DEVELOPMENT OF A ONE-POINT CONE TEST FOR DETERMINING MAXIMUM DENSITY OF GRANULAR MATERIALS

R. C. Mainfort

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ABSTRACT: Because of the success of a one-point chart for determining maximum density by the T-99 compaction method, a one-point chart also has been developed to be used in conjunction with the Michigan cone test. The cone test is used in Michigan in lieu of the T-99 test for testing granular materials and sands having a minus 200 fraction of less than 10 percent. By use of the one-point method, it is necessary to make only one wet density determination per test. With this value and the chart, the corresponding maximum dry density can be determined directly and much more quickly than by using the conventional method. Extensive field testing of the one-point chart method shows it to be suitable for normal compaction control procedure.

KEY WORDS: soil testing, soil sampling, density measurement, dry density/soils/, granular materials, sands.

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In a previous report (1) the development of a one-point chart for determining maximum density by the T-99 compaction method was described. The value of this chart to field density inspectors has been recognized and it now forms a permanent part of the Department's compaction control equipment. Use of the chart has allowed a substantial reduction in the number of samples that normally must be molded and tested during compaction control operations, thereby releasing density inspectors for other duties or permitting additional areas to be tested.

In Michigan, however, the T-99 compaction control method is applicable to only those materials whose minus 200 fractions (fines) exceed 10 percent. For granular materials and sands containing 10 percent fines or less, the Michigan Cone Test (2) is used to determine maximum design density. The one-point T-99 chart is not applicable to these materials.

In the hope that work required to conduct the Cone Test could be reduced in the same manner as the T-99 method, A. E. Matthews requested that research be inaugurated to investigate the feasibility of developing a one-point chart which could be used to determine the maximum, or design, density with the Michigan Cone Test. This request was forwarded to the Research Laboratory with a memorandum of approval from R. L. Greenman, dated January 27, 1966.

The first phase of this project consisted of a study of available cone test data on file with the Department and as currently available from field density inspectors and the Ann Arbor Testing Laboratory. This bulk data was supplemented by a number of controlled cone tests made by the Soils and Research Laboratory Sections in which different granular mixtures were compacted in cones over a range of closely spaced differences in moisture content. With these tests, studies were also made to establish the range of error to be expected with the cone test and, consequently, how well a newly developed method should check with conventional results. Results obtained by different operators were compared as were duplicate tests performed by the same operator. Figure 1 shows the results of one such series of tests in which two density inspectors each determined the maximum density of different materials and, in addition, performed three repetitive tests on samples of each material at essentially the same moisture content. These tests indicate that the dry weight density of a sample, as determined by the cone test, can vary by as much as 2.8 pcf when determined under controlled conditions by the same operator. With different operators, the results varied by as much as 5.1 pcf with an average difference of 3 pcf, dry density.

