Compaction of Coarse-Grained Granular Materials

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This paper presents laboratory data which indicate that for the two materials studied (a crushed limestone and a natural gravel) the method of controlling the compaction of granular materials as described by Humphres (HRB Bull. 159) is realistic and valid.

Laboratory compaction tests performed in 6-in. diameter molds employing a free-falling compaction hammer and granular materials with varying percentages of ± 4 materials present, indicate that the Humphres control curves represent a single level of compactive effort for some soils and for these materials a quick method of obtaining compaction control data is possible. For materials which do not fall into this category, the Humphres curves appear to be conservative in that points on the gradation-density chart obtained by laboratory compaction procedures either coincide with the Humphres curve or result in densities which are less than the Humphres curve values.

• ENGINEERS HAVE used the methods and principles enunciated by Proctor (*1*) for controlling the compaction of earthen materials since 1933. These methods and procedures normally employ, in the laboratory, only that portion of the soil sample which passes the No. 4 sieve (—4 material). When the resulting laboratory compaction curves are used in the field, where material larger than the No. 4 sieve is present, difficulties often arise.

Some engineers hold the opinion that the larger particles (+4 materials), present in the field-compacted material, are essentially inert and affect the density in compaction of the binder material (—4 material) to only a small degree. Field densities are, therefore, often obtained on only the —4 material. This is done by returning all coarse particles to the test hole prior to filling the hole with a calibrated material or the volume and weight of the +4 material are determined by other means and deducted from the total volume and weight of the sample.

Studies reported by the Road Research Laboratory in England (*2*), for example, have shown that it is often incorrect to assume that the +4 fraction acts as an inert material and that it does not affect the compacted properties of the binder soil. These same studies have shown that the presence of even small percentages of the coarse material affects the density of the binder material and that the effect becomes more pronounced as the percent of coarse materials becomes greater and greater.

To highway engineers, charged with the responsibility of controlling the compaction of coarse grained base course materials, this problem has often been a difficult one. Various laboratory schemes have been devised to surmount the difficulty. One method makes use of large diameter laboratory molds in which the entire sample, including material as large as the ¾-in. size and even larger is used. Another method suggested by the ASTM (*3*), makes use of a semi-rational formula to obtain the density of the composite field sample. This formula when applied to materials with more than 30 to 40 percent of the +4 fraction present, often leads to serious problems during construction.

Recently, a semi-theoretical method of preparing gradation - density curves was proposed by Humphres (*4*). This method employs the specific gravities and compacted and loose densities of both the —4 material and +4 material. With this laboratory information available, eight curves are plotted on the graduation-density chart and become the bases for constructing a control curve for a given soil. An example of these eight curves, A, B, C, D, E, F and G, is shown in Figure 1. Block diagrams are shown in Figure 2 to explain the state of compaction of both the —4 and +4 fractions required to produce each of the eight curves in a composite sample.

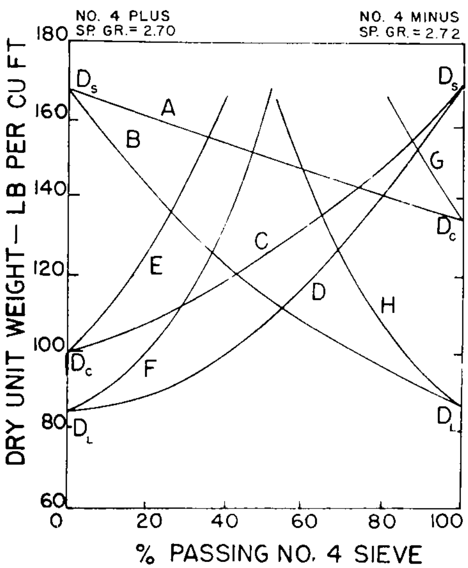

Figure 1. Theoretical density gradation curves.

To check the validity of this procedure in the laboratory, the following experimental program was conducted. Two materials, a crushed limestone and a natural gravel, were chosen for study. Both materials were obtained from quarries or pits which supply aggregates for highway purposes. The necessary laboratory tests were performed on these two materials to establish the Humphres' curves which are shown in Figures 3 and 4. Specific gravity and density data for these two materials are given in Table 1, gradation data in Table 2.

