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16. ABSTRACT

The practice of transporting and placing earth materials to form fills or embankments for highway construction is older than the term "highway" itself. In fact, the very name was adopted in ancient times to describe the more ambitious roads that had been built up above the surrounding terrain and hence were called "high" ways to distinguish them from the casual paths or byways. It is fairly well known that the construction of a modern highway or airport generally involves the moving of a considerable amount of dirt followed by the shaping and compacting of large areas to receive and support a pavement. Such a shaped and compacted area is called a subgrade. With higher standards of alignment and expansion of multilane freeways, the quantities of earth that must be moved often become tremendous, usually measured and paid for in the form of excavation.

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

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By

F.N. Hveem

Materials and Research Engineer

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F. N. Hveem*

The practice of transporting and placing earth materials to form fills or embankments for highway construction is older than the term "highway" itself. In fact, the very name was adopted in ancient times to describe the more ambitious roads that had been built up above the surrounding terrain and hence were called "high" ways to distinguish them from the casual paths or byways. It is fairly well known that the construction of a modern highway or airport generally involves the moving of a considerable amount of dirt followed by the shaping and compacting of large areas to receive and support a pavement. Such a shaped and compacted area is called a subgrade. With higher standards of alignment and expansion of multilane freeways, the quantities of earth that must be moved often become tremendous, usually measured and paid for in the form of excavation.

For centuries, embankments were constructed by the most simple and direct methods, using hand-barrows or horse-drawn scrapers operating from side borrow pits. With the development of motorized equipment, longitudinal haul became more prevalent,

*Materials and Research Engineer, California Division of Highways

moving material from the cuts and dumping it into the appropriate low areas that need to be brought up to grade. The construction of fills by end dumping methods continued into comparatively modern times and in certain cases is still the only feasible method. However, with improved standards of alignment and the necessity for constructing higher fills, resulting settlements and subsidence became serious and these settlements were especially undesirable and troublesome when more or less permanent and expensive pavements were placed over the newly constructed embankments. It became evident that if a highway on new alignment was to be paved and opened to traffic immediately, fills or embankments would have to be consolidated or compacted if the pavement was to remain anywhere near the planned grade line.

Attempts were made in California and elsewhere about 1925 to meet this problem by overloading the deeper fills; that is, by building the fills temporarily above profile grade in an amount proportional to the depth of the fill. These "hump-backed" or "camel-backed" fills presented a rather novel appearance in an otherwise conventional grade line but, with the well-known perversity of inanimate things, most of the fills refused to settle where the greatest surcharge had been applied and all too often the greatest subsidence occurred at the ends of the fill near the point of junction with the existing ground. This effect accentuated the hump in the center so this expedient was soon discarded.

The California Division of Highways' Standard Specifications for 1927 included the requirement that all embankments be constructed in layers and much argument and controversy developed because the specifications also required contractors to distribute haul equipment over the entire surface. About 1929, the Division adopted the practice of requiring that the layers be thoroughly rolled in order to forestall settlements. This requirement immediately raised the question of control and demanded a means for checking the contractors operations. The following is quoted from a paper written by Mr. T. E. Stanton in 1938[1].

> "The first work along this line was done by the California Division of Highways in 1929 when an extensive series of tests was conducted from which was developed field equipment and methods of consolidating soil samples to determine optimum moisture requirements before construction and subsequently the relative compaction of the completed embankment. This procedure and equipment was adopted as standard in August, 1929, and has been in use without substantial change to the present date.
>
> "About 1933 the engineers of the Bureau of Water Works and Supply of the city of Los Angeles conducted a similar study, the results of which were described in a series of articles by R. R. Proctor, field engineer of the bureau, published in several issues of Engineering News-Record, beginning August 31, 1933.

"Proctor describes a field consolidation outfit somewhat different from the California Division of Highways equipment but using similar consolidation procedure."

The Proctor method[2] of compaction control became widely known, and led to the widespread adoption of similar control test procedures such as the Standard AASHO method. With the tremendous expansion of military construction, particularly of airfields during the war years, the Corps of Engineers stepped up the compaction requirements by adopting a compaction procedure known as the Modified AASHO which sets a much higher standard of density and, as will be shown later, produces results closely comparable to those obtained by the long established California Impact Method. The army engineers had concluded that if embankments were to withstand the increasingly heavy loads and propeller vibration of military planes a higher standard of construction compaction would have to be established. Thus, some 27 years ago engineers began to talk about maximum density and optimum moisture of soils and today many seem to believe that these terms express fundamental basic constants like the gravity constant or the boiling point of water.

Table 1 lists the essential details of certain compaction test procedures used by various agencies under the designation shown.

It will be noted that while these various procedures have general similarities and that all accomplish compaction by the impact of a rammer there are differences in the weight of the ram and in the drop as well as the depth and number of layers of soil. The diameter of the ram and the area of the face are the same, however, for all of those listed. It is also pertinent to note that the California Impact and Mechanical Compactor methods are the only ones permitting coarse stone up to 3/4-in. in size. All others exclude coarse particles above No. 4.

Charts, Figures 1 through 8 represent typical curves showing moisture-density relationships for a series of soils selected to provide a range of types and on each chart the moisture-density curve as determined by the various methods is shown. It is clearly evident that there are marked differences in the maximum dry weight per cubic foot obtained by these different "standard" laboratory procedures. It is also evident that the devices giving the higher density generally indicate a lower percentage of moisture as "optimum." These charts then demonstrate a fact that is well known to many engineers; namely, that as the compactive force is increased the moisture content needed to produce maximum density is generally reduced. An examination of these charts leads also to the strong presumption that if the so-called optimum moisture is a variable depending upon the force and the <u>efficiency</u> of effort exerted in a laboratory test, it is also a variable depending upon the type or weight of rollers used during actual construction.

Table 2 lists the maximum density and optimum moisture for ready comparison. By referring to this table or to Figures 1 to 8, it will be noted that there is a fairly consistent order in the maximum density values produced in a soil by the several compaction methods under consideration. First, it is evident that in all cases the Standard AASHO produces the lowest dry weight per cubic foot and the optimum moisture content is higher than for the other methods. On the same relative scale, the Proctor method produces the next higher "maximum" density with a corresponding reduction in optimum moisture, but the California Impact Method and the Modified AASHO are consistently higher and about at a standoff as they produce nearly identical weights on certain soils while they tend to alternate for top position on others. As mentioned before, with the exception of the California method these test procedures establish the density for the material passing a No. 4 sieve and this practice leads to difficulties and uncertainties in check tests and interpretation when the material placed on the road contains particles coarser than No. 4.

An examination of the curves, Figures 1 to 8, show that for many soils a difference in weight of ten pounds per cubic foot may exist between the maximum density established by the Standard AASHO as compared with the Modified AASHO or with the California Impact. Viewed as a percentage, the data show a 10 per cent range for a clean sand and less than 5 per cent difference for a silty sand. One question naturally arises after an examination of these data -- Which one most nearly simulates the density to be expected on the road with modern rollers and construction equipment? Or, which "standard" laboratory procedure shows the best parallelism with the density to be expected on the job? This problem has confronted all engineering organizations dealing with the compaction of earth whether they were aware of it or not. For example, it has been noted many times in California that granular sandy gravels will compact quite readily and probably achieve the specified density with only a few passes of the roller or simply under the contractor's hauling equipment. On the other hand, clay soils and certain clay silts may be subjected to a tremendous amount of rolling and still fail to meet the specified density. It seems quite evident, based both on observation of results obtained on actual construction and upon theoretical considerations, that the arrangement of soil particles produced by impact within the confining space of a steel mold is not necessarily the same as that produced by steel or pneumatic tired rollers operating over large areas. It would not matter particularly whether the density obtained in the test method was consistently higher or lower than that which could be developed by construction equipment on the road. It is highly desirable, however, that the results with all types of soil should be reasonably parallel with those obtainable with construction equipment. While some of these devices may produce densities closer to the average densities obtained with certain soils on the road all fail to parallel construction compaction on all types of materials.

As part of a study seeking to improve the correlation between laboratory compaction and that obtained in the field, a series of samples were compacted in the California Impact test apparatus and the densities determined after differing numbers of blows per layer. The standard test procedure established in 1929 for this device has called for 20 blows of the hammer falling a distance of 18-in. on each of five layers approximately 2-1/4-in. deep, Figure 14. Figures 9 and 10 illustrate the smooth straight line curves obtained when the number of blows per layer is plotted on a semi-log scale against the density in pounds per cubic foot. This indicates an orderly increase in density that varies directly as the log of the number of blows per layer. Figures 9 and 10 therefore show a consistent increase in density for all materials when subjected to an increasing number of blows per layer of soil. As the density obtained under 20 blows was in general about equal to that obtained with the Modified AASHO and the density at five blows somewhat less than the Standard AASHO method, it seemed that we might superimpose the densities characteristic of the other methods upon this straight line plot developed in the California Impact equipment. Chart, Figure 11, represents an attempt to establish a comparison. In other words, we are trying to determine whether the density obtained in the other methods would be consistently duplicated by some given number of blows in the California Impact method. By selecting the data for certain soils, it is possible to demonstrate a rather satisfactory consistency of behavior and from this selected and limited number of comparisons it appears that the densities obtained in the Standard AASHO method will be duplicated by the density in the California Impact equipment using only seven blows per layer. In a similar manner an equivalent number of blows in the California Impact method may be assigned to the other devices. This tentative relationship is as follows:

Table 3

Compaction Method	Equivalent Number of Blows per layer in Calif. Impact Method
Standard AASHO	7 blows
Proctor	11 blows
Kneading Compactor	13 blows
Modified AASHO	18 blows
California Impact	20 blows

It is evident, however, that when compacted in these various devices the densities obtained with all materials do not follow a straight line on a semi-log plot ranging from the Standard AASHO to the California Impact if we apply the relationship indicated in Table 3. Some of the exceptions are shown in Figure 12 in which the densities obtained are plotted according to the above relationship. In order to connect the points curved lines are necessary indicating a departure or deviation from the relationship shown on Figure 11.

All of these procedures have several characteristics in common; namely, density is developed in a confining steel cylinder three or four inches in diameter and force is delivered by means of a hammer or ram having about three square inches area. An important point is that all use a ram smaller than the surface of the specimen, and all except the Kneading Compactor employ sharp impact.