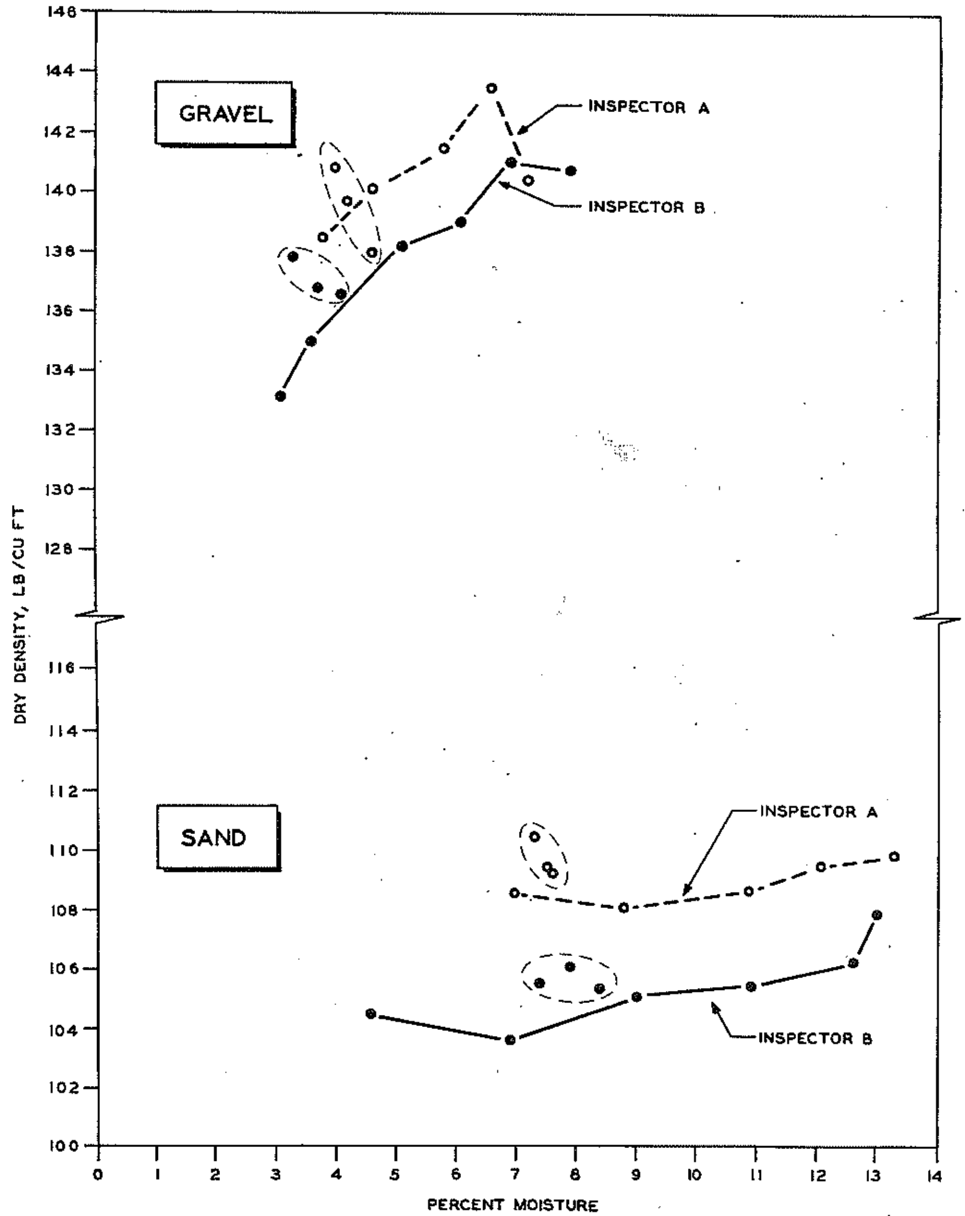

Figure 1. Typical Michigan cone density curves obtained by two different operators.