TABLE 1
SPECIFIC GRAVITY AND DENSITY

Determination	Crushed Limestone		Natural Gravel	
	+4	—4	+4	—4
Sp. gr. of solids	2.70	2.72	2.67	2.70
Comp. density (lb/cu ft)	100.0	133.0	108.3	119.5
Loose density (lb/cu ft)	85.0	87.0	90.6	79.5

TABLE 2
GRADATION OF EXPERIMENTAL MATERIALS

Sieve Size	Percent Passing	
	Crushed Limestone	Natural Gravel
1 in.	100	100
¾ in.	100	99.5
½ in.	—	96
⅜ in.	66.5	94
No. 4	40	88
No. 10	20	73
No. 40	10	26
No. 100	—	11
No. 140	—	9.5
No. 200	6	8.6

With the Humphres control curves established for these two materials, the —4 fractions of each material were compacted at optimum moisture content in a 6-in. diameter mold using a falling hammer and sufficient blows to produce the same density as

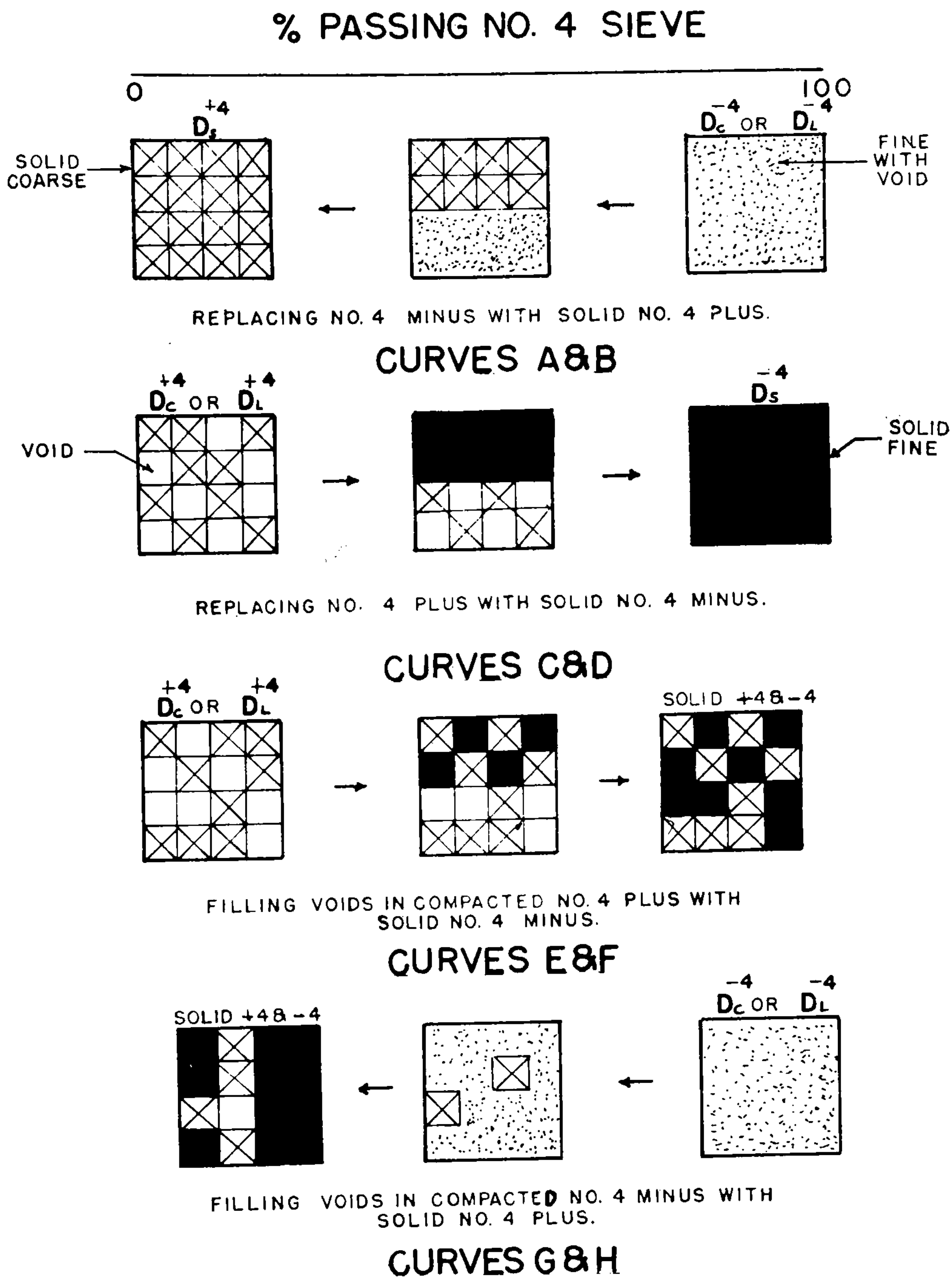

Figure 2. Block diagrams showing bases for theoretical curves.

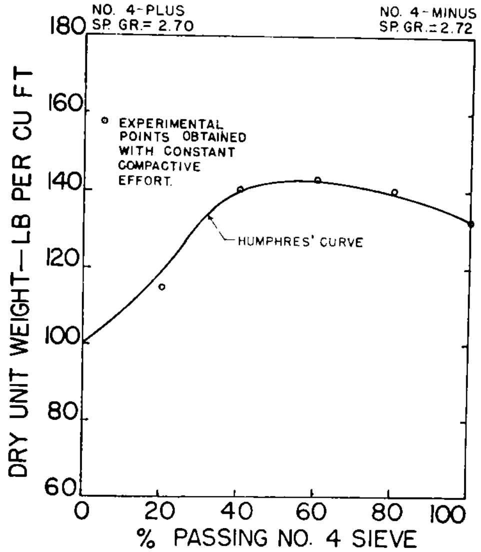

Figure 3. Gradation-density curve for crushed limestone.

that obtained with standard procedures in the 4-in. diameter compaction mold (D_c of the -4 material). This level of compactive effort was then used to obtain the maximum density of each material for several percentage combinations of the -4 and $+4$ fractions in a 6-in. diameter mold. These maximum densities for the crushed limestone are shown as plotted points in Figure 3. These