Effect of Mechanical Manipulation on the Plasticity of Soils

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● SOMEWHAT BAFFLING DISCREPANCIES in soil constants have been obtained in repetitious tests run on samples of the same soil in the course of routine and investigational soil testing work at the Minnesota Highway Department Laboratory and at the University of Minnesota. These tests include the liquid limit, plastic limit, optimum moisture content, and hydrometer analysis. The discrepancies have invariably been explained as results from variations in standard procedure or from the human element involved. In all cases, however, the assumption has been that the soil characteristic as determined by these tests are constant, and any deviation of corroborating tests results has its origin other than in the soil itself. In certain instances involving fully trained and experienced operators and utilizing sound testing procedures and reliable equipment, completely erratic results have been obtained which tended to arouse doubt concerning the actual constancy of these soil properties.

An example of a seeming change in soil constants was the experience with two Alaskan silty soils used in an investigation of soil thermal conductivity. These soils (as originally received) were given routine tests and judged to be nonplastic; that is, the plasticity indexes were zero. After considerable handling (being compacted into test cylinders, dug out and dried, moistened and again compacted) in the conductivity tests, the soils were stored and later used as standard samples to be assigned to students for moisture-density compaction (the so-called Proctor test) and liquid limit and plastic limit tests. The soils had developed definite signs of plasticity and had P I values of about 5.

A more marked change was noted in an investigation by the Minnesota Highway Department Laboratory in 1953. A silt loam soil being studied for compaction characteristics was subjected to repeated processes of compaction by a pneumatic compactor (a machine developed by F. N. Hveem). The soil was kneaded and compacted at a variety of moisture contents and at various unit pressures. The test constants made on this soil, before and after this treatment, are as follows:

	Liquid Limit	Plastic Limit	Plasticity Index
Before treatment	32.6	21.7	10.9
After treatment	40.6	18.7	21.9

The soil had an obvious difference in feel before and after the tests, although the hydrometer analysis did not indicate any significant changes in the grain size curves.

On the basis of these experiences and others, a series of tests were performed on several soils to determine what changes in the plasticity constants might occur as a result of prolonged physical manipulation of the soils.

Soils Tested

Laboratory tests were made on five soils; two were very silty materials, the other three were clays. The two silty soils, a clay, and a sandy loam were used for some field tests under traffic (Table 1).

Tests on Polk County Silt Loam

The largest amount of investigative work was done on a silt soil from Polk County, located in the Red River Valley

TABLE 1
GRADING AND CONSTANTS OF SOILS

Soil	Sand %	Silt %	Clay %	Colloids %	Liquid Limit	Plasticity Index
Polk Co. silt loam	8.0	73.8	18.2	14.5	26.5	5.1
Shakopee silt loam	17.0	70.5	12.5	8.0	24.1	1.3
Dodge Co. clay	45.0	22.2	32.8	23.8	34.8	21.8
Wadena Co. clay	30.0	32.7	37.3	27.0	42.8	24.4
Wilkin Co. clay	3.0	16.5	80.5	47.0	73.7	53.5
Hoyt Lakes sandy loam	56.0	31.5	12.5	5.8	16.2	0.2
Duluth clay	9.0	22.2	68.8	32.0	44.3	25.3

Sizes of Soil Separates

Sand	2.0 to 0.05 mm
Silt	0.05 to 0.005 mm
Clay	Below 0.005 mm
Colloidal Clay	Below 0.001 mm

of northwestern Minnesota. This soil was from the same location as the soil on which the compaction study had been made, although the original soil constants were somewhat different. Samples of this soil were subjected to four different treatments: repeated compactions as in the moisture-density test, cycles of wetting and drying, mixing in a Lancaster mixer, and compaction by the pneumatic (Hveem) apparatus.

For the moisture-density compaction treatment, a quantity of soil was moistened and allowed to cure in the moist cabinet overnight. In the test, just enough soil to fill the Proctor mold was used. The standard procedure of compaction in three layers and 25 blows per layer was followed (AASHO Method T99-38), after which the specimen was broken down and recompacted in the same manner. Small samples for moisture, P I, and hydrometer tests were taken before the tests and at 50 and 100 complete Proctor compaction tests (one Proctor test consisting of 3 x 25 or 75 blows with the standard hammer).