Leaving aside for the moment consideration of those materials that show an unusual pattern of response to the various methods, Figure 11, one might speculate upon the relationship between these various test results and the degree of compaction normally achievable on the road. In California practice, it is usual to require 90 per cent of the "standard." Thus a test maximum weight of 128 pounds would mean about 115 pounds on the grade. In order to produce the same degree of compaction on the road one would have to specify over 95 per cent compaction with the Standard AASHO. In another case, a 90 per cent requirement for soils developing 110 pounds in the California Impact method would be equal to requiring about 100 per cent of the Standard AASHO for the same soil.

In describing the discrepancies or differences between these existing test methods I am not ready to propose a better technique or procedure. It is obvious that any device used to establish the attainable density of a soil during construction must be reasonably simple, rugged and portable in order to be practicable for field control. It is the primary purpose here to point out the relationships that do exist as it seems that all engineers engaged in the design, preparation or enforcement of specifications for highway or airport construction should be aware of these differences. Figures 13, 14 and 15 show the equipment and typical test specimens for the laboratory compaction methods discussed. The test specimens were made with alternate layers of different colored soil to permit ready visual comparison and the specified height of drop <u>on each layer</u> is illustrated by the position of the ram. With the exception of the Proctor the force exerted on the specimen is the result of a free fall of the rammer. In the case of the Proctor method the operator is expected to exert additional force by hand, therefore, the force of the blow must vary somewhat depending upon the strength and enthusiasm of the operator. It may be pertinent to point out that two states are using the California Impact method and present day construction equipment is able to meet the densities called for in the specifications which refer to this method. It is equally pertinent to note that the Corps of Engineers who developed the Modified AASHO have used this method which sets a standard very close to that provided by the California Impact method, and presumably they have also found that specifications based on this test can be met by modern construction equipment.

In view of widespread interest in the AASHO test road project, and the necessity of sooner or later trying to apply to the construction problem in each state, any new lessons learned these differences in compaction standards should be fully realized by all. Furthermore, the influence of the federal aid standards on the inter-state system points to the need for consideration of the compaction standards to be followed if anything like uniform construction is to be achieved. While the standard reference method for compaction is of concern to those who plan the projects, write specifications and inspect the work, the construction engineers and the contractors are equally interested in the ability of present day compaction equipment to achieve the density specified. The last 15 years have seen many advances and new developments in compaction equipment. These include heavier steel tired rollers, tremendous pneumatic tired "Super Compactors," as well as improvements in the time-honored sheepsfoot or tamping rollers. Two new devices are of considerable interest, one the segmental type of roller and the other, the vibration principle being embodied in several new rollers or compaction devices.

It has been the practice for some years in the California Division of Highways to make comparative field tests whenever a new roller is introduced by the contractor on a construction project. Thus far, however, these full scale field trials have failed to bring forth convincing evidence that one type of roller is vastly superior to another. At least, the densities obtained when expressed as a percentage of the standard show surprisingly little variation. Here again, however, percentage figures can be somewhat misleading. For example, a soil that registers 130 pounds per cubic foot in the laboratory compaction test would meet the specification of 90 per cent if compacted to 117 pounds on the road. However, a silty sand giving 100 pounds per cubic foot in the test would, of course, show a variation of only 10 pounds for the same percentage difference.

The view has long been held that we should achieve all the compaction that is feasible or which can be reasonably obtained without exorbitant construction cost, but there is ample evidence to show that it requires a much greater amount of work to achieve the specified density with one type of soil than it may with another. There is a feeling among some engineers that a contractor should expect to do a certain minimum or standard amount of work in order that the specifying agency might have the benefit of whatever degree of compaction can be reasonably developed. Noting this difference, however, is only another way of saying that the densities and optimum moisture contents indicated by the laboratory devices do not always duplicate and, in fact, do not parallel the densities and optimum moisture contents that are characteristic of the various construction procedures on the same soils.

Some engineers have expressed the opinion that the amount of compaction produced in a soil material is directly proportional to the energy or force used in performing the compaction. This is not inevitably true as it is necessary to take into account the particular method or efficiency of compaction. The same amount of energy may produce different degrees of compaction, depending upon the method used. For example, the Modified AASHO develops about 56,250 ft-lb. per cu-ft. of soil and the California Impact develops 33,000, yet the latter produces the greater density on many soils.

It might be well to point out at this juncture that some misunderstanding arises because of the lack of distinction between the terms "density" and "compaction." The term "density" for all materials means, of course, the weight per unit volume, and for metals or solids is often used as more or less synonymous with specific gravity. When used in relation to soils, the term in effect reflects the ratio between the absolute or solid volume of the particles as compared to the total space occupied by the granular mass. The noun "compaction" is generally considered to be synonymous with density but the verb form "compacted" conveys the idea that materials have been subjected to tamping or pressure, and that the particles have been driven into close contact by forces exceeding the force of gravity. However, even after a great deal of compactive effort has been exerted, a mass of particles may still retain a considerable percentage of void space and hence may not be particularly "dense." By careful manipulation, often with the expenditure of but little energy, particles can be caused to fit closely together and develop low void spaces or high density without having been highly "compacted."

Present day engineering terminolgy does not recognize the need of clear-cut distinction between these two states. In other words, density developed by compactive effort is one thing. Density resulting from an efficient arrangement of particle sizes can be something else. Distinction is important because a well rammed or compressed soil or granular mass may develop high resistance to displacement; in other words, produce an engineering structure of considerable stability. However, a dense mass of low void volume may or may not have comparable structural properties. This, of course, brings up the question of whether one is interested in controlling density as such during construction operations, or whether a more direct focus of attention should not be placed on the compaction and the generally improved structural stability. After the foregoing was written, a paper by W. J. Turnbull and Charles R. Foster of the Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi, came to my attention[3]. The discussion and conclusions in that paper are all very informative and pertinent to this subject. The data included therein confirm our own findings[4] that increasing either the compaction or density or both may or may not be beneficial depending upon the particular soil, the degree of compaction and the moisture content.

While the answer may seem more or less obvious to all, it may be pertinent to consider the question - Why do we require compaction of soils? First, as stressed in the introduction, it is necessary if embankments are to maintain the planned grade line; in other words, to avoid settlements due to consolidation within the embankment material itself. Secondly, many materials do have improved bearing values or supporting power when thoroughly compacted, although the amount of liquid present is usually more significant. Compaction also tends to reduce the size of the void spaces; in other words, reduce porosity and thus to some extent limit the absorption of moisture. Again we must scrutinize the terminology because porosity does not necessarily correlate with permeability. This fact is readily perceived if we consider a well graded sand or gravel containing less than 30 per cent voids which may be quite permeable offering little resistance to the passage of water. On the other hand, clay may be virtually impervious with void space or "porosity" approaching 50 per cent. Like most similar questions, the problem will not be resolved until engineers visualize clearly just what it is they are interested in accomplishing. In other words, sooner or later we must separate the essential from the less essential and make sure that the terminology used is not misleading or diverting from the main purpose.

The expressions Maximum Density and Optimum Moisture are purely relative terms and mean nothing tangible unless all conditions and circumstances are clearly defined.

I wish to acknowledge the assistance of Mr. A. W. Root and Mr. W. S. Maxwell of the Materials and Research Department of California Division of Highways for data and suggestions used in preparing this paper.

Table 1

RELATIVE COMPACTION TEST METHODS IN USE BY VARIOUS AGENCIES

1. Summary of Laboratory Apparatus and Procedure:

Test Identification	Std. AASHO	Bureau Rec.	Std. Proctor	Calif. Impact	Mod. AASHO
MOLD:					
Diameter, in.	4"	4"	4"	3"	4"
Height, in.	4-5/8"	6"	4-5/8"	10-12"	4-5/8"
Volume, cu. ft.	1/30	1/20	1/30	Var.	1/30
TAMPER:					
Weight, lbs.	5.5	5.5	5.5	10.0	10.0
Free drop, in.	12"	18"	Struck*	18"	18"
Face diam., in.	2"	2"	2"	2"	2"
Face area, in.	3.1"	3.1"	3.1"	3.1"	3.1"
LAYERS:					
Number, total	3	3	3	5	5
Surface area, each, sq. in.	12.6	12.6	12.6	7.1	12.6
Compacted thickness, each	1-5/8	2-1/8	1-5/8	2-1/4	1
EFFORT:					
Tamper blows per layer	25	25	25	20	25
Ft.-lbs. per cu. ft.	12375	12375		33000	56250
MATERIAL:					
Max. size (passing)	#4	#4	#4	3/4"	#4
Correction for oversize	No	Yes	No	Yes	No

NOTES: All dimensions shown above are close, but not necessarily exact.

Layer thickness in all above except California Impact allow for 1/4" - 3/8" trim off of last layer.

*Proctor test employs a firmly rammed, or struck, blow from a 12" height instead of free drop.

While the basic procedures for AASHO and Proctor do not provide for compensation for rejected oversize aggregate, some agencies employing these tests do specify a correction method.

