Effect of Varying Tamping-Foot Width on Compaction of Cohesive Soil

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RECENT studies on soil compaction have indicated that soil density is affected by tamping foot size. This was investigated analytically by computing the stresses in the compacted layer beneath a tamping foot and determining the soil densities from the results of consolidation tests. It was also investigated experimentally by compacting a soil in a large cylinder with different layer thicknesses and different sizes of tamping feet. The results of both the analytical and experimental investigation indicate that compaction is improved as the ratio of tamping foot diameter to soil layer thickness is increased. When the ratio exceeds 2, however, the benefit obtained by increasing the ratio becomes less; and it may be obscured by the "bridging" of large-diameter feet over soft spots in the soil layer being compacted.

● THE problem of how large to make the feet on tampers or sheepsfoot rollers has been the subject of some discussion between engineers, contractors, and equipment manufacturers. All three are striving for higher compacted densities at lower cost, but unfortunately the basic principles involved are so obscure that the methods proposed may not be sound.

For example, it has long been recognized that higher compaction pressures usually result in higher densities.

While higher pressures can be obtained by constructing larger equipment, they may also be obtained by using smaller tamping feet. Such procedures have been widely advocated, and even provided for by interchangeable feet on sheepsfoot rollers. In fact, the authors have seen a number of compaction specifications which state both the required foot pressure and the maximum tamping foot diameter.

On the other hand, recent research at Georgia Tech (*1*) has indicated that compaction increases for a given tamper pressure as the tamping foot diameter increases with respect to the thickness of the compacted layer. Studies by the U. S. Waterways Experiment Station (*2*) and the Road Research Laboratory in Great Britain (*3*) also indicate that increasing the size of a tamping foot will increase the density of the compacted soil.

It was the purpose of this study to investigate the influence of tamping foot diameter and soil layer thickness both analytically and experimentally for a typical cohesive soil.

SOIL CHARACTERISTICS

The soil used in the investigation was an orange-brown sandy silty clay of low plasticity. It is classified as A-6 (*4*) by the Revised Public Roads System and as CL by the Casagrande System. The maximum dry density by the Standard Proctor Method is 106 lb. per cu. ft. at an optimum moisture of 19.6 percent. Such a soil is typical of the sandy clays found in many parts of the South which are widely used in fill construction.

For the experimental phases of this investigation, the soil moisture was maintained at approximately 14 percent or about ¾ of the optimum. At this moisture content, the Standard Proctor compaction produced a dry density of 90 lb. per cu. ft. or 85 percent of the maximum.

ANALYTICAL INVESTIGATION

The analytical investigation consisted of two steps: first, determining the stresses in the soil layer being compacted; and second, computing the soil densities resulting from these stresses. In both steps, assumptions were made which are not strictly in accordance with the actual soil behavior. Therefore, the results of the analyses should be looked on as a qualitative indication of what might be expected under field conditions.

STRESS COMPUTATION

Any of the various theories of stress analysis indicate that the pressure from a tamping foot is widely distributed through the mass of soil beneath and adjacent to the foot. The greatest concentration of pressure, however, is in the soil immediately beneath the foot itself. Therefore, this investigation was limited to that zone of soil beneath the tamping foot having a diameter equal to the foot diameter and a height equal to the thickness of the soil layer being compacted. The compacted layer thickness was termed *t*, and the foot diameter *d*, as shown in Fig. 1.

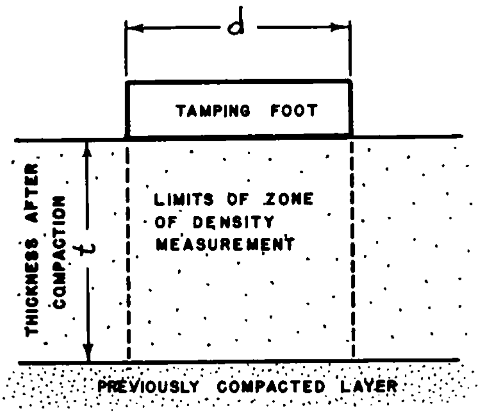

Figure 1. Limits of zone for stress computation and density measurement.

The average vertical stress in the cylindrical zone was computed using the Boussinesq theory. Obviously, this is not applicable at the beginning of compaction since the soil is not a semi-infinite homogeneous, isotropic, elastic solid as the theory assumes. After compaction, however, the soil approaches that condition. Therefore, the Boussinesq theory is probably an indication of the actual soil stresses. The results, Fig. 2, indicate that the average vertical stress is a function of the ratio of foot diameter to the compacted layer thickness, d/t. An increase of d or a decrease in t results in an increase in the average pressure in the soil for a given contact pressure beneath the foot. When the d/t ratio is 2, the average pressure is about 75 percent of the contact pressure. At higher ratios, the rate of increase in the average pressure takes place rather slowly.