The test constants obtained are shown in Table 2. The average moisture content during the first phase was 19.2 percent, very close to optimum for this soil. During the second phase (50 to 100 Proctor compactions) the average moisture content of the soil was 24.2 percent, considerably above optimum. A somewhat greater change is noted in the first phase of operation than in the second.

The effect of wetting and drying is also shown in Table 2. Each wet cycle consisted of 24 hours of curing in the moist cabinet and each dry cycle consisted of 24 hours of air drying at room temperatures of approximately 80 deg F. A moisture determination was made after each of these 24-hour periods. Liquid limit and plastic limit determinations were made after 0, 1, 3, 5, 10, 15 and 20 complete cycles. No significant change was noted in the P I values. Only the first and last determinations are given in the table.

The Lancaster mechanical mixer is a rotating, drum-type, general utility, laboratory mixer, usually used for mixing small concrete batches and bituminous trial mixes. The apparatus consists of a revolving bowl (13.1 rpm), mixing blade, side scraper, and roller wheel which is free to move vertically. The wheel is 4 in. wide, 8 in. in diameter, and weighs

TABLE 2
EFFECT OF PROCTOR COMPACTION TEST AND WETTING-DRYING ON SOIL CONSTANTS, POLK COUNTY SILT LOAM

Treatment	Test Constants LL	PL	PI
Original soil	26.5	21.4	5.1
50 Proctor compaction tests	28.2	19.9	8.3
100 Proctor compaction tests	28.9	19.3	9.6
20 Cycles of wetting and drying	25.8	19.1	6.7

72 lb. A 10-pound moist soil sample was placed in the mixer, and small test samples were taken at the conclusion of each 5-hour mixing period. Every ½ hour the machine was stopped momentarily while the mixer blade, roller wheel, scraper, and mixing bowl were scraped to prevent clogging and to insure uniform treatment of the entire soil sample.

The effect of 40 hours of this manipulation is shown in Figure 1. This type of manipulation (which is predominantly a rolling) had startling results on the Atterburg limits. The plasticity of the soil increased constantly with manipulation and, after the first five hours changed at what appears to be a constant rate. The results of the determination of the percentages of 5-μ (micron) clay and 1-μ collodial clay as obtained by the hydrometer analysis are also shown in Figure 1. The results were erratic, because decreases between 10 and 15 hours would be difficult to explain. In general, the increase in 5-μ clay content during the entire experiment is about ± 5 percent and the increase in 1-μ collodial clay is even less. This is a relatively small change as contrasted with the increase in the P I from 5.1 to 20.0.

The Hveem pneumatic compactor kneads or compacts soil in a container by means of raising and lowering a plunger. The action is hydraulic, and the compacting pressure can be regulated. The kneading foot has a cross-sectional area of 3.27 sq in. The soil was moistened (moisture contents varied from 21 to 26 percent) and placed in a 6-in. mold which was moved about by hand during the compaction process to insure uniform coverage of the sample by the kneading