Table 2

COMPARISON OF COMPACTION TEST PROCEDURES

Maximum Density

Data from Figures 1 to 8								
Figure No.	1	2	3	4	5	6	7	8
Calif. Impact	111	118	103	129	115	105	128	144*
Mod. AASHO	110	116	105	128	118	105	126	139
Proctor	108	111	98	124	112	98	122	133
Std. AASHO	103	107	95	121	98	95	119	130
Mech. Compactor	109			125	117	98	128	134

*Ten layer specimen

Optimum Moisture Content

Data from Figures 1 to 8								
Figure No.	1	2	3	4	5	6	7	8
Calif. Impact	17	14	15	10	15	21	12	7
Mod. AASHO	18	14	17	10	12	19	12	8
Proctor	18	16	19	11	17	22	14	10
Std. AASHO	21	18	20	12	23	23	14	11
Mech. Compactor	19			9	15	21	13	10

Column 1 - Sandstone and sand (40% coarse sandstone of Sp. Gr. 191 added to specimen for California impact test)
Column 2 - Sandy, silty clay
Column 3 - Clean sand
Column 4 - Silty sand
Column 5 - Silty clay
Column 6 - Silty clay loam
Column 7 - Sandy, silty clay (from AASHO test road in Illinois)
Column 8 - Crushed stone base (retained No. 4 eliminated)

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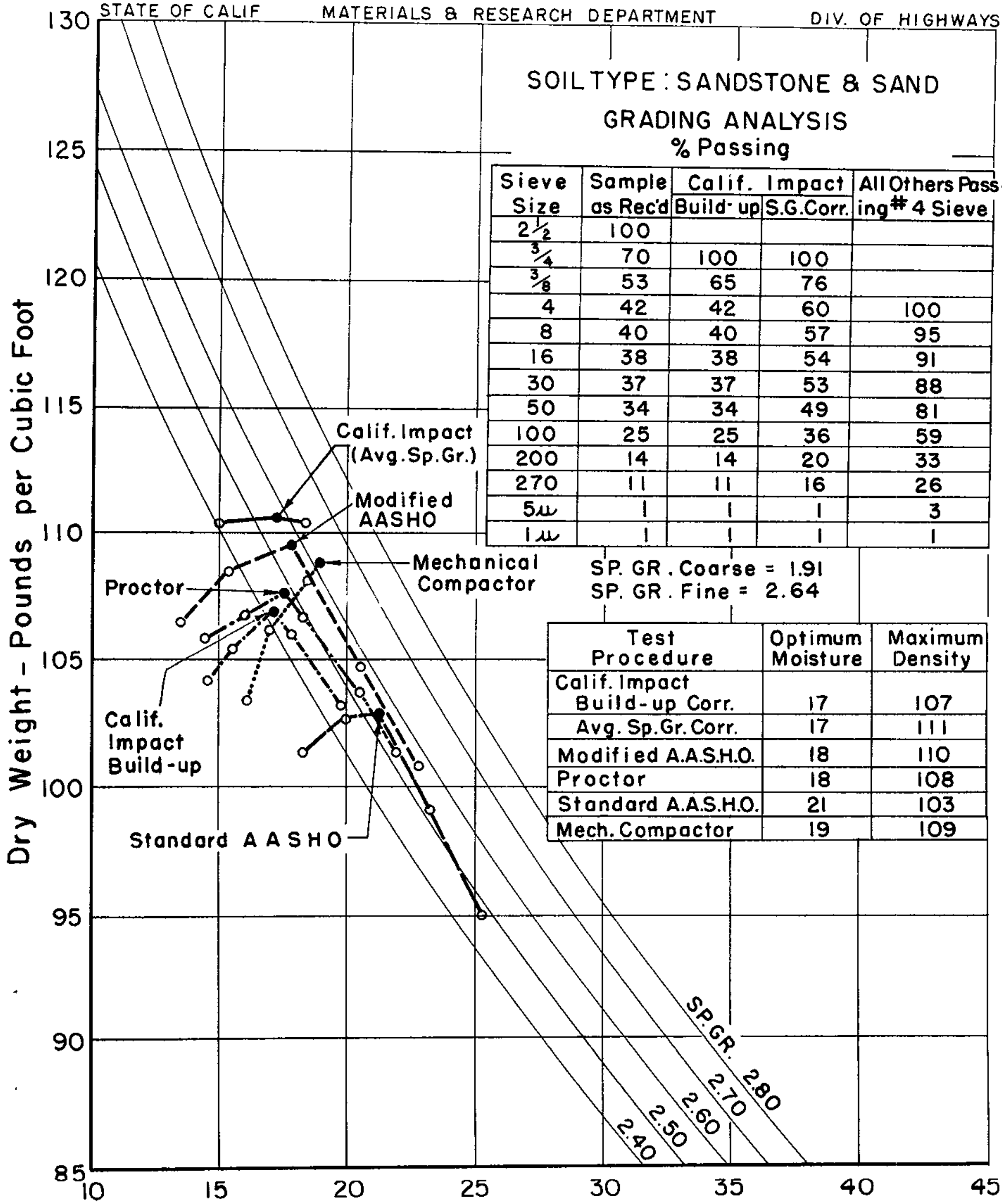


SOIL TYPE: SANDSTONE & SAND

GRADING ANALYSIS
% Passing

Sieve Size	Sample as Rec'd	Calif. Impact Build-up	Calif. Impact S.G. Corr.	All Others Passing # 4 Sieve
2½	100			
¾	70	100	100	
⅜	53	65	76	
4	42	42	60	100
8	40	40	57	95
16	38	38	54	91
30	37	37	53	88
50	34	34	49	81
100	25	25	36	59
200	14	14	20	33
270	11	11	16	26
5μ	1	1	1	3
1μ	1	1	1	1

SP. GR. Coarse = 1.91
SP. GR. Fine = 2.64

Test Procedure	Optimum Moisture	Maximum Density
Calif. Impact Build-up Corr.	17	107
Avg. Sp. Gr. Corr.	17	111
Modified A.A.S.H.O.	18	110
Proctor	18	108
Standard A.A.S.H.O.	21	103
Mech. Compactor	19	109

Fig. 1

COMPARISON OF VARIOUS LABORATORY COMPACTING PROCEDURES

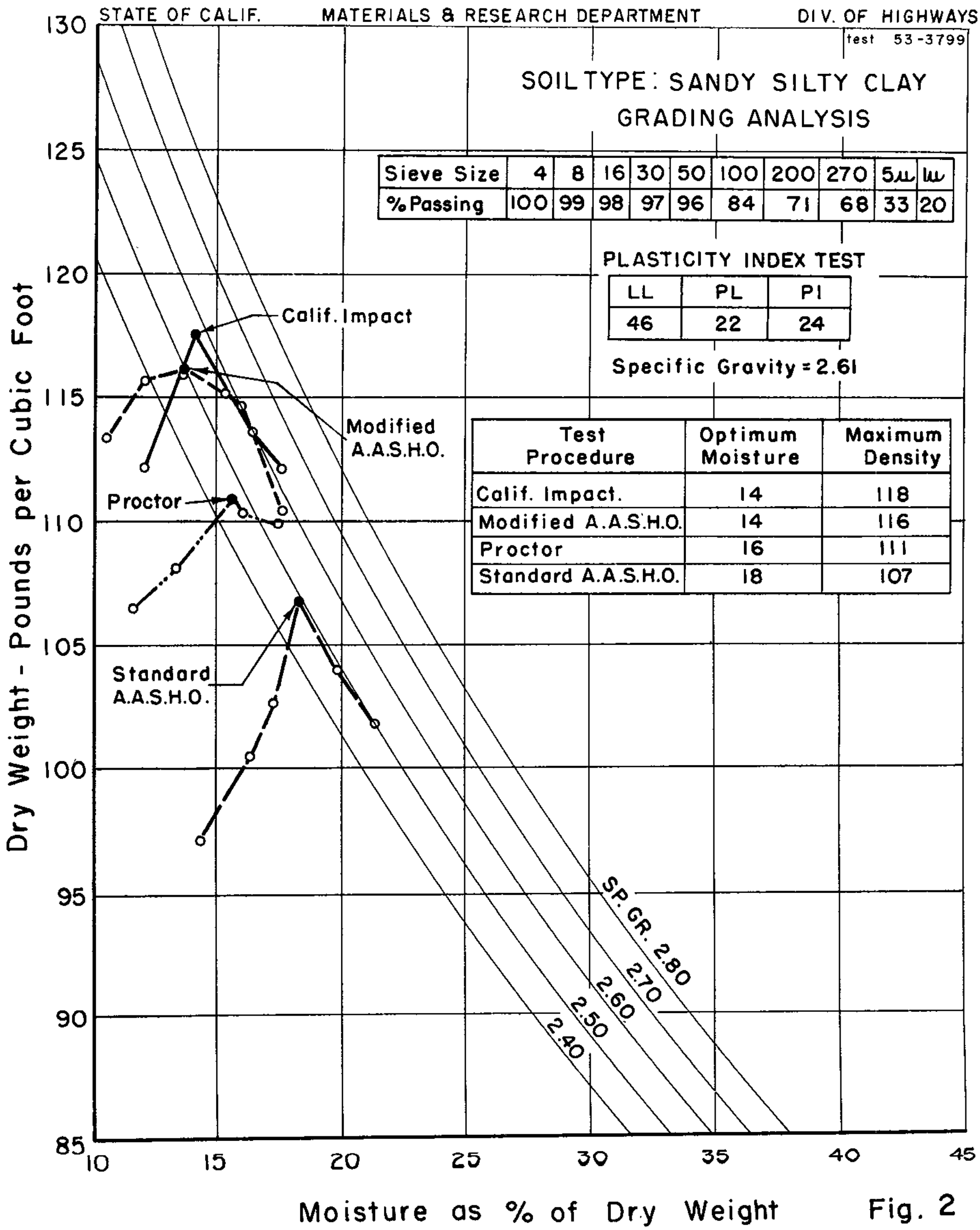
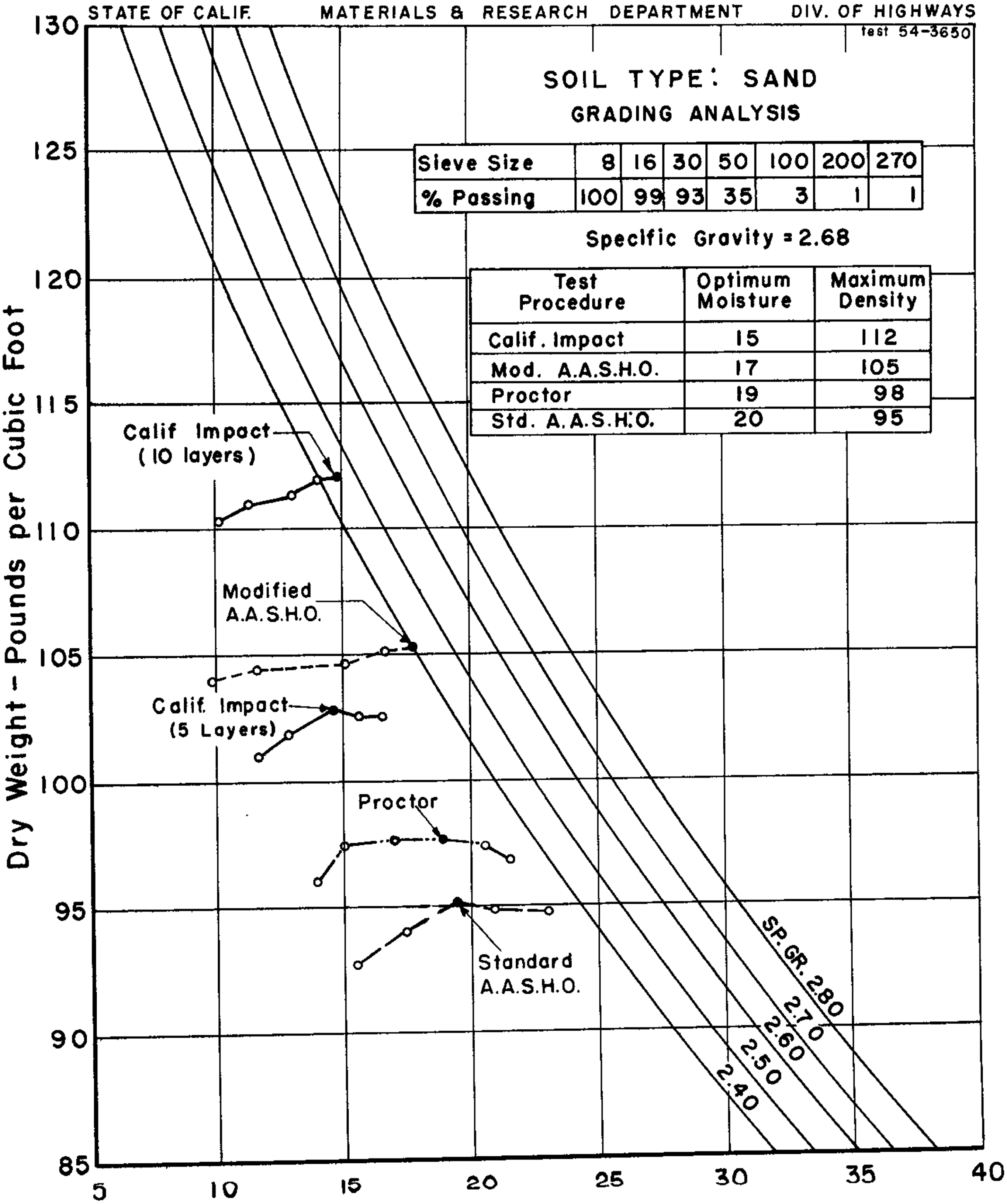


