DEPARTMENT OF SOILS, GEOLOGY AND FOUNDATIONS

Influence of Foot Size on Soil Compaction Efficiency

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Observations based on extensive performance testing of field compaction equipment in both Great Britain and the United States indicated that, for tamping rollers, there probably are optimum values of foot area and pressure that will give maximum soil compaction. A laboratory investigation was undertaken to determine the influence of foot size on the efficiency of soil compaction. For each foot size tested, a series of dynamic compactions was performed at varied water contents by an amount of work that was held constant. The results of the investigation indicate that the density obtained from dynamic compaction is dependent upon the area of the compacting foot and that this effect on density is greatest when the moisture content is near the optimum. The optimum moisture content produced by dynamic compaction, however, is not affected by the size of the compacting foot.

• COMPACTION is almost universally recognized as the key to construction of proper road foundations. Successful compaction, that is, obtaining a desired density with maximum economy and ease, depends in large measure on the methods and on the type and weight of equipment used for rolling. The tamping or sheepsfoot roller is most generally used for compaction of fine-grained soils in the United States. The weight of the roller, the area and shape of the feet, and the spacing of the feet are variables in the sheepsfoot roller which influence compaction. Other variables include soil type, moisture content, initial density, and thickness of lift.

COMPACTION EFFICIENCY

Even though there are many variables which affect the results obtained with the sheepsfoot roller, it is obvious that the tamping foot is the key to any investigation aimed at improving the efficiency of this piece of equipment. Efficiency, or, to the contractor, economy, is measured in terms of obtaining a desired degree of compaction with the least expenditure of energy which, with rolling equipment, is generally associated with the least number of passes. Synonymously, with a constant expenditure of energy in a particular soil, maximum efficiency is indicated by the maximum density obtained.

Results of investigations conducted at the Road Research Laboratory in Great Britain suggested that for any given load there probably are optimum values of foot area and pressure that will give maximum soil compaction (*1*). The Waterways Experiment Station reported results of field compaction tests in which the compaction effort was varied by varying the size of tamping feet while maintaining a constant foot contact pressure, and by varying the number of passes on the different foot sizes (*2*). Of special significance in this report was the conclusion that rather than increase or decrease ballast, a more practical method of varying the contact pressure might be to use a roller with the maximum weight that is economical to tow and to vary the size of tamping feet. The report suggested that this could be accomplished by designing sheepsfoot rollers with changeable feet; the proper foot size could be determined in the field for any given soil, thereby resulting in the most efficient compaction of any soil with a sheepsfoot roller.

Available data from carefully controlled field studies of rolling show moisture-density relationships very similar to those developed from laboratory tests (*3*). It is therefore entirely feasible that the proper size foot for a given soil and roller could be determined from laboratory tests, thereby obviating the need for field determination.

The author's purpose is to report the results of an investigation conducted at the Soil Mechanics Laboratory of the Georgia Institute of Technology on the effect of the size of tamping foot on the dry density-moisture content relationship at constant expenditures of compaction energy (*4*).

EXPERIMENTAL INVESTIGATION

The soil used throughout the investigation was a red-brown sandy clayey silt of medium compressibility. It is classified as A-7 by the Revised Public Roads System and as ML by the Unified Soil Classification System. The maximum dry density by the Standard Proctor Method is 100 pcf at an optimum moisture content of 22.0 percent.

Compaction effort was applied to the soil by a dynamic compaction device consisting of a 10-lb hammer adjusted for an 18-in. free fall. Four circular steel feet, with diameters of 2, 3, 4, and 5 in., were used to transmit the blows from the hammer to the soil. The mold used was a large steel cylinder of $10\frac{3}{16}$-in. internal diameter, and of a depth which was predetermined to give a mold volume of $\frac{1}{6}$ cu ft. This equipment is shown in Figure 1. The interchangeable tamping feet are shown in Figure 2.

British laboratory tests indicated that a constant amount of work applied to a unit volume of a given soil produced nearly identical moisture-density relationships (*5*). Kennedy, on the other hand, found that the amount of work per application was an important factor affecting the degree of densification attained (*6*). This variable was eliminated by using the same hammer and applying the total work with the same number of blows per layer throughout the tests.

For each size compaction foot, samples with water contents of 15, 18, 21, 24, and 27 percent were compacted. The principal compaction tests were conducted using the $\frac{1}{6}$-cu ft mold and a compaction effort of 12,420 ft-lb per cu ft, thus permitting

