TEMPERATURE EFFECT ON IRREGULARLY SHAPED COMPACTION CURVES OF SOILS

Peter Y. Lee and D. C. Hsu, Department of Civil Engineering,
South Dakota State University

ABRIDGMENT

•THIS investigation is the third stage of a series of investigations to examine the characteristics of irregularly shaped compaction curves. Because the change of temperature is an important factor in influencing the engineering properties of soil and prior research on temperature effect only examined the single-peak compaction curve, this paper attempts to investigate carefully the effect of temperature on the irregularly shaped compaction curve. Some investigations concerning the characteristics of irregular compaction curves were performed by Lee and Suedkamp (1). After investigating 34 different soils with the standard AASHO compaction test, they found that on the modified Casagrande's classification scheme there are 2 approximate regions that show irregularly shaped compaction curves. The soils with liquid limits greater than 70 and less than 30 usually create irregularly shaped compaction curves. On the other hand, the soils with liquid limits between 30 and 70 produce single-peak curves. Lee and Suedkamp also indicated that 4 types of curves exist: a typical single-peak compaction curve, a $1\frac{1}{2}$-peak curve, a double-peak curve, and an oddly shaped curve.

The importance of temperature on the compaction curves has so far been given little consideration. Johnson and Sallberg (2) found, primarily from a search of the literature, that increasing the temperature leads to an increase of the maximum dry density of the single-peak curve. They explained that the water in the soil is more viscous at the lower temperature, reducing the workability of the soil and inducing a lower dry density. Some investigations that were not involved in the compaction tests have shown the temperature effect on some soil properties (3, 4, 5, 6, 7, 8). Sherif and Burrous (3) concluded that an increase in the temperature causes a decrease in the shearing strength of the soil. That conclusion is in agreement with most other investigations, although not all indicate exactly the same results.

LABORATORY INVESTIGATION

Preparation of Soil

A description of the selected samples is given in Table 1. The samples represented a wide range of engineering characteristics as well as compaction curves of soils. In addition to the combinations of known minerals, some natural soils were chosen to be examined.

Each time the soils were air-dried and pulverized to pass a No. 4 sieve, they were mixed with water in increments of 2 or 3 percent. Every sample was put into a leakproof plastic bag. A batch of samples was sealed in a big plastic bag and stored in a moisture control room for at least 24 hours.

Apparatus and Test Methods

The specimens were tested at 40, 80, and 120 F with ±5 F deviation. To control the temperature, a thermal-insulated chamber was built with plywood and insulation to surround the standard compactor (Fig. 1). A deep freezer was connected to the right side of the insulated chamber to hold the cool air at 40 F. The higher temperatures were provided by a heater with a thermostat that ranged from 70 to 140 F.

The samples, which had been stored in the moisture control room, were deposited in the chamber under the desired temperature for more than 12 hours before testing.

Standard AASHO Designation T 99-70 Method A (also indicated as ASTM Designation D 698-70 Method A) was the primary method applied in this research.

RESULTS AND ANALYSIS

Lower Water Content

At the lower water content, the temperature seems to have no significant influence on the compaction curves, and data of various temperatures show no consistent relation. There are some reasons that can explain this pehnomenon.

The increase in dry density of the compaction curve due to increasing temperature is attributed to the increase in pore pressure. However, the pore pressure essentially has a negligible effect on the 1½-peak compaction curve of pure sand (soil 1, Fig. 2). Therefore, the compaction curve of pure sand is only negligibly affected by temperature. For the double-peak curve in the lower region (liquid limit <30), despite the fact that the pore pressure is an important factor in the shaping of the compaction curve (1), some other factors are involved causing the random results with water content from 0 to 7 percent (soil 2, Fig. 3). Also, for 1 natural soil (soil 8, liquid limit = 30, plasticity index = 25), the increase of temperature had no significant influence on the water content between 0 and 7.5 percent (Fig. 2). It must be pointed out here that other laboratory variables play a more dominant role than temperature, particularly for the more sensitive fine-grained soil containing a small amount of water. Thus, the results reflect the effect of the uncertainty due to laboratory variables rather than to the effect of temperature. For instance, when the compaction ram dropped onto the fine-grained soil with lower water content, the force of the compaction ram expelled the fine soil particles out of the mold as dust; thus, the accuracy was reduced. Even though these factors influence the data accuracy, they do not significantly change the shape of the compaction curve. Results show that those samples (liquid limit >70, Fig. 4), whose water content ranges from 0 to about 15 percent, behave as randomly as the samples selected from the lower region (liquid limit <30). It is known that the highly cohesive soils are very difficult to mix evenly with water, especially at the lower water content. Because water plays an important part in the compaction process, the uneven distribution of water, in addition to the variable factors discussed above, will also affect the oddly shaped compaction curves. Therefore, the resulting data are quite scattered.