Fig. 2

COMPARISON OF VARIOUS LABORATORY COMPACTING PROCEDURES



Moisture as % of Dry Weight

Fig. 3

COMPARISON OF VARIOUS LABORATORY COMPACTING PROCEDURES

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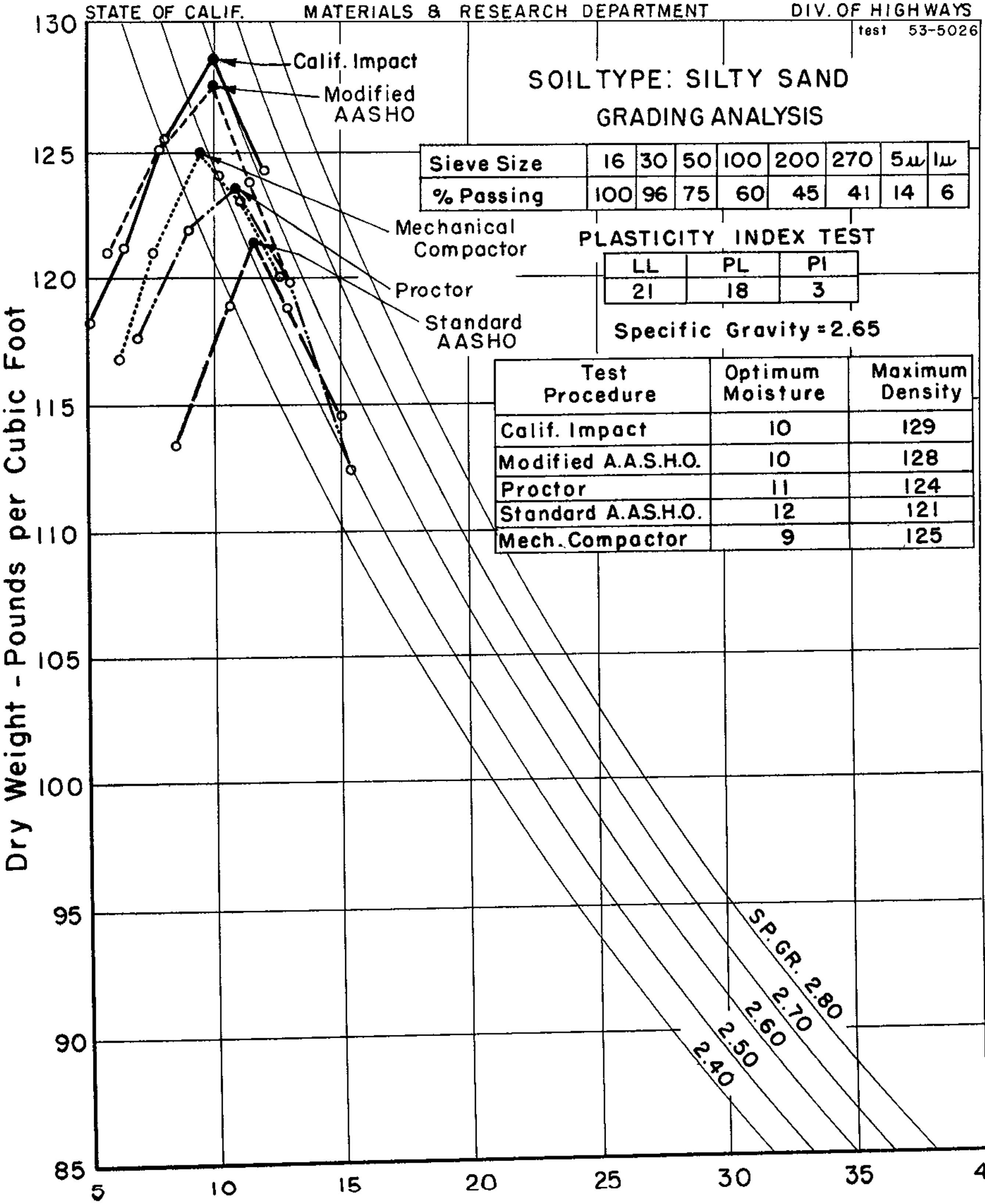


Sieve Size	16	30	50	100	200	270	5μ	1μ
% Passing	100	96	75	60	45	41	14	6

LL	PL	PI
21	18	3

Test Procedure	Optimum Moisture	Maximum Density
Calif. Impact	10	129
Modified A.A.S.H.O.	10	128
Proctor	11	124
Standard A.A.S.H.O.	12	121
Mech. Compactor	9	125

