Compaction Characteristics of Some Base and Subbase Materials

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Laboratory compaction tests using a vibrating table and field compaction experiments furnished data for a study of the compaction characteristics of base and subbase materials. Unit weights were compared to those produced by standard methods. Results indicate that laboratory vibration produces densities comparable to maximum field densities, that usual methods of correcting density for the presence of oversize particles are of limited applicability, and that density specifications should be based on the requirement that actual tests performed with apparatus yield results equivalent to those obtained in the field.

•RECENT developments in materials testing and research have indicated that some existing methods of specifying and measuring the unit weights of highway components are obsolete. For this reason, the Virginia Council of Highway Investigation and Research initiated studies of field and laboratory compaction of base, subbase, and surface course materials.

Virginia's present procedure is to require that base or subbase materials in the field be compacted to a given percentage of the standard laboratory density corrected for oversize particles. The correction formula used is given in the Appendix. It is desired to develop a laboratory method which can predict practicably attainable maximum densities.

Other States use the relative density method (1), the compaction ratio (2), or other methods.

All methods require the determination of the maximum laboratory density, and several tests have been developed for determining this density. A cooperative study by Felt (3) indicated that vibratory compaction of coarse material was most efficient. Accordingly, a vibratory compaction table, as described by Pauls and Goode (4), was constructed and used as the maximum density test apparatus by the Research Council's Soils Laboratory.

This paper concerns the compaction studies to date by the Soils Lab. These studies had four original objectives: (a) to determine the effects of water content and gradation on the density of certain granular cohesionless materials, (b) to compare the compaction characteristics of different types of aggregates, (c) to correlate the results of dynamic and vibratory compaction tests, and (d) to investigate the efficiency of several methods of correcting density for the presence of oversize particles.

For these studies, samples of 21 representative base and subbase materials were secured from Virginia's eight construction districts. The materials represent crushed and natural aggregates with a wide range of angularity, gradation, and surface texture (descriptions of these are given in Table 1). Three of the materials (60-8, 60-65, and 60-98) were from field compaction test sections.

LABORATORY TESTS

The samples of base and subbase material were compacted at five levels of gradation, four levels of water content, and with three replications, for a total of 60 tests on each material having a plus No. 4 fraction. The top size tested was ¾ in. The vibratory compaction test (4) involves vibrating an 800-g sample for at least 20 min

TABLE 1

GRADATIONS AND DESCRIPTIONS OF MATERIALS TESTED

Soil No.	Percent Passing Sieve No.							Description		
	$^3/_8$	4	10	20	40	100	200	Color	Soil Type	District
59-17	72	48	41	35	28	20	16	Pale brown	Subangular creek gravel	Salem
59-18	76	52	32	22	18	14	12	Light gray	Angular dolomite	Salem
59-19	51	37	32	27	18	9	7	Pale brown	Subangular sandstone	Bristol
59-20	59	49	33	18	13	8	7	Light gray	Angular limestone	Bristol
59-22	87	76	64	47	30	17	14	Reddish brown	Subangular gravel	Fredericksburg
59-24	64	48	37	31	25	12	7	Light gray	Angular granite	Richmond
59-25	59	37	31	26	20	6	4	Reddish yellow	Subrounded gravel	Culpeper
59-26	66	48	30	22	16	10	8	Very pale brown	Angular granite	Richmond
59-27	86	73	66	48	26	9	7	Pale yellow	Subrounded crushed stone	Richmond
59-28	80	54	33	19	15	11	10	Light gray	Angular limestone	Staunton
59-29	89	57	42	30	21	14	10	Light gray	Angular granite	Suffolk
59-30	-	-	-	100	99	21	2	Light yellowish brown	Subrounded sand	Suffolk
59-31	55	39	30	23	19	13	10	Light gray	Angular marble	Lynchburg
59-32	-	100	89	77	50	24	14	Light yellowish brown	Angular disintegrated quartz diorite	Lynchburg
59-33	80	62	50	34	20	9	4	Light yellowish brown	Subangular gravel	Richmond
60-08	100	97	94	78	46	11	2	Light yellowish brown	Subangular sandy clay	Fredericksburg
60-65	86	69	36	20	13	7	5	Light gray	Angular limestone	Culpeper
60-98	78	66	44	29	21	9	6	Light gray	Angular shalestone	Culpeper
60-117	64	46	29	20	12	9	7	Light greenish gray	Angular greenstone	Culpeper
60-120	43	36	35	34	31	14	9	Reddish brown	Subrounded gravel	Staunton
60-121	-	-	100	93	51	1	0	Light brownish gray	Subrounded sand	Suffolk

with a vertical amplitude of 0.012 in. and a frequency of 3,420 cpm with a surcharge of 1.75 psi.

Gradations included 0, 33, 67, and 100 percent plus No. 4, as well as the percent as received. Water contents ranged from comparatively dry to rather wet; water contents at the end of test are reported because water sometimes ran out during the test.

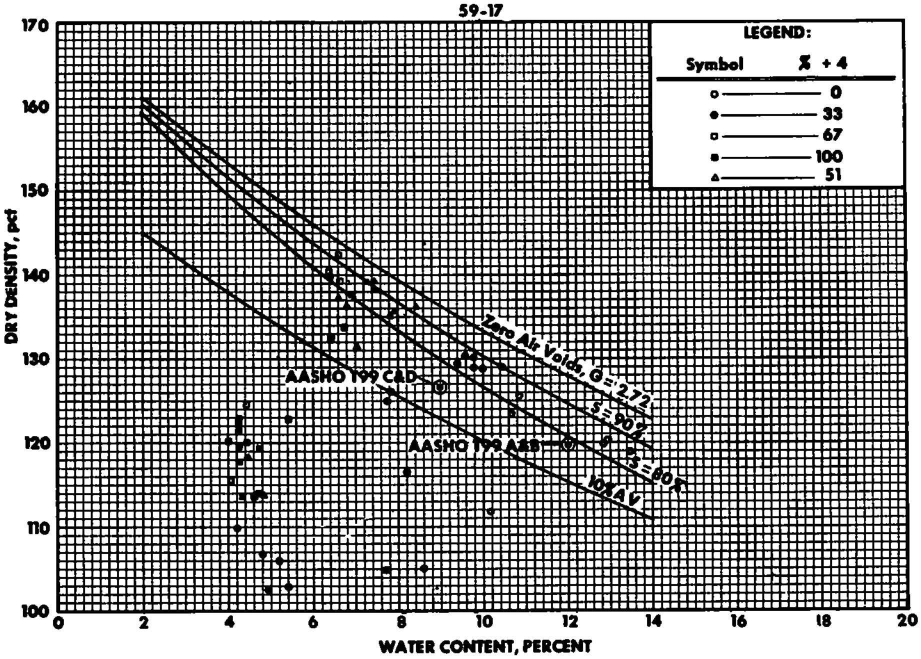

Figure 1. Laboratory test results, sample 59-17.

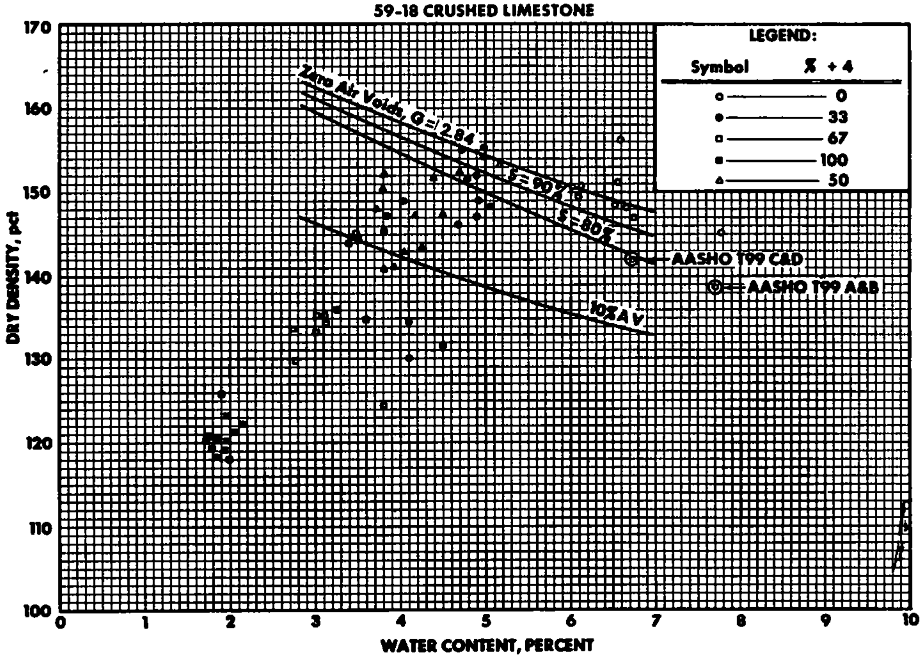

Figure 2. Laboratory test results, sample 59-18.