Higher Water Content

When more water is added, the temperature starts to reveal some effects on the compaction curves, although the effect is not clearly apparent on the 1½-peak curve of pure sand (Fig. 2). For soils with a liquid limit <30 and water content from about 7 percent to optimum point (soil 8, Fig. 2 and soil 2, Fig. 3) and soils with liquid limit >70 and water content from about 15 percent to saturation point (Fig. 4), the increasing temperature tends to increase the dry density. An increase in temperature decreases the viscosity of water and expands the electric double layers of soil particles, thereby producing a greater dry density. Essentially, one of the predominant factors is that the increasing temperature reduces the rigid state of water that surrounds the individual soil particles, increasing the pore pressure. Increasing pore pressure is associated with decreasing effective shear strength, which allows the soil particles to slide closely to each other and results in a higher dry density. Some of those highly cohesive clays in the portion of higher water content, for instance, soil 4, still show some scattered data, and others, e.g., soil 5 (Fig. 5), show some well-distributed data. The reason is that pore pressure is only a part of the influence on the shape of oddly shaped compaction curves, and the most logical explanation would be to consider the physicochemical characteristics of the minerals present (1). The temperature effect on the wet side of the compaction curve decreases for all soils.

Table 1. Selected soil samples.

Sample	Sand[a] (percent)	Montmorillonite[b] (percent)	Illinite[c] (percent)	Kaolinite[d] (percent)	Liquid Limit	Plasticity Index
1	100	0	0	0	0	NP
2	75	0	0	25	13	NP
3	0	0	100	0	51	21
4	50	50	0	0	230	198
5	25	50	25	0	172	142
6	0	50	50	0	170	129
7	0	25	50	25	105	73
8[e]					30	25
9[e]					72	32

[a]Pure sand obtained locally.
[b]Bentonite obtained from Baroid Div. of Nat. Lead Co., Houston.
[c]Grundite obtained from Green Refractionery Co., Morris, Illinois.
[d]Clay Hydrite-121 obtained from Thompson-Hayward Chemical Co., Kansas City, Kansas.
[e]Natural soil.

Figure 1. Test setup.

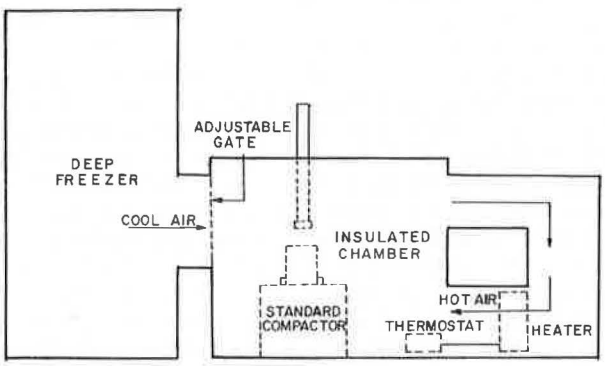


Figure 2. 1½-peak curve showing effects of temperature.

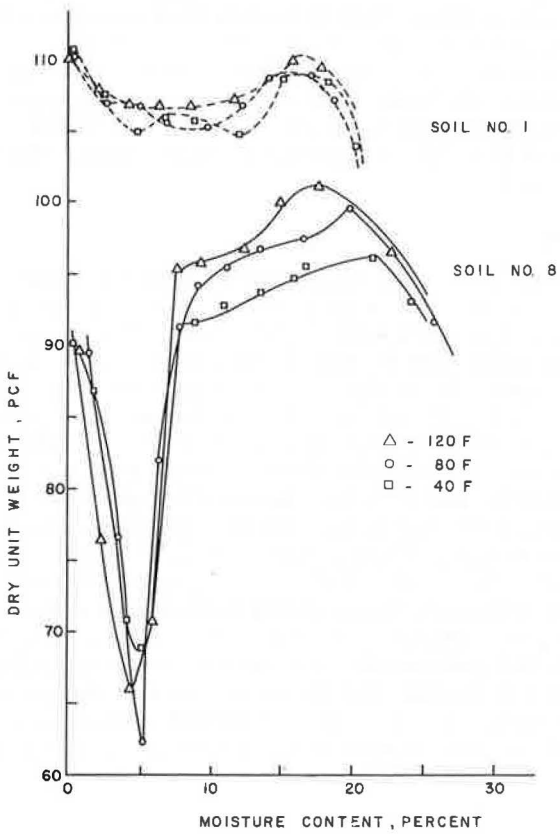


Figure 3. Double-peak curve showing effects of temperature.