Moisture as % of Dry Weight Fig. 4

COMPARISON OF VARIOUS LABORATORY COMPACTING PROCEDURES

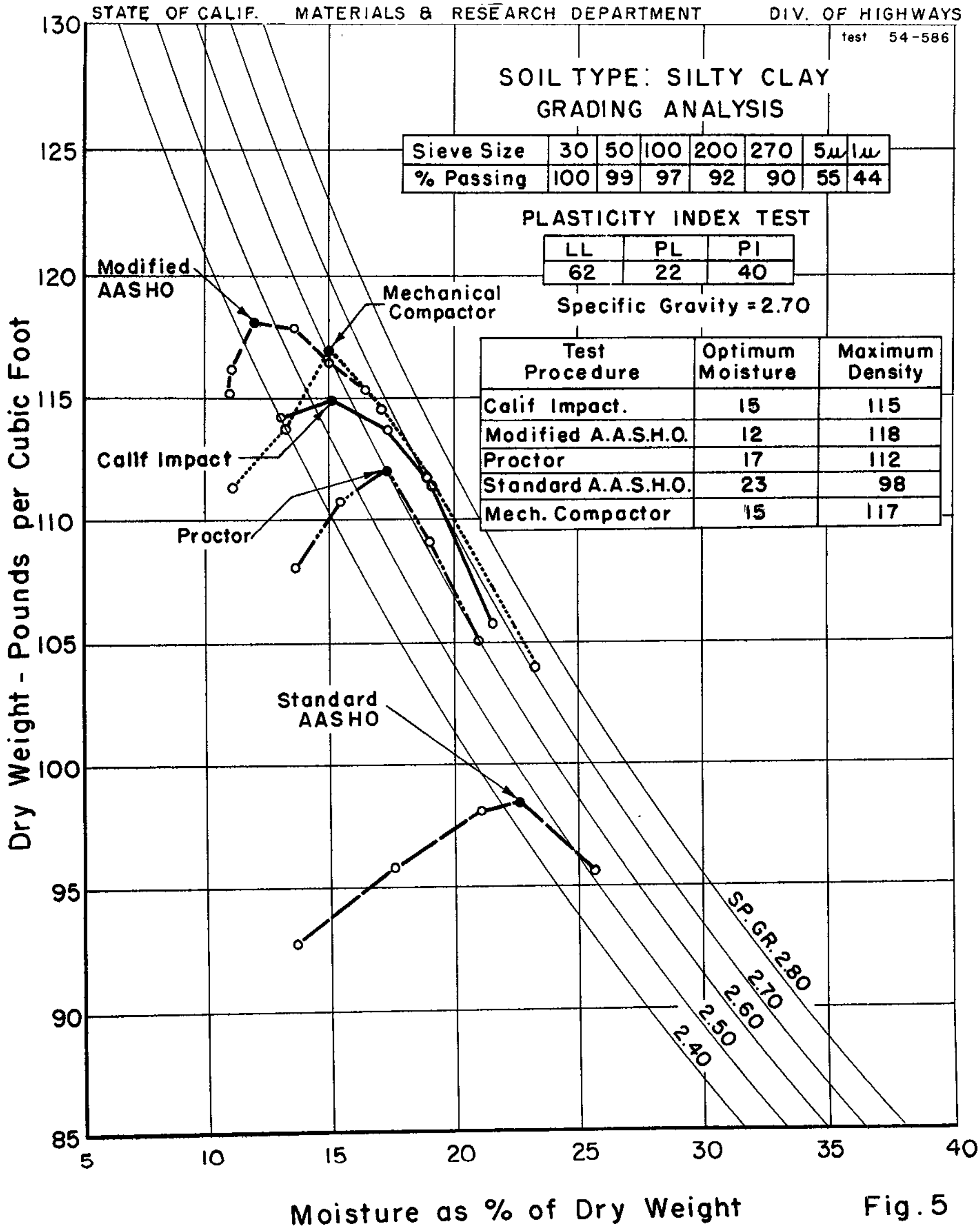
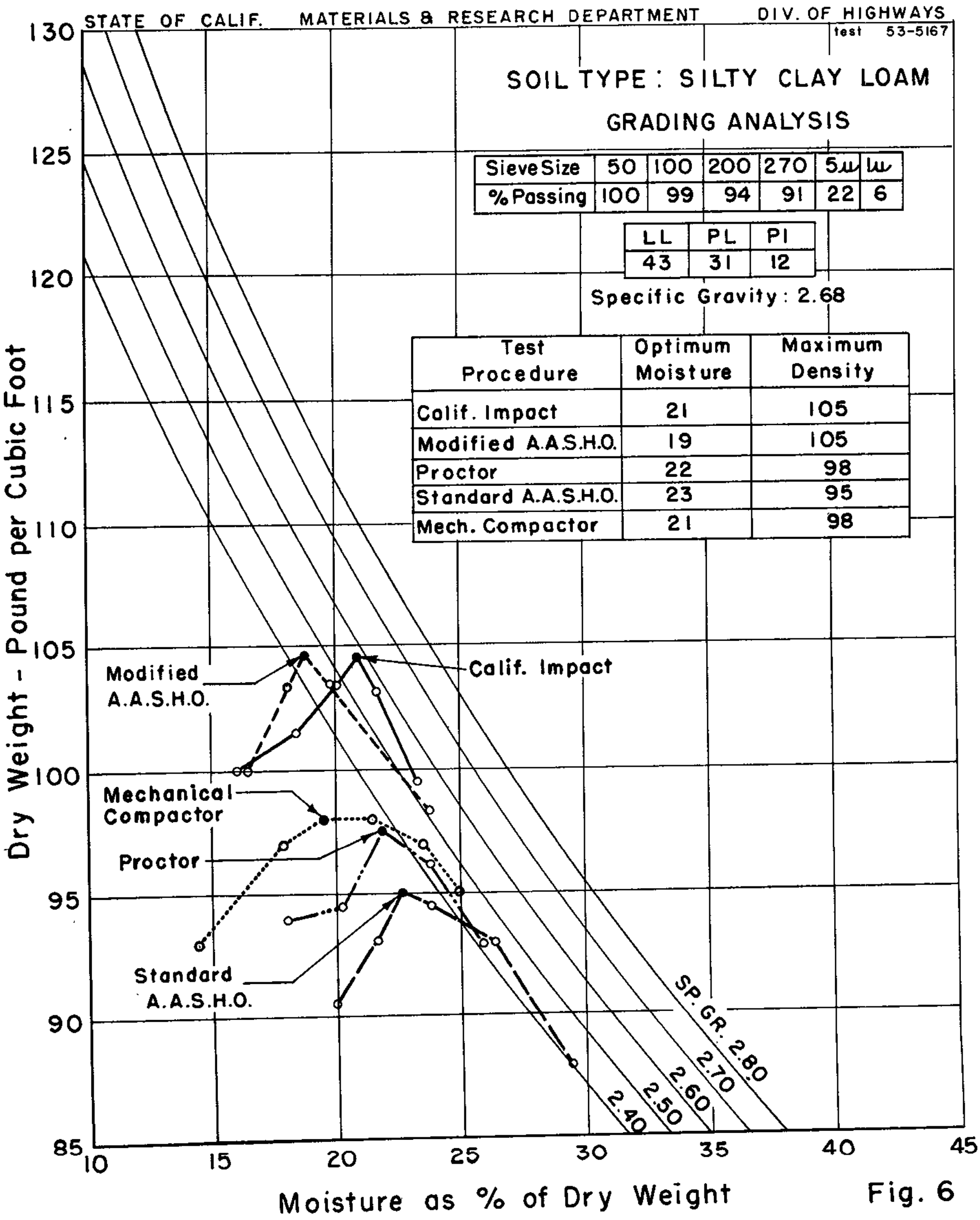


Fig. 5

COMPARISON OF VARIOUS LABORATORY COMPACTING PROCEDURES



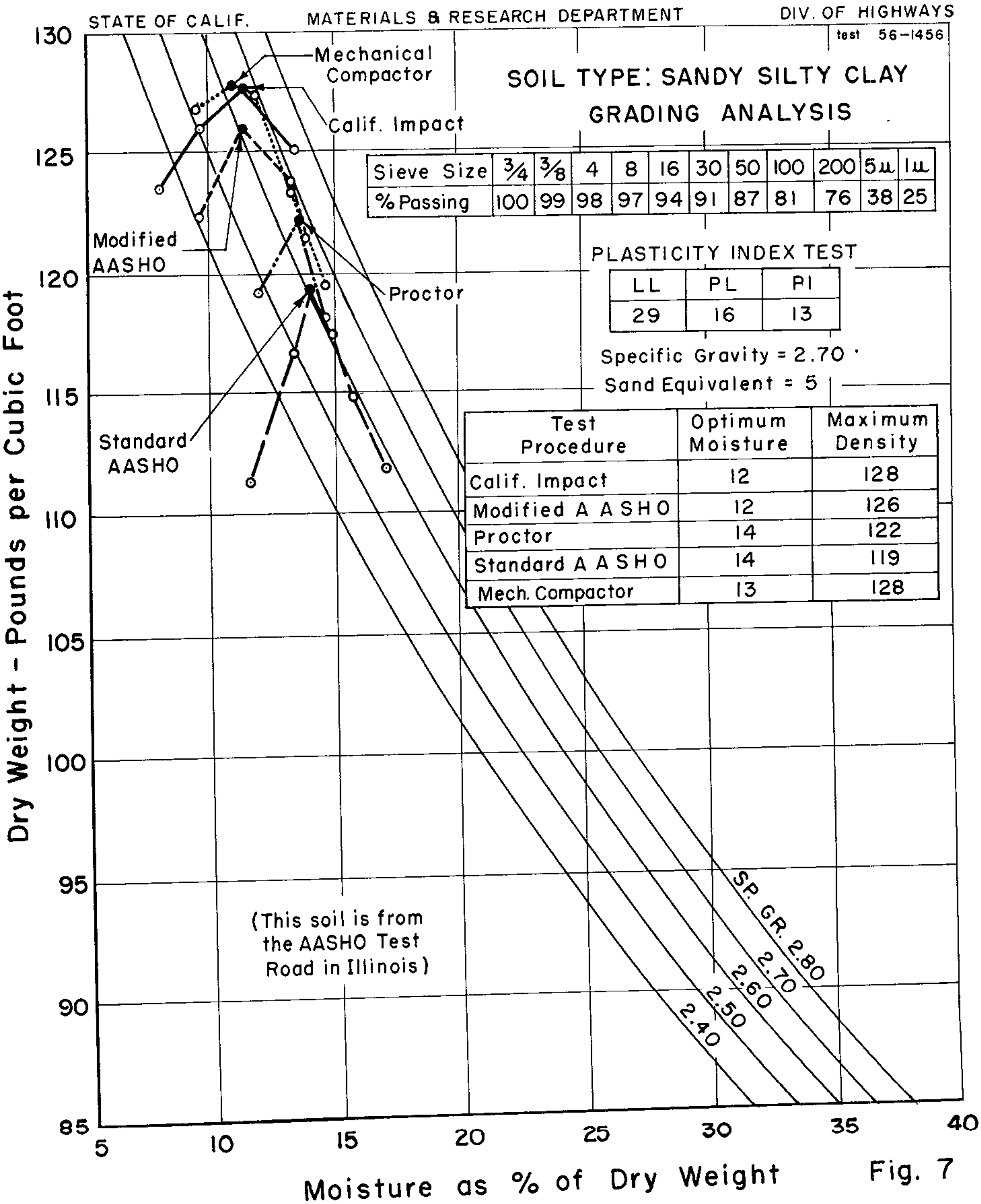
Sieve Size	50	100	200	270	5µ	1µ
% Passing	100	99	94	91	22	6

LL	PL	PI
43	31	12

Test Procedure	Optimum Moisture	Maximum Density
Calif. Impact	21	105
Modified A.A.S.H.O.	19	105
Proctor	22	98
Standard A.A.S.H.O.	23	95
Mech. Compactor	21	98

Fig. 6

COMPARISON OF VARIOUS LABORATORY COMPACTING PROCEDURES



Sieve Size	3/4	3/8	4	8	16	30	50	100	200	5μ	1μ
% Passing	100	99	98	97	94	91	87	81	76	38	25

LL	PL	PI
29	16	13

Test Procedure	Optimum Moisture	Maximum Density
Calif. Impact	12	128
Modified A A S H O	12	126
Proctor	14	122
Standard A A S H O	14	119
Mech. Compactor	13	128

Fig. 7

COMPARISON OF VARIOUS LABORATORY COMPACTING PROCEDURES

test 56-2159

SOIL TYPE: UNTREATED BASE

All tests performed on passing #4 fraction.

