A STUDY OF THE RELATIONSHIP BETWEEN THE COHESIVE PROPERTIES OF DIFFERENT SOIL MIXTURES

THESIS FOR THE DEGREE OF B. S.

Morris A. Cornell

1934

THESIS

Road materials

cop. 2

A Study of the Relationship Between the Cohesive Properties of Different Soil Mixtures

A Thesis Submitted to

The Faculty of

MICHIGAN STATE COLLEGE

of

AGRICULTURE AND APPLIED SCIENCE

By

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Candidate for the Degree of

Bachelor of Science

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Index

Acknowledgment

The writer wishes to sincerely thank Mr.Lee DePree and Mr.W.R.Collings of The Dow Chemical Co. who so kindly offered the facilities of that firm for this series of tests and who loaned to Michigan State College the equipment and materials for experiment on stabilized soil mixtures. The author also wishes to thank Mr.L.J.Rothgery of the College Engineering Experiment Station for his advice and help in preparing this thesis.

Introduction

For many years road builders have known that the performance of a road depended on the properties of the soil that it contained.

As many as fifteen years ago a government bulletin stated:

"In general, the physical characteristics of gravel which determine its suitability for use in surfacing a road are:

1. The durability of the pebbles or rock fragments
2. The quality of the binder
3. The grading of the pebbles, and,
4. The proportion in which the binder is present."

Later in the same booklet appears the following paragraph:

"The sand content should be at least twice as great as the clay content; and the sand and clay, when thoroughly mixed should be sufficient to fill the voids between the larger gravel particles."

Control and correct proportioning of the constituent parts of the road surfaces has not been easy, however. Characteristics of the materials vary in different localities, and reliable methods of measurement were not available to compare the merits of different soils. Until very recently the men who have become proficient in proportioning soil materials have done so only through years of experience by the trial and error method.

During the last few years a great deal of progress has been made in improving means for measurement of the clay content and properties of the combined sand-clay filler.

Soil Theories

The most commonly accepted definition of stability is resistance to lateral flow when loaded in all kinds of weather or climatic conditions.

Stable road surfaces are mixtures of a number of soil constituents, each of which contributes certain properties to the mixture in a manner similar to that in which the component parts of concrete determine its characteristics.

The three representative types of soils commonly found in road stabilization work are as follows:

1. Gravel and sand---Soils high in frictional constituents, and containing little or no cohesive material.
2. Clays---Soils high in cohesive materials and containing little or no gravel or sand. Commonly used to stabilize gravel and sand mixtures which are low in cohesion.
3. Gravel-sand-clay mixtures---Soils which contain appreciable proportions of both

frictional and cohesive materials. Sta-
bilized road materials are included in
this type.

Of these types of soils, dry sand, and wet clay, and, to a lesser degree, loose gravel are unstable.

All soil and gravel road behavior can be explained in terms of the presence or absence of the following five basic soil properties:

Internal Friction---the resistance of soil grains to sliding over each other.

Capillarity---the ability of a soil mass to transmit water in all directions regardless of the action of gravity or other forces.

Cohesion---the stickiness of soil grains or their resistance to being pulled apart.

Compressibility---the ability of a soil mass to be compacted without lateral movement and without loss of water or air from its pores and to remain after removal of load.

Elasticity---the ability of a soil to be compacted without loss of water or air from its pores and to rebound after the removal of load.

Of these five properties, only internal friction and cohesion are desirable to road surface stability.

When dry and free of clay, gravel and coarse and fine sand possess only internal friction. Resistance to sliding is greatest when the particles are rough and have sharp angular sides and is least when the particles are round like pebbles and beach sands.

Frictional properties are best determined by mechanical analysis.

Cohesion is supplied in any or all of four ways:

1. Clay content---Clay supplies a sticky coating to soil grains and provides a resistance to being pulled apart. Excessive amounts of clay, however, upon becoming wet, lubricate the sand particles and cause wet weather instability.
2. Water content---In a limited amount, moisture provides some cohesion. This is demonstrated by observing the difference between wet and dry sand.
3. Compaction---Bringing surfaces into close contact.
4. Proper grading---Increasing the amount of surfaces in contact with each other by correct proportioning of the sizes of grain used.

Cohesive properties are measured by means of two tests, called the liquid limit and plastic limit.

Let us summarize, then, the properties of gravel roads by saying that for a stable road, especially in wet weather, both internal friction and cohesion are needed, and that these may be furnished by a correct amount of sand and clay together with the right proportion of silt to provide embeddment for the sand grains.

Soil Tests

In the study of gravel and other road soils, writers generally refer to the material retained in the 10-mesh sieve as coarse material or gravel, and that passing the 10-mesh sieve is called the soil mortar. This latter fraction contains all the sand and finer materials from the original mixture, and its properties greatly influence the behavior of the sample.

The physical tests that are usually run, however, are carried out on that portion of the soil which passes the 40-mesh sieve, and the properties of these screenings are actually measured. This portion of the soil is called the soil-fines. It has been well established that a gravel having a stable soil-fines fraction will have very good stability even though it is contained in a large amount of gravel whose stability range varies widely.

It has been previously stated that the stable properties of a soil mixture may be measured in two ways---mechanical analysis and plastic and liquid limits. Of these two tests, the latter was used in an attempt to correlate the relationship between the cohesive properties of different soil mixtures.

Before describing the laboratory procedure followed, it might be well to consider the definition and values of the tests used.

1. Plastic limit test---A means of finding the moisture content at which soils containing cohesive material pass from the solid to the liquid state.
2. Liquid limit test---A means of determining the moisture content at which soils pass from the solid or plastic states to the liquid state.
3. Plasticity Index---A means of measuring the cohesion of a soil under damp conditions. It is the difference between the two preceding values.

When water is added to a sample of soil-fine, it becomes sticky and gradually assumes a state in which it is plastic, that is, it can be formed into a shape by the hands. The amount of water which must necessarily have been added to cause the mass to reach this state was the measure of the plastic limit test.

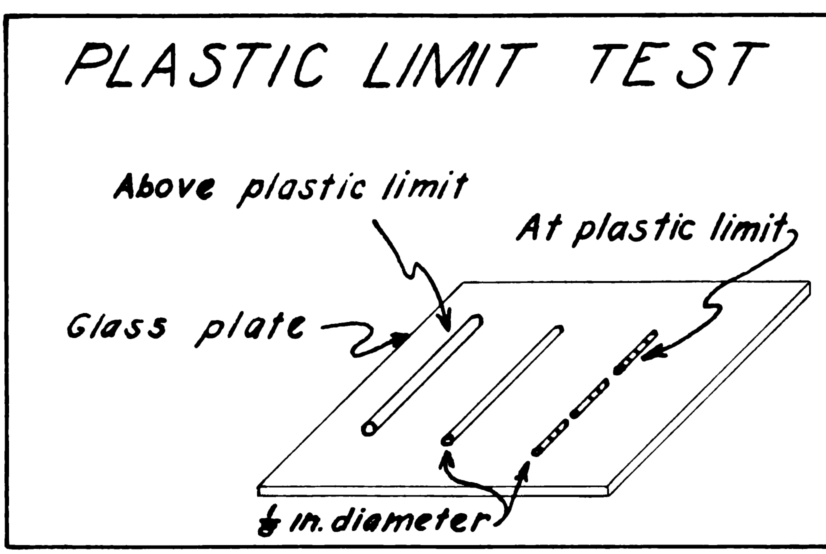
If more water be added the mixture will change from a condition in which it was plastic to one in which it is not able to hold its shape when it is placed in a receptacle and lightly tapped. The total quantity of water added is again measured and this becomes the amount of the liquid limit test.