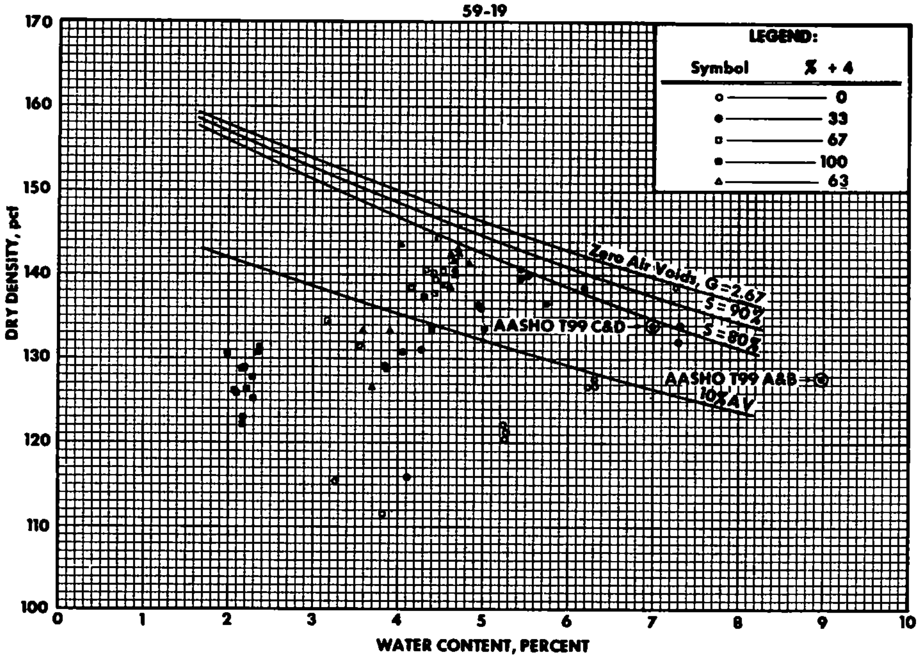

Figure 3. Laboratory test results, sample 59-19.

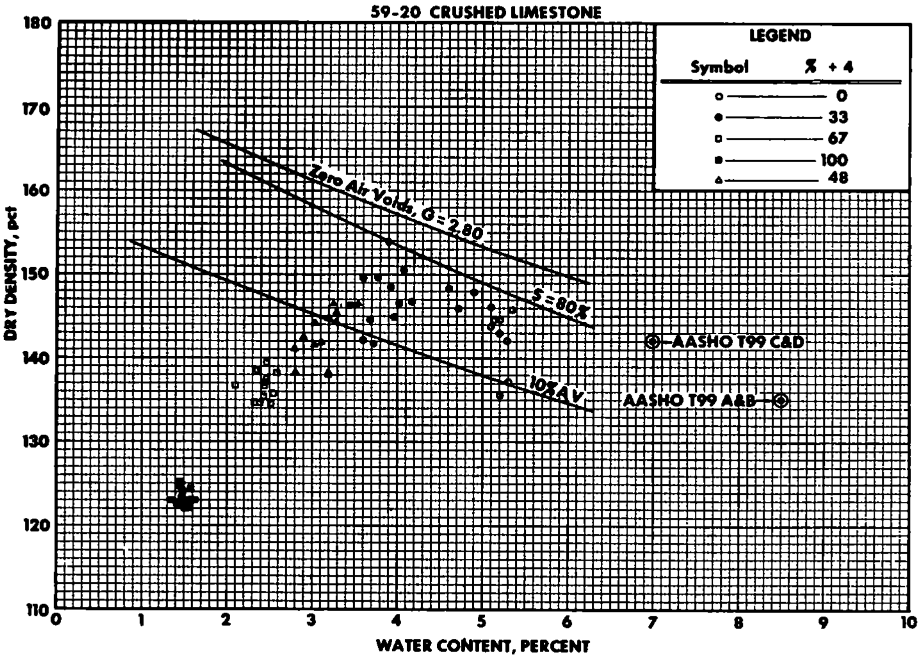

Figure 4. Laboratory test results, sample 59-20.

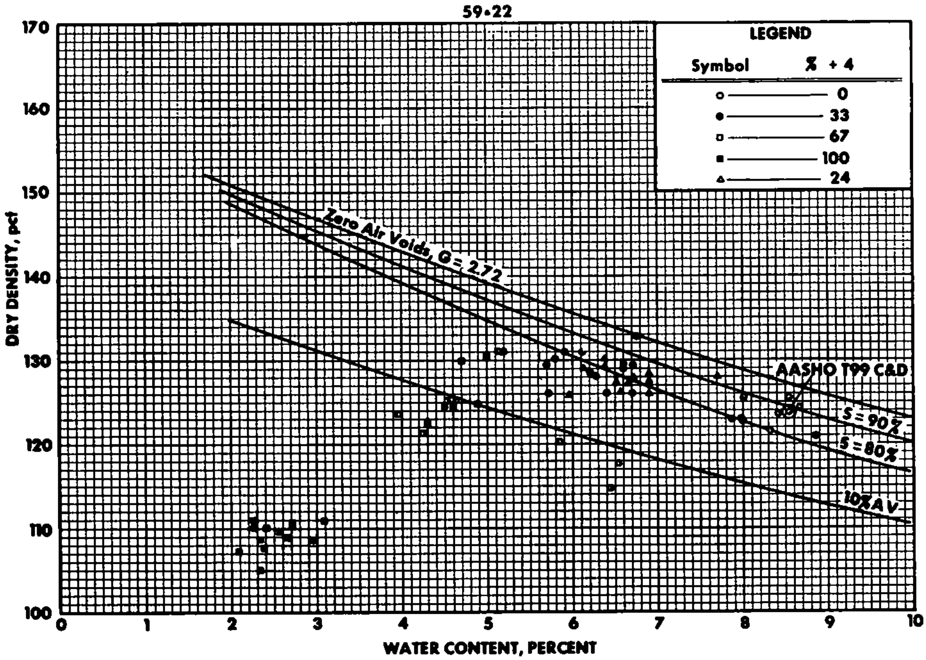

Figure 5. Laboratory test results, sample 59-22.

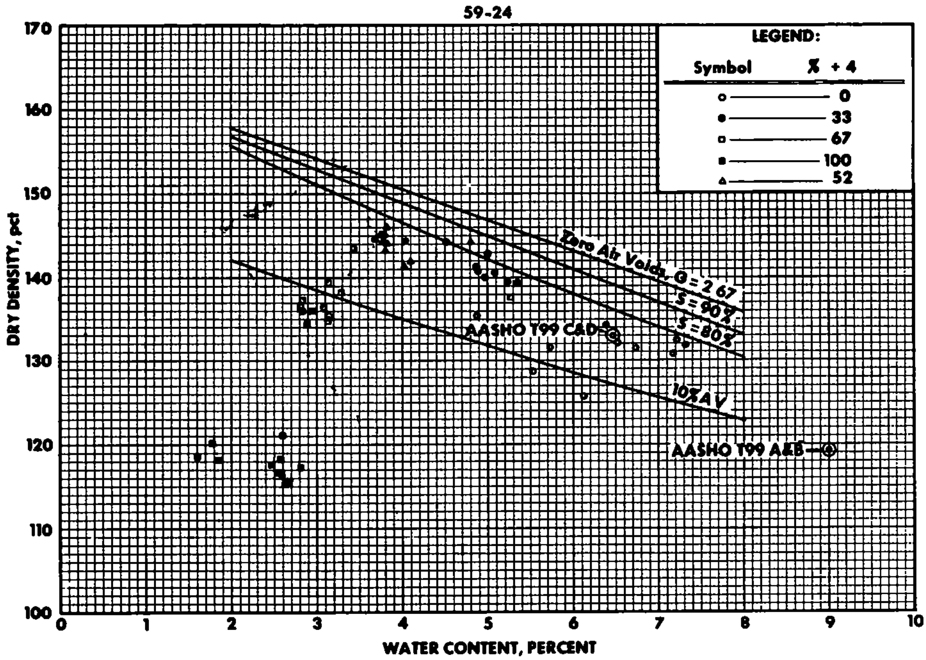

Figure 6. Laboratory test results, sample 59-24.