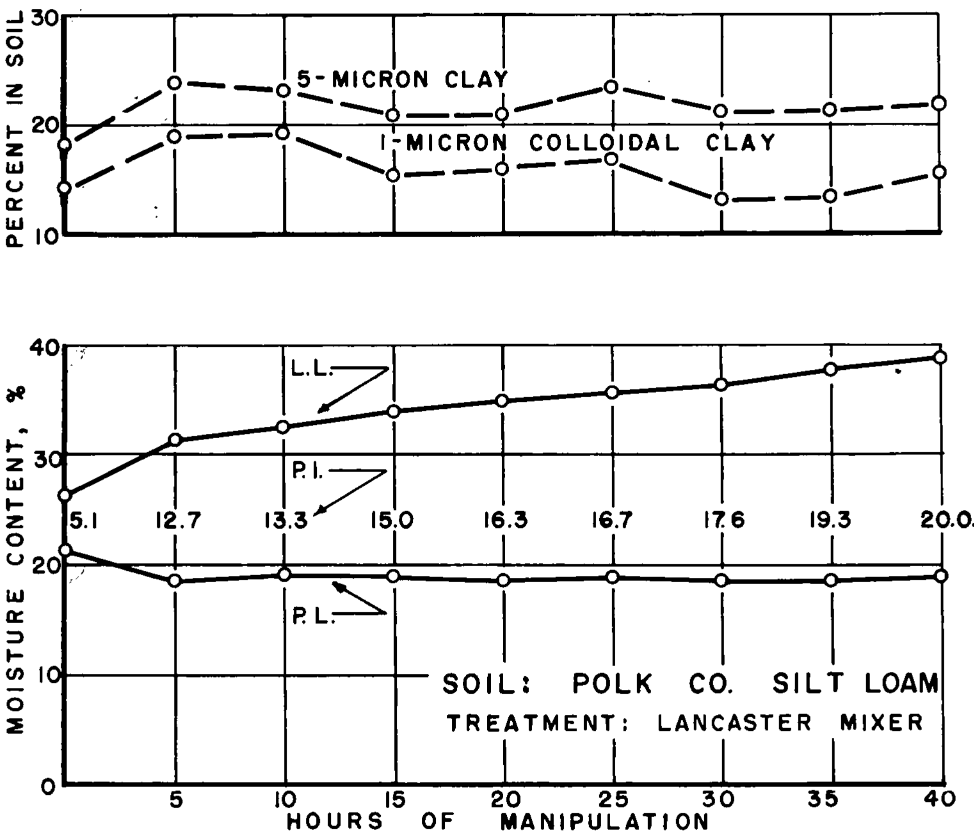

Figure 1. Changes with manipulation, Polk County silt loam.

foot. A pressure of 100 psi was used in the test. At 500 strokes and at every 1000 strokes to a total of 8000, samples were removed for plasticity and hydrometer analysis tests (Figure 2). In 2,000 compaction strokes the P I of the soil was somewhat more than doubled, but beyond that point there was little change. This is in contrast to the results in the Lancaster mixer, where the P I showed a steady increase with manipulation. The change in colloidal clay (1-μ) and total clay (5-μ) in the Hveem compactor was about 3 or 4 percent for both sizes. (The test on the sample with 500 strokes appears to be out of line.)

Tests on Other Soils

The changes in P I of the Polk County silt loam, brought about by manipulation in the Lancaster mixer and the pneumatic compactor, were of such magnitude that it was desirable to run similar tests on other soils. Four soils were selected: Shakopee silt loam and clays from Dodge, Wadena, and Wilkin Counties (Table 1). The Shakopee soil is one of the siltiest soils of the area around Minneapolis. The Wilkin County clay is a heavy clay for Minnesota.

The manipulation test results on the Shakopee silt loam are shown in Figure 3. The mixing in the Lancaster machine caused a marked, progressive increase in P I — the soil changing from a mellow-feeling material with a P I of 1.3 to a definitely plastic material with a P I of 16.1. Hydrometer analyses were made only at the start and at the completion of 20 hours of manipulation. Definite in-