If we then subtract the amount of water for the plastic limit from that of the liquid limit, we have left the amount of water necessary to cause the change from a plastic to a liquid state, or in other words, a measure of the cohesiveness of the soil mixture.

Laboratory Procedure

After the various samples are received by the laboratory, they are filed, graded, and recorded according to standard practice. Only the soil-fines or "through 40" materials are used in these tests. The total amount of this material is mixed thoroughly in order that the results shall be a reliable figure for the mixture.

"For the Plastic Limit Test about 20 gms. of "thru 40" material are used. They are put in an evaporating dish and mixed with water until plastic enough to be easily shaped into a ball. A small portion is formed into a ball and rolled into a thread one-eighth inch in diameter. If the soil can be rolled to this diameter without crumbling, it is too wet. If it crumbles so that it cannot be rolled down to this diameter, it is too dry. The moisture content should be so adjusted by the addition of either water or dry soil that the soil starts to crumble as the diameter approaches one-eighth inch, and that when one-eighth inch is reached, the soil thread has broken into several short segments. The sections of soil threads are placed in

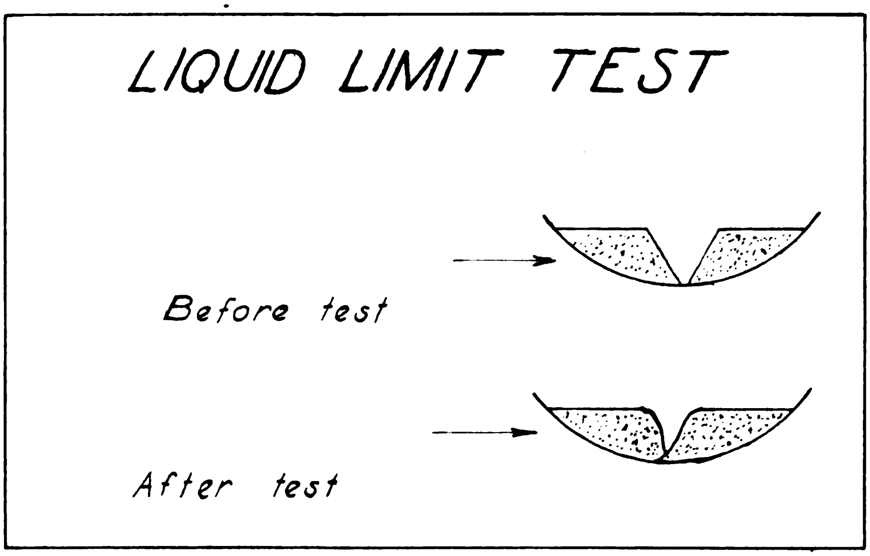


the oven to dry at 105 degrees C. After two hours, the sample is reweighed."

The weights are recorded in a manner similar to that shown following the explanation of the liquid limit test.

"For the Liquid Limit Test, about 15 gms. of the "thru 40" material are added to the plastic mix remaining in the evaporating dish. The mass is thoroughly mixed and water is added until the mixture becomes pasty. It is then smoothed with a spatula into a layer about three-eighths of an inch thick at the center. A groove is made in the wet soil with the grooving tool at right angles to the edge of the evaporating dish, dividing the soil into two portions. The groove must extend through the soil down to the dish so that the dish is clearly visible at the bottom of the groove. The upper surface of the grooving tool must come flush with the surface of the soil at the deepest part of the groove. This shows that the groove is exactly three-eighths of an inch deep. Having the groove exactly this depth is very important. The dish with the sample is placed in the liquid limit machine with the groove in the soil opposite the mark on the machine. The sample is given ten blows by means of ten turns of the crank.

"If the lower edges of the groove do not join with ten blows, the soil is too dry and should be moistened. If they join before the ten blows have been struck, the soil is too wet and dry soil should be added. The edges are considered joined when they are in contact and cannot be separated along the original line of division when carefully pulled apart with a spatula. When the lower edges have just joined after ten blows have been struck, the



moisture content is equal to the liquid limit. A small portion of that part of the sample which has flowed is transferred to a weigh bottle and weighed. The sample in the weigh bottle is dried for two hours at 105 degrees C. and reweighed."

The Plasticity Index is equal to the difference between the liquid limit and the plastic limit.

When working with soils of low plasticity indexes

Sample Recording of Plastic Limit and Liquid Limit Tests.

Sample 5134

No. of weigh bottle and identification of test	PL138	LL134
(a) Wt. of wet sample & weigh btl.-	14.944	15.483
(b) " " dry " & " " -	14.786	14.977
(c) " " weigh bottle------------	14.036	13.975
(d) " " dry sample only, b - c---	.750	1.002
(e) " " water lost, a - b--------	.158	.506
(f) % of water $\frac{e}{d}$ x 100------------	21.5	50.5
(g) Plasticity index--------------	(29.0)	

the operator may hage some difficulty in adjusting the moisture content so that the soil ribbon will break apart at just the right time during the plastic limit test. In a mixture of this sort a fairly wide variation in moisture content is hardly noticeable in the action of the ribbon and care must be exercised to secure accurate results. The liquid limit point for this type of soils is more easily defined. There is usually a relatively small moisture content at the liquid limit and the grooving tool will make a clear division so that the point or points of joining will be easily discernible and the results should be fairly accurate, if reasonable care is exercised.

Conversely, with soils of high plastic index, a very small amount of water need be added to bring the mixture to the liquid limit. The natural tendency of the beginner is to add an excess of water, and, of course, more of the soil-fines will need to be added to lower the moisture content to the plastic limit. This point is fairly easy to ascertain if the operator uses caution in rolling and judging the fitness of the sample. For these soils with high plasticity index, the liquid limit is the harder to determine. Because of the high water content at the point, even a skilled operator may have a hard time drawing the grooving tool through the soil pat to form a well-defined, firm line. The soil may have a tendency to cling to the tool and make the sides of the groove hollowed out. This, of course, decreases the accuracy of the test, so care must be taken to make a good groove. Here again a fairly large variation in moisture content will not change the action of the test a great deal so that the operator must be very observant to determine the true plastic limit.

Data

Before sending the samples to be used in this series of experiments, The Dow Chemical Company very kindly ran mechanical analysis and approximate Plastic and Liquid Limit tests on them as a check to the writer in order to eliminate chance of error insofar as possible.

The first step then was to verify these plasticity and liquid limit results. In general, the verifications on the following page were quite similar to the figures with the materials. The next thing to do was to make combinations of the soil samples to determine if the plasticity indexes followed a straight line variation according to the proportion of constituents used. Take a simple example for instance:

A gravel may have a plasticity index of 2 and a clay one of 42. If we take a mixture of 50% of each material and run tests on it, we might expect the combination to have a result equal to half the differences between the two plasticity indexes, all added to the smaller index ($[(42-2) \div 2]+2$) or 22. Similarly, for a mixture of 25% of the clay and 75% of the gravel we might expect a plasticity index of 12 and for one of 75% clay and 25% gravel an index of 32. Theoretically, the variations should occur along a straight line in a manner similar to this.