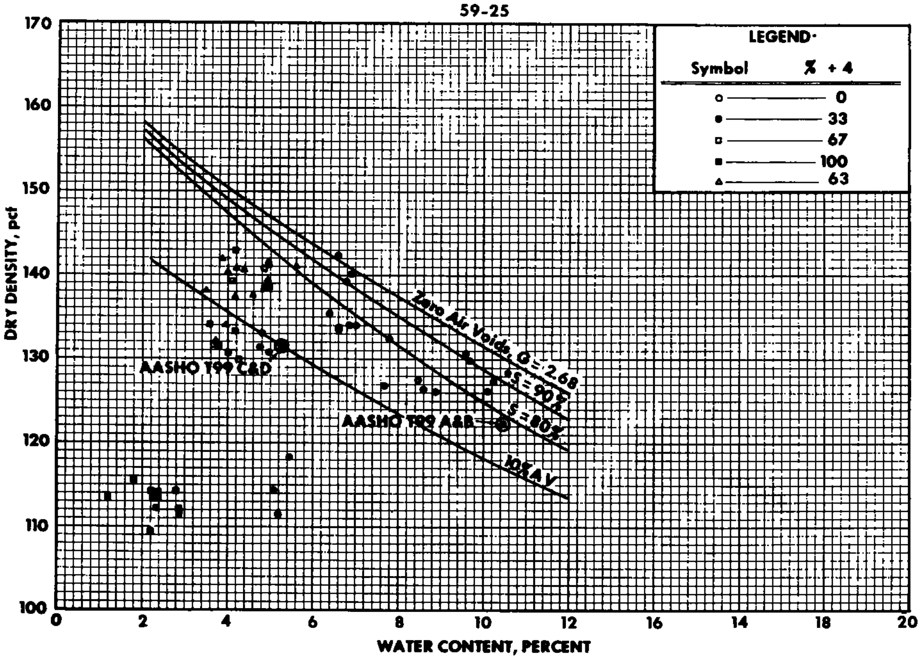

Figure 7. Laboratory test results, sample 59-25.

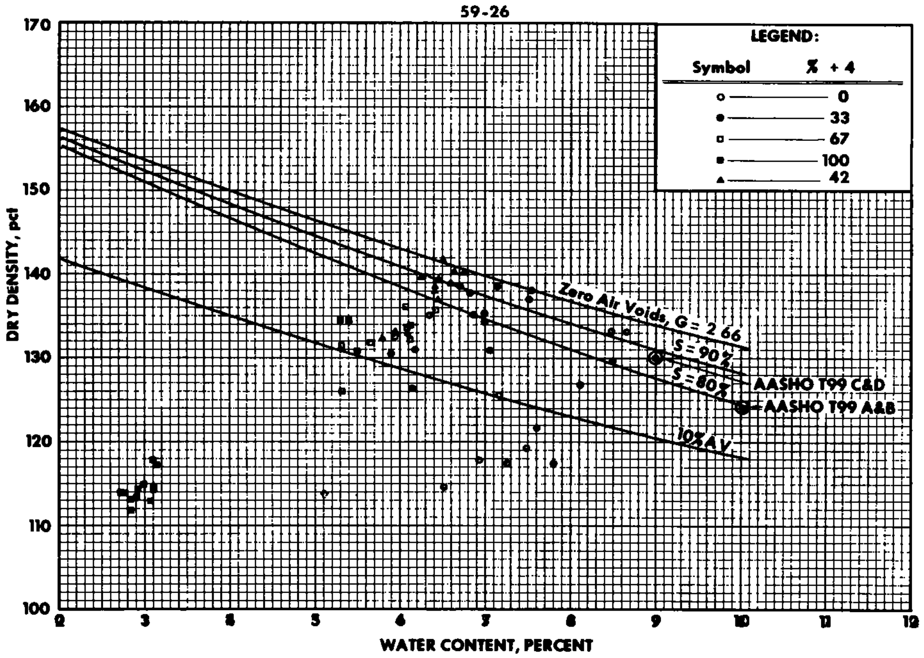

Figure 8. Laboratory test results, sample 59-26.

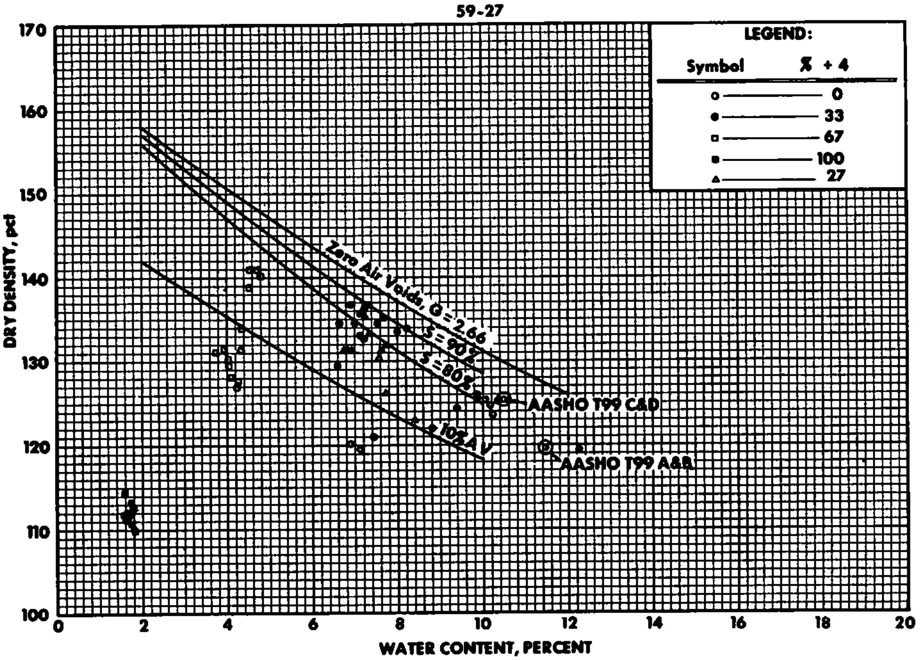

Figure 9. Laboratory test results, sample 59-27.

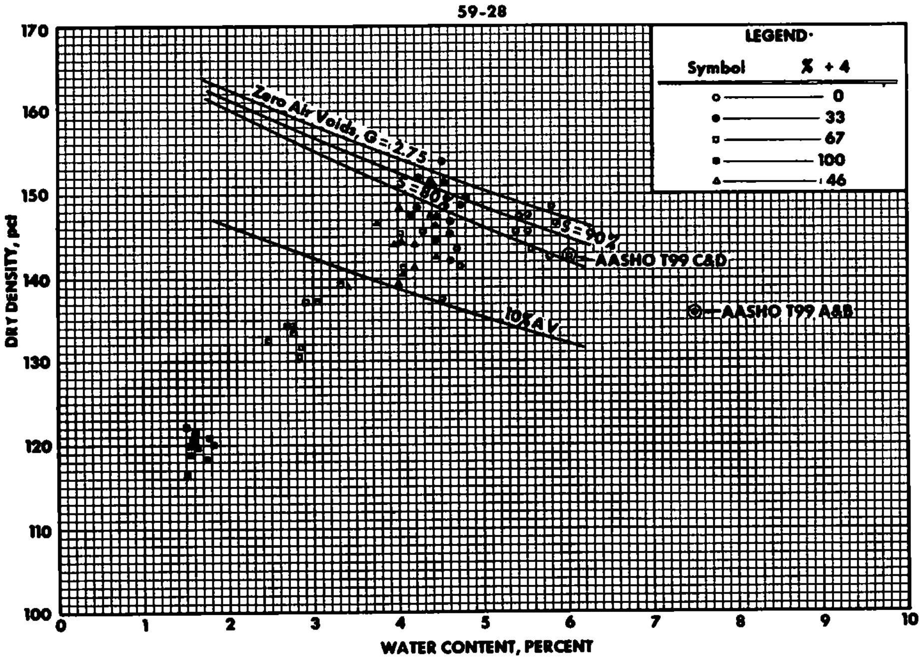

Figure 10. Laboratory test results, sample 59-28.