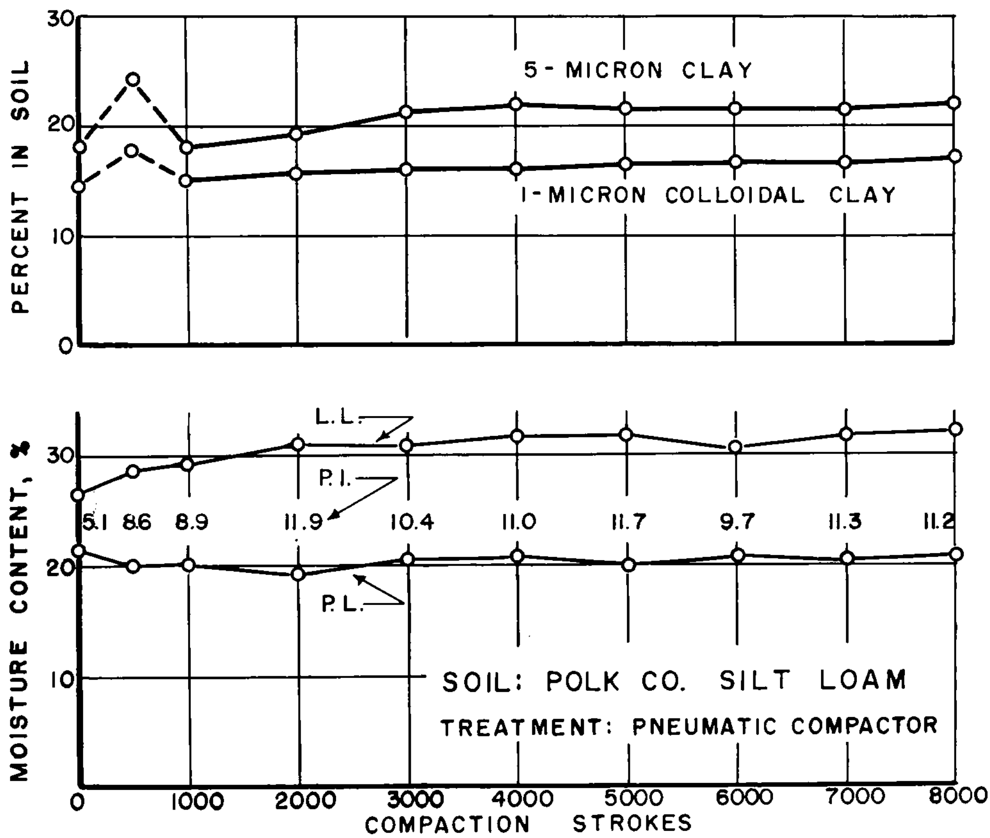

Figure 2. Changes with manipulation, Polk County silt loam.

creases in clay and colloidal clay contents were shown.

The effect of compaction or kneading with the Hveem machine to a total of 4000 strokes is much less pronounced. The final P I was 5.4, although only small changes were indicated at 3000 strokes. The increase in clay and colloidal clay contents was 0.7 and 1.2 percent (5-μ clay 12.5 to 13.2 percent; 1-μ colloidal clay 8.0 to 9.2 percent).

The tests on the clay soils, all of which had P I values greater than 20 in their initial unworked condition, showed some changes due to manipulation, but to a much lesser degree than the silty soils.

The test results on the Dodge County clay are shown in Figure 4. Twenty hours in the Lancaster mixer increased the P I from 21.8 to 26.8. There was also a marked increase in the 5- and 1-μ clay percentages in the hydrometer analyses, both increasing about 7 percent. Using the pneumatic compactor, the results were unusual: a decrease occurred in the P I from 21.8 to 17.4, although there was a slight increase (about 2 percent) in clay and colloidal clay contents. The Wilkin County clay indicated a similar tendency in one test. No explanation is offered for this change. The soils were handled in essentially the same manner for all tests, and the result does not seem attributable to any variations in testing procedures or preparation of samples.

The Lancaster mixer tests on Wadena County clay (Figure 5) shows a definite increase (24.4 to 35.5) in P I for the first 5 hours of mixing but practically no additional change for 15 additional hours. Substantial changes occurred in the hydrometer test results. Similar results occurred with the pneumatic compaction; the P I increased to 33.2 for 500 strokes and changed little for 3500 additional strokes. Changes in clay and colloidal clay contents were less in these tests than for the Lancaster mixer.

