dividing the particle sizes into sections, each log 2 wide, from the largest down to the smallest particle present in the soil.

(c) Invisible flocculation during the sedimentation test is referred to and examples of its presence are shown. A few notes on its detection and prevention are provided in the Appendix.

(d) The computation of the classification area, that contained between the grading curve and the ordinate through 0.0000112 mm., is explained with examples.

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XII a 4

## A SUGGESTED MODERN ENGINEERING CLASSIFICATION OF SOILS


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SYNOPSIS

Engineers have tried for many years to correlate the structural properties of soils (bearing power of natural soils as they exist in the ground and the suitability of soils for compacted fill use), with some system of soil classification that consists principally of describing the soil by the use of either gravel, sand, silt, clay, or peat as the noun, and then proceeding to select whichever of the foregoing appear to be suitable adjectives to modify the selected noun, often resulting in such descriptions as "dark red silty sandy clayey peat," with the possible addition of "and some gravel". This type of classification is very well suited for its original purpose - agriculture, but is of no value at all as a medium for expression of the engineering properties of a soil because of the easily established, simple fact that any soil can be found in place in the ground at any density from the original loose, freshly deposited condition to the high state of compression occasioned by deep submergence below the surface of the earth and subsequent erosion that has brought the soil again to or near the surface. This condition has been recognized universally because of the attempts to add to the classification such words as dense, unconsolidated, well consolidated, firm, soft, spongy, etc., that do very well for agricultural purposes but really are worse than useless as engineering terms because no two persons will use the same word in the same sence. One soil was found in a dam foundation at a dry weight of 112 lb per cu ft near the surface and at a few feet below the surface its dry weight was 122 lb cu ft. Obviously the designation of this soil as a "dark brown sandy clay" would give no hint of this variable density. Also, the lighter (in dry weight) portion of the soil was dry and hard and the denser (higher dry weight) portion was damp and softer so that, actually, the dry but light portion appeared the harder and the more dense. However, the addition of water soon disclosed the difference.

The proposed new method of soil classification described hereinafter provides means for evaluating this softening of soils from saturation and for predicting the settlement (consolidation) that may occur from the application of a foundation, pavement, or other loading to the soil. It also provides for the classification of soils from consideration of their characteristics when compacted in a standard manner in similar fashion to those methods used successfully for many years in connection with the investigation of foundation soils for dams and for the preparation of soils for compaction in embankments. The fineness and specific gravity are also made a part of the classification. The foregoing factors of soil classification should enable anyone familiar with them to determine immediately the approximate supporting power of a soil in place and its general usefulness for subgrade, foundation, or compacted fill purposes, all of which information will be secured from consideration of results from precisely made tests rather than from uncertain visual and other sensorial "classifications".


### FIELD AND LABORATORY TESTS FOR SOIL CLASSIFICATION

Determination of Density of Soil in Place.- The proposed soil classification factors are determined from field and laboratory tests similar to those customarily made in connection with dam construction 1), 2), 3). The moist density of the soil is measured in place in the field after which the moisture content is determined and the weight of the moisture is deducted to secure the dry weight per cubic foot of the soil, which is plotted as shown by point A on Fig. 1. The soil classification is based

