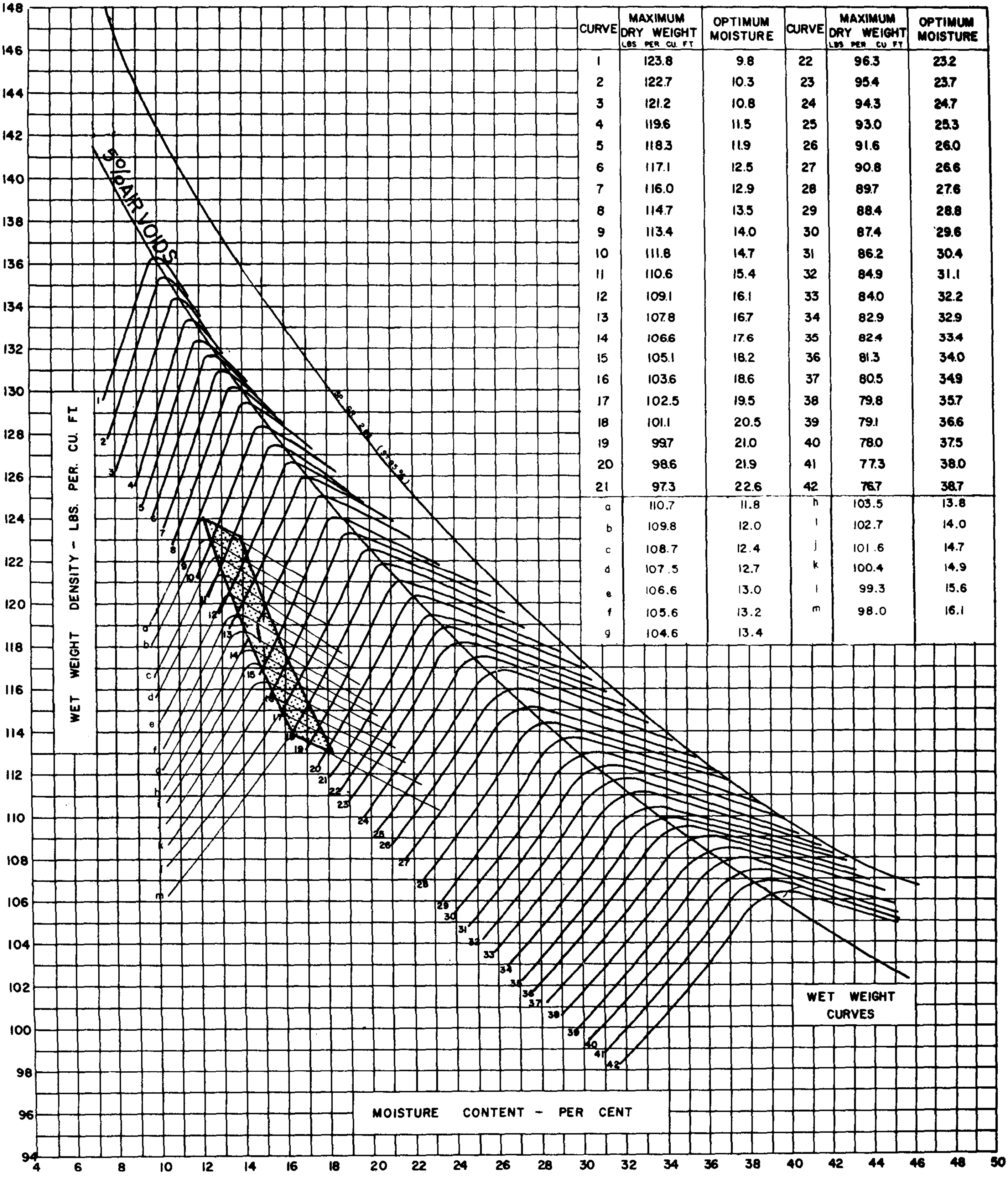
102.5 - 101.1 = 1.4 x .50 = 0.7 lbs/cu. ft. difference in density and;

20.5% - 19.5% = 1.0% x .50 = 0.5% difference in moisture content, thus;

102.5 - 0.7 = 101.8 or 101.1 + 0.7 = 101.8 lbs/cu. ft. and 20.5 - 0.5 = 20% or 19.5 + 0.5 = 20% moisture content, therefore;

maximum dry density = 101.8 lbs/cu. ft.
optimum moisture = 20%

Figure 7



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10	111.8	14.7	31	86.2	30.4
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14	106.6	17.6	35	82.4	33.4
15	105.1	18.2	36	81.3	34.0
16	103.6	18.6	37	80.5	34.9
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18	101.1	20.5	39	79.1	36.6
19	99.7	21.0	40	78.0	37.5
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21	97.3	22.6	42	76.7	38.7
a	110.7	11.8	h	103.5	13.8
b	109.8	12.0	i	102.7	14.0
c	108.7	12.4	j	101.6	14.7
d	107.5	12.7	k	100.4	14.9
e	106.6	13.0	l	99.3	15.6
f	105.6	13.2	m	98.0	16.1
g	104.6	13.4			

TYPICAL MOISTURE - DENSITY CURVES

Method of Compaction LDH TR: 418 *Maximum size aggregate - Minus #4 material only.*

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1. Concrete Pavement Research. H. L. Lehmann and C. M. Watson, Part I (1956), Part II (1958).

2. Use of Self-Propelled Pneumatic-Tired Rollers in Bituminous Construction and Recommended Procedures. A Special Report, 1958.

3. Use of Explanded Clay Aggregate in Bituminous Construction. H. L. Lehmann and Verdi Adam, 1959.

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7. Lightweight Aggregate Abrasion Study. Hollis B. Rushing, Research Project No. 61-7C, February 1963.

8. Texas Triaxial R-Value Correlation. Harry L. Roland, Jr., Research Project No. 61-1S, March 1963.

9. Asphaltic Concrete Pavement Survey. S. C. Shah, Research Project No. 61-1B, April 1963.

10. Compaction of Asphaltic Concrete Pavement with High Intensity Pneumatic Roller. Part I. Verdi Adam, S. C. Shah and P. J. Arena, Jr., Research Project No. 61-7B, July 1963.

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14. Service Temperature Study for Asphaltic Concrete. P. J. Arena, Jr. Research Project No. 61-3B, October 1964.

15. Quality Control Analysis. S. C. Shah, Research Project No. 63-1G, November, 1964.

16. Typical Moisture-Density Curves. C. M. Higgins, Research Project No. 61-11S, May 1965.