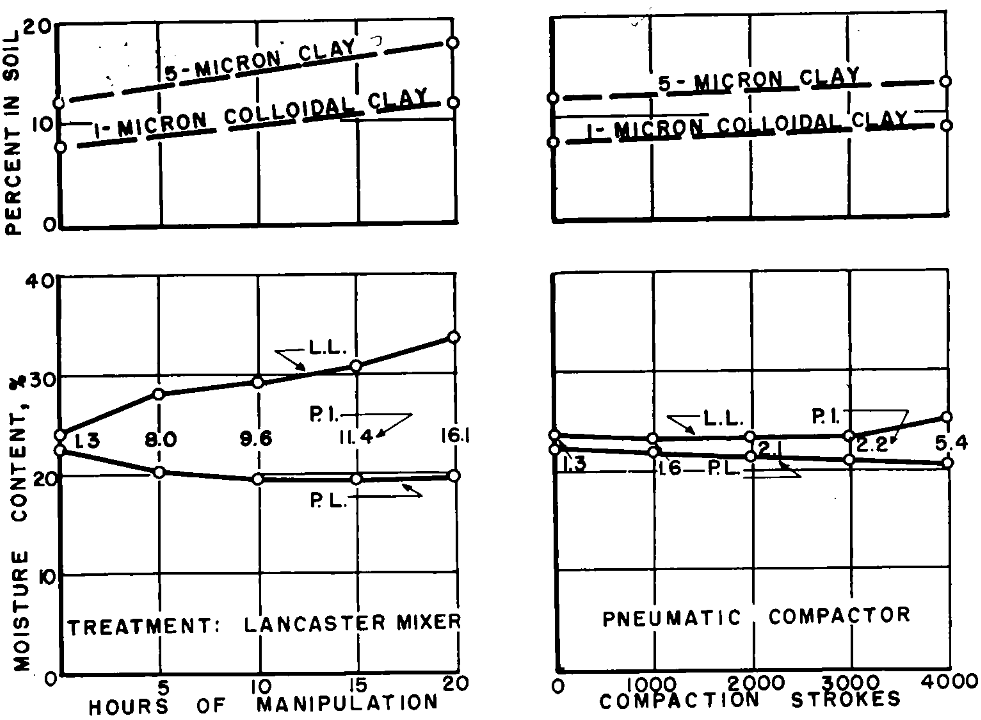

Figure 3. Grading and soil constant changes, Shakopee silt loam.

The Wilkin County clay, the heaviest soil tested, showed peculiar results with manipulation in the Lancaster mixer. An almost steady decrease in P I with time of mixing occurred (Figure 6). Twenty hours of mixing in this machine caused an increase in the P I of all soils tested except for this one. A slight increase occurred in the clay and colloidal clay contents. In the pneumatic compactor test a very slight increase in P I occurred, with 1 to 3 percent increase in the content of clay and colloidal clay.

For a soil with an initial P I of 53.5, a clay content of 80.5 percent, and 40.7 percent colloids, perhaps a change of 7 or less in the P I is not particularly significant. The changes obtained might be due to factors other than physical manipulation of the sample.

In all tests except that on the Wilkin County clay, the treatment in the Lancaster mixer caused a greater increase in the P I of the soils than the manipulation in the pneumatic compactor. The increase in percentage of 5- and 1-μ clay was also greater for the Lancaster mixer samples. Twenty hours in the mixer was a longer time than that required for 4000 strokes in the Hveem apparatus (this required about 2¼ hours), but since the actions are different in the two pieces of equipment it is difficult to compare the actual amounts of manipulation. Both tests cause greater handling than a soil might have in normal construction processes in the field.

Field Tests

A field test was made to investigate the possible practical aspects in the changes in a soils characteristic beneath a thin pavement mat subjected to the impact and vibrations of traffic.

Four soils were used in this series of tests. One was the Polk County silt loam and another was the Shakopee silt loam from the laboratory tests. The other two soils (Hoyt Lakes sandy loam and Du-