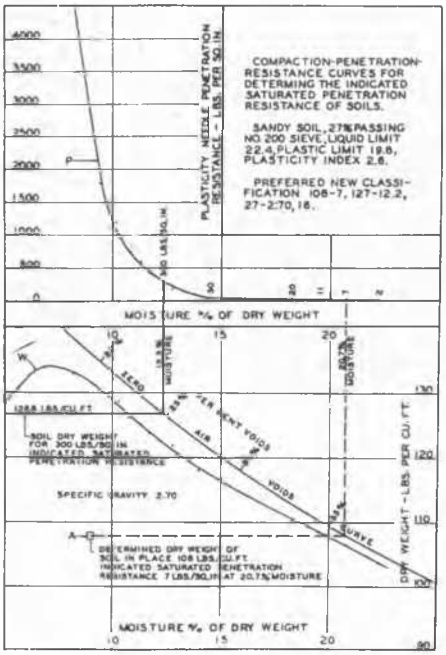


FIG. 1

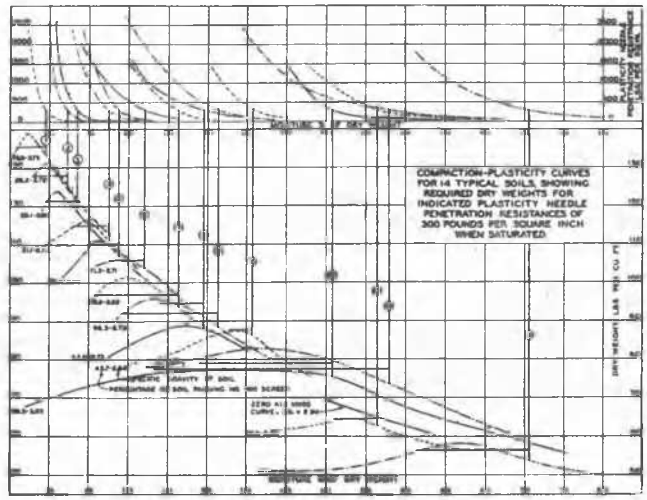


FIG. 2

on laboratory tests on the materials passing the No. 4 screen.

Laboratory Determination of Dry Weight and Penetration Resistance Curves.- The soil is taken to the laboratory and compacted at various moisture contents to develop Dry Weight Curve W and Penetration Resistance Curve P (Fig. 1); the specific gravity and the percentage of the soil that can be washed through the 200 mesh sieve (0.074 mm clear opening) are also determined. The zero air voids curve represents combinations of soil moisture contents and dry weights for complete saturation of the soil with water; it is impossible for the soil dry weight and moisture content to plot to the right of the zero air voids curve; soil conditions that plot to the left of the zero air voids curve show the soil is not saturated.

## SOIL CLASSIFICATION FACTORS AND THEIR USE

The Dry Weight of a Soil as Found in Place. Referring to Fig. 1, it is assumed that the soil being classified was found to have a dry weight of 108 lb per cu ft at a moisture content of 9% as shown at point A. This moisture content means that the weight of the water contained in the soil was 9% of the soil dry weight.

The Indicated Saturated Penetration Resistance of a Soil in Place.- The intersection of 108 lb cu ft dry weight with the zero air voids curve is found at 20.7% moisture content, as shown on Fig. 1. At this moisture content (complete saturation of the soil), the indicated saturated penetration resistance is 7 lb per sq in., (about the consistency of good, workable cement mortar), as shown by the dotted line extending from the zero air voids curve to the Penetration Resistance Curve P.

The foregoing determination is for the purpose of ascertaining to what extent this soil as found in place could become saturated with water and, if so, what would the effect be on the bearing power of the soil. In this case any object exerting a greater pressure than 7 lb per sq in. would sink into the soil.

It is thus seen in the case of this particular soil that dry weight in place of the indicated saturated penetration resistance indicate that it is not at all suitable for a foundation for anything if it is liable to become saturated with water. However, this same soil may be as much as 15 or 20 lb per cu ft heavier at a few feet of depth below the surface. In connection with stripping operations for an earthfill it is customary to continue measuring the soil dry weight at increased depths until the soil is found to have a high enough density, with a resulting high enough indicated saturated penetration resistance to be suitable for the proposed foundation.

Estimating Settlements under Loading from the Indicated Saturated Penetration Resistance.- The approximate settlement of soils under loading has been determined in terms of the indicated saturated penetration resistance, enebling the prediction of the percent of consolidation of a soil once its indicated saturated penetration resistance is known. Table 2 shows approximate percentages of soil consolidation for various loadings and indicated saturated penetration resistances.