From tests by The Dow Chemical Company, it

Sample No.	Description of Sample	Mechanical Anal. % by Weight								Physical Test	
		Gravel					Soil Fines				
		On 1 inch	Pass 1 inch; on $\frac{3}{4}$ inch	Pass $\frac{3}{4}$ inch; on No. 4	Pass No. 4; on No. 10	*Coarse Sand; Pass No. 10; on No. 40	Fine Sand Pass No. 40; on No. 270	Silt	Clay	Liquid Limit	Plasticity Index*
	A. Standard Samples										
1400	Sand-Clay	0	0	0	0	0	67	14	19	20.5	10.5
2412	Clay	0	0	0	0	0	11	13	76	56	36
	B. Samples for Testing										
	1. Soils low in cohesion,										
2510	Surface Soil; Barry Co. Michigan	0	1	30	18	21	22	4	4	14.9	1.5
2557	Road Metal; Midland Co. Michigan	0	0	32	20	13	23	6	6	16.6	3
	Bank Sand; "	0	0	0	0	12	88	0	0		0
871	Pit gravel; "	0	0	20	33	17	23	3	3	15.2	0
6172	Road Metal; Brown Co., Indiana	0	0	14	13	20	26	16	11	19	2.5
6506	Creek Gravel; Johnson Co., Indiana	2	5	40	11	10	10	17	5	28	3.5

* For practical purposes coarse sand is considered as passing No. 10 and retained on No. 40 sieve.

Sample No.	Description of Sample	Mechanical Analysis Per Cent by Weight: Gravel: On 1 inch	Pass 1 inch; on 3/4 inch	Pass 3/4 inch; on No. 4	Pass No 4; on No. 10	* Coarse Sand; Pass No. 10; on No. 40	Soil Fines: Fine Sand Pass No. 40; on No. 270	Silt	Clay	Physical Test: Liquid Limit	Plasticity Index
	B 2. Soils with considerable cohesion.										
5134	Clay, Wisconsin	0	0	0	0	2	15	52	31	49	29
5142	" "	0	0	0	0	2	15	51	32	47	24.3
6192	" ; Scott, Ind.	0	0	0	1	3	8	44	44	43	19.5
2400	" ; Minnesota	0	0	0	0	0	5	29	66	71	39
2467	" ; Iowa	0	0	0	2	7	34	28	29	53.3	35.4
2463	Caliche; Texas	0	0	0	6	3	36	15	40	36	19.6

* For practical purposes coarse sand is considered as passing No. 10 and retained on No. 40 sieve.

has been determined that soil mixtures having a plasticity index of around 10 and graded in the proper proportions are most suitable for stabilized gravel road construction.

Keeping this in mind, then, the next step was to make combinations of the different soil samples, using the plasticity indexes previously determined and attempting to combine the materials in amounts that will give indexes of 10.

Take for example samples No.5134(P.I.=29) and No.6506(P.I.=3.5). Since the index sought is 10, it is necessary to find the amount the P.I. of each must vary in order to reach this point.

No. 5134	No. 6506
29	10
-10	- 3.5
19	6.5

Therefore the P.I. of No. 5134 must change 19% and No. 6506 must change 6.5% to reach the desired point, in this case 10. Because the total amount of water change for each material must be the same to reach the required P.I., a simple proportion will determine the relative part of each constituent needed.

$\frac{6.5}{19} = \frac{1}{x}$ $\quad x = 2.923$

This means that 1 part of No. 5134 (high P.I. material) and 2.923 parts of No. 6506 (Low P.I. material) should combine to form a mixture with plasticity index of 10. In other words, 10 gms. of No. 5134 and 29.23 gms. of No. 6506 should give the desired result when combined.

The percentage of each constituent in the mixture is found by proportioning the relative part of the constituent to the total mixture and multiplying by 100 per cent.

No. 6506

$$\frac{2.923}{3.923} \times 100 = 74.4\% \text{ of the total mixture}$$

No. 5134

$$\begin{array}{r} 100.0\% \\ -\ 74.4 \\ \hline 25.6\% \end{array} \text{ of the total mixture}$$

When the tests were run on a mixture of these proportions, the resulting P.I. was actually only 8.1, due probably to some error in laboratory technique. Over the whole range of combinations, some of the results were above 10 P.I. and some below, so that when they were all averaged together, there was very little difference between the theoretical and actual indexes.