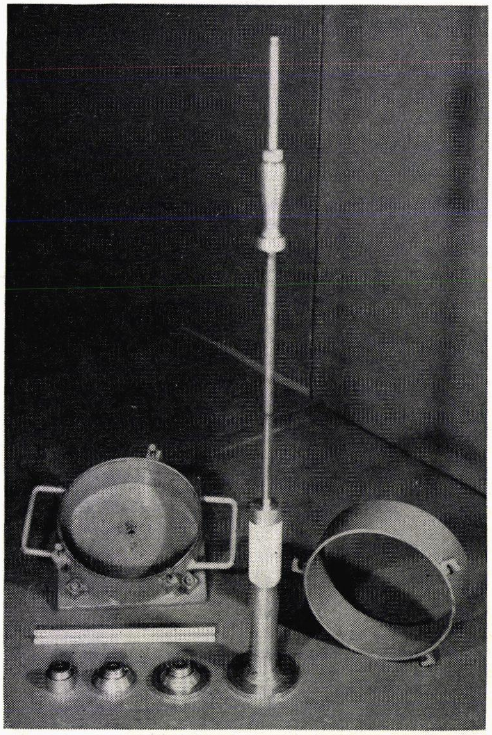

Figure 1. Compaction mold, collar, and hammer with changeable feet.

comparison with the Standard Proctor laboratory test. With the previously described test equipment, this effort required 46 blows on each of three soil layers.

EXPERIMENTAL RESULTS

Results of the compaction tests are listed in Table 1; the dry density-moisture content curves obtained from these data are shown in Figure 3. It is apparent that the densities produced at like water contents are not identical. There are several observations that can be made from these curves.

Although the maximum dry density obtained varied depending upon the diameter of the tamping foot, the optimum moisture content remained the same. This is considered an important discovery and indicates that should it become advantageous during field rolling operations to change the diameter of the tamping

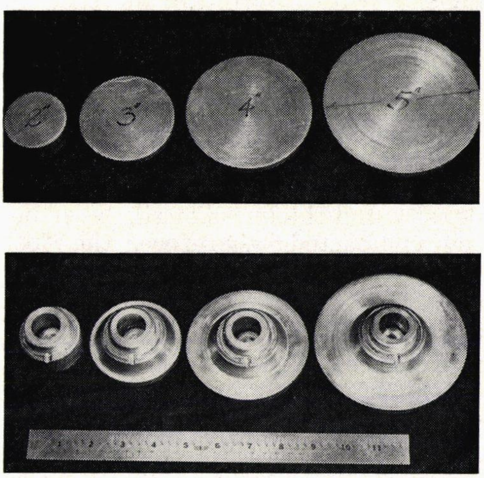

Figure 2. Compaction feet: 2-, 3-, 4-, and 5-in. diameters.

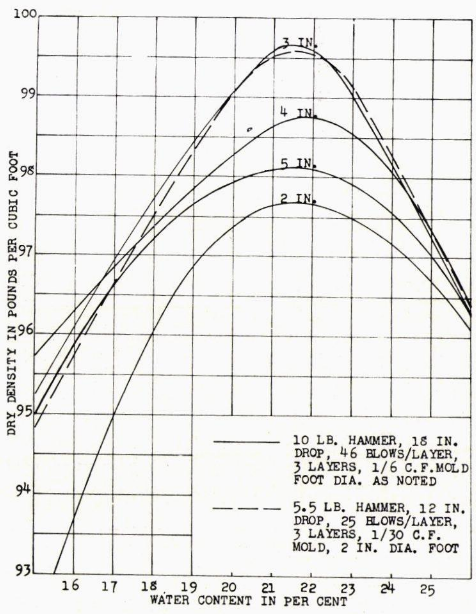

Figure 3. Effect of foot diameter on moisture-density relationships.

TABLE 1
COMPACTION TEST DATA

Foot Diam. (in.)	Compaction Effort [a] (ft-lb/cu ft)	Water Content (%)	Dry Density (pcf)
2	12,420	15.1	92.3
		17.5	95.5
		19.9	96.4
		20.4	98.1
		23.0	97.5
		25.7	96.5
		25.8	96.0
	18,630	19.7	101.5
3	12,420	14.7	96.5
		15.4	95.5
		16.4	96.6
		17.3	97.0
		19.4	98.5
		20.7	99.5
		22.4	99.5
		23.1	98.8
		25.8	96.4
	18,630	19.8	102.1
4	12,420	14.9	95.6
		17.9	97.4
		17.9	97.0
		21.1	98.0
		21.4	97.8
		23.1	99.3
		23.3	98.2
		23.9	98.1
		25.9	96.4
		25.9	96.5
	18,630	20.4	101.3
5	12,420	15.0	94.9
		17.6	97.0
		20.6	97.5
		21.4	98.1
		23.0	97.9
		26.2	96.0
	18,630	20.1	100.7
b	12,375	14.1	94.1
		14.2	93.8
		16.9	96.8
		17.1	96.5
		19.9	99.0
		19.9	99.0
		22.8	99.0
		23.0	99.5
		25.6	96.0
		25.9	96.5

[a] A 10-lb hammer and 1/6-cu ft mold were used in all tests.
[b] Standard Proctor Test.

foot, the moisture content of the soil would not have to be adjusted accordingly.

Of equal importance is the fact that the greatest effect, or variation in dry density, of foot diameter occurred at a water content equal to the optimum. Since this is the moisture content almost invariably striven for in field compaction operations, it is of interest to know that this is the very condition at which the dry density is most susceptible to variations in the diameter of the tamping foot.