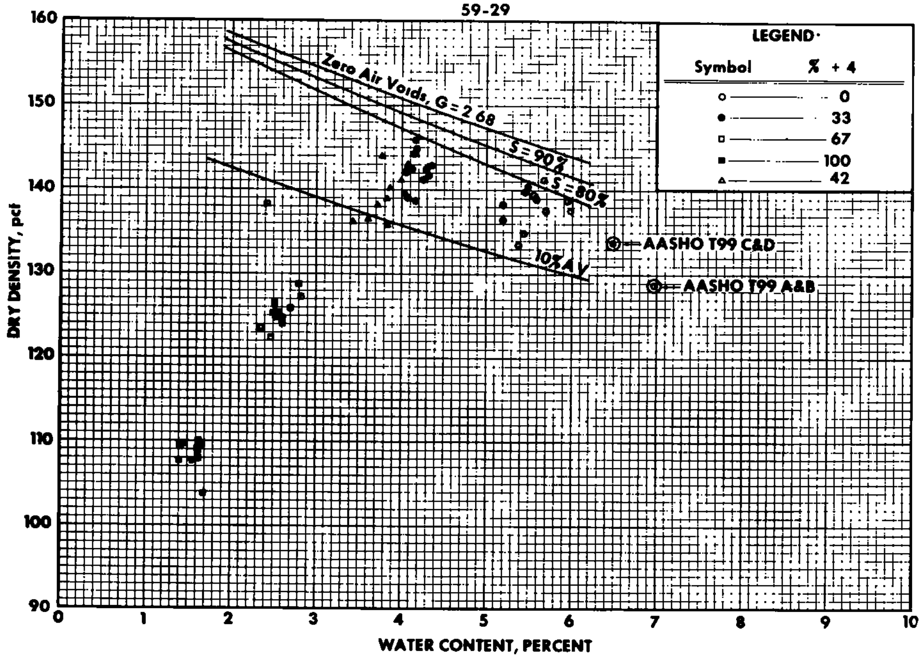

Figure 11. Laboratory test results, sample 59-29.

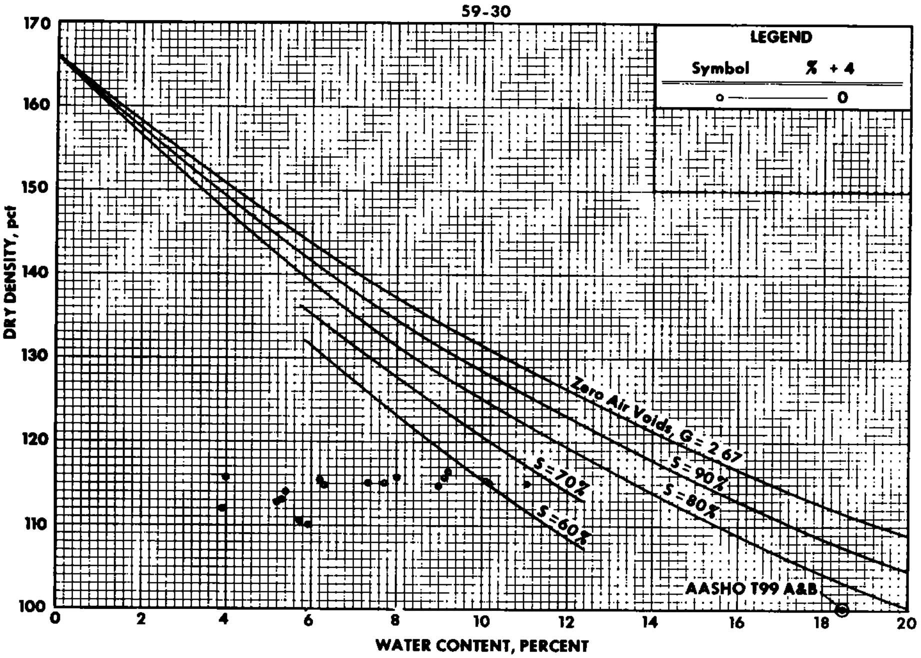

Figure 12. Laboratory test results, sample 59-30.

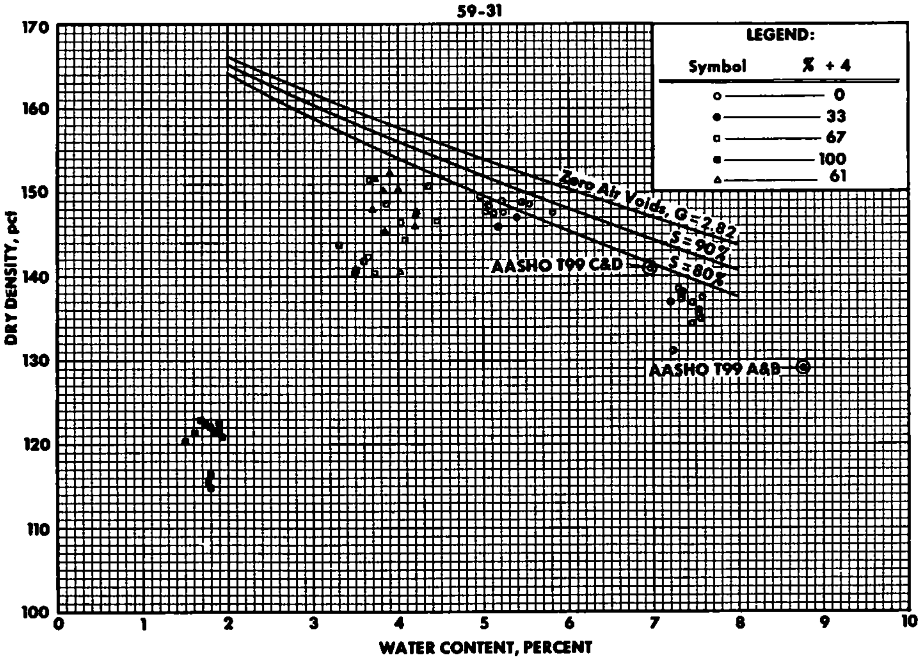

Figure 13. Laboratory test results, sample 59-31.

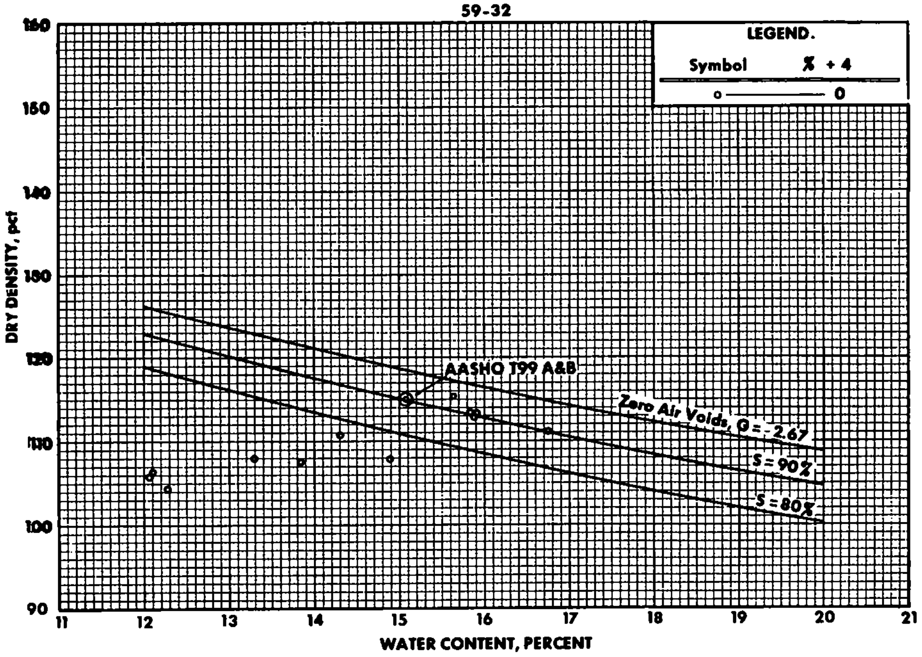

Figure 14. Laboratory test results, sample 59-32.

