Portage Mountain Dam, II, by G.C. Morgan and M.L. Harris. Canadian Geotechnical Journal, Vol. 4, No. 2, May 1967, pp. 175-178.
8. T.G. Williamson. Embankment Compaction Variability—Control Techniques and Statistical Implications. HRB, Highway Research Record 290, 1969, pp. 9-22.
9. O.G. Ingles. Statistical Control in Pavement Design. Proc., 1st International Conference on Applications of Statistics and Probability to Soil and Structural Engineering, Hong Kong Univ. Press, 1972.
10. M.M. Johnson. Laboratory Compaction Tests Using Compacted Fine Grained Soils. Proc., 7th International Conference on Soil Mechanics and Foundation Engineering, Mexico, Vol. 1, 1969, pp. 197-202.
11. J.A. Hooper and F.G. Butler. Some Numerical Results Concerning the Shear Strength of London Clay. Geotechnique, Vol. 16, No. 4, 1966, pp. 282-304.
12. P. Lumb. The Variability of Natural Soils. Canadian Geotechnical Journal, Vol. 3, No. 2, May 1966, pp. 74-97.
13. R.K. Morse. The Importance of Proper Soil Units for Statistical Analysis. Proc., 1st International Conference on Applications of Statistics and Probability to Soil and Structural Engineering, Hong Kong Univ. Press, 1972, pp. 347-357.
14. R.J. Hodek. Mechanism for the Compaction and Response of Kaolinite. Purdue Univ., West Lafayette, IN, PhD thesis, Dec. 1972.
15. W.R. Hudson. State-of-the-Art in Predicting Pavement Reliability From Input Variability. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, Contract Rept. S-75-7, Aug. 1975.

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Base-Course Gravel-Compaction Control by the Comprimeter

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A new device called the comprimeter developed to measure in situ density of granular materials has been proved to effectively monitor the compactness of a typical gravel used as road base course. Its operation is quick and efficient, and it directly determines relative compactness at the test location.

Measurement and control of compaction of soil materials are very often an essential aspect of construction. The popular compaction-measuring methods that employ the drive cylinder, sand cone, and balloon tests have the inherent drawback of requiring a separate moisture determination and reference to previously determined Proctor density tests. The nuclear densiometer is very efficient and rapid, but the device is rather expensive to obtain and operate, and results also must be referenced to independent Proctor tests on comparable soils.

A new device called the comprimeter, developed by the Norwegian Geotechnical Institute in cooperation with A. Eggestad, Chief Engineer of the Geotechnical Division of the Municipality of Oslo, promises to allow quick and reasonably accurate monitoring of the state of field compaction of moist, cohesionless materials. Relative compaction is determined directly, without reference to companion Proctor tests. In the calibration of the instrument, extensive testing was done on sands, with a general size range of 0.06-2 mm. One grain-size distribution included 35 percent gravel in the 3-10 mm range.

Eggestad also mentioned some tests done on crushed stone with a gradation of 0-30 mm. Noting this, a series of tests was conducted on Michigan Department of State Highways (MDSH) 22-A gravel, which was typical of well-graded road base course, to determine the suitability of the comprimeter for monitoring the state of compaction under normal field construction circumstances.

THE COMPRIMETER

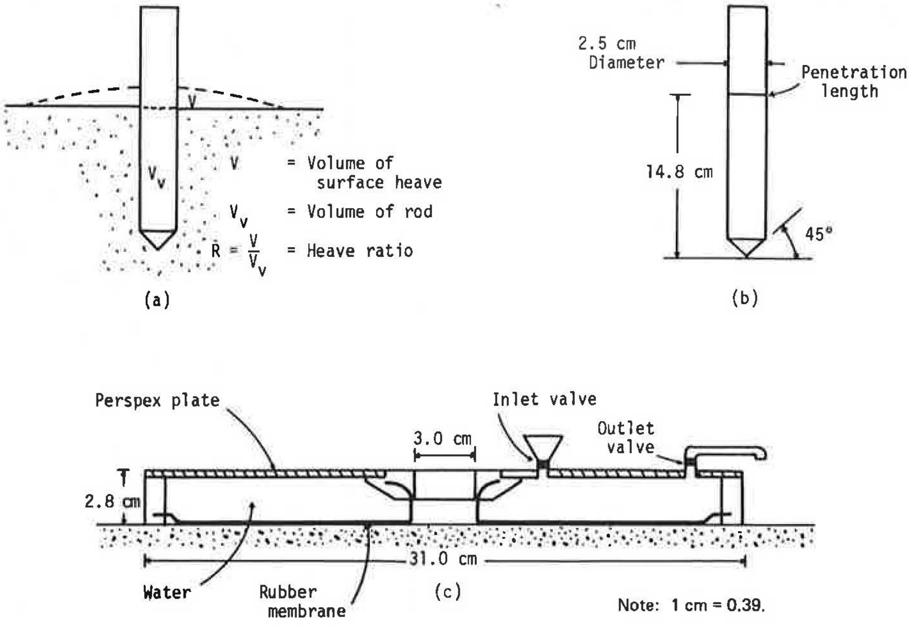
A complete description of the comprimeter is given by Eggestad elsewhere (1) and will not be reiterated here. The device and its principle of operation are diagramed in Figure 1. The operating principle is based on the fact that the denser a granular soil, the more it will dilate when subjected to large shear strains. With the comprimeter, the shear strains are produced by a rod of known volume that is driven into the material. The volume of heave is measured by the volume of water expelled from a water-filled membrane that covers the surface around the point where the rod is driven. This heave volume is empirically related to the degree of compactness by means of a series of controlled density tests. The instrument can be calibrated for both the standard and the modified Proctor compaction tests.

