dry density in pounds per cubic foot. The equations for the silt and clay soils apply for moisture contents of 7 percent or more; those for the sandy soils, of 1 percent or more.

The equations for sandy soils are largely based on tests on fairly clean sands. For sandy soils with a relatively high silt and clay content (for example 40 percent), conductivity values intermediate between those calculated by two equations might be a reasonable prediction. It is expected that judicious use of the equations with an understanding of their limitations, will give conductivity values not more than 25 percent in error.

ACKNOWLEDGEMENT

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# EFFECT OF MATERIAL RETAINED ON THE NUMBER 4 SIEVE ON THE COMPACTION TEST OF SOIL

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## SYNOPSIS

The purpose of the investigation was to determine the effects of larger size fractions of gravel in soil on maximum density and optimum moisture content, and to ascertain if it would give satisfactory results to make the compaction test on samples containing the material retained on the No. 4 sieve up to ¾ in. The common practice is to make the test on the material passing the No. 4 sieve and make a correction for the effect of the larger material.

Comparative tests were made on samples containing the material retained on the No. 4 sieve and samples passing the same sieve. In these tests the samples containing the coarser material gave greater values for maximum density and smaller values for optimum moisture than did the material from which the coarse particles had been removed. This indicates that data from samples containing all fractions as received are necessary for application to field conditions.

The use of larger molds was investigated without disclosing any variance from the foregoing results.

In the standard method of determining moisture-density relations in soil[1] only that portion of the soil sample passing the No. 4 sieve is used in the compaction test. This results in the portion of the soil sample retained on the No. 4 sieve not being tested, and inasmuch as the purpose of the test is to simulate field compaction conditions, it is desirable that the soil to be tested in the laboratory have the same gradation that is to be used in the field. While it is realized that an upper limit must be placed on the top size of material that can be tested in small quantities such as are used in the Proctor mold of 1/30 cu. ft. volume, it was hoped that some investigation into the use of larger material would show that the top size could be raised from material passing the No. 4 sieve to some other maximum size.

### CORRECTION FOR LARGER SIZE MATERIAL

When any appreciable portion of the soil sample is retained on the No. 4 sieve, a procedure often used is to run the compaction test on the soil finer than the No. 4 and then make a correction for the effect of the stone or gravel present. This correction is necessary because the presence of larger material will increase the apparent density due to the higher specific gravity of the stone or gravel as compared with the bulk specific gravity of the

[1] ASTM Tentative Method of Test for Moisture Density Relations of Soils, D-698-42T and AASHO Standard Laboratory Method of Test for the Compaction and Density of Soil, T99-38.

compacted dry soil. The correction often used is to figure that the added coarse material displaces its volume of soil but has no other influence on the maximum density or other properties of the soil portion of the soil-gravel mixture. A formula based on this method of correcting the maximum density for larger size material which may be used is:

$$X = \frac{1}{\frac{1-P}{W} + \frac{P}{62.4S}} = \frac{62.4\,SW}{62.4S(1-P)+WP} \qquad (1)$$

in which:

$X$ = density of gravel and soil compacted to maximum dry density in 1 cu. ft.
$P$ = ratio of weight of gravel to total weight of soil-gravel mixture,
$S$ = specific gravity of gravel,
$W$ = density of soil alone compacted to maximum dry density,
62.4 = weight of 1 cu. ft. of water.

Another method of correcting for larger size material is used in the California Bearing Ratio test, where particles up to $\frac{3}{4}$-in. sieve size are used and a substitution of material passing the $\frac{3}{4}$-in. sieve and retained on the No. 4 is made for the percentage of material retained on the $\frac{3}{4}$-in. sieve. In a similar manner in the compaction test, fine grit passing the No. 4 sieve might be substituted for coarser rock.

## SOIL CLASSIFICATION TESTS

Since the purpose of this investigation was to determine the effects of larger size fractions of gravel in soil on the maximum density and optimum moisture content, and to find out if it would be feasible to include material up to $\frac{3}{4}$-in. in size in the compaction test, a soil which had been passed through a No. 4 sieve was used as the fine fraction of all soil-gravel mixtures which were tested. To this soil were added known percentages of larger size material, and a series of compaction tests were run on each soil-gravel mixture to establish the moisture-density relationship. However, to identify the properties of this soil, several of the standard soil classification tests were performed on the basic soil, the results of which are shown in Table 1.