DENSITY

Consolidation tests were run on the soil using a 4.25 in. diameter 1¼ in. thick sample. Different tamping foot pressures were assumed and the resulting densities were computed using the curve of Fig. 2. The results are given on Fig. 3. As might be expected, these results indicate that soil density increases as the ratio of d/t increases, but at a decreasing rate. Again, the greatest rate of increase occurs up to a d/t ratio of 2. At higher ratios, the increase is much less.

EXPERIMENTAL INVESTIGATION

The experimental investigation consisted of compacting the soil with various sizes of tamping feet and measuring the resulting densities. A 12 in. diameter cylinder was used for all the tests. It was first filled to a depth of 6 in. with the test soil, which was thoroughly compacted by static pressure higher than any used during the subsequent investigation. Four circular steel tamping feet were used –1 in., 2 in., 3 in. and 4 in. in diameter. Loose soil was placed in the mold on top of the compacted soil base and then compacted by a single application of static pressure from one of the feet. The cylindrical zone of soil immediately beneath the foot, Fig. 1, was cut from the compacted layer and its density measured. This was done for various layer thicknesses, and tamping foot pressures of 150, 200 and 250 psi. The results are given graphically on Figs. 4, 5, and 6. (Included for com-

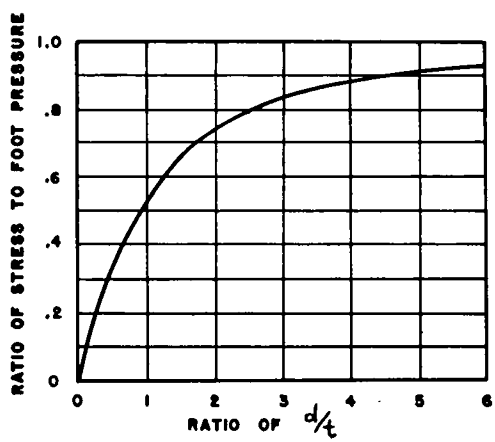

Figure 2. Ratio of average vertical stress in cylindrical zone to tamping foot pressure.

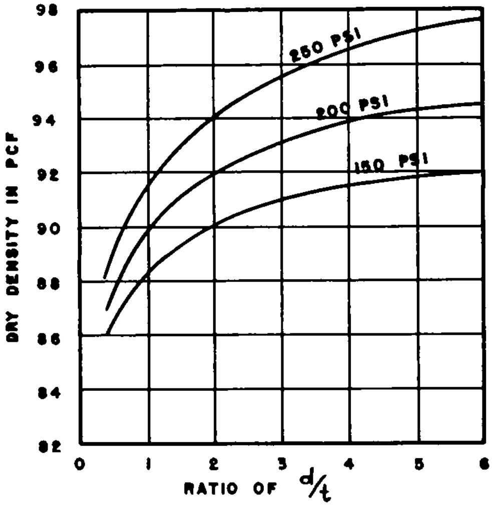

Figure 3. Densities computed from stresses for different ratios of foot diameter to layer thickness.

parison are the densities computed from the stresses and the consolidation test data.)

EXPERIMENTAL RESULTS

As might be expected from the theory, the experimental results indicate that the compacted density increases as the ratio of d/t increases. Also, the rate of increase decreases as d/t increases. The analytical investigation did not, however, bring out one fact which is obvious from the experimental results: that the compacted density is also a function of the foot diameter.

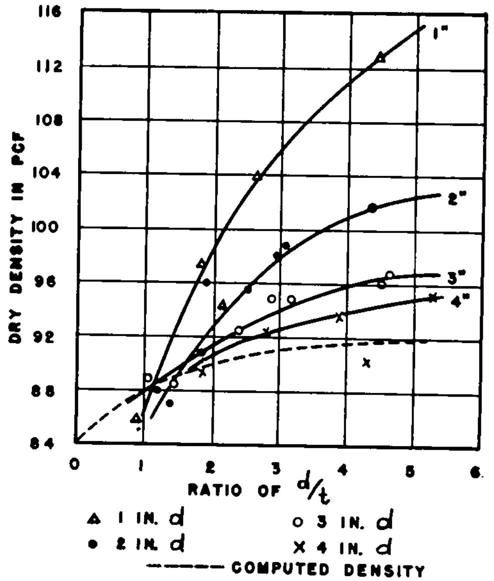

Figure 4. Densities measured for different sizes of tamping feet and 150 psi foot pressure.

