Effect of Repeated Load Application on Soil Compaction Efficiency

GEORGE F. SOWERS, Professor of Civil Engineering, and
C. M. KENNEDY III, Graduate Student;
Georgia Institute of Technology

Soil compaction is essentially a process of consolidation. Our knowledge of that process leads to the conclusion that the greatest amount of soil consolidation is produced by the fewest cycles of application of load. This has been demonstrated by recent research at the Georgia Institute of Technology. Different methods of compaction such as tamping, hammering, and squeezing were employed, each exerting the same amount of work. The fewer the applications of pressure neccessary to exert the same amount of work, the greater the density obtained.

● IN the past, soil engineers have emphasized the need for controlling and evaluating compaction and have largely left the problem of obtaining it to the contractors and equipment manufacturers. The few studies which have been made, such as those by the U. S. Waterways Experiment Station (1) and the Road Research Laboratory in England (2) have done much to point out how better compaction can be obtained easily. Much research remains to be done, however, on the basic factors which control the effectiveness of compaction. It is the authors' purpose to discuss just one aspect of the problem, the effect of repeated load applications on compaction efficiency, and to point out how this affects both laboratory and field compaction results.

COMPACTIVE EFFORT AND COMPACTION

The amount of work exerted in compacting a soil is the compactive effort. It may be described by the number of blows of a certain weight hammer falling a fixed distance, the number of applications of a certain pressure to the soil surface, or by the number of passes of a roller of known weight and pressure over a specified lift of fill. Technically it is most accurately expressed by the work in foot-pounds or inch-pounds applied to each cubic foot of soil.

A number of field and laboratory studies of compaction utilizing different amounts of work applied have come to the same conclusion: that soil density increases as the compactive effort increases for any given soil condition. The relationship is not linear, however, for the rate of increase in density decreases with increasing work. For example, research by the Waterways Experiment Station (1) indicates that a linear relationship exists between dry density and the logarithm of the number of hammer blows in a laboratory test or the logarithm of the number of passes of a sheepsfoot roller.

Little has been said about the effect of the way in which the compactive effort is applied to the soil. In fact, some investigators have implied that soil density will always be about the same for a given effort in foot-pounds per cubic foot regardless of the manner in which the effort is exerted.

Others have pointed out that considerable differences in compaction effectiveness do exist. For example, moisture-density curves developed by the Standard AASHO procedure (Standard Proctor Test) do not necessarily have the same shape as the moisture density curves developed by actual rolling in the field. The difference has been attributed to the fact that the standard laboratory test involves tamping or dynamic compaction while the compaction of a sheepsfoot roller is produced by an increasing static pressure. Some laboratory procedures have been developed to simulate the action of the sheepsfoot.

Research in the Soil Mechanics Laboratory at Georgia Institute of Technology (3) has shown considerable difference between the densities produced by different compaction methods even though all utilized the same total compactive effort. For example, identical soil samples were compacted using first, the Standard AASHO method, and sec-

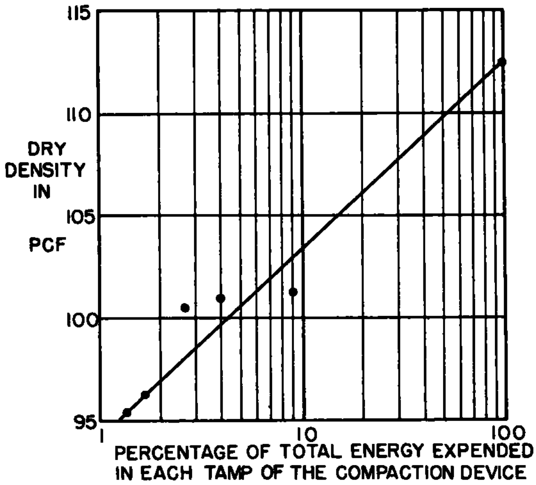

Figure 1. Relationship between the compacted density of the soil and the percentage of total energy exerted by each tamp of the compaction device (typical example).

ond, single applications of static pressure to each of three layers of soil in a standard compaction mold. The second method was adjusted by trial and error to utilize the same amount of total effort as the first. The density obtained by the first procedure was 107 pcf. and by the second method was 119 pcf. This indicates that the second method is more effective in utilizing the work done in producing compaction.

EXPERIMENTAL STUDY OF FACTORS AFFECTING COMPACTION EFFECTIVENESS

A program of study was undertaken at Georgia Tech to determine the factors which affect compaction effectiveness (3). The work was carried out with a single soil type (low plasticity clay, A-6), a limited number of moisture contents, and a single compactive effort of 34,000 foot-pounds per cubic foot. The latter was selected as it is between the standard and the modified AASHO efforts and is representative of modern compaction requirements.