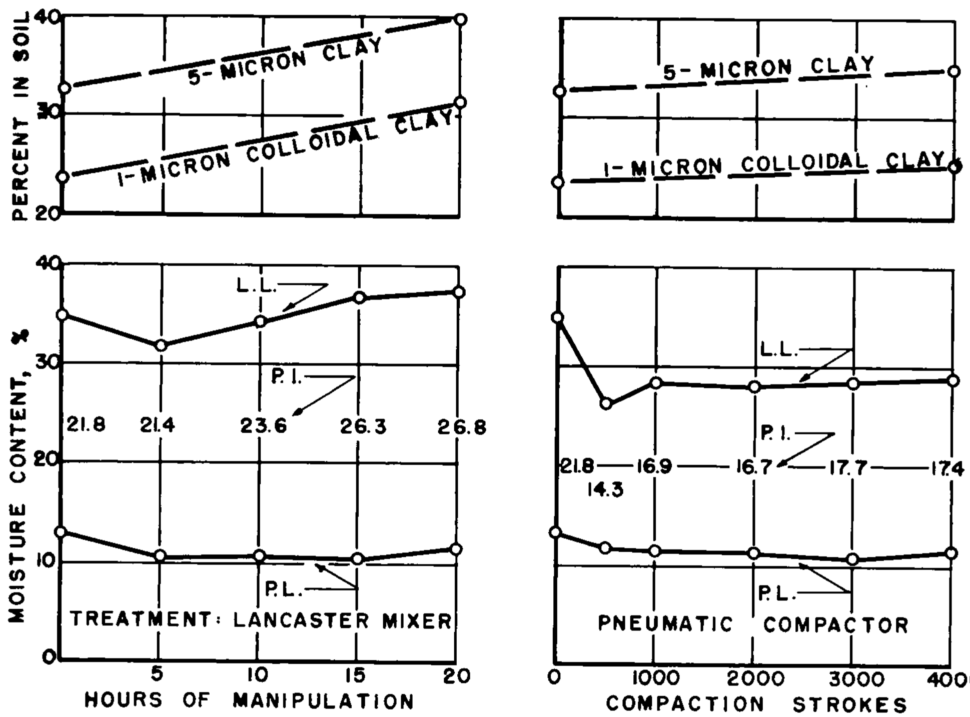

Figure 4. Grading and soil constant changes, Dodge County clay.

luth red clay) were from the general area of the field site in northeastern Minnesota (Table 1).

The field tests were conducted on the plant-site road leading to Erie Mining Company's Taconite Plant near Aurora, Minnesota. The average amount of traffic on this road was about 3400 vehicles per day. The road was surfaced with a 2-in. road-mixed bituminous (M C-2) mat. Twelve test points were placed in this road at distances of about 6 to 10½ ft from the edge of the mat in a zig-zag pattern to attain a uniform amount of traffic on all points. Each of the four soils was used in three different types of test points as follows:

Type I. A section of the bituminous mat approximately 12 in. by 18 in. was chopped out, and 4 in. of base material removed and replaced with test soil in a saturated condition. The bituminous mat was then replaced and a smooth riding surface restored.

Type II. A section of the bituminous mat was removed and 8 in. of base material was removed. Four inches of test soil in a saturated condition was tamped in place and covered with 4 in. of the original base material. The bituminous mat was then replaced and a smooth riding surface restored.

Type III. A section of bituminous mat was removed and 4 in. of base material removed and replaced with test soil base material in a saturated condition. The bituminous mat was then replaced and a smooth riding surface restored.

The soil base material used in this test series was manufactured especially for this purpose. A good pit-run base material was obtained and thoroughly washed through the No. 20 screen to remove all fines. This material was then separated on 1-in., No. 4, No. 10, and No. 20 sieves and recombined with the various test soils to conform to the following gradation which constitutes the soil base