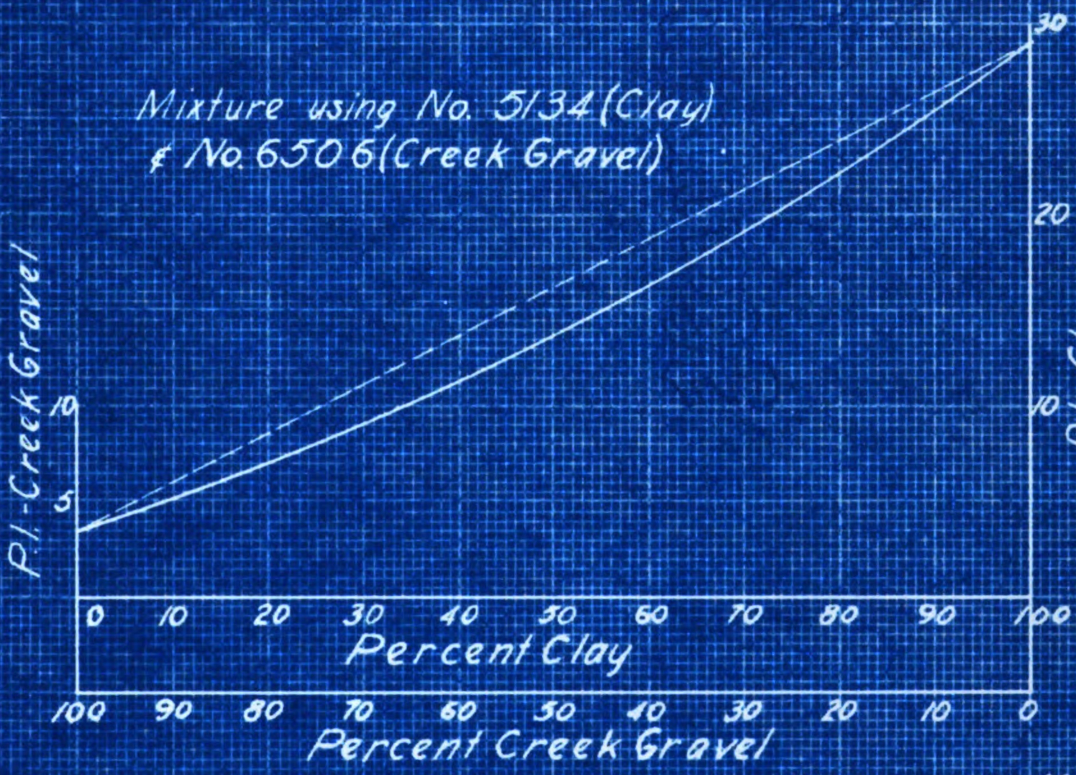
Data for Combinations Used

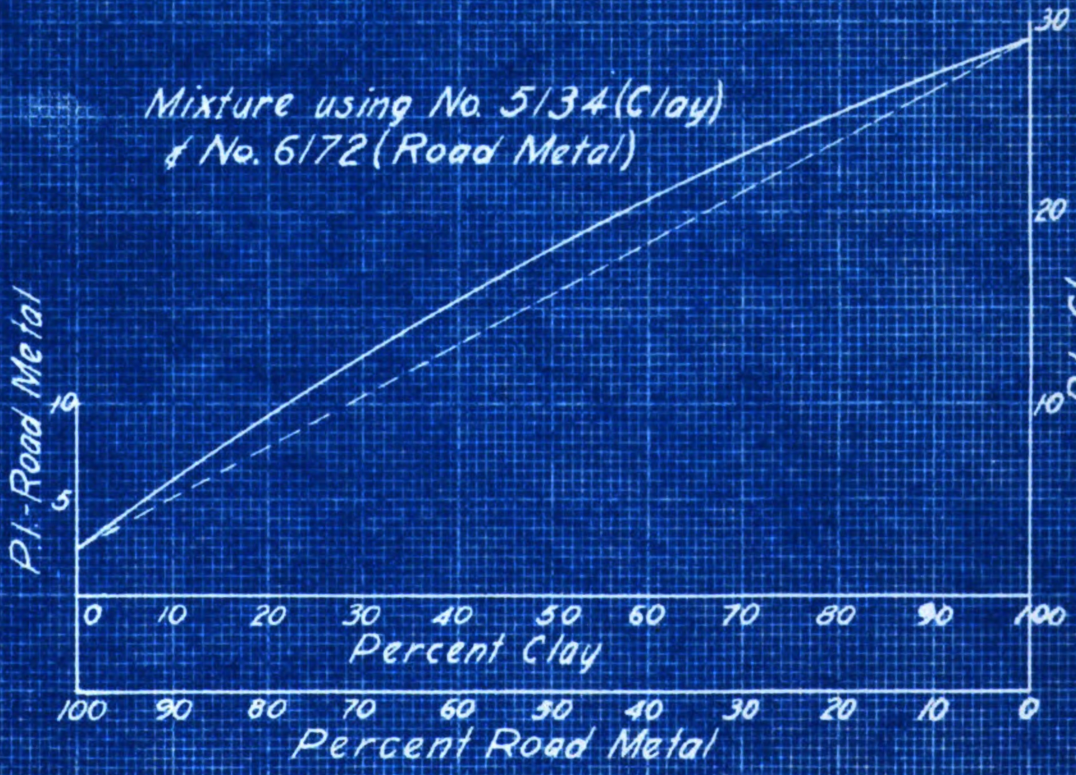
Low P.I. Material			High P.I. Material			P.I. Mix.
No.	P.I.	% of Mix	No.	P.I.	% of Mix	
6506	3.5	74.4	5134	29	25.6	8.1
6172	2.5	71.6	5134	29	28.4	12.0
2510	1.5	69.5	5134	29	30.5	9.6
871	0.0	65.6	5134	29	34.4	8.6
2510	1.5	52.8	6192	19.5	47.2	11.6
2510	1.5	75.0	2467	35.4	25.0	12.2
871	0.0	48.7	6192	19.5	51.3	10.4
6172	2.5	55.8	6192	19.5	44.2	10.6
871.	0.0	71.7	2467	35.4	28.3	9.0
6506	3.5	59.4	6192	19.5	40.6	9.4
6172	2.5	77.4	2467	35.4	22.6	11.5
6506	3.5	79.6	2467	35.4	20.4	9.6
Avg.	1.88	50		27.97	50	15.7

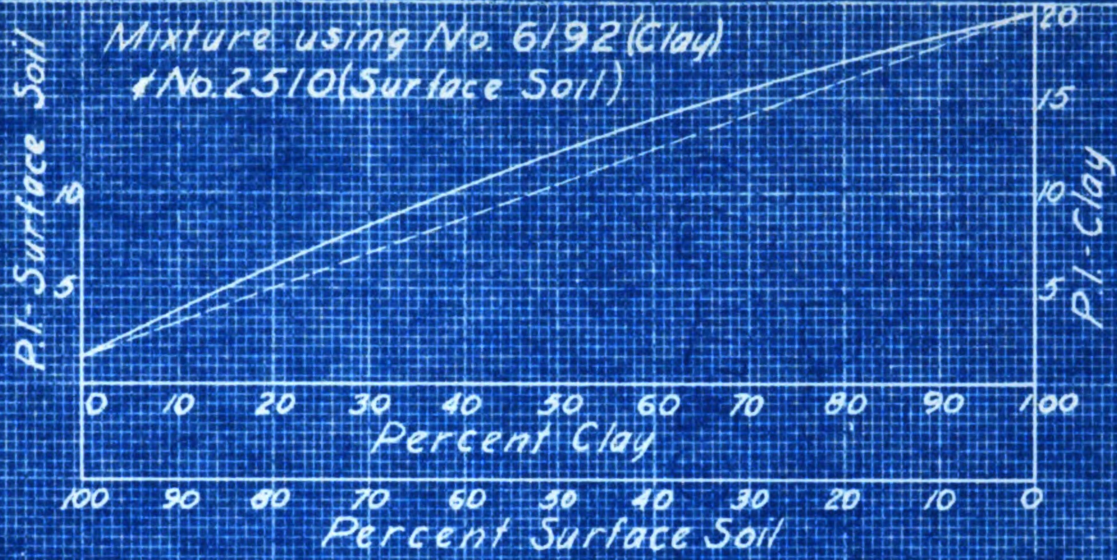
P.I. Avg. Mix. theoretically should be------14.9

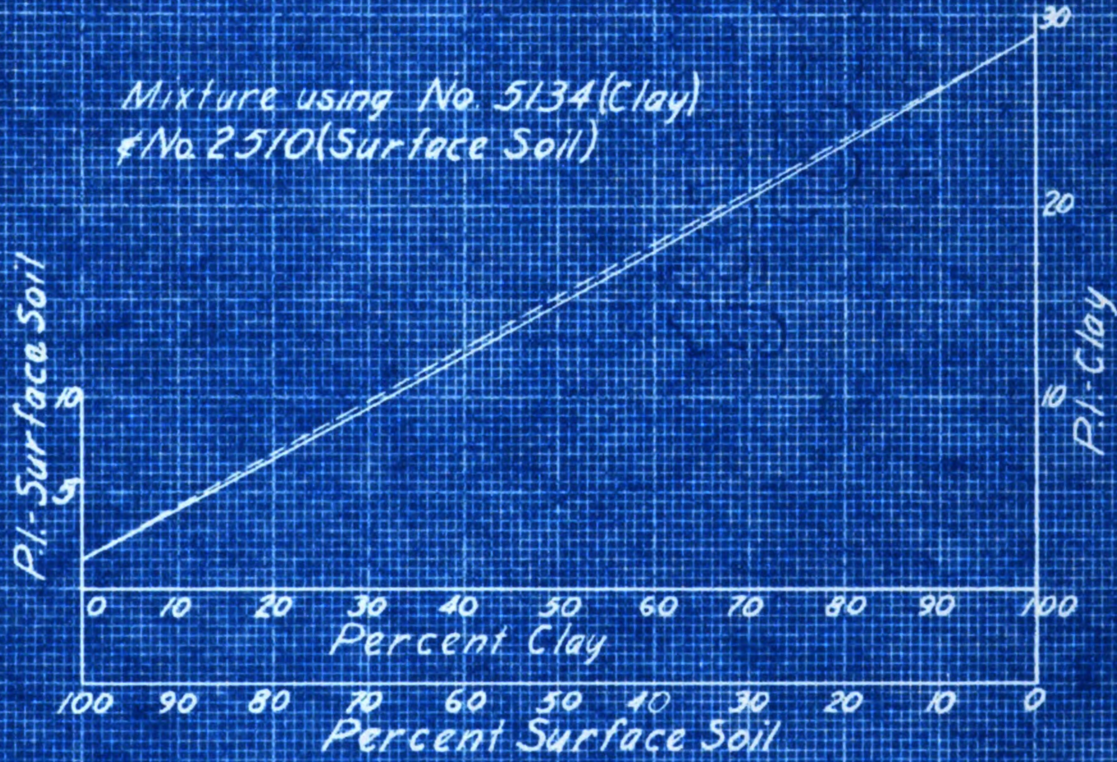
The variations of Plasticity Indexes (P.I.'s) for various soil mixtures.