plotted points follow very closely the Humphres curves and indicate that the Humphres' density-gradation curve represents a single level of compactive effort throughout a full range of gradations for this material.

The results of similar tests on the natural gravel, in which an improved hammer was used, are shown in Figure 4. For this material, the Humphres curve does not represent a single level of compactive effort, since the plotted points do not always lie on this curve. Nevertheless, where differences between the Humphres curve and experimentally determined densities occur, the latter are always less than the former. This indicates that the Humphres curve is conservative in this case.

As a result of these studies, it appears that the Humphres' method of controlling the compaction of granular materials for most purposes is valid and reasonable. For some materials, the Humphres density-gradation curves represent a single level of compactive effort. For other materials, this may not be true; nevertheless, the Humphres' method appears to be conservative, even for these materials.

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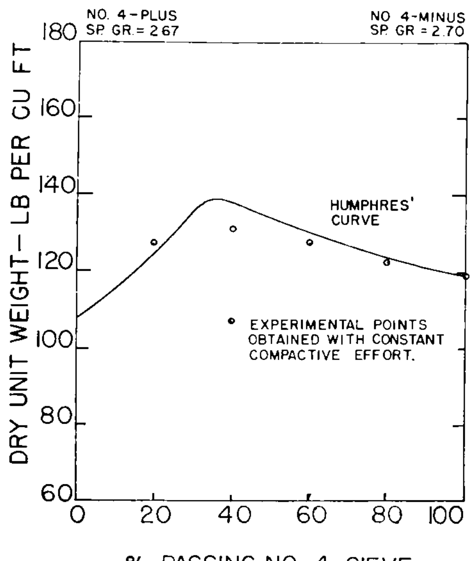

Figure 4. Gradation-density curve for natural gravel.

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