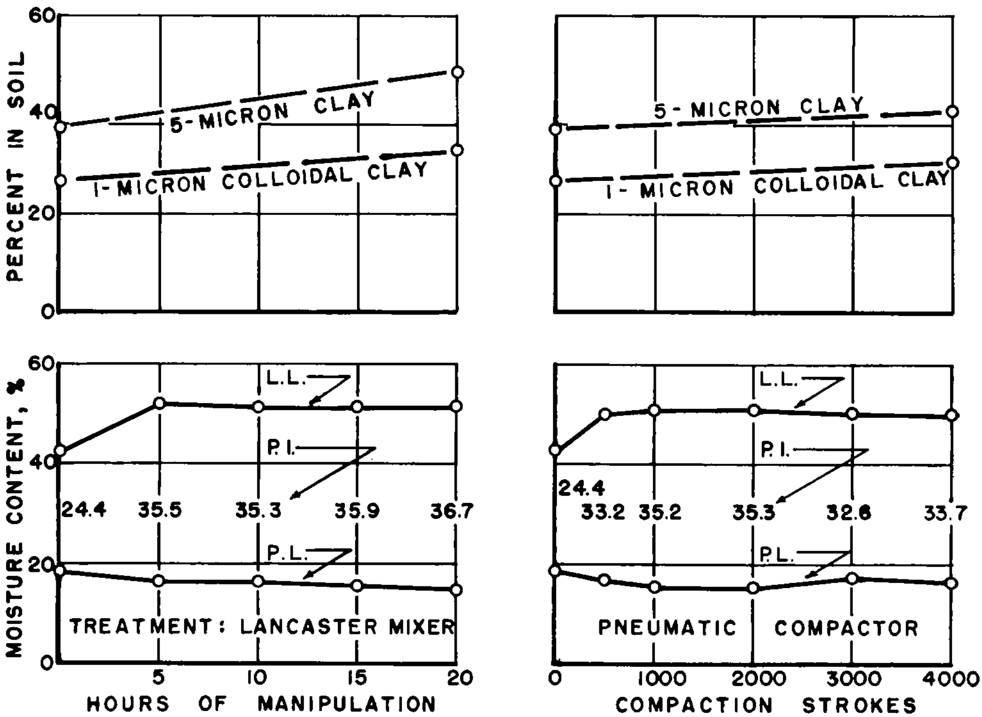

Figure 5. Grading and soil constant changes, Wadena County clay.

material used in the Type III test series:

Screen Size	% Passing
1 in.	100.0
No. 4	50.0
No. 10	40.0
No. 20	30.0

This is a poor base material, having some 30 percent fines; however, for the purpose of this study, it was an acceptable one because a definite separation of the P I sample (passing No. 40 sieve) from the coarser base materials was wanted.

The entire field test series, therefore, was designed to determine (a) if any change in soil properties occurs due to the manipulative action of traffic, (b) if this effect penetrates to any significant depth, and (c) if the effect is noticeable in soil gravel mixtures and if so, to what extent.

The soils were placed during the last week of June 1955, and removed the first week in November 1955; thus the samples were subjected to four full months of concentrated traffic action.

The results of the plasticity tests on the four soils are summarized in Table 3. The changes noted in these tests are much less than those found in the laboratory testing. Changes were so small that there may be a question if they have any significance. However, the following may be noted.

The soil placed at the depth of 0 to 4 in. beneath the mat showed increases in P I with all four types. The increases varied from 0.2 to 5.0; two of them were less than 1.0.

At a 4- to 8-in. depth beneath the mat increases were shown for three of the four soils. The amounts of increase were 0.6, 2.6, and 1.9. In all three cases the increase at this depth was less than that for the 0- to 4-in. depth. For the other soil the final P I was 0.9 compared to an original value of 1.3.

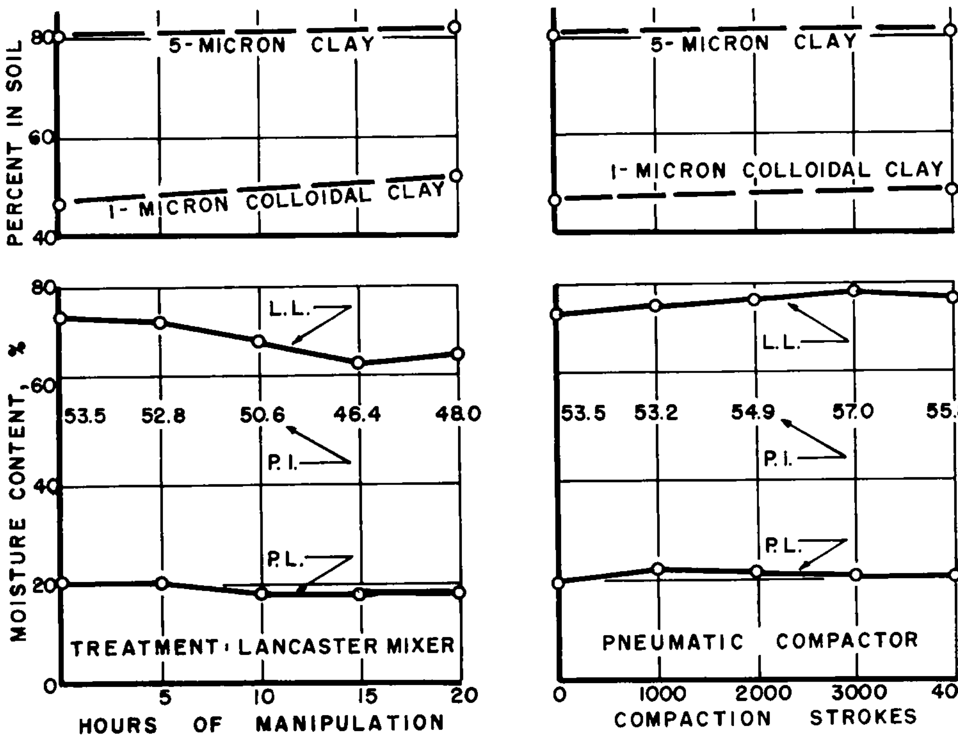

Figure 6. Grading and soil constant changes, Wilkin County clay.