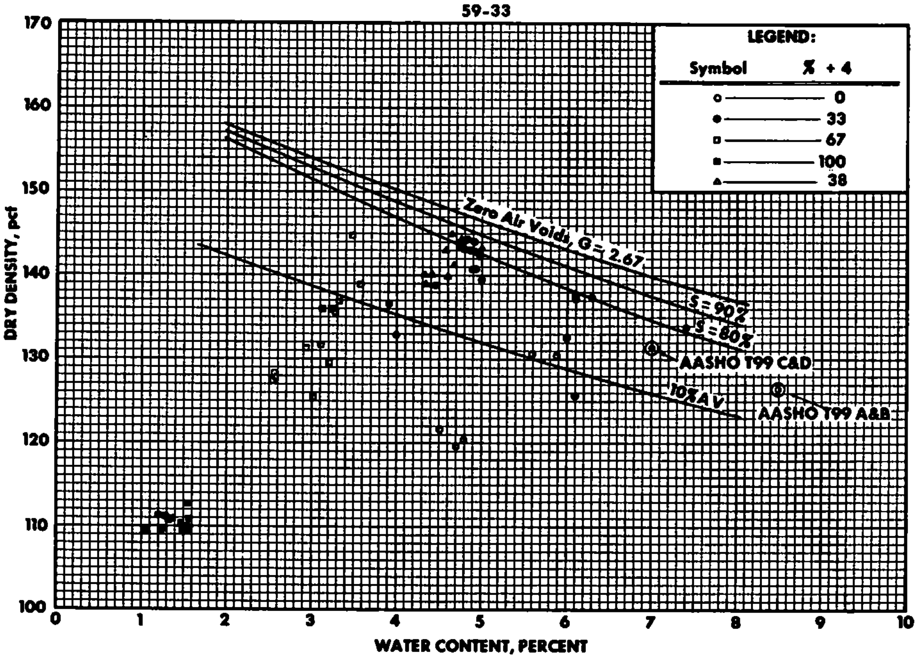

Figure 15. Laboratory test results, sample 59-33.

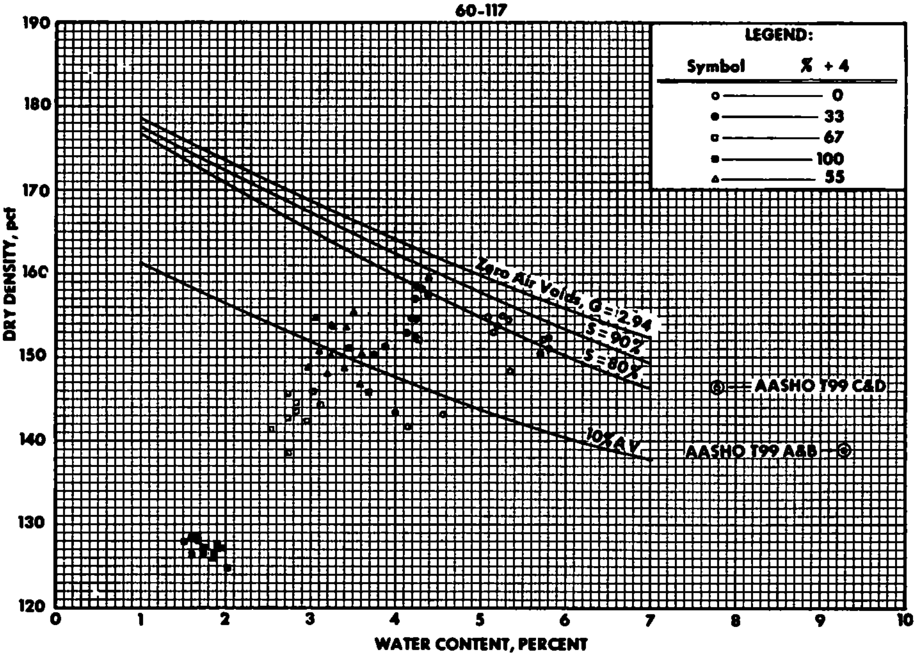

Figure 16. Laboratory test results, sample 60-117.

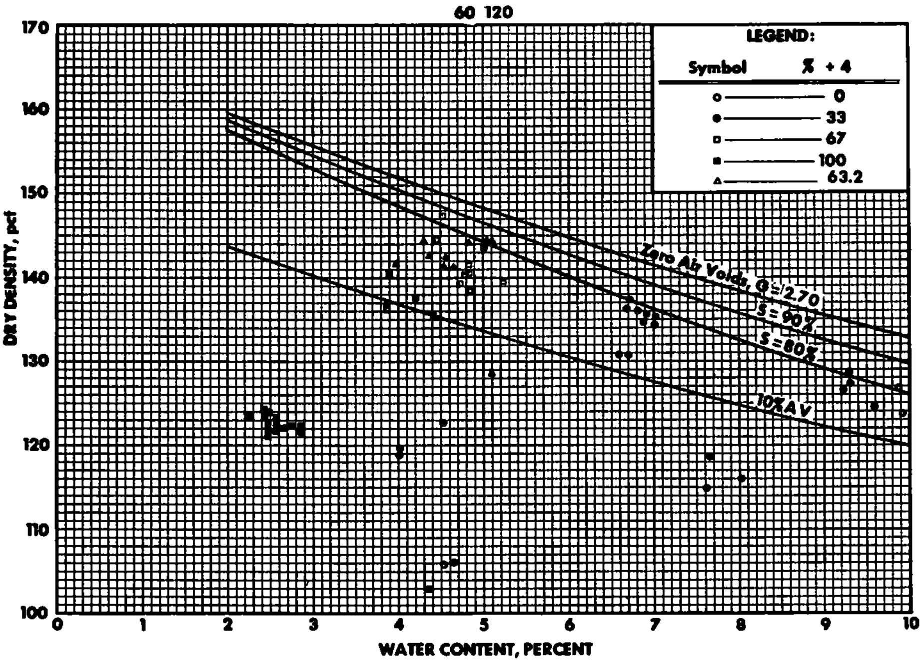

Figure 17. Laboratory test results, sample 60-120.

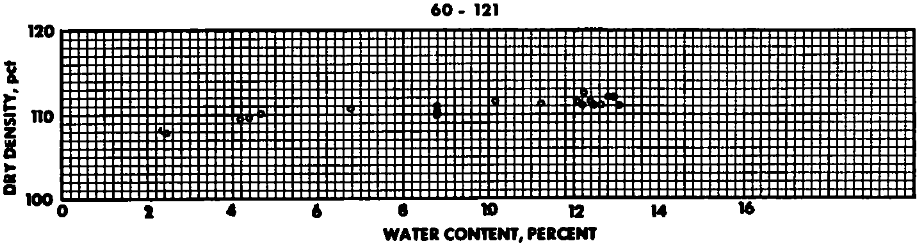

Figure 18. Laboratory test results, sample 60-121.

The 60 tests were performed in a randomized order to reduce order effects, and a standard sample was tested at intervals during the study as a check on the control.

The minus No. 4 gradation was constant, as received, and the plus No. 4 minus $^3/_4$-in. fraction was composed in each case of 50 percent minus $^3/_4$-in. plus $^3/_8$-in. and 50 percent minus $^3/_8$-in. plus No. 4. Time limitations precluded detailed study of gradation variables other than these.

Results of the tests are shown in Figures 1 through 18. From the original data, Figures 19 through 33 were developed and show the variation in density with +4 fraction. Results of AASHO T-99-A and -C tests are indicated on the figures. Values of density in Figures 19 through 33 are representative high measured ones.

FIELD TESTS

The Research Council's Pavement Evaluation Section has conducted field density tests on several experimental projects in which base and subbase courses were compacted by a number of roller types. Gradation and number of passes have been varied. Data are available for three materials from both laboratory and field tests. Figures 34 through 42 show the field densities compared to the laboratory densities.

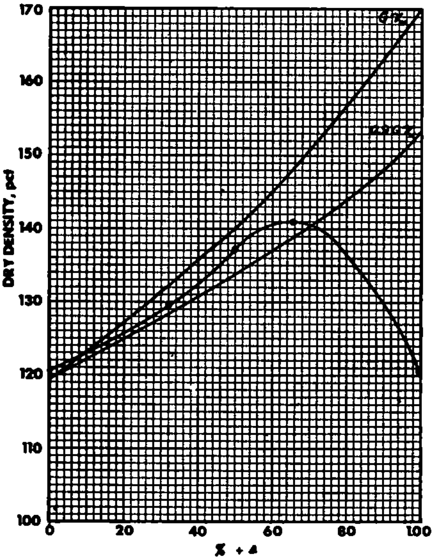

Figure 19. Laboratory density vs percent plus No. 4, sample 59-17.