Dotted lines show the theoretical and solid lines the actual behavior.






Mixture using No. 6192 (Clay)
& No. 2510 (Surface Soil)
P.I.-Surface Soil
P.I.-Clay
5
10
15
20
0 10 20 30 40 50 60 70 80 90 100
Percent Clay
100 90 80 70 60 50 40 30 20 10 0
Percent Surface Soil


Mixture using No. 5134 (Clay)
& No. 2510 (Surface Soil)
P.I.-Surface Soil
P.I.-Clay
5
10
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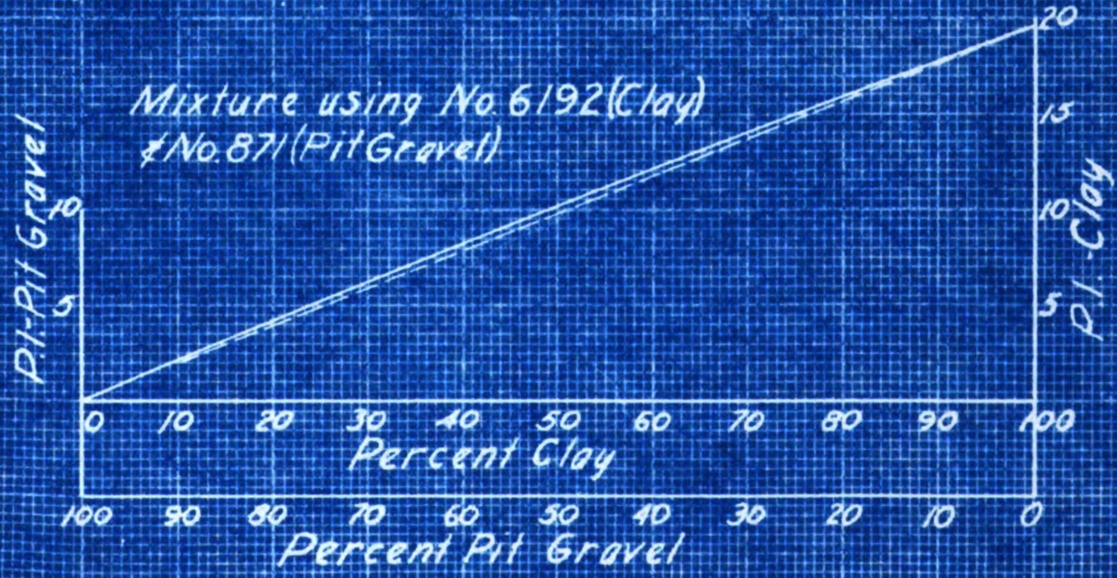
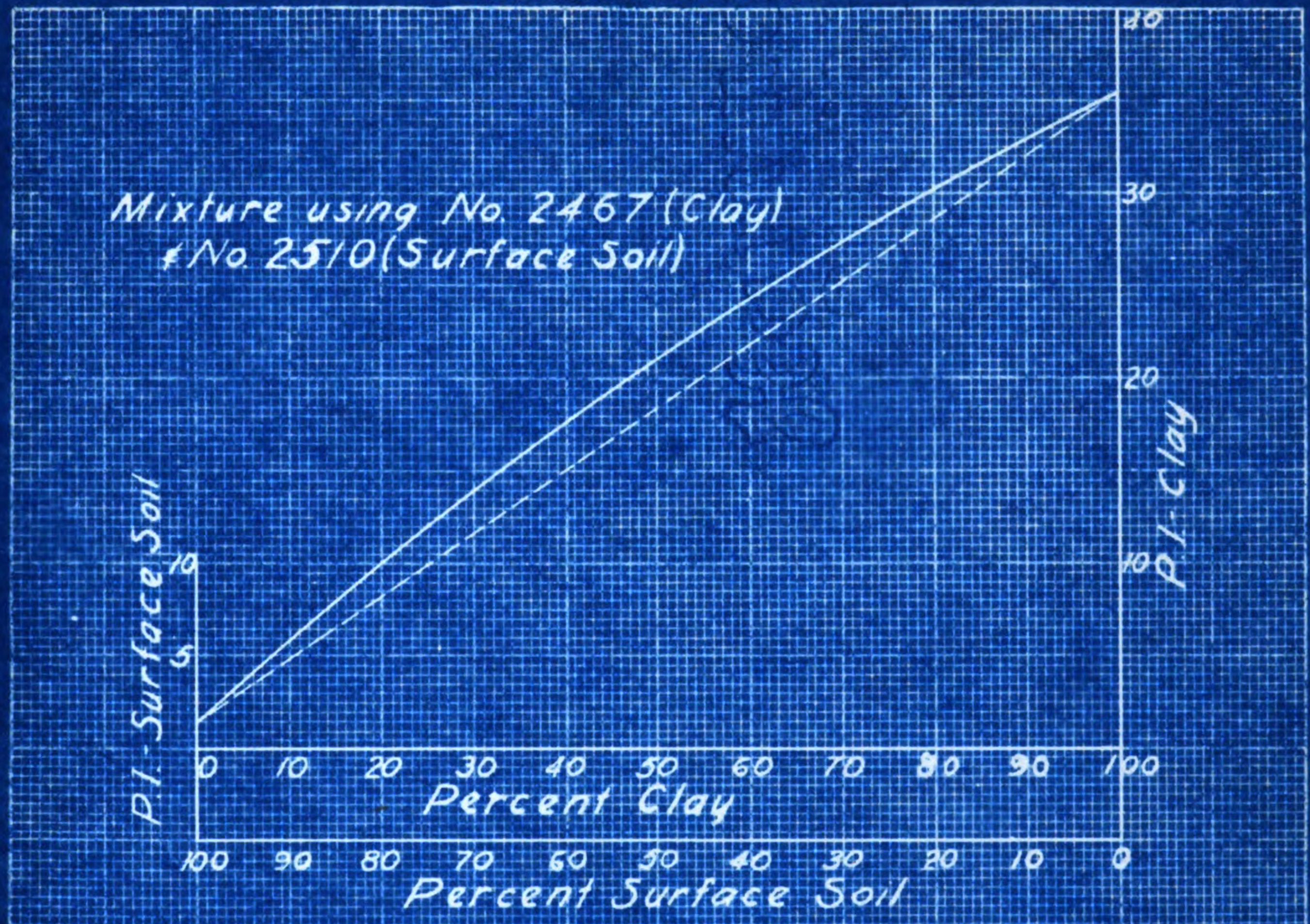
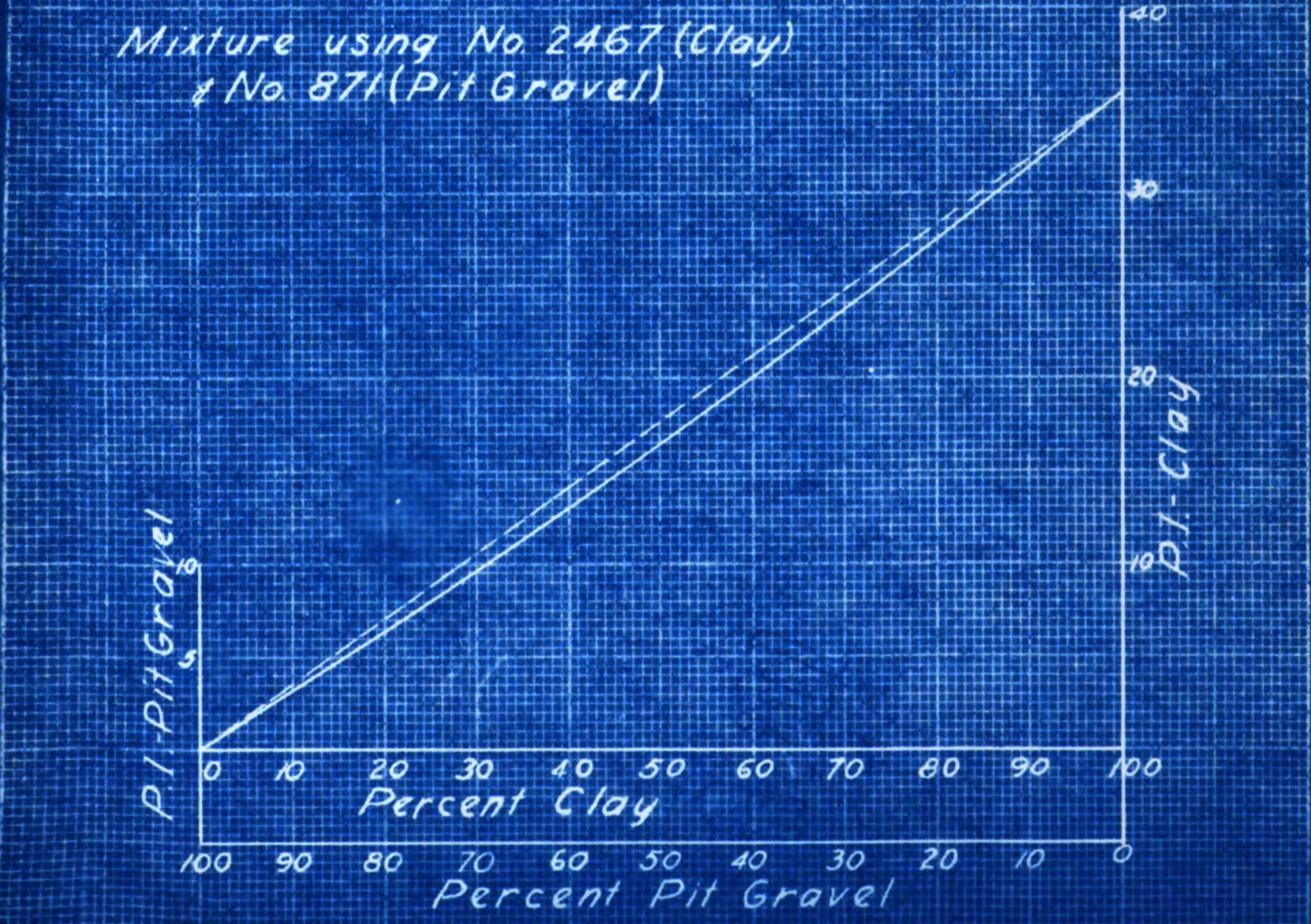
0 10 20 30 40 50 60 70 80 90 100
Percent Clay
100 90 80 70 60 50 40 30 20 10 0
Percent Surface Soil