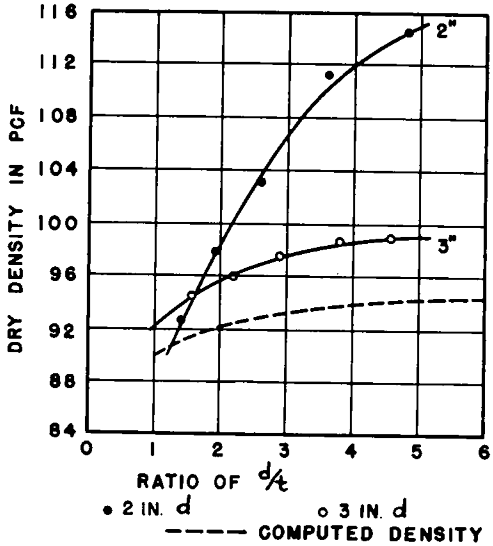

Figure 5. Densities measured for different sizes of tamping feet and 200 psi foot pressure.

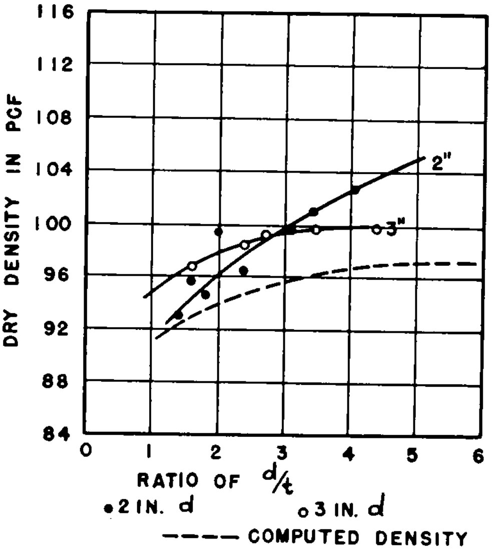

Figure 6. Densities measured for different sizes of tamping feet and 250 psi foot pressure.

At low d/t ratios, where the soil layers are thick with respect to the foot diameters, the largest feet produced the highest densities for given values of d/t. For high ratios of d/t, the smallest feet produced the highest densities.

The explanation for the size effect, when the d/t ratio is low, appears to be soil bearing capacity. The bearing capacity of a partially saturated clay such as that used in this investigation is a function of the diameter of the loaded area. Small feet induce soil failure more readily than large feet and, therefore, the smaller feet produce lower densities.

As d/t becomes larger, the shear zone necessary for bearing capacity failure beneath the tamping foot becomes restricted. Eventually, a point is reached for each foot pressure where shear cannot occur, and at that point the densities for all the different foot should be the same. This point occurs at a d/t ratio of about 1.4 for a contact pressure of 150 psi. At higher contact pressures, it would be expected that the required d/t ratio would be higher. This is confirmed by the experimental results where a d/t ratio of 1.6 is necessary at 200 psi and 2.6 is necessary at 250 psi.

The explanation of the size effect for high d/t ratios is more obscure. The probable cause 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. The wider the foot, the greater are the irregularities in the density and thickness of the layer to be compacted. The foot tends to ride on the high hard spots and leave the remainder uncompacted.

A comparison of the experimental curves with the computed ones indicates that they have the same shape, but that the experimental densities are higher. At the lower d/t ratios, the experimental densities are only slightly higher than the computed. At d/t ratios of two or more, the differences becomes greater. At least two reasons for this difference may be suggested. First, the stresses computed by the Boussinesq theory are probably lower than the real stresses. Second, the conditions for soil compaction (consolidation) in a 4.25 in. consolidometer are not the same as beneath tamping feet ranging from 1 to 4 in. in diameter. The largest tamping feet (3 in. and 4 in.) produced densities that are closest to the computed.

CONCLUSIONS

The results of this investigation indicate: (1) increasing the ratio of tamping foot diameter to layer thickness will increase the soil density for a given foot pressure; (2) the increase is particularly noticeable up to a d/t ratio of 2; (3) increasing the ratio by increasing d is particularly effective for thick soil layers where d/t is less than about 2 and where higher tamping foot pressures are desired; at high d/t ratios, the bridging of the rigid tamping foot may offset to some extent the benefits; (4) if the foot diameter cannot be increased, it will be beneficial to reduce the layer thickness; and (5) if the tamping foot pressure is too great for the soil bearing capacity, it will be helpful to reduce the layer thickness; the benefits do not begin until the d/t ratio is greater than about 2.

Of course, these conclusions apply only to the soil tested and to compaction with circular tamping feet such as those used in this investigation. Further research is advisable on different soils and for a wider range of conditions than those used in this investigation. These results do, however, point out what might be expected in actual field compaction.

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