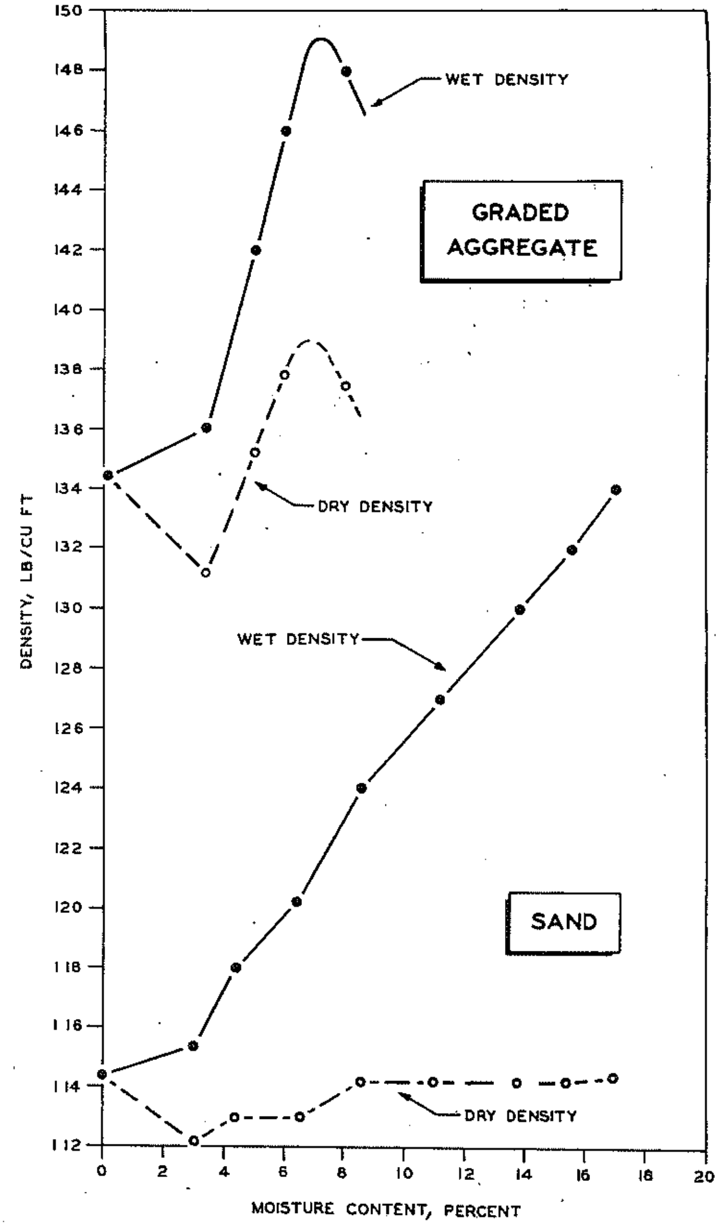

Figure 2. Basic patterns of Michigan cone moisture-density curves.

Under carefully controlled conditions, using well trained density inspectors from the Soils Division, the average difference between inspectors, based on about 100 tests, was approximately 1.5 pcf, with a maximum of 5.3 pcf. For 70 percent of the tests, differences did not exceed 2 pcf. For this reason, it was felt that any new procedures should check the conventional method within 2 pcf, 75 percent of the time.

Study of a large number of cone test results indicated that the shapes of the field moisture-density curves fell into two basic patterns, depending upon the gradation of the material being tested. For graded aggregates, a peaked curve, as normally associated with compaction tests, was obtained while the more uniformly graded materials, such as sands, yielded a flat curve with no clearly defined peak. Figure 2 shows typical curves of the two types, plotted for both wet and dry densities.

After several trial models, the one-point chart assumed the form shown in Figure 3. To obtain maximum dry density by means of this chart, it is necessary to determine the wet density and moisture content of only a single sample. Using these values, the chart is entered, as shown, and the maximum dry density read directly. The values obtained are more accurate when the moisture content of the test sample is above three percent and does not exceed values determined by the line MN. The line MN represents moisture contents beyond which, for a given soil, there is no appreciable increase in density with an increase in moisture content (optimum moisture