Sieve analysis of the soil showed that all of the soil passed the No. 10 sieve, 96.6 percent passed the No. 40 sieve and that 57.7 percent passed the No. 200 sieve.

In an attempt to maintain uniformity of grading in the classification and compaction tests the soil was room dried, pulverized and thoroughly mixed in a Hobart mixer, after which it was further mixed in a small concrete mixer and by hand, using a shovel. Before any compaction tests were run with addition of gravel, the standard tests for moisture-density relations and penetration resistance were performed on the soil. The zero percent gravel curve in Figure 1 shows the compaction curve obtained for this soil. The maximum dry density was 119.6 lb. per cu. ft. at 13.3 percent moisture.

TABLE 1
RESULTS OF SOIL CLASSIFICATION TESTS

| | |
|---|---|
| Specific Gravity | 2.69 |
| Liquid Limit | 24 |
| Plastic Limit | 17 |
| Plasticity Index | 7 |
| Shrinkage Limit | 14 |
| Shrinkage Ratio | 1.82 |

## PROCEDURE FOR SOIL-GRAVEL MIXTURES

In running the compaction tests with the additions of various percentages of gravel, the standard method was used as far as applicable. The standard mold of 4-in. internal diameter and height of about 4.6 in. with a capacity of $\frac{1}{30}$ cu. ft. was used with the 5.5-lb. hammer dropped from a height of 12 in. However, there were parts of the test which either could not be applied or had to be modified because of the special conditions. Of course the presence of gravel or stone prevents the use of a penetration test, for results vary markedly depending upon how near the surface a piece of gravel may be at the spot where the penetration needle is placed.

The gravel used was a hard quartz gravel with a very low moisture absorption of about 0.4 percent. To obtain the soil-gravel mixtures a certain weight of the gravel was added to a known weight of room dry soil with correction being made for hygroscopic moisture present in the soil. In the first tests gravel of $\frac{3}{4}$-in. top size was used with a grading of 50 percent $\frac{3}{4}$ in. to $\frac{3}{8}$ in. and 50 percent $\frac{3}{8}$ in. to No. 4 sieve. After thorough mixing, water was added and the first compaction test was made. When the moisture sample had been taken, the soil-gravel mixture was then broken up, more water added and the next compaction test run, this being continued until the mixture was very wet. It should be noted that, in striking off the mold to determine the density, more care must be used to counterbalance the gravel protruding above the top of the mold with depressions than is used for soil alone, although a small error in striking off the mold makes a very small percentage error in density computations.

### USE OF SMALL MOISTURE SAMPLE

In the first compaction tests on soil-gravel mixtures, moisture contents were obtained by oven drying a small sample of the mixture and recording the wet and dry weights. The plotted points obtained by this method were so erratic that it was difficult to draw a smooth curve through them. When moisture-density curves were drawn for the various percentages of gravel, there was no consistent relationship among the curves, although the moisture contents for maximum density should have decreased as the percentage of gravel in the soil-gravel mixture increased. It was found that the reason for the erratic nature of the curves lay in the method of obtaining the moisture contents, for in a small moisture sample it was impossible to obtain a representative sample of soil and gravel.

### MOISTURE CONTENTS FROM ENTIRE SOIL-GRAVEL MIXTURE

Accordingly, the tests were repeated, the moisture determinations this time being made by weighing the whole sample of soil and gravel prior to any particular compaction run. By knowing the original oven dry weight of the soil-gravel mixture, and by being careful not to lose any material during the compaction tests, moisture contents are very easily and quickly computed. This method is apparently the only one satisfactory for moisture determinations on soil-gravel mixtures. For this series of tests 10, 20, 30, 40, and 50 percents by weight of the total soil-gravel mixture were used. Using this method of making moisture determinations, the set of curves shown in Figure 1 was obtained. It can be seen that increased amounts of gravel tended to increase the unit weight of the mixture and also to reduce the moisture content at maximum density. Table 2 shows the optimum moisture content and the maximum density for each percentage of gravel.