A number of different devices were used. These included hammers weighing 5.5, 10, and 25 lb. with heights of fall ranging from 3 to 18 inches, a low velocity punching tamper to simulate the action of a sheepsfoot roller foot, and a piston for applying slow, static pressure to the soil. The results of 64 tests indicate that for moisture contents above the standard Proctor optimum all methods produced substantially the same densities while at moisture contents equal to or below the optimum, the densities were quite different.

A number of factors were considered which might be the cause of the difference. These included: (1) velocity of hammer at point of impact; (2) momentum of the hammer; (3) hammer weight; (4) ratio of the diameter of the compacting device to the thickness of the soil layer; and (5) percentage of the total energy exerted during each tamp or application of pressure.

The results of these tests indicate that the velocity of the hammer or tamper as it strikes the soil has no discernible influence on the effectiveness of compaction. Neither do the momentum or the weight of the hammer. These results contradict the conclusion reached by some investigators that the difference between the standard laboratory tests and field results lies in the fact that the laboratory tests are essentially dynamic (with high velocity of impact) while the field work is essentially static (with low velocity of impact).

The ratio of the hammer or tamper diameter to the soil layer thickness was found to be an important factor. Research is con-

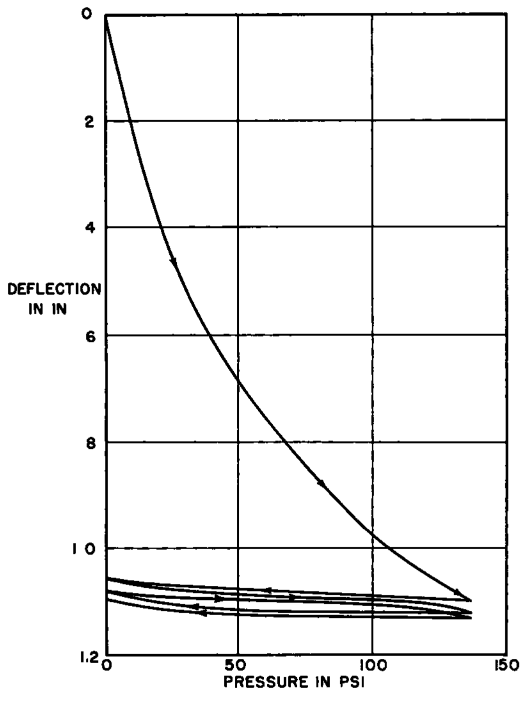

Figure 2. Pressure-deflection curve for three load applications.

tinuing on this point at Georgia Tech, but the tentative conclusion is that the soil density increases with the square of this ratio, until the ratio equals approximately 1.

The most-important factor was found to be the percentage of the total energy which was applied in each tamp, blow, or application of energy to the soil. The greatest density in every case was produced when all the energy was utilized in a single application; the greater number of applications required to apply the same amount of energy, the smaller will be the resulting density. A typical curve from these tests is given in Figure 1.

CONSOLIDATION AND COMPACTION

The cause of this reduction in compaction effectiveness as the number of applications of the compaction energy increases must lie in the mechanics of the compaction process. Additional research was therefore directed toward that end.

Compaction of cohesive soils is essentially consolidation with limited lateral support. This is produced by pressure regardless of whether the soil is tamped, hammered, or just loaded statically. When increasing pressure is applied to a soil it deforms or compacts. When the pressure is released, the soil swells but not to its original volume. If the same pressure is reapplied, additional consolidation will take place, but not nearly as much as during the first application. The rebound will be proportionally greater. Each successive application of pressure will produce less and less consolidation and proportionally more and more rebound until the two are equal and no further consolidation occurs. The pressure-deflection curves for three successive applications of a 140-psi. pressure to a 3-sq.-in. compaction foot acting on a 2-inch soil layer are shown in Figure 2.

The amount of work exerted in each cycle of pressure application and release can be found by integrating the pressure deflection curve. From Figure 2 it can be seen that the amount of work exerted is greatest during the first pressure application and much less during each successive application. Figure 3 shows how both the amount of compaction and the amount of work decrease sharply with successive load applications.

The effectiveness of the compaction can be expressed by the compaction ratio—the ratio of the amount of compaction to the work done in producing it. Figure 3 shows that it becomes less with each successive pressure application until it probably eventually becomes zero. In other words, the first application of pressure produces by far the most compaction for the amount of work required, and is therefore the most efficient.