Complete Classification of Soil Used for Fig. 1.- The complete designation of the soil shown in Fig.1 then becomes:

- 108 - Dry weight in place (not including materials retained on No. 4 screen)
- 7 - Indicated Saturated Penetration Resistance in place.
- 126.8 - Soil dry weight for 300 lb per sq in. Indicated Saturated Penetration Resistance.
- 12.2 - Moisture content for complete saturation at an Indicated Saturated Penetration Resistance of 300 lb per sq in. (calculated to dry weight of soil passing No. 4 screen).
- 27 - Percentage passing the No. 200 sieve (not including materials retained on No. 4 screen).
- 2.70 - Specific gravity (not including materials retained on No. 4 screen).
- 16 - Percentage retained on No. 4 screen.

Expressed as follows: 108-7, 127-12.2, 27-2.70, 16

Classification of Fourteen Typical Soils.- Fig. 2 shows the basic data similar to Fig. 1 for fourteen widely variable soils. Because of

TABLE 1

PROPOSED SOIL CLASSIFICATION FACTORS FOR THE FOURTEEN SOILS USED FOR PREPARATION OF FIG.2

| NO. | SOIL TYPE | Soil Conditions for 300 Lb Per Sq In. Indicated Saturated Penetration Resistance | | | |
|---|---|---|---|---|---|
| | | SOIL DRY WEIGHT LB/CU FT | SOIL MOISTURE CONTENT PER CENT | PERCENTAGE PASSING 200 SIEVE | SPECIFIC GRAVITY |
| 1 | Gray brown clayey sand | 135.5 | 9.5 | 19.5 | 2.73 |
| 2 | Brown clayey sand | 128.0 | 12.3 | 25.2 | 2.72 |
| 3 | Gray brown clayey sand | 121.5 | 13.5 | 28.1 | 2.62 |
| 4 | Gray sandy clay | 115.0 | 17.5 | 31.1 | 2.72 |
| 5 | Gray clayey sand | 110.0 | 18.8 | 21.4 | 2.66 |
| 6 | Light brown sandy clay | 106.0 | 22.0 | 71.3 | 2.71 |
| 7 | Soft sandy shale | 97.0 | 26.3 | 62.6 | 2.62 |
| 8 | Chalky shale silty clay | 92.0 | 21.3 | 96.3 | 2.73 |
| 9 | Black adobe | 94.8 | 29.6 | 82.5 | 2.73 |
| 10 | Clayey sandstone | 87.9 | 35.7 | 45.7 | 2.84 |
| 11 | Red volcanic clay | 77.3 | 53.0 | 83.0 | 3.69 |
| 12 | Red volcanic clay | 79.0 | 45.8 | 92.5 | 3.03 |
| 13 | Black adobe with humus & fine silt | 64.5 | 51.5 | 76.5 | 2.24 |
| 14 | Diatomaceous shale | 56.5 | 70.5 | 100.0 | 2.48 |

the considerable differences in specific gravities of these soils it was impossible to show all of the zero air voids curves. However, to use No. 13 as an illustration, a short portion of its zero air voids curve has been drawn; similar zero air voids curves could be drawn for the others but are not required if it is realized that the critical intersection is shown.

Table 1 shows the customary classification for each of these soils and then all of the proposed soil classification factors are shown, except the dry weights and indicated saturated penetration resistances of the soils in place, which data are not available.

## CONCLUSION

The author has presented the factors that he has been using for many years to classify soils in his own mind in connection with dam and reservoir construction. This habit was acquired from the use of soil compaction curves as it was observed that after using soil compaction curves for a short time one no longer looked to see whether the soil had been classified as a silty clay or clayey silt, or whether it was brown, black, red or green, but instead, the first thing observed was the position of the two lines indicating the 300 lb per sq in. indicated saturated penetration resistance, which are drawn on all compaction curves to serve as a standard reference line with which to make comparisons. Of the foregoing factors for soil classification it is surprising to realize that the least used of all has been the percentage passing the No. 200 sieve.