Mixture using No. 6192 (Clay)
& No. 871 (Pit Gravel)
P.I.-Pit Gravel
P.I.-Clay
5
10
15
20
0 10 20 30 40 50 60 70 80 90 100
Percent Clay
100 90 80 70 60 50 40 30 20 10 0
Percent Pit Gravel


Mixture using No. 2467 (Clay)
& No. 2510 (Surface Soil)
P.I. - Surface Soil
5
10
P.I. - Clay
10
20
30
40
0 10 20 30 40 50 60 70 80 90 100
Percent Clay
100 90 80 70 60 50 40 30 20 10 0
Percent Surface Soil


Mixture using No. 2467 (Clay)
& No. 871 (Pit Gravel)
P.I. - Pit Gravel
5
10
P.I. - Clay
10
20
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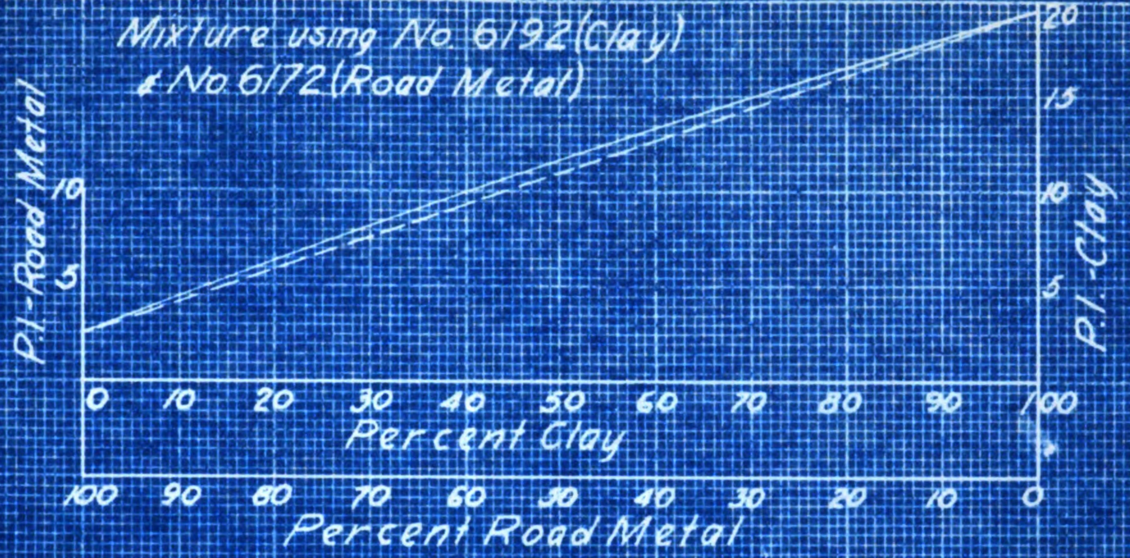
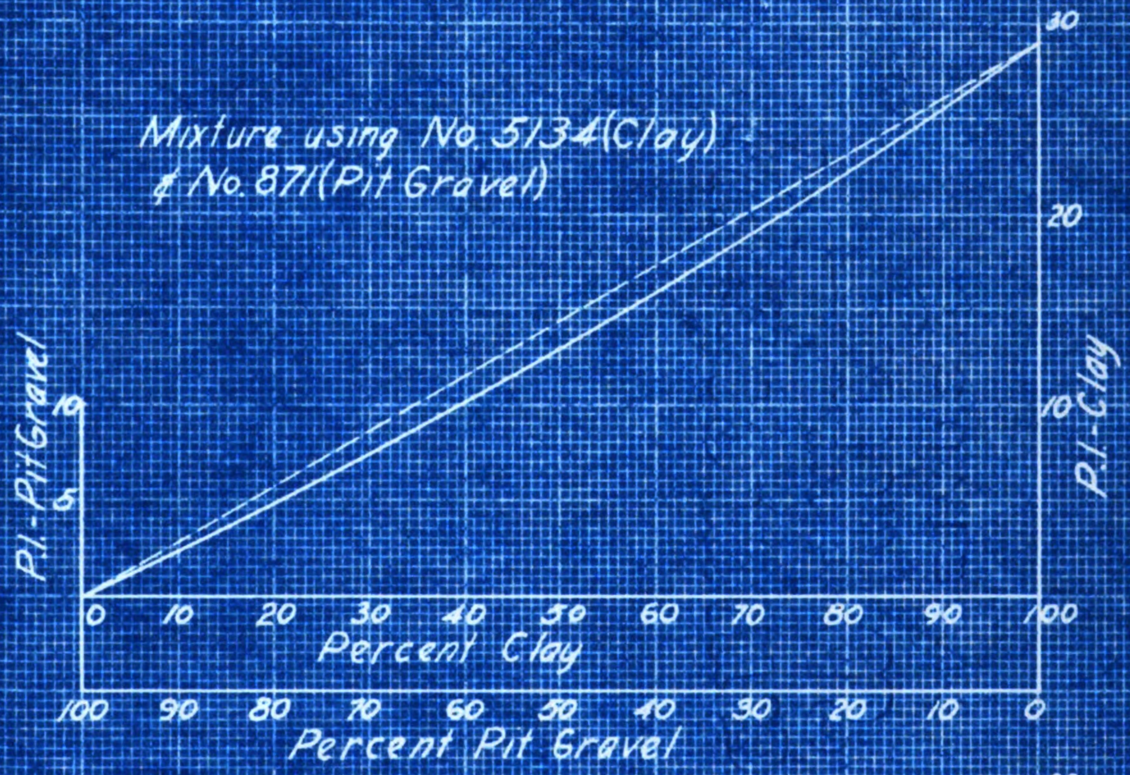
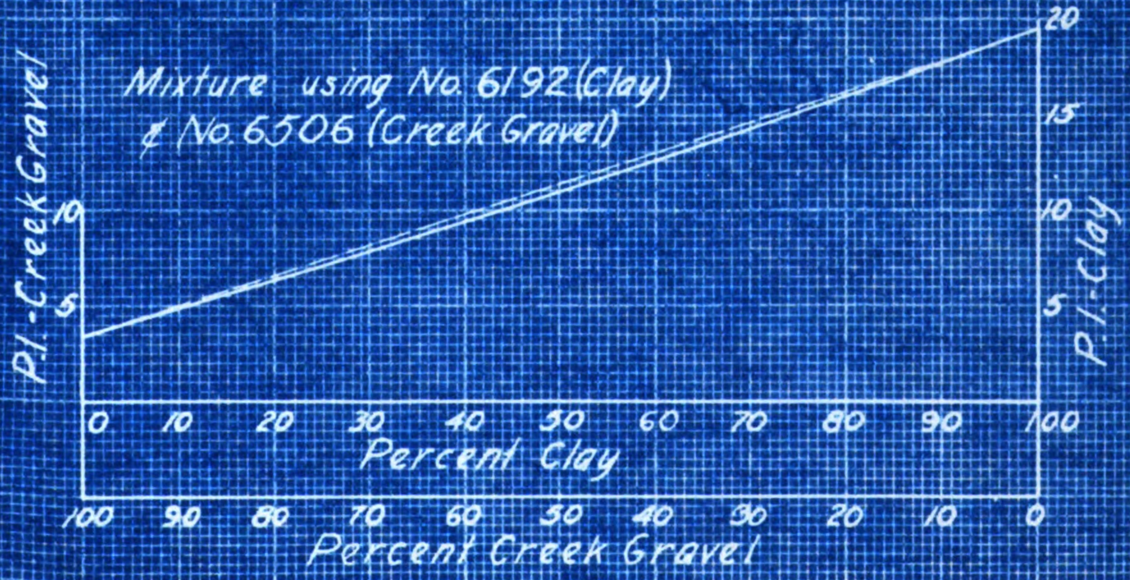
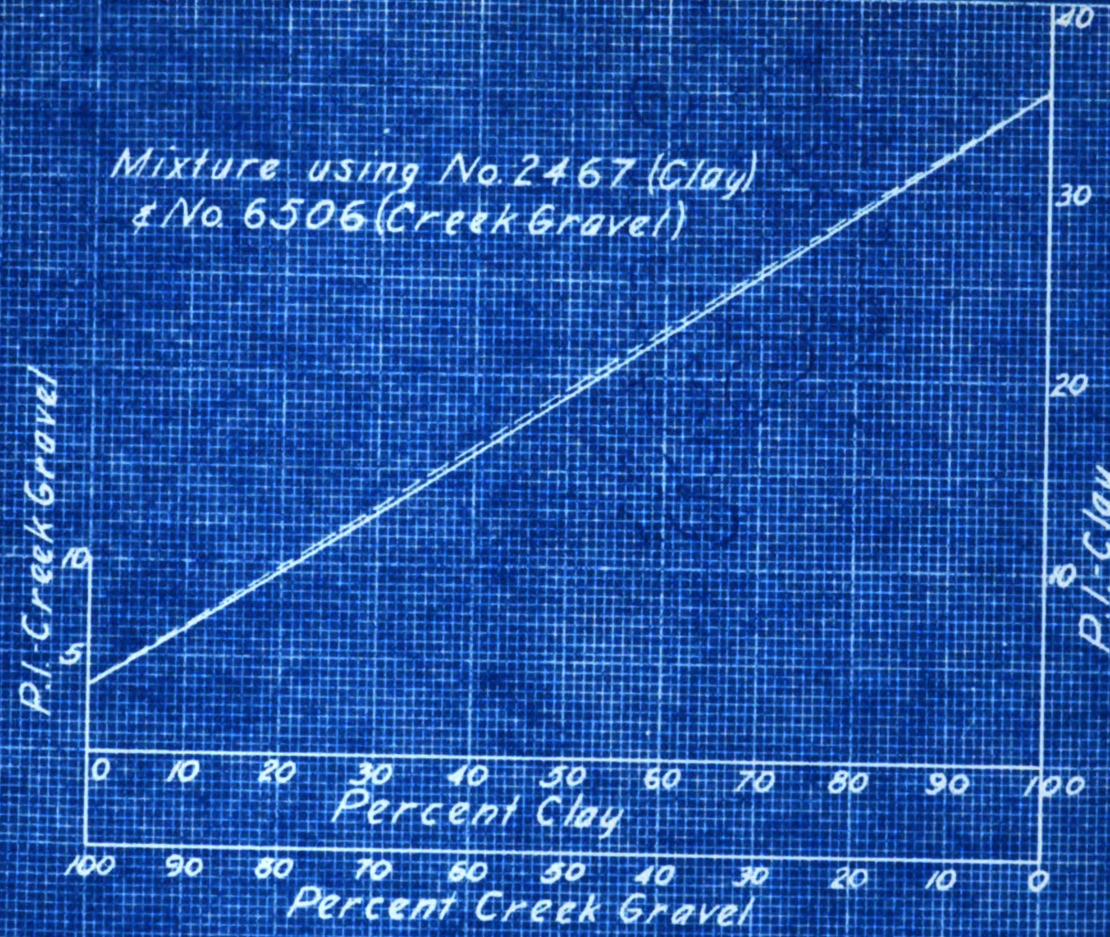
40
0 10 20 30 40 50 60 70 80 90 100
Percent Clay
100 90 80 70 60 50 40 30 20 10 0
Percent Pit Gravel

