Functional Relationships Between the Content of Particles Smaller than 0.05 mm. and 0.002 mm. in Size, and the Plasticity Index of Soils

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INTRODUCTION

Plasticity is one of the most useful soil properties from the standpoint of engineering. Hydraulic conductivity, pH, particle-size distribution, strength against shearing, and consolidation characteristics are among other soil properties of special interest to engineers. These engineering properties of soils are becoming increasingly important because they affect the construction and maintenance of building foundations, roads, airports, drainage systems, water-storage systems and others. Some of these properties are also of interest from the standpoint of agriculture.

There is urgent need in Puerto Rico and elsewhere for more extensive and more adequate knowledge of these engineering properties. Because of the special interest of soil plasticity both for engineers and agriculturists, a study was conducted to determine the mathematical relationship between the plasticity index and other more simple soil parameters. The idea was to develop an equation that could allow the prediction within reasonable limits of the plasticity index of soils based on other soil measurements. This paper presents data on this study and proposes an equation to predict the plasticity index.

It must be stated at the outset that the use of this equation does not eliminate the need for on-site sampling for testing soils as required for design and construction of major engineering works. The equation may be used simply as a preliminary general guide in planning for more detailed soil investigations.

PLASTICITY INDEX DEFINED

The plasticity index is the numerical difference between the liquid limit and the upper plastic limit. It really indicates the moisture-content range within which the soil is in a plastic condition. The liquid limit is the moisture content at which the soil passes from a plastic to a liquid state. The upper plastic limit is the moisture content at which the soil passes from a semisolid to a plastic state. These tests measure the effect of moisture on the consist-

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ency of the soil. From the standpoint of agriculture, the plasticity index is an important reference point as to the workability of the soil under given conditions. From the standpoint of engineering, the plasticity index is specially useful in designing structures.

NATURE OF THE SOILS TESTED

In general terms the major soils of the Lajas Valley Area exhibit certain characteristics in common (*1,2,3*).[2] They are very deep soils with a strikingly high, almost uniform, clay content, with predominantly small pores and very slow hydraulic conductivity in the subsoil; but with a topsoil of about 1 foot, and in a few cases 2 feet, that conducts water rather well. They are high in soluble salts and exchangeable sodium, particularly below the upper 24-inch depth, the hazard increasing below the 48-inch depth.

PROCEDURE

The data used in this work were obtained from the Soil Survey of the Lajas Valley area (*2*). The data were considered, upon inspection, suitable for this type of study. They were obtained from clays, clay loams, sandy loams, silty clays, and fine sands. Fourteen soils were used in the tests with a total of 39 values. The soil tests were performed by the Soils Mechanics Laboratory, Engineering and Watershed Planning Unit, Soil Conservation Service at Spartansburg, S. C., in accordance with standard procedures of the American Association of State Highway Officials (AASHO). Mechanical analyses were performed according to the AASHO Designation T 88-57. In this procedure the fine material is analyzed by the hydrometer method and the various sized fractions are calculated on the basis of all the material, including that coarser than 2 mm. in diameter. The liquid-plastic limit and the upper-plastic limits were determined following the ASTM[3] Designations D 423-54T and D 424-54T, respectively. The plasticity index was then calculated from these values.

For the statistical work the plasticity index and the percentage of particles smaller than 0.002 mm. and 0.05 mm. were used. The least-squares method (*4*) was employed in the correlation analysis of the data. Coefficients of determination and correlation coefficients were calculated. The coefficient of determination is the ratio of the difference between the squared standard deviation and the squared standard error of estimate to the original variability. It indicates the proportion of the variability of the plasticity index that can be explained on the basis of the percentage of particles smaller than

[2] Numbers in parentheses refer to Literature Cited, p. 350.

[3] American Society of Testing Materials. Personal communication from Luis Catoni, Soil Conservation Service, Nov. 22, 1967.

0.002 mm. and 0.05 mm. as used in this work. The correlation coefficient indicates the closeness of the relationship between plasticity index and percentage of particles of a given size.