GRADING ANALYSIS

Sieve Size	4	8	16	30	50	100	200
% Passing	100	88	78	59	38	26	20

Specific Gravity: 2.70

Sand Equivalent: 40

Test Procedure	Optimum Moisture	Maximum Density
Calif. Impact	7	144
Modified A.A.S.H.O.	8	139
Proctor	10	133
Standard A.A.S.H.O.	11	130
Mech. Compactor	10	134

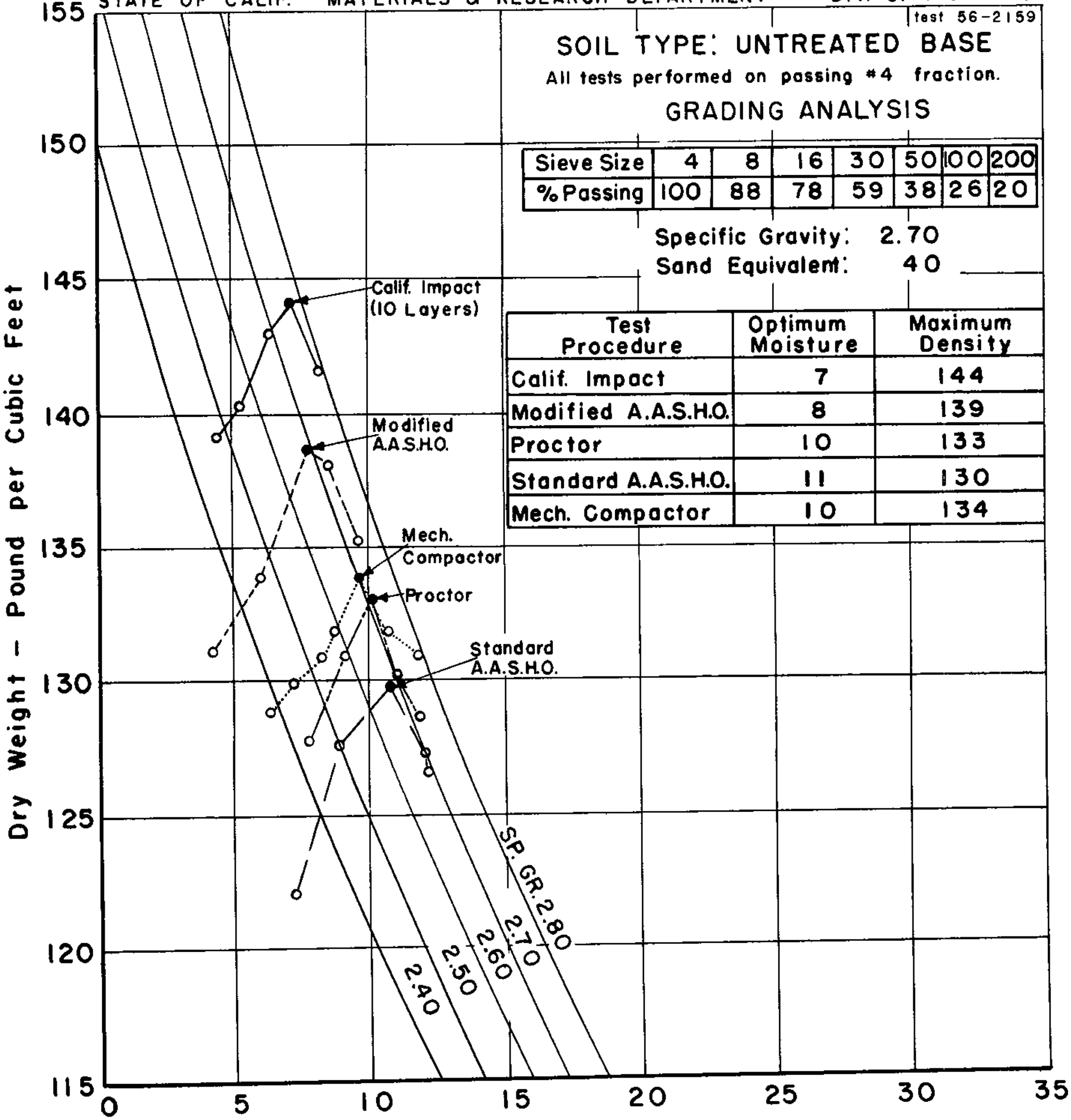
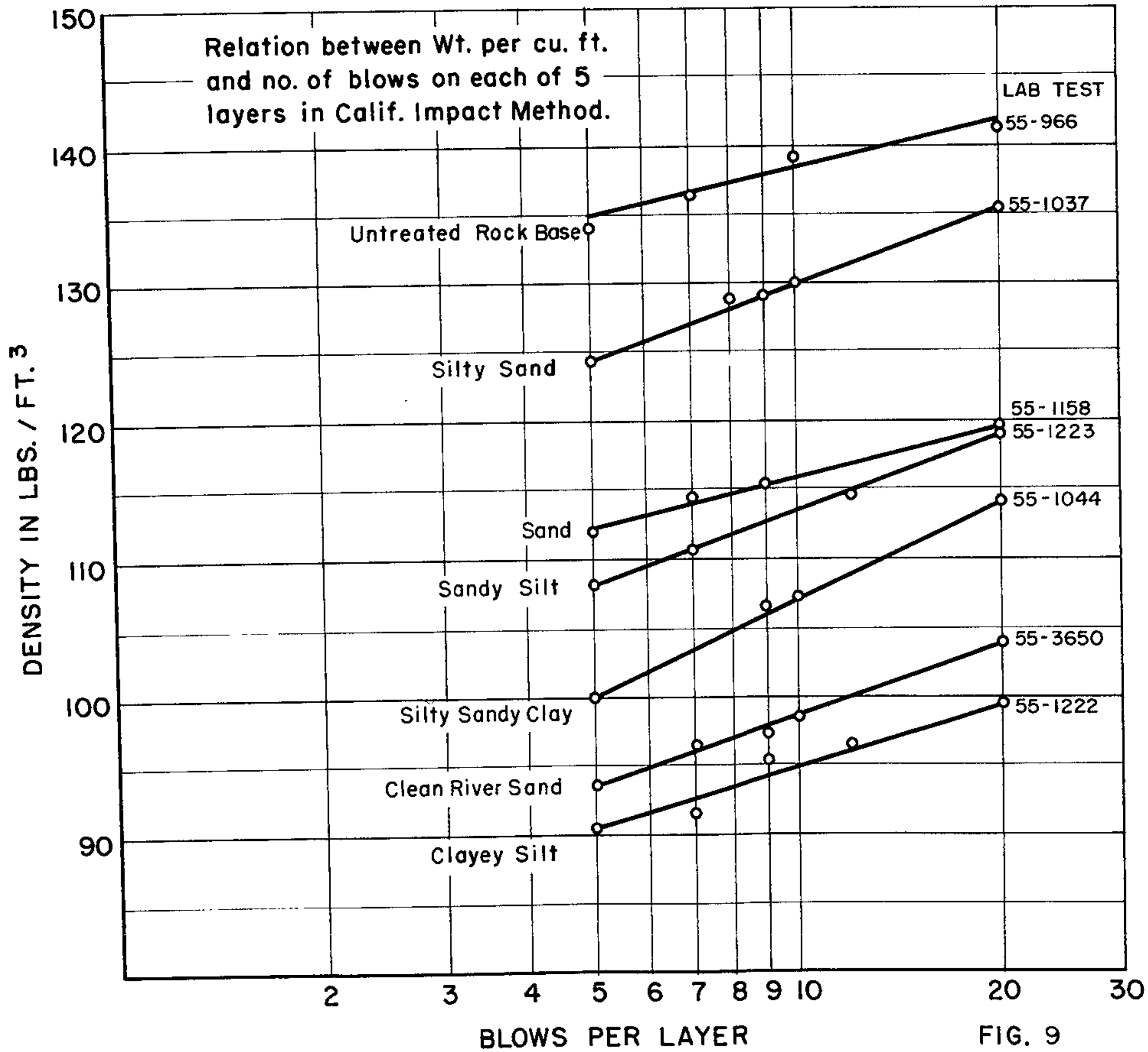


Fig. 8

COMPARISON OF VARIOUS LABORATORY COMPACTING PROCEDURES



Relation between Wt. per cu. ft. and no. of blows on each of 5 layers in Calif. Impact Method.
LAB TEST
55-966
55-1037
55-1158
55-1223
55-1044
55-3650
55-1222
Untreated Rock Base
Silty Sand
Sand
Sandy Silt
Silty Sandy Clay
Clean River Sand
Clayey Silt
150
140
130
120
110
100
90
DENSITY IN LBS. / FT. 3
2
3
4
5
6
7
8
9
10
20
30
BLOWS PER LAYER

FIG. 9

Relation between Wt. per cu. ft. and no. of blows on each of 5 layers in Calif. Impact Method