In connection with dam construction it has been found that borrow pit soils may be grouped very successfully on the basis of similar soil dry weights required for a 300 lb per sq in. indicated saturated penetration resistance when the saturated soil moisture contents to satisfy this condition are substantially the same. The foregoing grouping of soils is better than consideration of their fines (percentage passing No. 200 sieve) for construction purposes. The use of the foregoing soil classifica-

TABLE 2

| SOIL LOADING, LB PER SQ IN. | INDICATED SATURATED PENETRATION RESISTANCE POUNDS PER SQUARE INCH | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 40 | 75 | 150 | 300 | 600 | 1200 |
| 10 | 18.2 | 10.6 | 7.0 | 4.5 | 3.0 | 2.4 | 2.0 | 1.7 | 1.2 | 0.7 |
| 20 | 21.8 | 13.2 | 8.9 | 6.2 | 4.2 | 3.5 | 3.0 | 2.5 | 1.9 | 1.2 |
| 30 | 24.1 | 15.0 | 10.4 | 7.3 | 5.1 | 4.3 | 3.7 | 3.1 | 2.5 | 1.7 |
| 40 | 26.1 | 16.4 | 11.5 | 8.2 | 5.7 | 5.0 | 4.2 | 3.5 | 2.8 | 2.0 |
| 50 | 27.9 | 17.8 | 12.5 | 9.0 | 6.3 | 5.5 | 4.7 | 3.9 | 3.2 | 2.3 |
| 60 | 29.4 | 18.9 | 13.4 | 9.7 | 6.8 | 6.0 | 5.1 | 4.3 | 3.5 | 2.6 |
| 70 | 30.7 | 19.9 | 14.2 | 10.3 | 7.3 | 6.4 | 5.5 | 4.6 | 3.8 | 2.8 |
| 80 | 31.6 | 20.6 | 14.9 | 10.9 | 7.8 | 6.8 | 5.9 | 4.9 | 4.0 | 2.9 |
| 90 | 32.4 | 21.4 | 15.5 | 11.4 | 8.2 | 7.2 | 6.2 | 5.1 | 4.2 | 3.1 |
| 100 | 33.2 | 22.0 | 16.0 | 11.9 | 8.7 | 7.5 | 6.5 | 5.3 | 4.4 | 3.2 |

Table of soil consolidation, expressed as the percentage of test specimen height, under various loadings at Indicated Saturated Penetration Resistances that are typical of those to be found in natural soils.

(This Table prepared from Fig. 3, Paper IXb 12)

tion could have prevented a very costly borrow pit mistake in connection with one very high earthfill dam constructed recently. The borrow pit selected contained too much moisture for compaction, yet a similar soil nearby was so dense in place that when fully saturated with water the moisture content was approximately correct for compaction.
With the described type of soil classification the indicated saturated penetration resistance in place was 50 to 300 lb per sq in. for the selected borrow pit soils, indicating them to be far too wet, and was 2000 to 4000 lb per sq in. for other exactly similar saturated materials, indicating them to be correctly moistened for use in the compacted earthfull even through fully saturated in place.

This proposed method of soil classification should be especially useful for showing soil conditions along proposed highways and airplane landing fields where the relative density of near ground surface soils is of utmost importance and almost always neglected entirely. In special cases the proposed classification system could be modified by adding the moisture content of the soil in place, particularly where there is apparently little seasonal variation or where the soils appear saturated. There are many variations to the use of this classification; for instance, logs of auger holes made for exploring compacted fill borrow pits would need only to show the required dry weight and moisture content for the 300 lb indicated saturated penetration resistance the percentage of fines, and the specific gravity. Wher these factors remain the same at various depths the soils will invariably be found to be substantially the same even though they change in color or appearance. To show subgrade soil conditions along existing or proposed highway profiles it will only be necessary to show the indicated saturated penetration resistance at various depths below the pavement; the approximate settlement to be expected under a given loading is thus indicated. The author knows of no better way to bring realization of the extreme variations that occur in the density of natural soils than their expression in terms of their indicated saturated penetration resistance. For instance, few engineers will at first believe that a "brown sandy clay" soil can vary from a saturated penetration resistance of 5 to 200 lb per sq in. within a few feet of depth below the ground surface. It is not uncommon at all for the author to be requested to estimate the bearing power of some type of soil for which there is no data at all regarding its relative density, thus making it impossible to say whether the soil will settle 2, or 3 inches or not al all under the proposed loading.

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