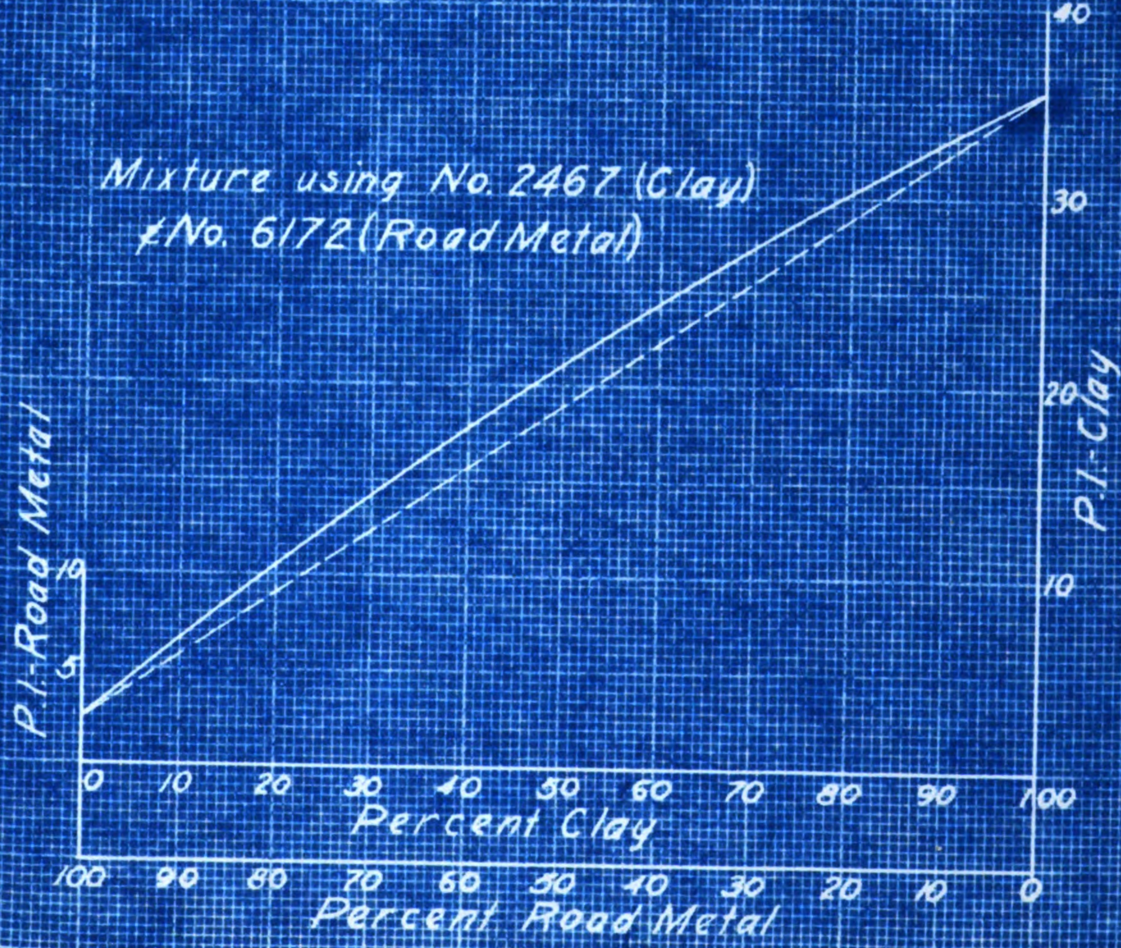

Mixture using No. 6192 (Clay)
& No. 6172 (Road Metal)
P.I.-Road Metal
10
5
20
15
10
5
P.I.-Clay
0 10 20 30 40 50 60 70 80 90 100
Percent Clay
100 90 80 70 60 50 40 30 20 10 0
Percent Road Metal


Mixture using No. 5134 (Clay)
& No. 871 (Pit Gravel)
P.I.-Pit Gravel
10
5
30
20
10
P.I.-Clay
0 10 20 30 40 50 60 70 80 90 100
Percent Clay
100 90 80 70 60 50 40 30 20 10 0
Percent Pit Gravel


Mixture using No. 6192 (Clay)
& No. 6506 (Creek Gravel)
P.I.-Creek Gravel
10
5
20
15
10
5
P.I.-Clay
0 10 20 30 40 50 60 70 80 90 100
Percent Clay
100 90 80 70 60 50 40 30 20 10 0
Percent Creek Gravel

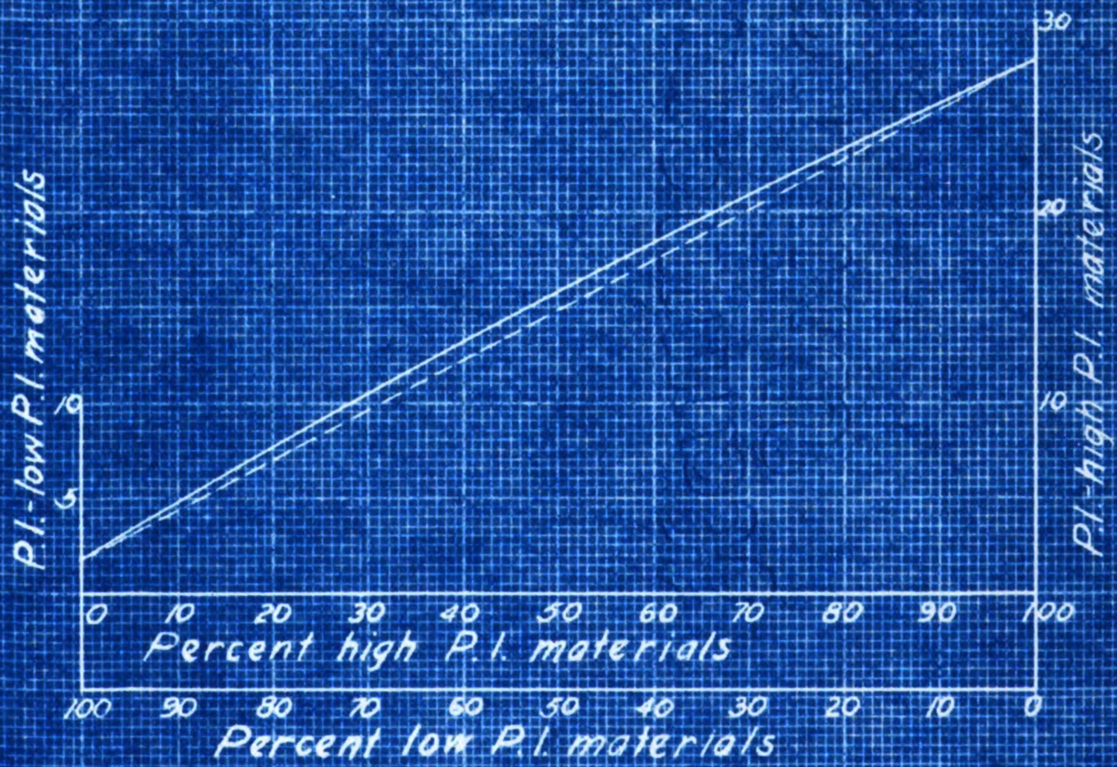


Mixture using No. 2467 (Clay)
& No. 6506 (Creek Gravel)
P.I.-Creek Gravel
P.I.-Clay
5
10
10
20
30
40
0 10 20 30 40 50 60 70 80 90 100
Percent Clay
100 90 80 70 60 50 40 30 20 10 0
Percent Creek Gravel



Mixture using No. 2467 (Clay)
& No. 6172 (Road Metal)
P.I.-Road Metal
P.I.-Clay
5
10
10
20
30
40
0 10 20 30 40 50 60 70 80 90 100
Percent Clay
100 90 80 70 60 50 40 30 20 10 0
Percent Road Metal

Composite graph, showing the average of all mixtures used.



Conclusion

From this series of tests it can be easily recognized that there is close correlation between a theoretical straight line variation and the actual behavior of combinations of soil samples with regard to their plasticity index. The variation from one side of the straight line or the other is not enough to determine a general formula for the discrepancy so that in general it may be stated that with reasonable care in performing the plastic and liquid limit tests, for all practical purposes, a straight line variation may be assumed to exist between the plasticity indexes of soil samples in combination.

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