The theoretical maximum dry density of the soil-gravel mixture was computed for the soil and gravel used in this investigation, using Formula (1). Figure 2 shows the theoretical and actual relationships that exist between

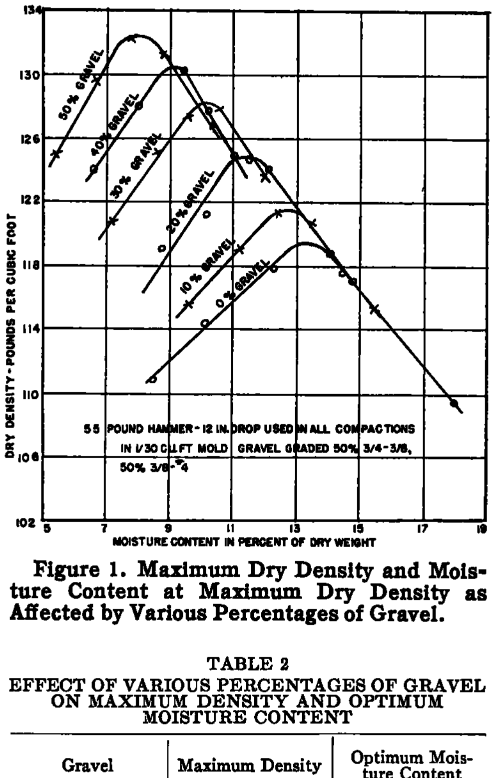


**Figure 1. Maximum Dry Density and Moisture Content at Maximum Dry Density as Affected by Various Percentages of Gravel.**

TABLE 2
EFFECT OF VARIOUS PERCENTAGES OF GRAVEL ON MAXIMUM DENSITY AND OPTIMUM MOISTURE CONTENT

| Gravel | Maximum Density | Optimum Moisture Content |
|---|---|---|
| % | *lb. per cu. ft.* | % |
| 0 | 119.6 | 13.3 |
| 10 | 121.5 | 12.9 |
| 20 | 125.0 | 11.4 |
| 30 | 128.3 | 10.1 |
| 40 | 130.3 | 9.2 |
| 50 | 132.7 | 8.0 |

the percentage of gravel and the maximum dry density. The curve which shows the theoretical change in maximum density for changes in gravel content is approximately a straight line. The curve showing the actual relationship is close to the theoretical values at lower percentages of gravel (below 30 percent) but diverges at higher percentages until at 50 percent the actual maximum density is over 5 lb. per cu. ft. less than the computed maximum density. This divergence is probably caused by interference among the individual pieces of gravel which leads to incomplete compaction of the soil between the gravel particles.

When the moisture content for maximum dry density of soil-gravel mixtures was found to decrease almost uniformly with increased amounts of gravel, an attempt was made to determine whether this reduction in moisture

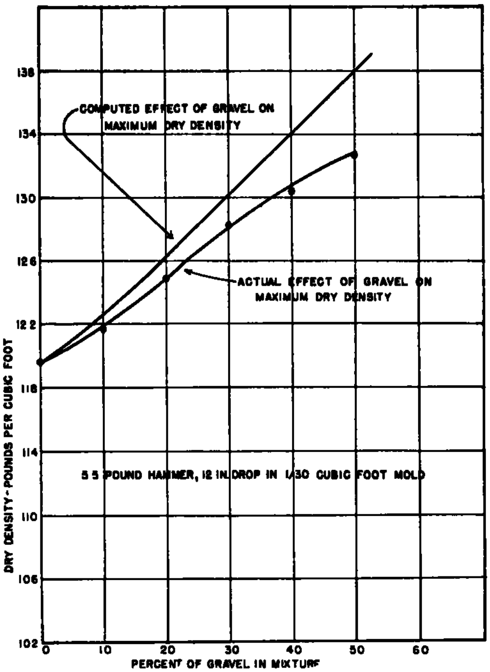


**Figure 2. Effect of Various Percentages of Gravel on Maximum Density**

content could be computed. Two assumptions were made:

1. The moisture content of the soil portion of the mixture at maximum density remains constant for various percentages of gravel.
2. The gravel absorbs 0.4 percent of moisture and retains 0.6 percent free moisture for a total of 1.0 percent moisture. This percentage of total moisture was chosen because it was considered to be about the maximum amount of moisture that the gravel could hold which would not drain off.

With these assumptions one can easily compute the expected optimum moisture content expressed as a percentage by weight of the soil-gravel mixture for any percent of gravel, using the simple formula:

$$Y = M(1 - P) + C(P) \qquad (2)$$

In which:

$Y$ = Computed optimum moisture content as a percentage of oven dry weight of soil-gravel mixture,
$M$ = Actual optimum moisture content for the soil,
$C$ = Percentage of moisture on gravel,
$P$ = Ratio of weight of gravel to total weight of soil-gravel mixture.