TESTING PROGRAM

Materials tested are representative of road base-course gravel and meet the requirements of Michigan Department of State Highways (MDSH 22-A). Gradations are shown on Figure 2 for field, ideal, and gap-graded distributions. Each contained a minimum of 25 percent of crushed material and consisted of natural glacial gravels obtained from a local commercial pit.

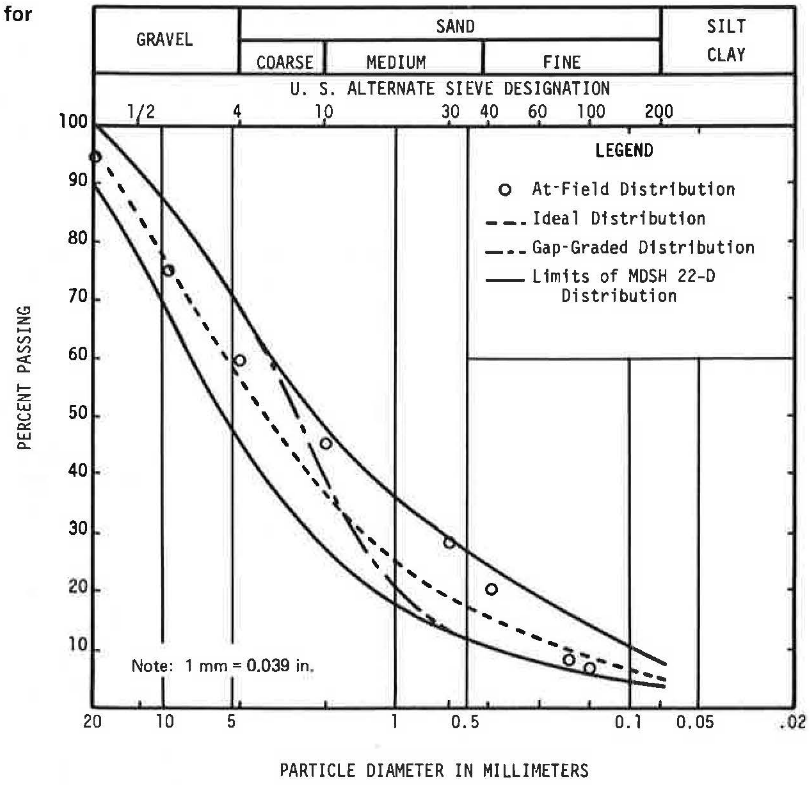
Standard and modified Proctor tests (AASHTO T99 and T180, respectively) were determined for each of the three particle distributions; results are summarized in Table 1. Maximum densities by the modified Proctor test range from 2256 to 2288 kg/m^3 (141 to 143 lb/ft^3), which are consistent with the well-graded character of the gravel.

Figure 1. The comprimeter: (a) principle of operation, (b) penetrating rod, (c) diagramatic cross section.



Note: 1 cm = 0.39.

Figure 2. Particle size distribution for MDSH 22-A gravel.



Note: 1 mm = 0.039 in.

Table 1. Results of Proctor compaction tests on MDSH 22-A gravel.

Test Location	Particle Size Distribution	Maximum Density (kg/m³)		Optimum Water Content (%)	
		Standard	Modified	Standard	Modified
Laboratory	At-field	2224	2264	7.4	6.9
Laboratory	Ideal	2232	2298	7.5	6.1
Laboratory	Gap-graded	2197	2261	8.8	7.2
Field	At-field	-	2269	-	9

Note: 1 kg/m³ = 0.06 lb/ft³.

Table 2. Effect of water content on heave volume.