TABLE 3
SUMMARY OF FIELD TESTS

Soil	Treatment	Test Constants		
		LL	PL	PI
Polk Co. silt loam	Original soil	26.5	21.4	5.1
	4-in. depth, under traffic	25.2	18.8	6.4
	8-in. depth, under traffic	24.0	18.3	5.7
	Base mat'l. under traffic	21.6	18.2	3.4
Shakopee silt loam	Original soil	24.1	22.8	1.3
	4-in. depth, under traffic	21.3	19.8	1.5
	8-in. depth, under traffic	21.7	20.8	0.9
	Base mat'l. under traffic	19.0	18.3	0.7
Hoyt Lakes sandy loam	Original soil	16.2	16.0	0.2
	4-in. depth, under traffic	18.6	15.4	3.2
	8-in. depth, under traffic	19.2	16.4	2.8
	Base mat'l. under traffic	16.2	15.1	1.1
Duluth red clay	Original soil	44.3	19.0	25.3
	4-in. depth, under traffic	49.5	19.2	30.3
	8-in. depth, under traffic	48.8	21.2	27.2
	Base mat'l. under traffic	41.8	16.7	25.1

The P I determinations on the soil which had been mixed with the clean base course materials showed decreases in three of four cases and an increase of less than 1.0 in the other. The problem of separating the original soil from the base material without some contamination with broken down base material was more serious than had been anticipated, and it is thought that this did affect the results.

Hydrometer analysis tests were also made on the soils in the field tests. Although contamination seems to have affected some of these tests, adjustments to the curve to make the grain size analysis curves start at a common point at the initial hydrometer reading usually indicate that the 1-μ colloidal clay percentages increased by from 1 to 5 after the field period.

Although the changes in the field are slight, they do indicate a trend, and an exposure to traffic for a period of several years may cause a more significant change. Some of the soils were left in place so that later tests can be made.

SUMMARY AND CONCLUSIONS

The experiments confirm the observation that extended manipulation such as mixing and kneading of soils in a wet condition may change the plasticity constants to give larger values of the plasticity index. The action is most pronounced on soils with high silt contents which originally would be judged as being only very slightly plastic.

In these tests, two silt loams with P I's of 1.3 and 5.1 were altered through mechanical manipulation by various processes to attain P I values of from 5.4 to 16.1 for the first and 9.6 to 20.0 for the second. The manipulation also changed the mechanical analysis of the soil as determined by the hydrometer test, but the increases in 1- and 5-μ clay contents seem small in some tests as contrasted with the changes in P I. The manipulation may alter some aspect of the soil surface moisture film relationship which has an effect on the plasticity constants.

Laboratory manipulation experiments on three clay soils gave come instances of causing increases in P I, although the change was not as great as for the silty soils and in some tests no change or even a decrease in the P I occurred. This indicates that the change which occurs is dependent on the soil itself. The tests were not extensive enough to indicate which types of clay soils can be expected to show change and which types will not.

Field tests subjected soils to the action of traffic under a flexible mat and showed very slight increases in P I. The changes are of insufficient magnitude to signify more than a trend.

The test results of this study (liquid limit and plastic limit determinations) are considered to be reliable to the highest degree attainable following standard procedures; they were made by an operator engaged in such test work for a period of several years.

The results of this study may help to explain inconsistent test results obtained in investigations on soils manipulated repeatedly in the course of extensive testing. The manipulative efforts on the soils were much greater than any which would be encountered in normal field construction procedures. The possibility exists that subsoils immediately beneath a pavement may be subjected to movements or flexing by traffic which could have a similar effect on soil constants.

ACKNOWLEDGMENT

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