The 2-in. foot, which transmitted the maximum pressure to the soil, produced the smallest densities, particularly when compaction was performed at moisture contents less than the optimum moisture. Peak densities were obtained with the 3-in. foot; density values diminished when the foot size was increased. This behavior seems to substantiate previously described theories regarding the effect of bearing capacity with relation to stress intensity on the face of the tamping foot. During the tests the small foot completely disturbed the soil by punching deep and fast and displacing a large volume of soil in an outward direction. This displacement gradually decreased as the density increased until finally excellent compaction appeared to be achieved with the small foot. Bearing capacity decreases with decrease in size of the loaded area for soils which depend on their frictional qualities for bearing capacity; the fact that the 2-in. diameter foot sheared the soil excessively when at moisture contents less than optimum is a logical phenomenon since the effective stresses increase and the soil becomes more and more friable as the moisture content is decreased. Sowers and Gulliver (*7*) indicated that the probable cause of the decrease in density with continued increase in foot size is the rigidity of the tamping foot. A loose, irregular, uncompacted soil layer is sandwiched between a rigid steel disk and a semi-rigid compacted soil layer. They explain that the wider the foot the greater are the irregularities in the density and thickness of the layer being compacted; therefore, the foot tends to ride on the high hard spots and leave the remainder uncompacted.

Another observation from Figure 3 is the similarity of the laboratory curve produced by the 3-in. diameter foot and the modified hammer to that produced by the Standard Proctor procedure with fresh soil specimens used for each point on the curve.

The only explanation plausible seems to lie in the effect of the size of the compaction mold with respect to the size of the compaction foot. No attempt was made to investigate this effect further. Compacted samples are shown along with their respective molds in Figure 4.

Plots of dry density versus foot diameter for conditions of equal moisture content are shown in Figure 5. The results show that the effect of foot size is much more pronounced at lower values of moisture content than at the higher values; when the moisture content approached saturation conditions, as represented by a water content of 27 percent, foot size had no effect whatever on the density obtained.

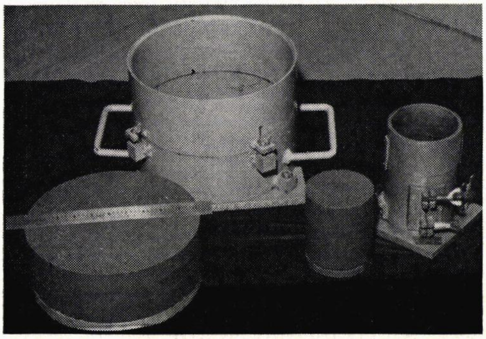

Figure 4. Compacted samples and molds: ⅙ and 1/30 cu. ft.

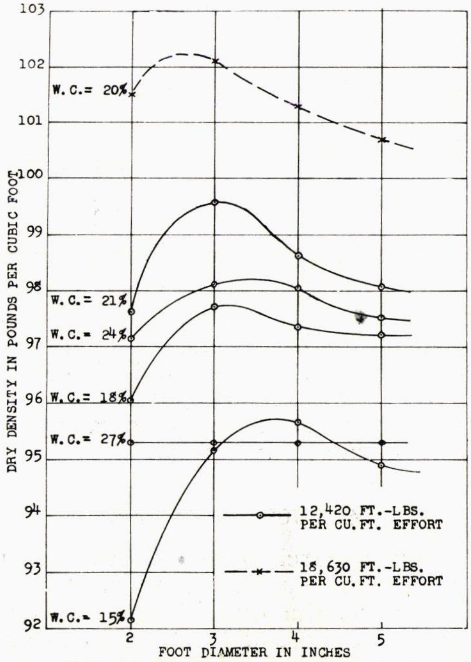

Figure 5. Dry density-foot diameter relationships at various water contents.

A test series was conducted at approximately 20 percent moisture content using a compaction effort 50 percent greater than that used previously. The water content was selected to approximate the optimum moisture content at this particular compaction effort. These results are also shown in Figure 5. A comparison of the dry density-foot diameter relationships at the different compaction efforts shows a tendency for the foot size which produces the maximum compaction to decrease as the compaction effort increases.

CONCLUSIONS

1. The density obtained from dynamic compaction is dependent upon the area, or diameter, of the compacting foot.

2. For a given soil, moisture content, and method of dynamic compaction, there is a particular foot diameter which will produce the most efficient compaction, that is, achieve the greatest value of dry density with the same expenditure of compaction effort.

3. The effect on dry density of the size of the compacting foot is greatest when the moisture content is near the optimum. At high values of moisture content which approach a saturated condition, the size of the compacting foot has little or no effect on density.

4. The optimum moisture content produced by dynamic compaction at like amounts of work is not related to the area of the compacting foot.

5. The optimum foot diameter appears to decrease as the compaction effort increases. The most efficient compaction operation would thus appear to be one in which the foot diameter was reduced at successive stages of the compaction process.

These conclusions, of course, apply only to the soil tested and to compaction with circular tamping feet. Further research is recomended for different soils and a wider range of conditions than those used in this investigation. The results of the investigation, however, definitely suggest that the efficiency of the compaction process can be improved.

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