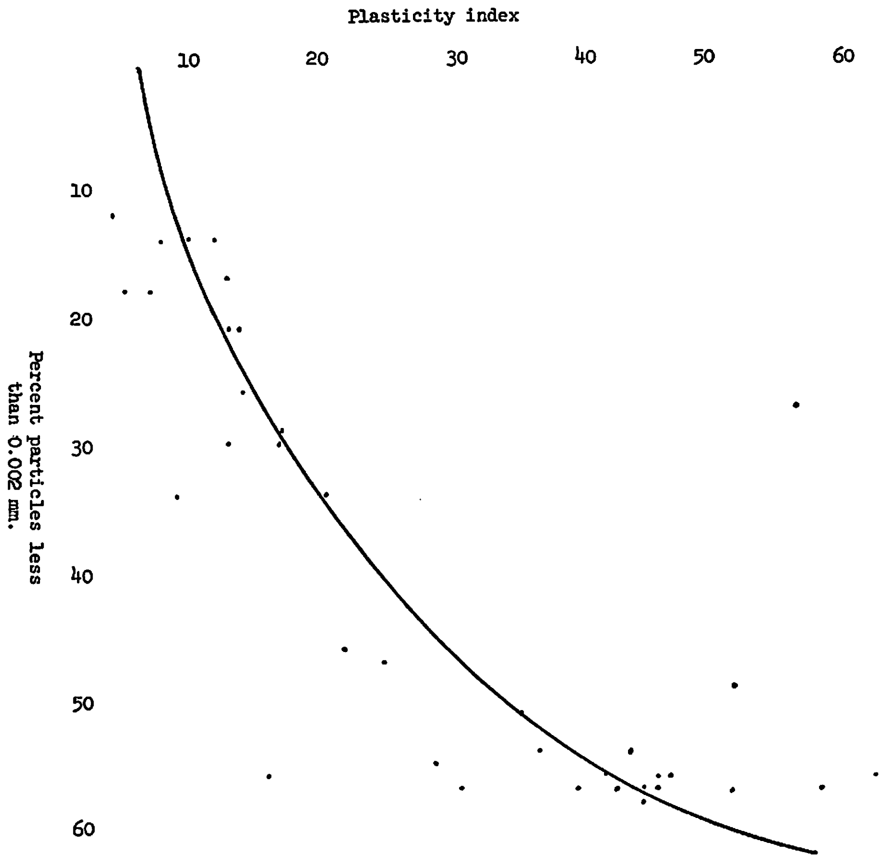

FIG. 1.—Relationship between plasticity index of soils and the percentage of particles smaller than 0.002 mm.

RESULTS AND DISCUSSION

The data available were plotted on graph paper using the plasticity index as the Y-axis and the percentage of particles smaller than 0.002 mm. and 0.05 mm. as the X-axis in each respective case. From the graphs (figs. 1 and 2) it was evident that the curves that best fitted the data were exponential. In each case a positive correlation was obtained. In both cases the equation that best fits the data is as follows: $Y = A + Ce^{Bx}$, where