TABLE 3
COMPUTED AND ACTUAL OPTIMUM MOISTURE CONTENTS FOR VARIOUS PERCENTAGES OF GRAVEL

| Gravel | Computed Optimum Moisture Content | Actual Optimum Moisture Content |
|---|---|---|
| % | % | % |
| 0 | 13.3 | 13.3 |
| 10 | 12.1 | 12.9 |
| 20 | 10.8 | 11.4 |
| 30 | 9.6 | 10.1 |
| 40 | 8.4 | 9.2 |
| 50 | 7.1 | 8.0 |

For the soil used in this study with optimum moisture content of 13.3 percent and the percentages of gravel used here, Table 3 shows the computed optimum moisture contents and the actual optimum moisture contents. While the computed optimum moisture contents can be made to agree with the actual optimum moisture contents by assuming a higher percentage of moisture on the gravel, tests show that for this gravel, any moisture in excess of about 1 percent could not be retained.

Figure 3 graphically shows the actual reduction in optimum moisture content as well as the computed reduction as the amount of gravel increased. Since the actual optimum moisture content is more than the computed, it seems logical to assume that the moisture content of the soil portion of the mixture at maximum density increased as higher percentages of gravel were used.

## EFFECT OF LARGER MOLD

To investigate the effect of using a larger size mold, similar compaction tests were made on soil-gravel mixtures with the larger mold used in the California Bearing Ratio test.

This mold of 6-in. height and internal diameter of approximately 6 in. with a volume of 0.1025 cubic foot presented a problem with respect to the kind of compactive effort to use in simulating the compactive effort used in performing the previous tests in the small mold. It was finally decided to compact the mixture in three layers and to apply the same amount of energy per unit volume of material. This amounted to using 74 blows per layer of

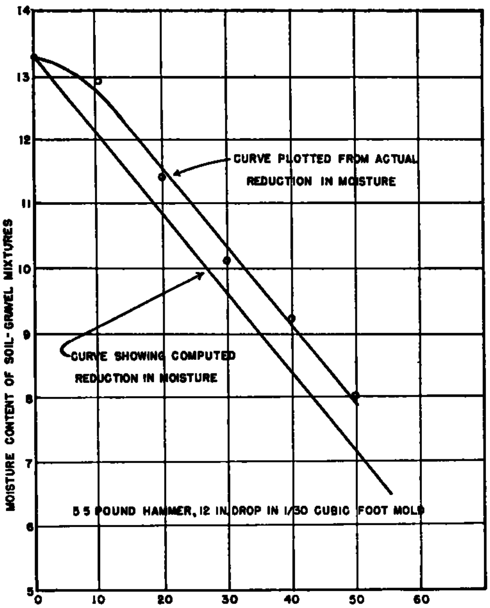


**Figure 3. Effect of Various Percentages of Gravel on Moisture Content at Maximum Dry Density**

the 5.5-lb. hammer dropped 12 in. In Figure 4, showing the comparison between compactions run in the larger mold and in the smaller mold, the same effects of adding gravel to soil are apparent in both molds. This figure shows that the densities in the larger mold are less than those obtained when the smaller mold was used. This was contrary to what might have happened if, in the smaller mold, the gravel by contact with the edges of the mold, had prevented full compaction of the soil. That this perimeter effect was not a serious factor is shown by the almost constant ratio of the densities obtained in the larger mold to the densities obtained in the smaller mold for the three percentages of gravel which were compared. Whether a larger top size of gravel could be permitted in the soil if this larger mold were used was not investigated.

## CHANGE IN GRADING OF GRAVEL

The final part of the project consisted of a check of the smaller mold using a different grading of gravel but retaining the top size of $\frac{3}{4}$ in. A gap grading of 100 percent $\frac{3}{4}$-in. to $\frac{3}{8}$-in. gravel with no material between the $\frac{3}{8}$ in. and No. 4 sieve, when compacted with the