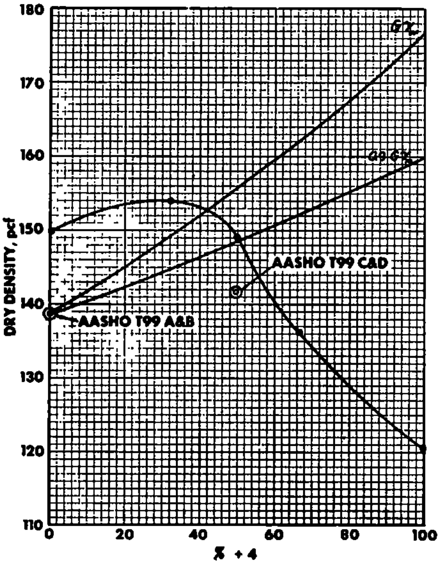

Figure 20. Laboratory density vs percent plus No. 4, sample 59-18.

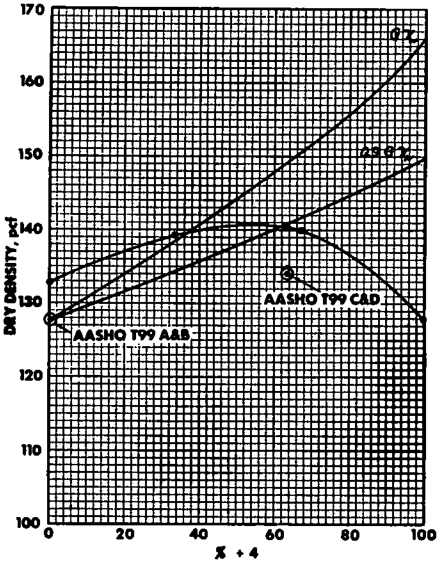

Figure 21. Laboratory density vs percent plus No. 4, sample 59-19.

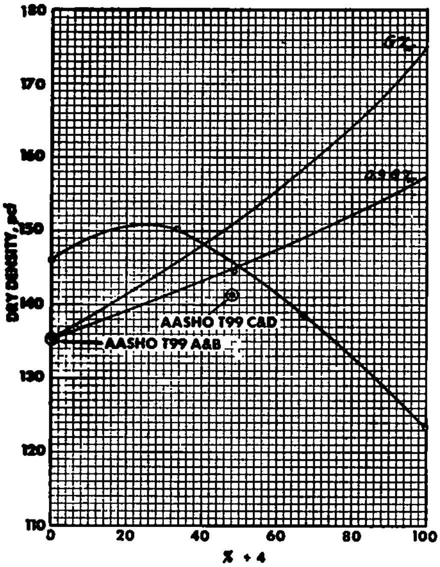

Figure 22. Laboratory density vs percent plus No. 4, sample 59-20.

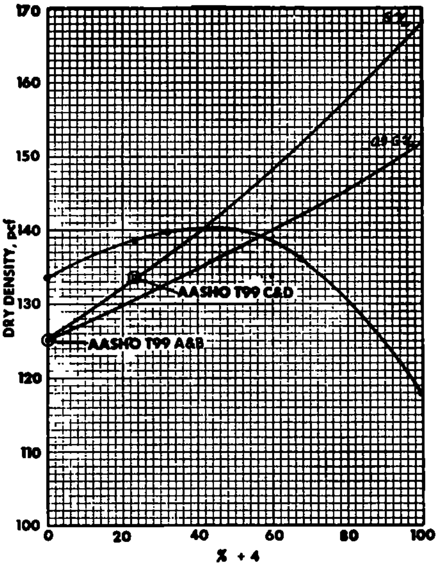

Figure 23. Laboratory density vs percent plus No. 4, sample 59-22.

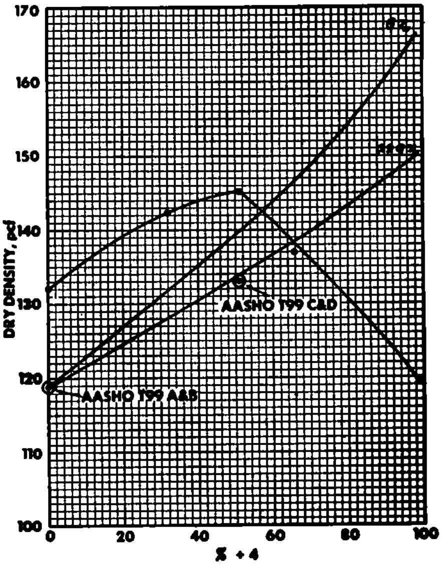

Figure 24. Laboratory density vs percent plus No. 4, sample 59-24.

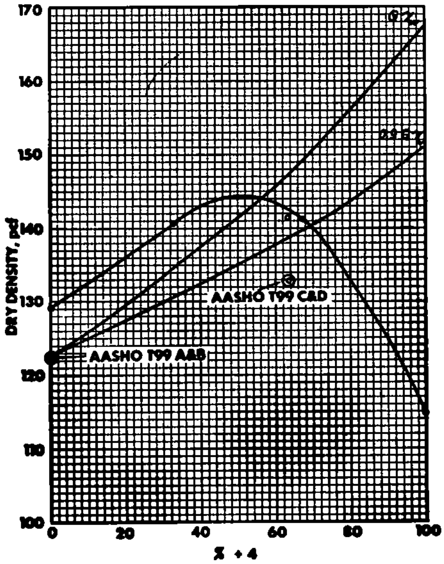

Figure 25. Laboratory density vs percent plus No. 4, sample 59-25.

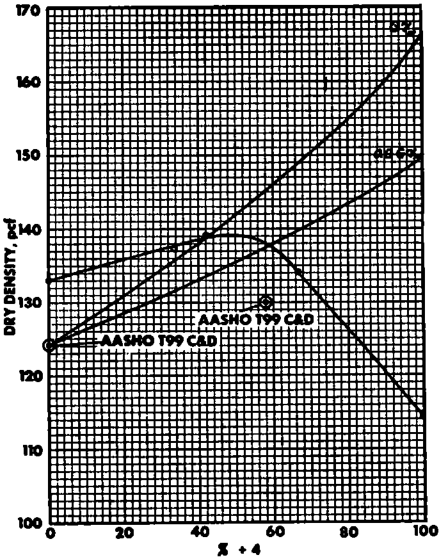

Figure 26. Laboratory density vs percent plus No. 4, sample 59-26.

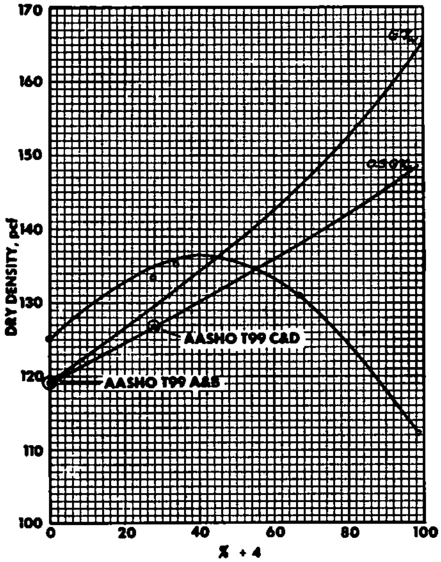

Figure 27. Laboratory density vs percent plus No. 4, sample 59-27.

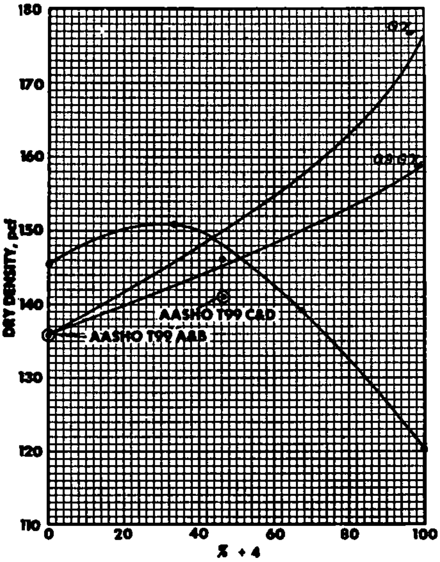

Figure 28. Laboratory density vs percent plus No. 4, sample 59-28.

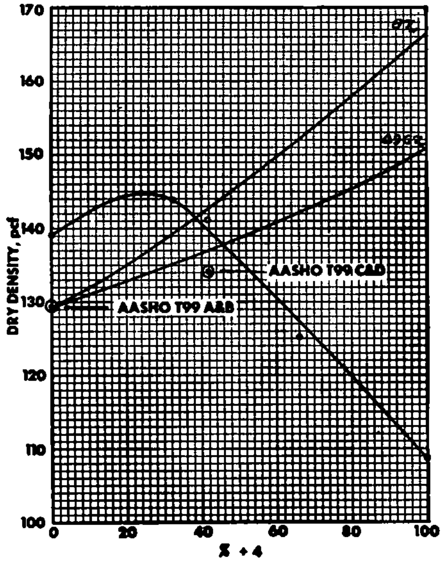

Figure 29. Laboratory density vs percent plus No. 4, sample 59-29.