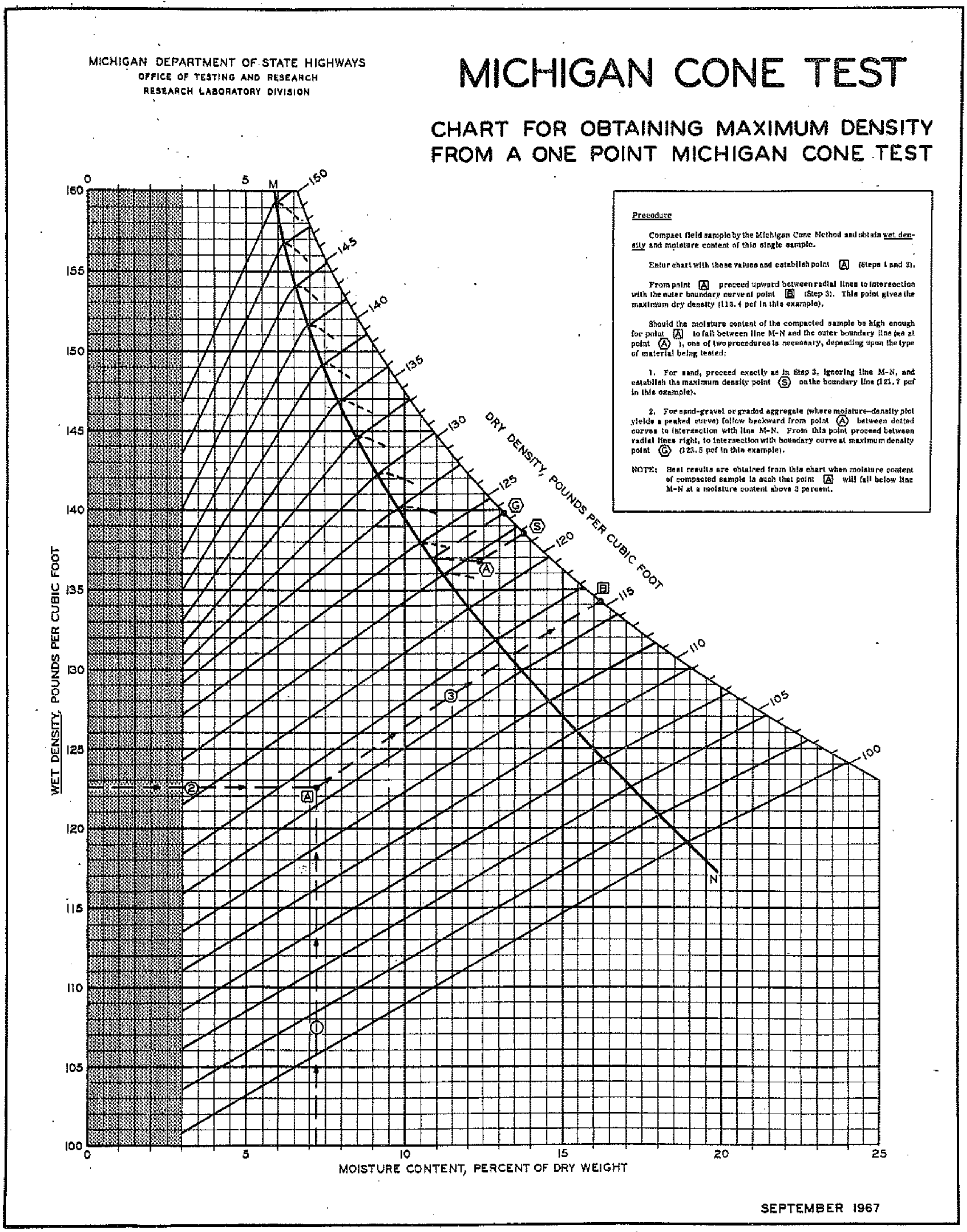

Figure 3. One-point cone test chart.

content for graded materials but less clearly defined with sands).

No particular problems were encountered in blending both the peaked and flat shaped curves into a single chart. However, in the case of the peaked curves, a special procedure should be followed if the moisture content of the test sample exceeds the optimum, (falls to the right of the line MN). If the excess moisture does not exceed one percent, the appropriate dotted curve should be followed backward to its intersection with line MN before projection to the dry density line. If the moisture exceeds optimum by more than one percent, the sample should be dried back to optimum or less and retested. With sands, the higher moisture contents present no problems in the use of the chart. In certain borderline cases (usually in the 120 to 125 pcf density range) the type material being tested may not readily be apparent. In this case, the judgment of the inspector should determine the appropriate test method to use when the moisture content falls beyond the MN line. If in doubt, the sample should be retested at a lower moisture content.

At the lower range of moisture contents, it was found desirable to conduct tests only on samples above 3 percent moisture. Below this value, the full lubrication mechanism of the soil and water is not mobilized so that moisture-density relationships do not lend themselves to significant projection as do the values at higher moisture content. Best overall results with the one-point chart are obtained when the moisture content of the samples is at, or near, optimum moisture.

The chart was tested over a 60-day trial period by density inspectors of the Soils Division in order to determine its suitability for field use. During this evaluation period, maximum densities were determined both by conventional and by one-point cone methods. Correlation results for 304 such tests are shown in Figure 4. The regression line for these tests is practically parallel to a 45-degree line of equal value, with the one-point values being, in general, about one-half pound higher (on the conservative side) than are those of the conventional method. This is due, primarily, to the fact that conventional tests are not normally made at moisture contents approaching saturation where highest densities are often obtained. The maximum values obtained from the one-point chart represent the highest value of density obtainable throughout a moisture range between zero percent and saturation. The conventional method does not cover such a wide range of moisture contents.

Based on the data shown in Figure 4, the one-point method should check the conventional method within $\pm$ 2 pcf 95 percent of the time throughout the entire range of densities. However, it can be seen that density values above approximately 130 pcf (where graded aggregates predominate) did not correlate quite so well as did those of lower densities. When computed separately, the correlation at the 95-percent confidence limit, was $\pm$ 3.1 pcf for densities above 130 pcf and $\pm$ 1.4 pcf for those below this value. The