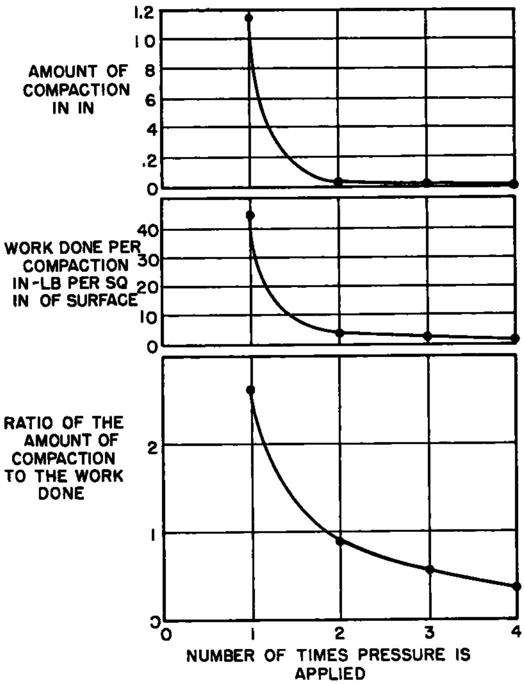

Figure 3. The amount of compaction, the work done and the compaction ratio (ratio of compaction to work) as functions of the number of pressure applications.

The cause can be inferred from our knowledge of soil structure. The compaction of the soil under pressure is the result of elastic deflection of the soil structure and plastic movement of the soil grains into a more dense arrangement. The elastic deflection absorbs work in the form of strain energy while the plastic deformation absorbs work and transforms it to heat. When the pressure is removed, the elastic part of the deflection is largely recovered. The strain energy is dissipated in the viscous resistance of the soil to swelling and in some plastic deformation and re-arrangement. During a second load application the deflection is largely elastic with only a small amount of plastic deformation because the grains were already readjusted during the first loading. The only reason additional compaction is produced is that some readjustment took place during swelling. After many load applications the deflection is entirely elastic and no additional grain adjustment takes place. Work is still exerted, however, to overcome the viscous resistance to deformation although no additional compaction results from it.

SUMMARY OF CONCLUSIONS

The results of this research lead to three conclusions which have important implications in field and laboratory practice: (1) Each successive application of the same pressure to the soil results in less and less work done per application. (2) Each successive application of pressure results in less compaction per unit of work. (3) For a given amount of work, the greatest compaction results when the work is exerted in a single application.

APPLICATIONS TO FIELD AND LABORATORY COMPACTION

When the action of modern compaction equipment is evaluated with respect to the above conclusions, some devices are seen to be inefficient. The sheepsfoot roller, for example, requires theoretically from 10 to 15 passes to secure complete coverage of an area. Actually with random rolling many parts of an area are rolled two or three times and other parts not at all. A roller designed with more and larger feet would produce less overlapping and better compaction for the amount of work done. The same applies to rubber-tired rollers. For greatest efficiency these should have tire spacings and arrangements so that all parts of the surface can be covered just once without appreciable overlap.

Specifications should be written to require just one complete surface coverage. If sufficient density is not obtained in a single coverage (and the soil moisture is correct) the equipment is inadequate, and additional rolling with the same equipment would be largely a waste of time and money. This is particularly important when the owner must pay for all passes of the roller above a certain minimum.

The difference between the moisture-density curves developed in the laboratory by the customary 25 blows of a hammer on layers of soil in a 4-inch-diameter mold and moisture-density curves developed by rolling can be easily explained by these studies. In the laboratory test the large number of blows results in an average of six applications of pressure to the soil. In contrast, even 10 passes of a sheepsfoot roller (a large number) may not even produce one complete coverage of the surface. Furthermore the constant pressure exerted by the sheepsfoot roller means a decreasing amount of work for each pass of the roller while the laboratory compaction hammer exerts an equal amount of energy each time. The remedy would be to use a much heavier hammer for laboratory compaction and fewer blows, say six per layer. On this basis the author believes that a laboratory compaction test can be developed which will retain the simplicity of the present standard Proctor and yet be similar in its results to field experience.

References

1. Corps of Engineers, "Soil Compaction Investigations, Reports 1-4, "Technical Memo 3-271, U. S. Waterways Experiment Station, 1949.
2. F. H. P. Williams and D. J. McLean, "The Compaction Soil," Road Research Technical Paper No. 17, Department of Scientific and Industrial Research, Road Research Laboratory, London, 1950.
3. C. M. Kennedy, A Laboratory Investigation of the Efficiency of Different Methods of Soil Compaction, M. S. Thesis, School of Civil Engineering, Georgia Institute of Technology, 1953.