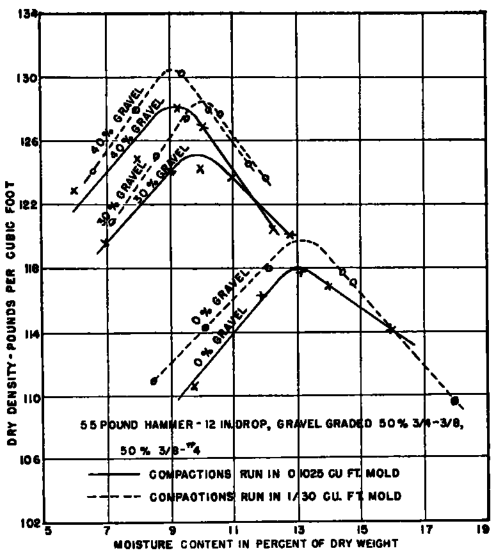


**Figure 4. Effect of Mold on Moisture-Density Relations for Soil-Gravel Mixtures**

same compactive effort previously used in the smaller mold, showed almost exactly the same effects of gravel in soil as previously found, although use of the gap graded gravel gave slightly less density at maximum density for each percentage of gravel tested. It is thought that the use of this gradation resulted in more particle interference than was found in the previously used, better graded gravel, and therefore resulted in slightly lower densities for soil-gravel mixtures.

## CONCLUSION

This limited series of tests shows that, in the compaction test, if any appreciable quantity of the soil is retained on the No. 4 sieve, the maximum density is larger and the optimum moisture is less than when the test is made with the coarse material removed. Therefore, to obtain significant data applicable to field conditions, the sample, graded as received should be used.

While no material larger than the $\frac{3}{4}$-in. sieve size was tested, no difficulty was found in compacting soil-gravel mixtures up to this top size. It is realized that there is an upper limit on the top size of stone or gravel which can be permitted in the sample, but this limit would have to be determined experimentally. Great Britain has adopted the AASHO method of test for compaction and density of soil, using the small $\frac{1}{30}$-cu. ft. mold, but permitting a top size of $\frac{3}{4}$-in. material.[2]

[2] MacLean, D. J. and Williams, F. H. P., "Research on Soil Compaction at the Road Research Laboratory", *Proceedings*, Second International Conference on Soil Mechanics and Foundation Engineering, Vol. IV, p. 247 (Rotterdam 1948).

For small amounts of gravel (less than 30 percent) the change in maximum density caused by the gravel can be computed to within about 2 lb. per cu. ft. For all percentages of the gravel used in this study the change in optimum moisture content can be computed to within one percent of moisture.

Changes in size of mold and differences in grading of the gravel appear to have little if any effect on the above conclusions.

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This investigation was made as part of the requirements of the graduate course in Soil Mechanics at the University of Maryland. The author wishes to express his gratitude to Professor E. S. Barber of the University of Maryland for his assistance in outlining the project, and his suggestions and helpful criticisms in performing the tests.

## DISCUSSION

MR. W. H. CAMPEN, *Omaha Testing Laboratory*—Mr. Zeigler shows, by a series of laboratory experiments, that the maximum density of soil and plus No. 4 aggregate is less than that calculated from the specific gravity of the coarse aggregate and the density of the soil. His results confirm the work of others. No doubt the discrepancy is due to loss of density in the minus No. 4 portion. This loss of density can be accounted for by assuming that the plus No. 4 material prevents densification of the minus No. 4 material by interlocking or by the inability of the coarse aggregate to transmit energy to the minus No. 4 material.

Because of this discrepancy Mr. Zeigler concludes that laboratory moisture-density tests should be made on the entire sample. He shows that the standard Proctor mold can be used successfully if the maximum size of the coarse aggregate does not exceed $\frac{3}{4}$ in. I concur in this suggestion but have some suggestions of my own. I believe that all material larger than the $\frac{3}{4}$ in. should be replaced with material passing $\frac{3}{4}$ in. and retained on $\frac{1}{2}$ in.

We have been using the entire mixture for a number of years. To eliminate the tedious job of levelling off the sample we use a tight-fitting, calibrated extension and measure the unfilled portion with sand. For maximum sizes in excess of $\frac{3}{4}$ in. we use a 6-in. diameter mold, 6 in. high and use 2-in. layers. The hammer and drops are modified to obtain results comparable to the standard method.

In connection with this discussion, I wish to call attention to the report[a] of a committee, of which the writer was chairman, in which it is stated that "The testing of compacted mixtures containing aggregate larger than the opening of a No. 4 sieve is causing some confusion and controversies in the field." The report, after elaborating on the controversies concludes as follows: "As a remedy either the moisture density relation should be determined on the entire sample or proper corrections should be applied if the test is made only on a portion of the sample."

[a] "Methods of Subgrade, Sub-base, and Base Preparation for Strength", *Proceedings*, Highway Research Board, Vol. 25, Page 21 (1945).