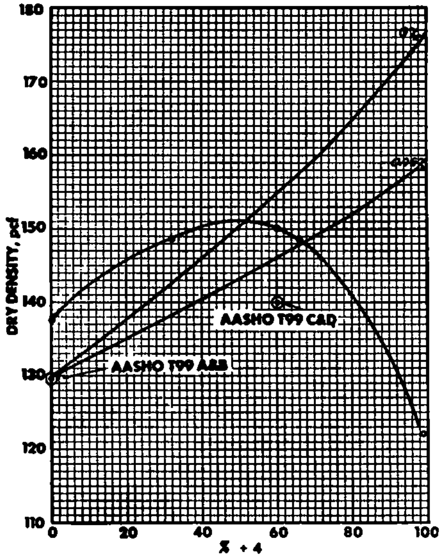

Figure 30. Laboratory density vs percent plus No. 4, sample 59-31.

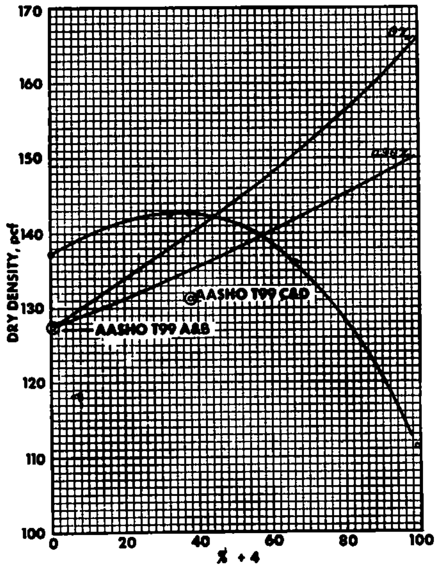

Figure 31. Laboratory density vs percent plus No. 4, sample 59-33.

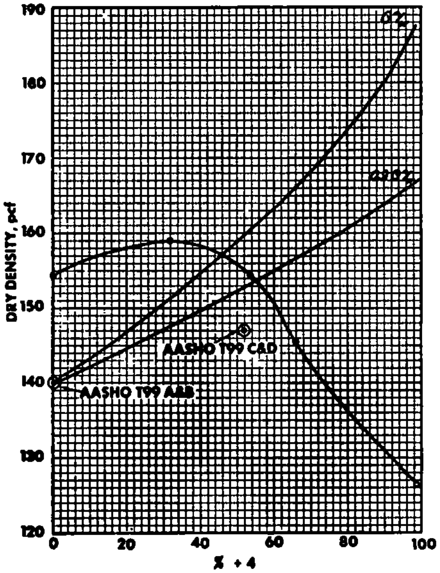

Figure 32. Laboratory density vs percent plus No. 4, sample 60-117.

CONTROL TESTS

A standard sample of crushed stone was tested at intervals during the program to assure that the testing process was still in order. The control chart is given in Figure 43.

Other tests were conducted to measure sample degradation during compaction, and this degradation was found to be on the order of 1 percentage increase on the percentage passing a given screen after 1-hr vibration and was thought to be not significant.

DISCUSSION

It is apparent that all the materials do not exhibit identical compaction characteristics. In particular, most of the compaction curves had no negative slope because water added past a certain point merely ran out of the mold during vibration; final degrees of saturation were quite variable and ranged from 60 to 98 percent.

No constant fraction of coarse material produced maximum densities; values of "optimum plus No. 4" varied significantly.

Precision of results was satisfactory; the coefficient of variation for the control sample density was only 1.7. The randomization procedures and uncontrolled variations in the gradation of the minus No. 4 fractions cause the scatter in results; however, realistic data is thus obtained and enough replication was provided to secure reliable data.

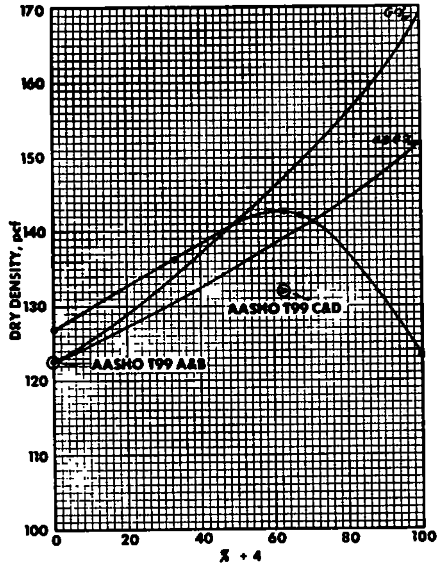

Figure 33. Laboratory density vs percent plus No. 4, sample 60-120.

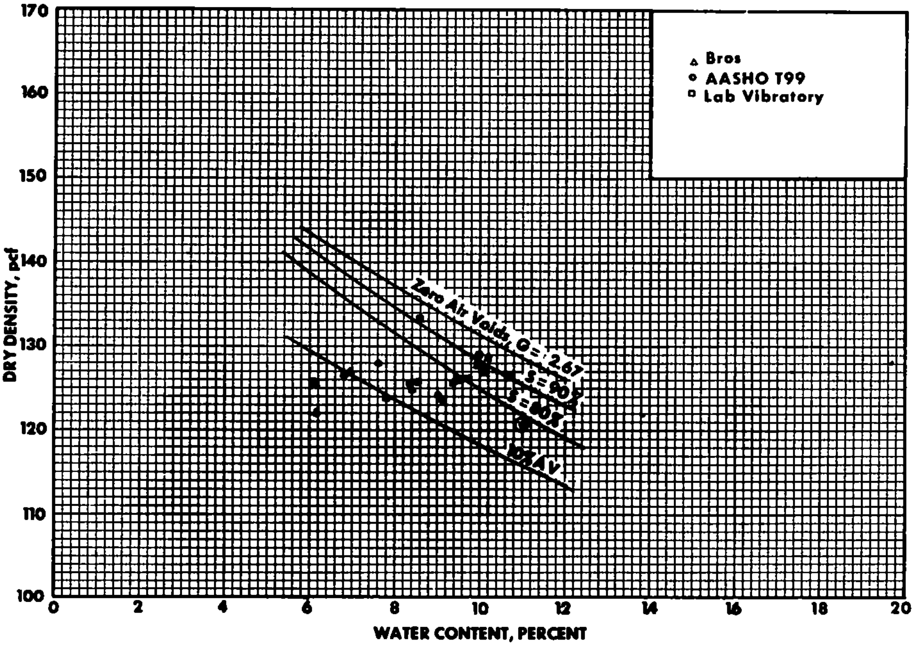

Figure 34. Laboratory and field test, sample 60-8.

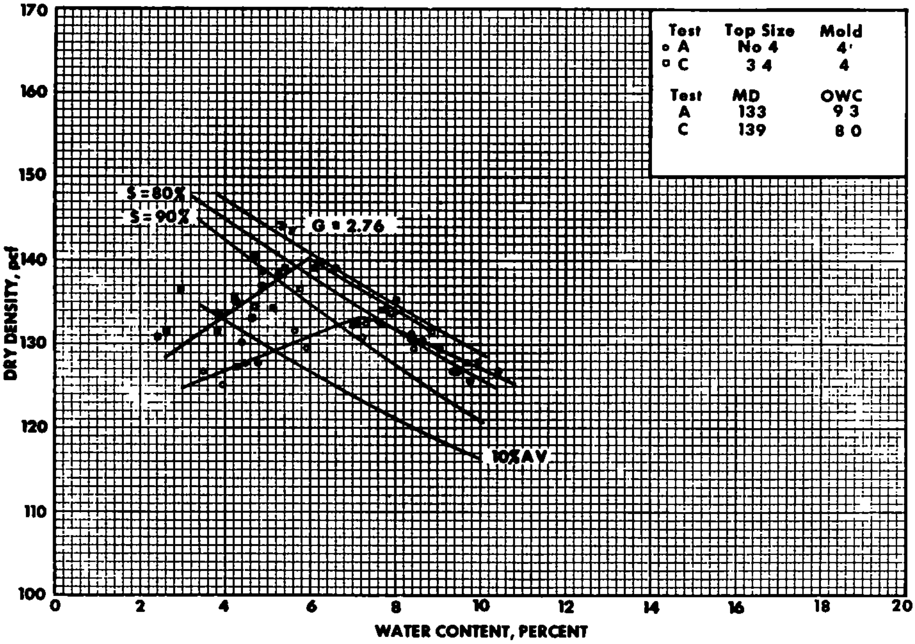

Figure 35. Standard compaction test results, sample 60-65.