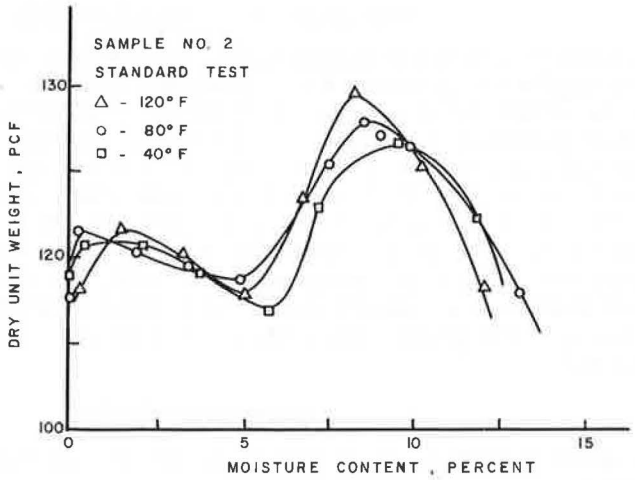


Figure 4. Oddly shaped curve showing effects of temperature on soils 4 and 6.

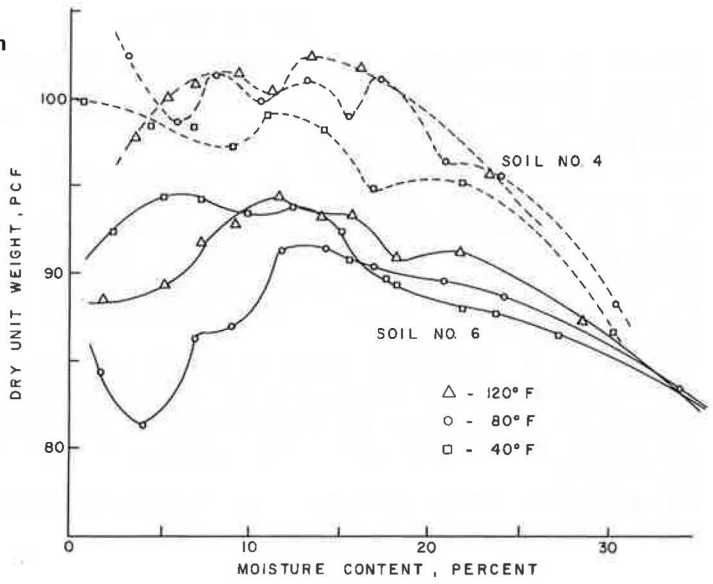
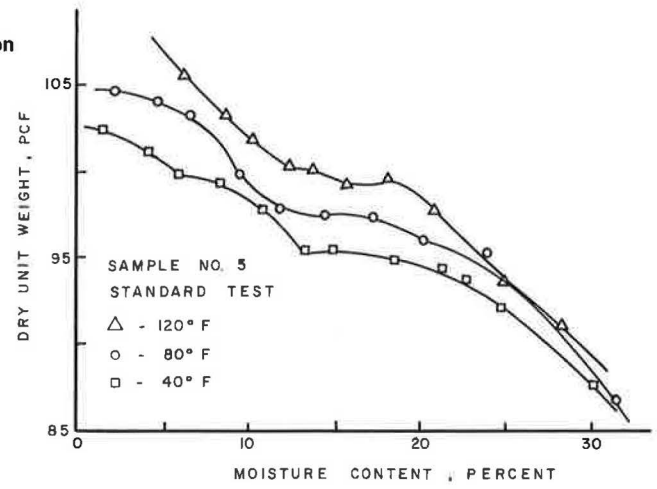


Figure 5. Oddly shaped curve showing effects of temperature on soil 5.



SUMMARY AND CONCLUSIONS

On the basis of a series of temperature-controlled experimental tests, several conclusions can be established. The investigated variation in temperature produces no significant influence for all the soils at the lower water content. The range of water content showing negligible temperature effects is from 0 to 7 percent for soils with a liquid limit <30 and from 0 to about 15 percent for soils with a liquid limit >70. Temperature has a negligible effect on the 1½-peak compaction curve of sandy soil that has an extremely low liquid limit. For soils with a liquid limit <30 and a water content from about 7 percent to the optimum point and soils with a liquid limit >70 and a water content from about 15 percent to the saturation point, the increasing temperature results in an increase of dry density because the higher temperature is associated with lower strength. This phenomenon tends to decrease after the saturation moisture content is reached.

ACKNOWLEDGMENTS

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