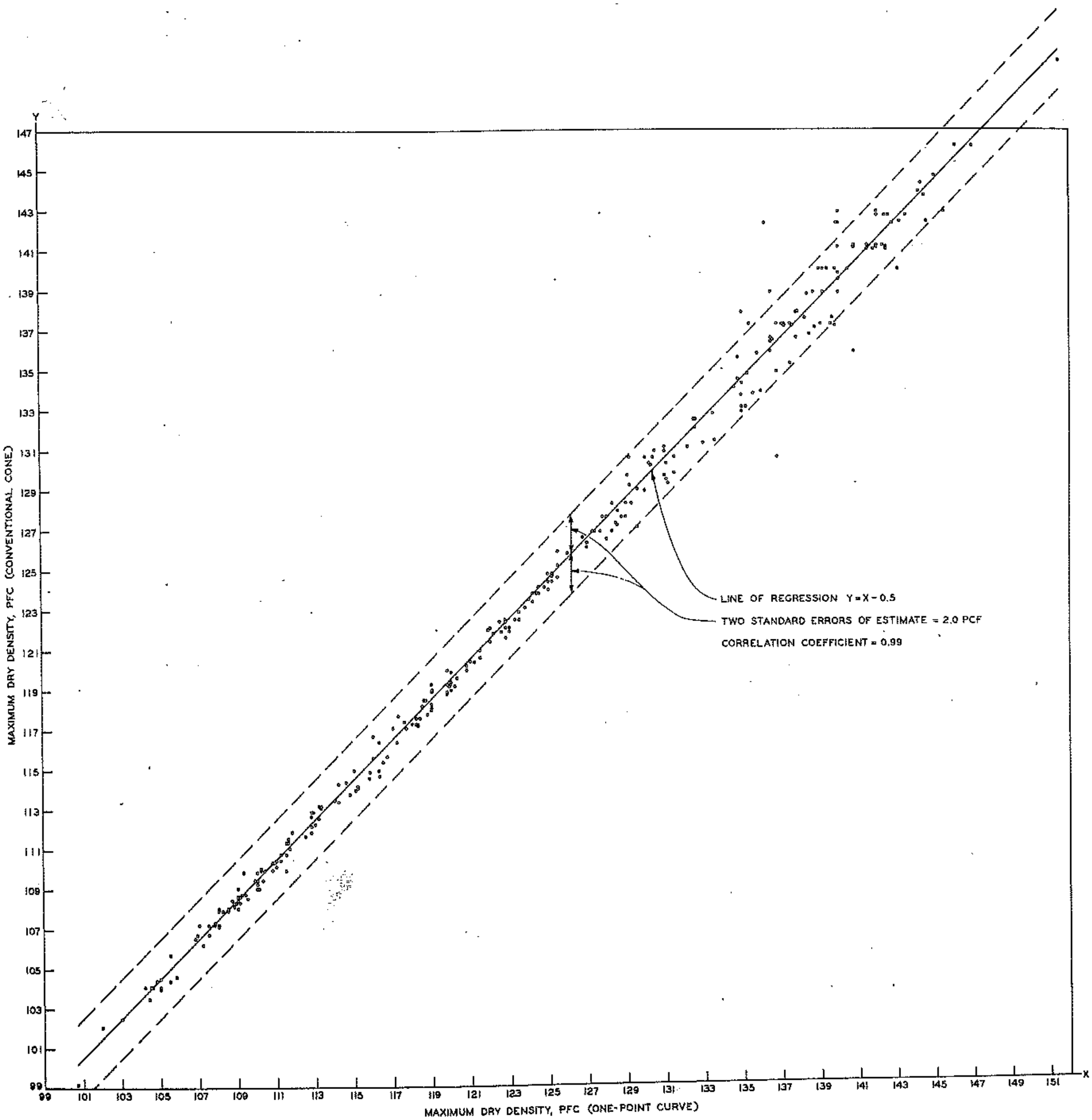

Figure 4. Correlation between maximum densities as obtained by conventional and one-point cone density tests.

higher value is well within tolerable limits, however, so that no adjustment to the chart is required at this time. The correlation coefficient for all of the data is 0.99, an exceptionally fine correlation.

Because of the satisfactory field results obtained with the one-point chart, this method has been approved for use by the Department and by the Bureau of Public Roads. As in the case with the T-99 one-point chart, the one-point cone data, as obtained from the field, will continue to be studied and the chart modified if future conditions warrant. In its present form, however, the method appears to yield reliable results and its use certainly permits a substantial saving of time and effort in the determination of design density for granular materials, especially in those areas where there is a considerable variation of these materials.

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