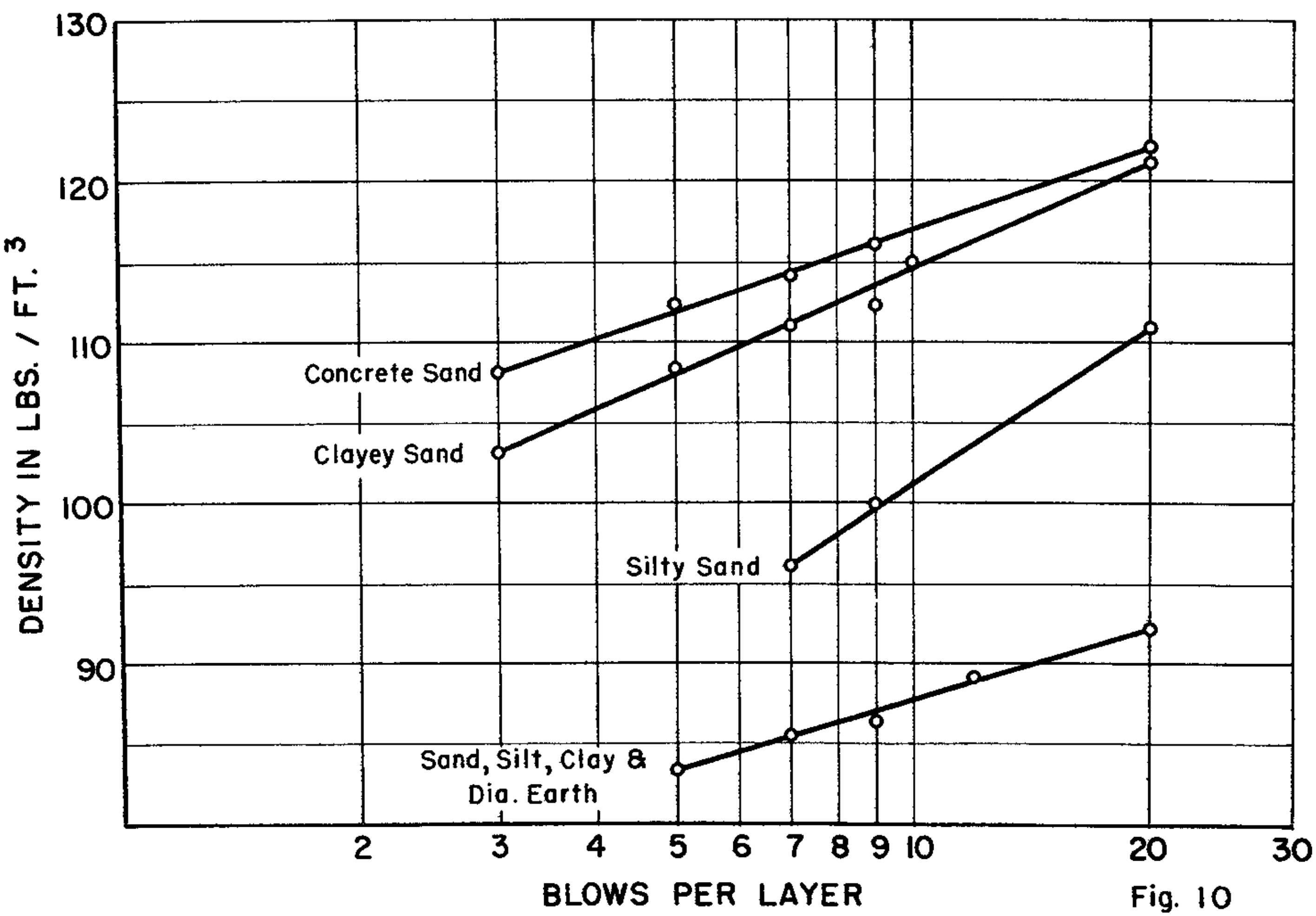
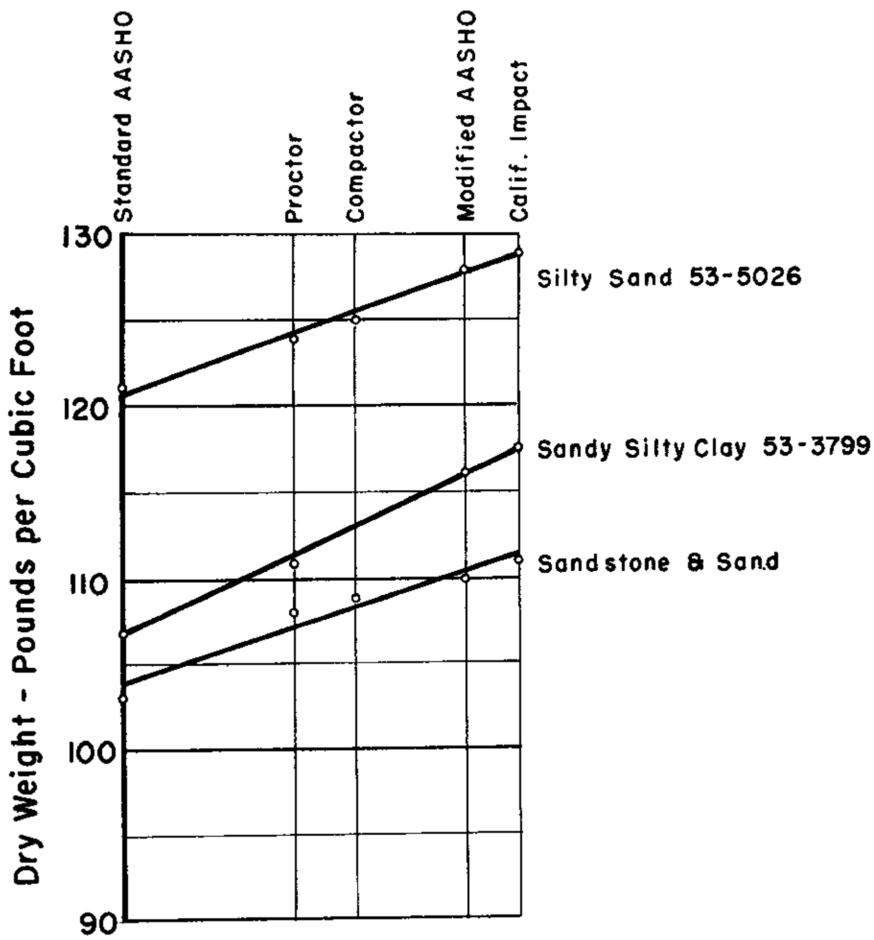
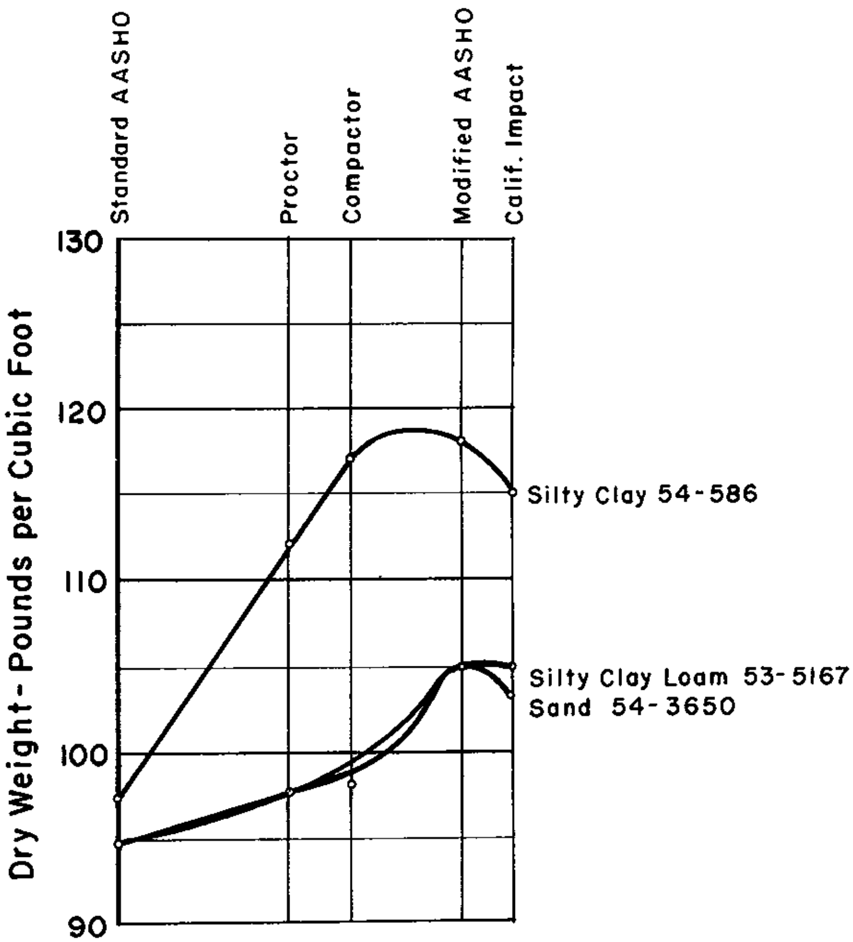


Fig. 10



COMPARISON BETWEEN DIFFERENT LABORATORY METHODS USED TO ESTABLISH MAXIMUM DENSITY FOR COMPACTION CONTROL

Fig. 11



COMPARISON BETWEEN DIFFERENT LABORATORY METHODS USED TO ESTABLISH MAXIMUM DENSITY FOR COMPACTION CONTROL

Fig. 12

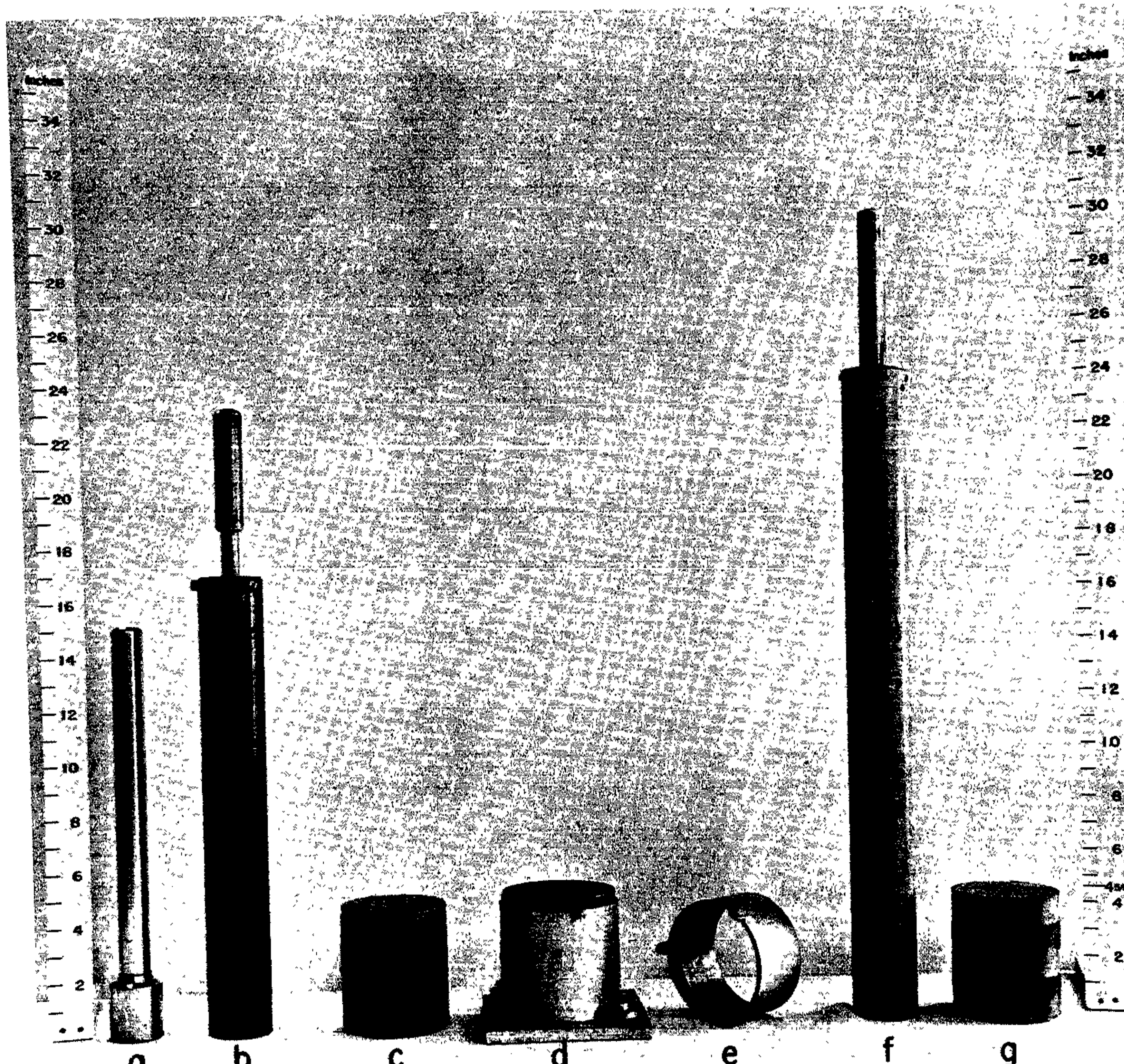


Fig. 13 Proctor & AASHO Compaction Test Apparatus

Legend for Figure 13
Proctor and AASHO Compaction Test Apparatus

a. Proctor 5.5 lb. tamper for 12" firm stroke.

b. Standard AASHO 5.5 lb. tamper inside control sleeve to maintain 12" height of tamper free drop.