Y = plasticity index,

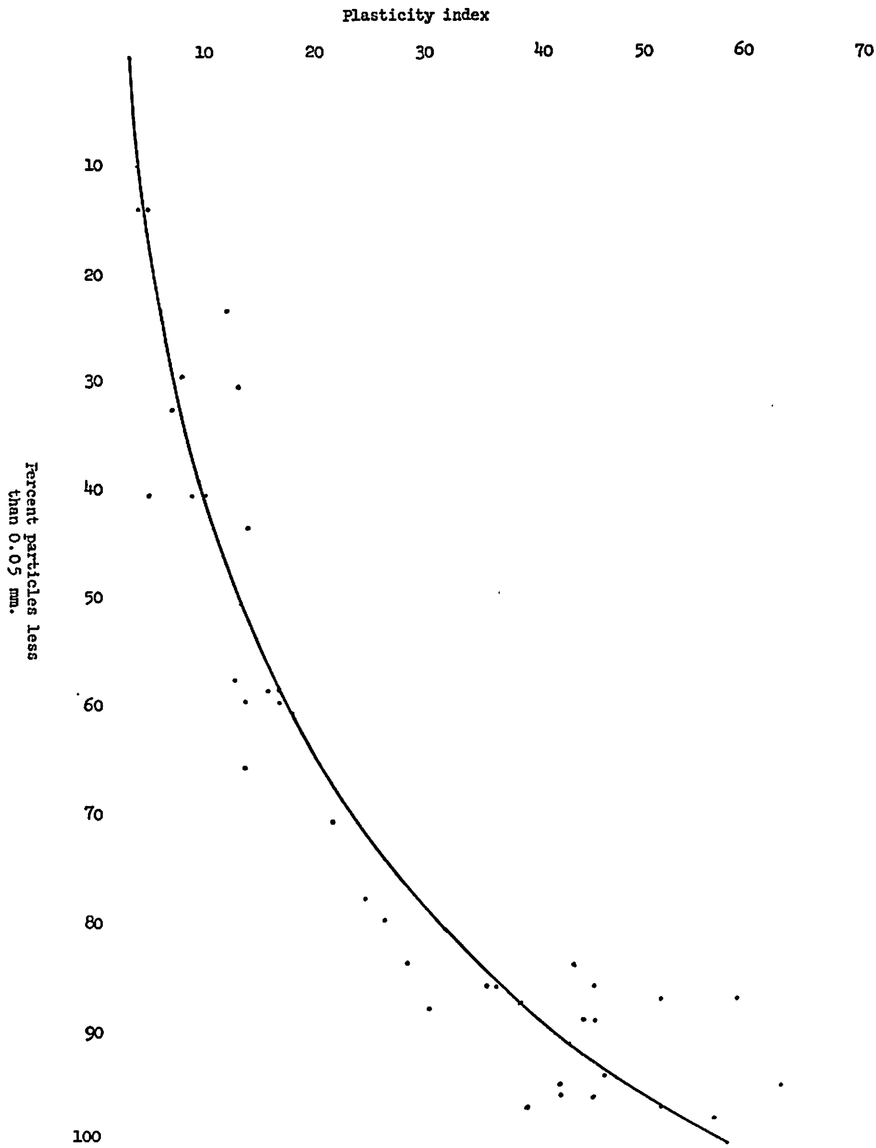

FIG. 2.—Relationship between plasticity index of soils and the percentage of particles smaller than 0.05 mm.

A = a constant that determines the deviation of the curve from the X-axis,

B = a constant related to the degree of concavity of the curve

C = a constant that modifies the effect of B,

e = the base of the natural logarithms, = 2.71828, and
X = the percentage of particles smaller than a given size, i.e., either 0.002 or 0.05 mm., as the case may be.

TABLE 1.—*Comparison of measured and estimated values for plasticity index of sails calculated on basis of the percentage of particles smaller than 0.002 mm.*

Percentage of particles smaller than 0.002 mm.	Measured plasticity index	Estimated plasticity index	Deviation
11	4	9.3	−5.3
17	5	11.7	−6.7
17	7	11.7	−4.7
13	8	10.1	−2.1
33	9	20.4	11.4
13	12	10.1	1.9
16	13	11.2	1.8
29	13	17.8	−4.8
20	14	13.0	1.0
25	14	15.5	1.5
33	14	20.4	−6.4
55	16	42.2	−26.2
28	17	17.2	−0.2
45	22	30.4	−8.4
46	25	31.4	−6.4
48	27	33.6	−6.6
54	29	40.8	−11.8
56	31	43.5	−12.5
50	36	35.8	−0.2
53	37	39.5	−2.5
57	40	45.0	−5.0
56	40	43.5	−3.5
56	43	43.5	−0.5
56	43	43.5	−0.5
53	44	39.5	4.5
57	45	45.0	0.0
56	46	43.5	2.5
55	46	42.2	3.8
56	46	43.5	2.5
55	47	42.2	4.8
48	52	33.6	18.4
56	52	43.5	8.5
26	57	16.0	41.0
56	59	43.5	15.5
55	63	42.2	20.8

In the first attempt, the relationship between plasticity index and the percentage of particles smaller 0.002 mm. in size was determined. The values obtained were as follows: $A = -2.02296$, $B = 0.0308342$, and $C = 8.10406$. In table 1 the values obtained in the laboratory are compared with the values calculated from the equation. A positive correlation coefficient of 0.77 was obtained. Thus, on the basis of the percentage of particles smaller than 0.002 mm. almost 60 percent of the variability in plasticity index could be explained.