	In Situ Condition		After Soaking	
Field Density (modified Proctor) (%)	Displaced Volume (cm³)	Water Content (%)	Displaced Volume (cm³)	Water Content (oven-dried) (%)
96.6	138	4.3	96	6.8
95.5	144	4.5	79	6.4

Note: 1 cm³ = 0.06 in³.

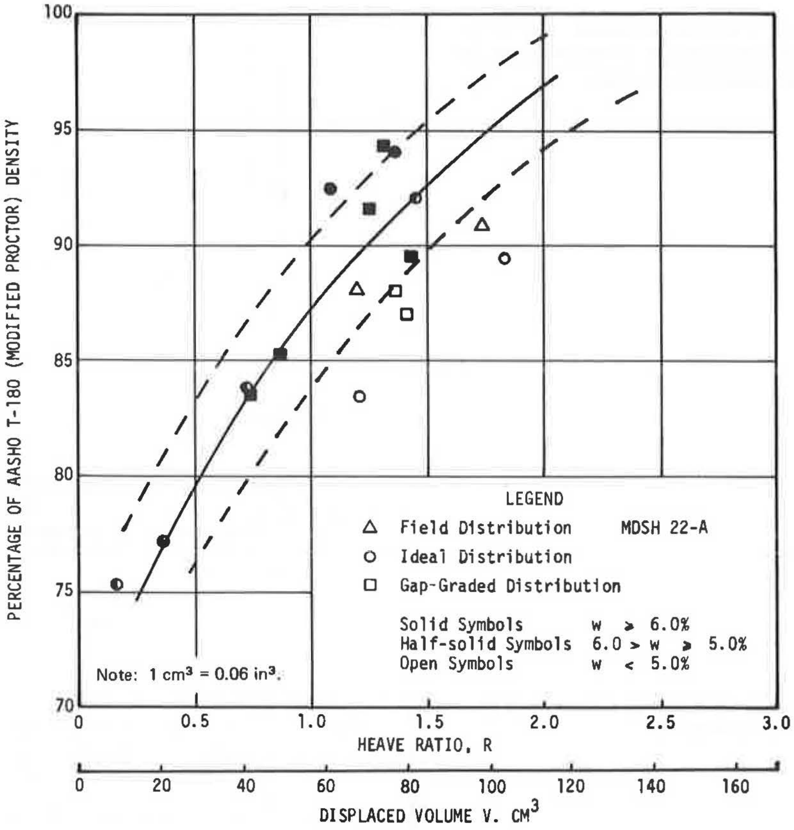


Figure 3. Results of laboratory tests on MDSH 22-A gravel.

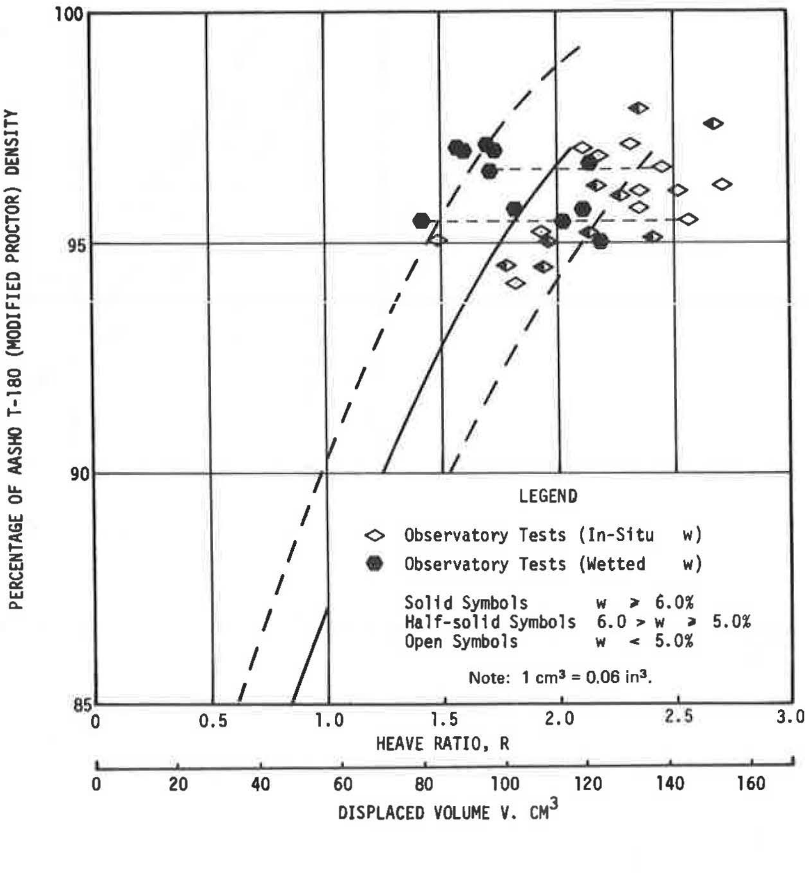


Figure 4. Results of field tests on MDSH 22-A gravel.