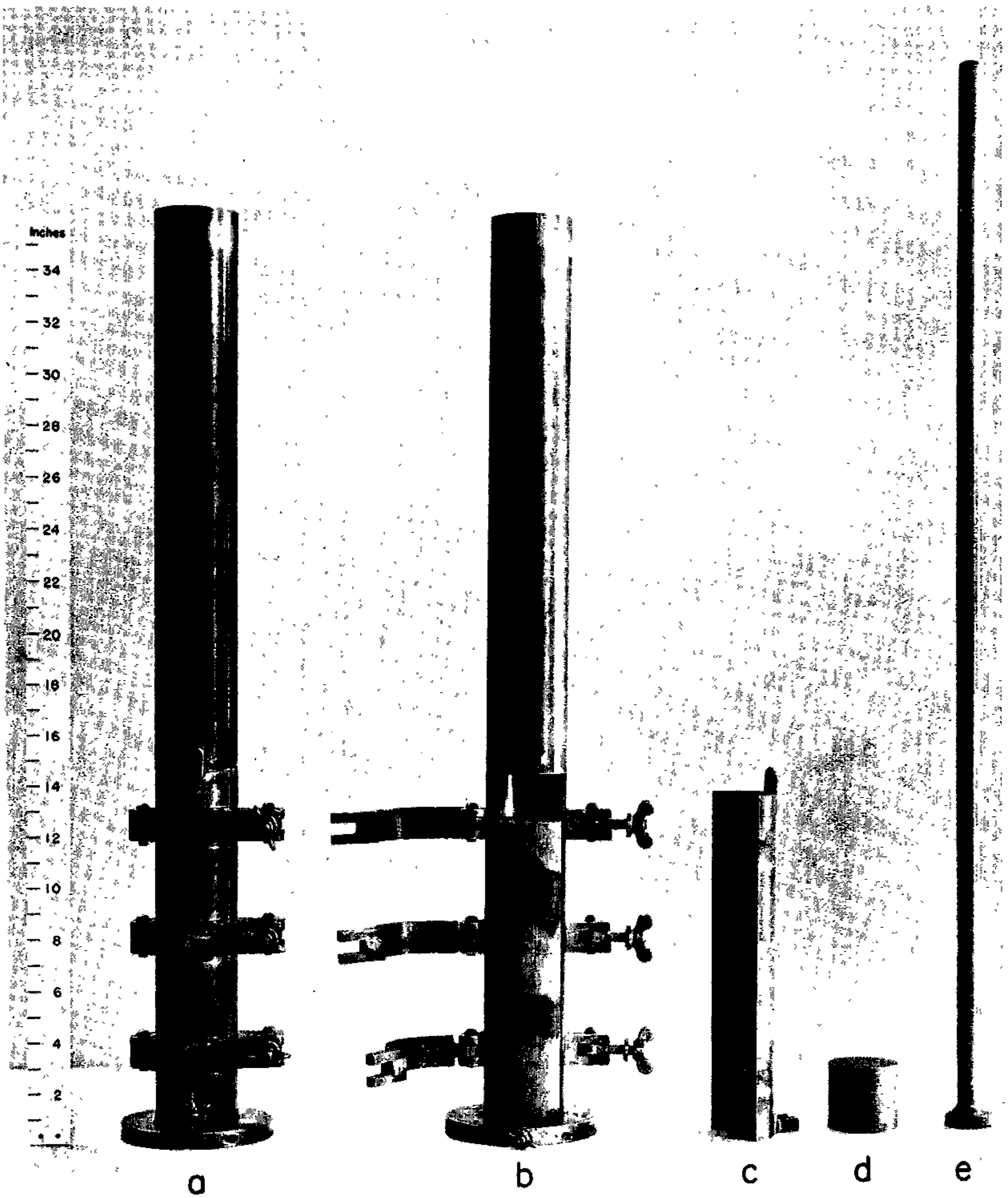
c. Typical 1/30 c.f., 3 layer test specimen representing either Proctor or Standard AASHO specimen.

d. Identical 4" x 4.6" test mold used for each of the three test procedures.

e. Extension used on mold when placing soil therein and later removed to permit trimming specimen to 4.6" height.

f. Modified AASHO 10 lb. tamper inside control sleeve to maintain 18" height of tamper free drop.

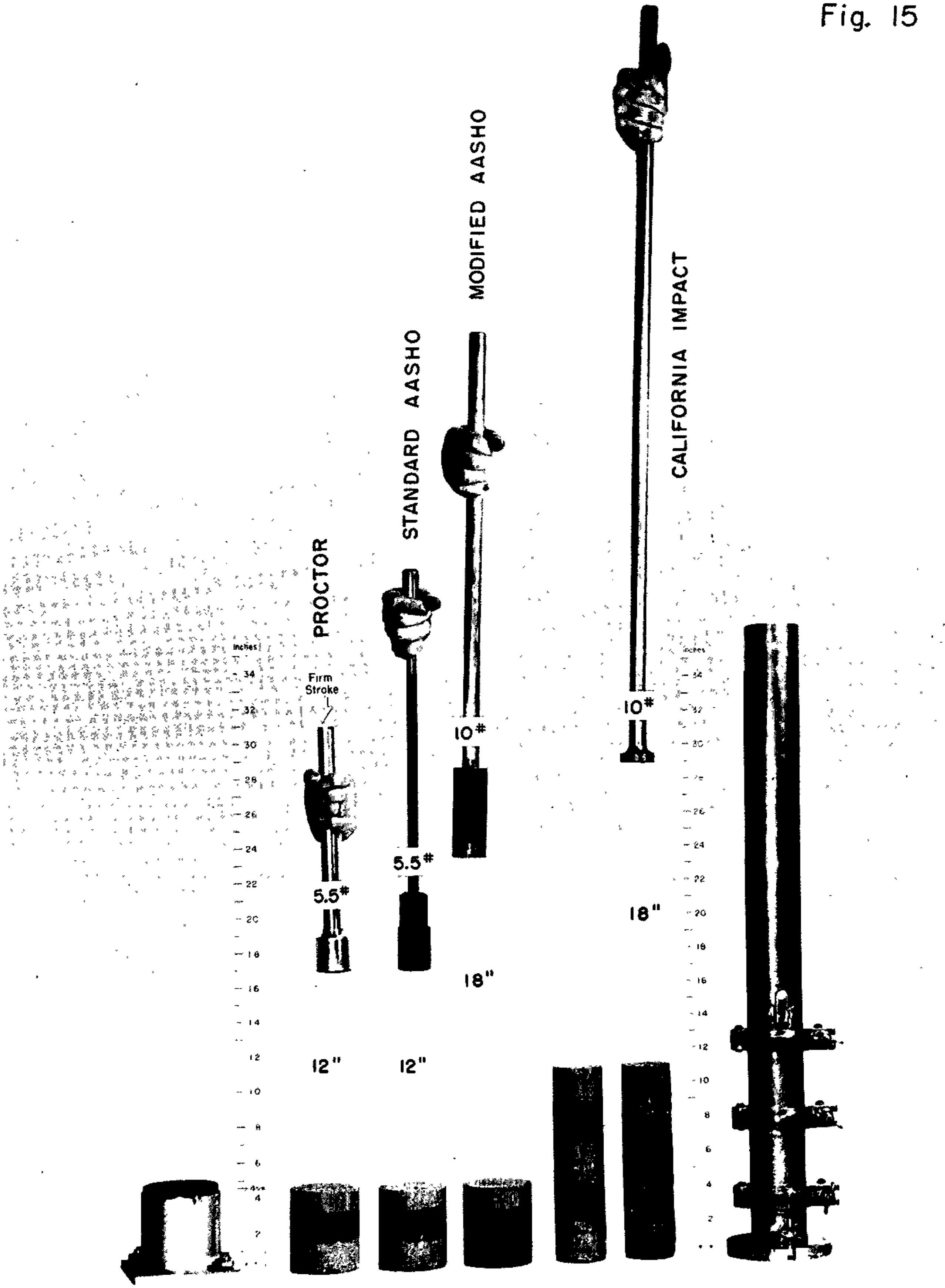
g. Typical 1/30 c.f., 5 layer, modified AASHO test specimen.



California Impact Compaction Test Apparatus

Fig. 14

Fig. 15


PROCTOR
STANDARD AASHO
MODIFIED AASHO
CALIFORNIA IMPACT
Inches
Firm Stroke
5.5#
5.5#
10#
10#
12"
12"
18"
18"

Legend for Figure 14
California Impact Compaction Test Apparatus

a. Assembled test mold.

b. Mold with test specimen in place and removable section of mold detached.

c. Removable section of mold.

d. Piston used to level off surface of final layer of test specimen.

e. Free drop tamper weighing 10 lbs.

NOTE: When applied to soils containing clay and silt fractions, specimens are compacted in 5 layers with 20 blows each.

When applied to granular materials having Sand Equivalent of 25 or more, specimens are compacted in 10 layers with 20 blows each.