When the plasticity index was related to the percentage of particles smaller than 0.05 mm. a highly significant correlation coefficient was obtained. The values obtained were as follows: $A = -0.052394$, $B = 0.029284$, and $C = 3.1538$. The correlation coefficient was on the order of

TABLE 2.—*Comparison of measured and estimated values for plasticity index of soils calculated on basis of the percentage of particles smaller than 0.05 mm.*

Percentage of particles smaller than 0.05 mm.	Measured plasticity index	Estimated plasticity index	Deviation
14	4	4.7	−0.7
40	5	10.1	−5.1
32	7	8.0	−1.0
29	8	7.3	.7
40	9	10.1	−1.1
23	12	6.1	5.9
30	13	7.5	5.5
57	13	16.7	−3.7
43	14	11.1	2.9
65	14	21.1	−7.1
59	14	17.7	−3.7
58	16	17.2	−1.2
59	17	17.7	−.7
70	22	24.4	−2.4
77	25	30.2	−5.0
79	27	31.8	−4.8
83	29	35.8	−6.8
87	31	40.2	−9.2
85	36	37.9	−1.9
85	37	37.9	−.9
87	40	40.2	−.2
96	40	52.4	−12.4
95	43	50.8	−7.8
94	43	49.4	−6.4
83	44	35.8	8.2
88	45	41.4	3.6
85	46	38.0	8.0
88	46	41.4	4.6
95	46	50.9	−4.9
93	47	47.9	−.9
86	52	39.1	12.9
96	52	52.4	−.4
97	57	54.0	3.0
86	59	39.1	19.9
94	63	49.4	13.6

0.92. Thus, 85 percent of the variability in plasticity index could be explained on the basis of the percentage of particles smaller than 0.05 mm. A comparison of measured and estimated plasticity index values is presented in table 2.

For soils similar in nature and properties to those of the Lajas Valley Area, the prediction of plasticity index values on basis of the percentage of particles smaller than 0.05 mm. in size can be used with a rather fair degree of accuracy. The equation developed is as follows:

Plasticity index $= -0.052394 + 3.1538e^{0.029284X}$, where $e = 2.71828$ and X is the percentage of particles smaller than 0.05 mm.

This equation can be rather useful as a general guide in planning detailed soil-engineering investigations. Furthermore, the determination of the percentage of particles below 0.05 mm. is a rather simple and easy laboratory measurement that can be made quickly with inexpensive equipment. The direct laboratory determination of the plasticity index requires two more elaborate measurements of both the upper plastic limit and the liquid limit of soils. Thus, this equation provides a rather easy indirect way of obtaining fairly accurate approximations of the plasticity index based on a single easy laboratory determination, and rather easy and quick calculations. Such an equation might be particularly useful in areas where laboratory facilities are not easily available and where there is need for approximate values of the plasticity index.

SUMMARY

A mathematical approach is presented herein to determine the plasticity index of soils on the basis of the percentage of particles smaller than 0.05 mm. in size. The particle-size distribution can be determined easily and quickly, and then, with a few calculations, the plasticity index can be estimated with fair degree of precision. The laboratory determination of plasticity index requires more laborious work. The equation developed is exponential, as follows:

Plasticity index $= -0.052394 + 3.1538e^{0.029284X}$, where $e= 2.71828$ and X is the percentage of particles smaller than 0.05 mm. in size.

The correlation coefficient obtained was on the order of 0.92. On the basis of the percentage of particles smaller than 0.05 mm., about 85 percent of the variability of the plasticity index values was explained.

The plasticity index is one of the more useful engineering properties of soils.

RESUMEN

En este trabajo se presenta un enfoque matemático que permite estimar el índice de plasticidad de los suelos a base del porcentaje de partículas inferiores en tamaño a 0.05 mm. La determinación del porcentaje de estas partículas por su tamaño es una tarea relativamente fácil y rápida, y mediante cálculos sencillos puede estimarse el índice de plasticidad con bastante precisión. Por otra parte, la determinación del índice de plasticidad en el laboratorio requiere un esfuerzo mayor. La ecuación exponencial desarrollada es la siguiente:

Indice de plasticidad $= -0.052394 + 3.1538e^{0.029284X}$, donde $e = 2.71828$ y X es el porcentaje de partículas inferiores en tamaño a 0.05 mm.

Se obtuvo un coeficiente de correlación de 0.92. Por tanto, a base del porcentaje de partículas inferiores en tamaño a 0.05 mm., se pudo explicar alrededor del 85 por ciento de la variación en el índice de plasticidad.

El índice de plasticidad es una de las propiedades más útiles de los suelos desde el punto de vista de la ingeniería.

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