The gravels, in turn, were compacted to various densities and water contents in a container 41 cm (16 in) in diameter and 24 cm (9.5 in) deep.

The energy per unit volume for Proctor tests was maintained by using standard Proctor hammers and by adjusting the number of blows per layer. Comprimeter tests were performed on the leveled surface after compaction was completed. The measured volume of heave observed was plotted against the density of the test sample, expressed as a percentage of the related standard or modified Proctor density. In Figure 3 the density of the test sample was expressed as a percentage of the modified Proctor density.

A second series of tests was conducted in the field on the compacted roadbed material during the reconstruction of Observatory Avenue in Ann Arbor, Michigan. MDSH 22-A gravel was compacted in three lifts to a total depth of 36 cm (14 in) by means of a (Raygo 400) vibrating roller. Modified Proctor compaction test results for this material are given in Table 1. Comprimeter and nuclear densiometer tests were run concurrently at points on the roadbed surface no more than 46 cm (18 in) apart. The object was to correlate the results from each device.

The nuclear densiometer determined dry density and water content of the material. The water contents of some samples taken from the site were determined by oven drying. In other cases the water contents of the gravel were increased by pouring water over the surface before the comprimeter test was run but after the test by the nuclear densiometer. The results of these tests are presented in Table 2. In Figure 4 the nuclear densiometer density results are plotted against the heave determined by the comprimeter.

DISCUSSION OF RESULTS

In Figures 3 and 4 the heave ratio R is defined as the volume of heave divided by the volume of that portion of the rod that is inserted in the soil below the original surface level; i.e., $R = V/V_r$. The relationship of heave ratio to displaced volume is shown in this figure by the use of two abscissa scales. On these figures are plotted the calibration curves (solid lines) derived by Eggestad for the sands he tested. These curves apply to sands with water contents ranging from 4 to 12 percent. The envelopes (dashed lines) shown represent more than 85 percent of the results from tests in sands.

The tests in MDSH 22-A gravel were conducted at water contents varying from 3.5 to about 8.5 percent, for which the results indicate a general decrease in heave ratio. This is consistent with the findings of the designer who found that in the dry and saturated states a particulate material has a "loose fabric" in which particles are free to move to their most stable states. In a moist state, however, surface tension in the water induces an apparent cohesion between soil particles, which results in more bulking.

In two instances during the field tests, two tests were run at adjacent points. The first was conducted on the material as it existed, and the second was run after 2 L (0.5 gal) of water were poured over the surface. The difference in the resultant heave ratio is shown where test points are connected by a horizontal dashed line in Figure 4. The data are also presented in Table 2. The increase in water content to about 8.5 percent (the apparent maximum with normal drainage for this material) caused a reduction in heave that put the test point within or reasonably close to the calibrated range of the instrument.

APPLICATION

The practical significance of these results is that the comprimeter may be used as a quick, safe, and reliable monitor of the state of compaction of MDSH 22-A gravel and similar materials. In field applications, the density and water content are unknowns.

Assuming that a comprimeter test on this compacted material produces a heave ratio of 1.5 (86 cm^3 displaced in volume), then, if the water content is between 3 and 4 percent, the modified Proctor may range from 85 to 90 percent (Figure 4); but, if the water content is 6 percent or more, the modified Proctor is likely to be in the range of 90 to 95 percent. To eliminate doubt regarding the density range, the material can be moistened just before the test is run. The effect will be an increase in water content of at least 6 percent. This action provides control over the nature of heave during a test. The simplicity of the test facilitates repetition for statistical purposes. In contrast to other density tests, no water content determination is necessary when the comprimeter is used as described above. Testing time is short compared to most other tests and, with operating experience, is equivalent to the testing time for the nuclear densiometer.

A rule of thumb that may be useful in using the comprimeter for monitoring the density of MDSH 22-A gravel is that a heave ratio of 1.5 or more in the very moist state will assure compaction of 95 percent modified Proctor. The actual heave will depend in part on the actual water content as the results indicate. In the very moist state—i.e., around 8 percent water content—the lubricating effect of the excess moisture produces the least heave in the material, and a heave ratio around 1.5. This, then, should be the minimum value when a test is run on this gravel after the surface has been moistened with about a liter of water.

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REFERENCE

1. A. Eggestad. A New Method for Compaction Control of Sand. Geotechnique, Vol. 24, No. 2, June 1974, pp. 141-153.

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