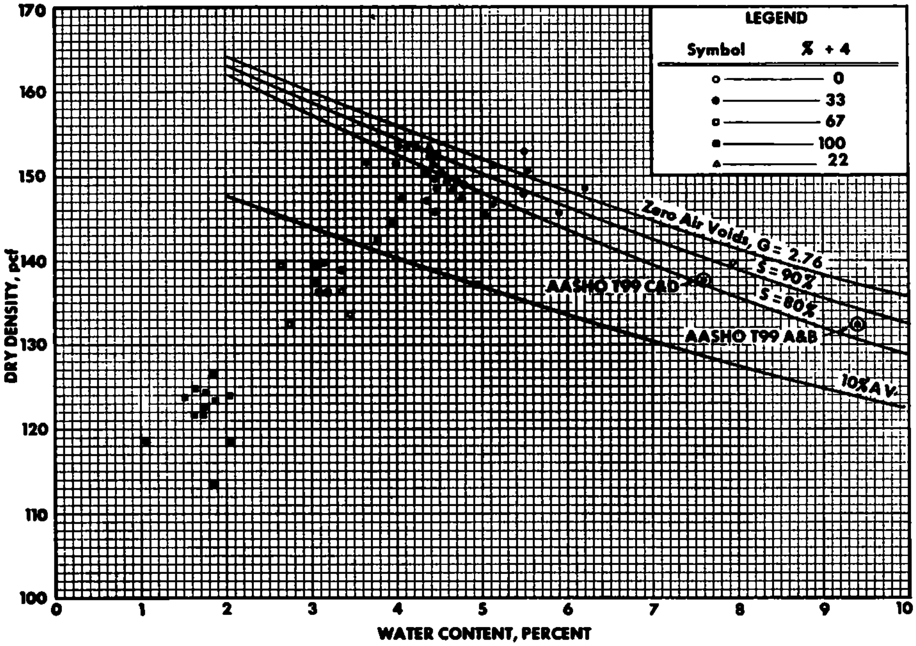

Figure 36. Laboratory compaction tests, sample 60-65.

The ratio of vibrated density to standard density was one or greater with the exception of a single material, 59-32, which was somewhat of a borderline case.

Increasing quantities of coarse material caused the expected increase, then decrease in density and the effect of water content was diminished at high plus No. 4 fractions. Neither of the correction formulas used was effective in predicting densities.

A study of the data shows no apparent typical behavior of the classes of materials except the beach sand; that is, all the crushed stone did not reach maximum density at a given gradation, and water content variation had different effects on the gravels, etc. Data was reduced to void ratios and porosities in an effort to find general comparisons, but to no avail.

Examination of the density vs percent +4 curves (Figs. 19-33) shows that the correction curves and the density curves are approximately parallel to 20 percent plus No. 4 only; this indicates the upper limit of usefulness for the correction curves.

The laboratory vibrated densities correlated well with maximum field densities in the three cases studied, as can be seen in Figures 34-42. Further work on laboratory-field correlation is scheduled.

It is apparent that current AASHO standard methods for determinations of

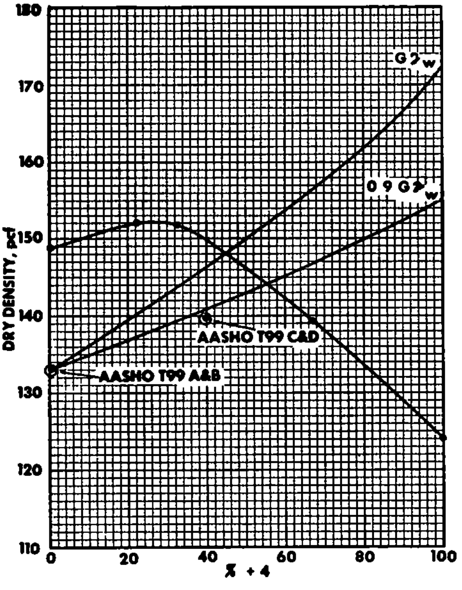

Figure 37. Density vs percent plus No. 4, sample 60-65.

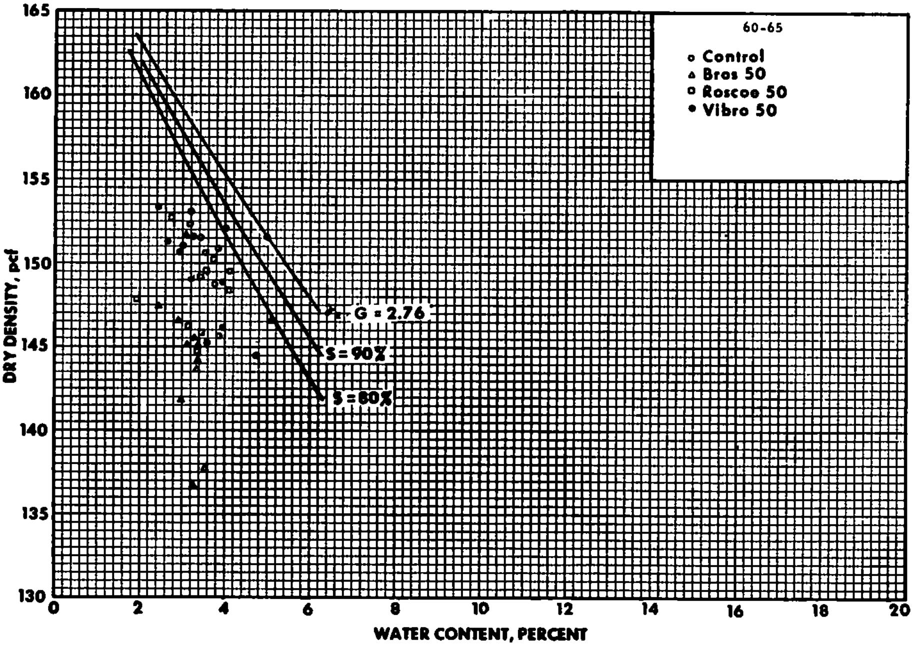

Figure 38. Field density measurements, sample 60-65.

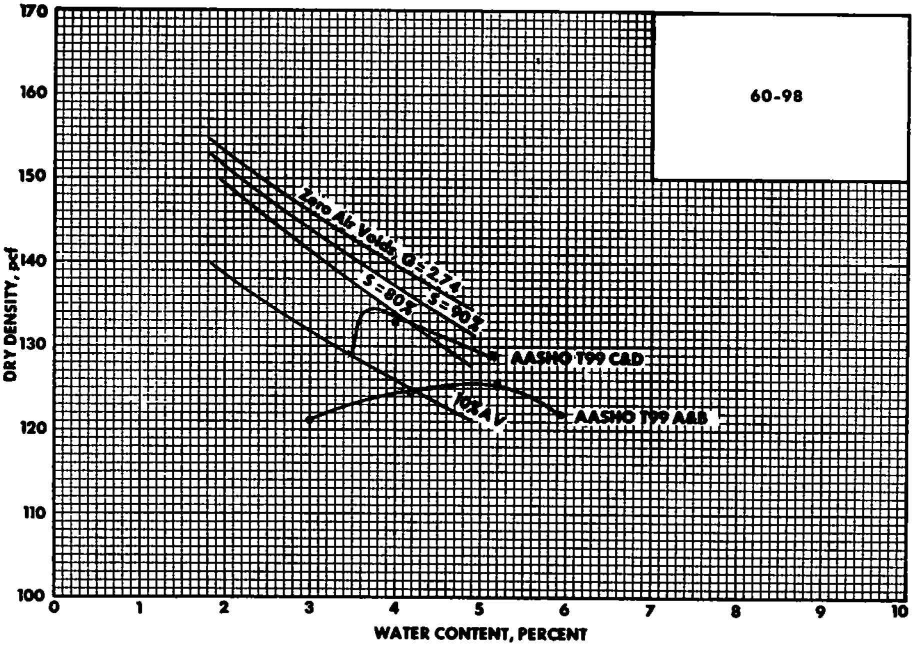

Figure 39. Standard compaction tests, sample 60-98.

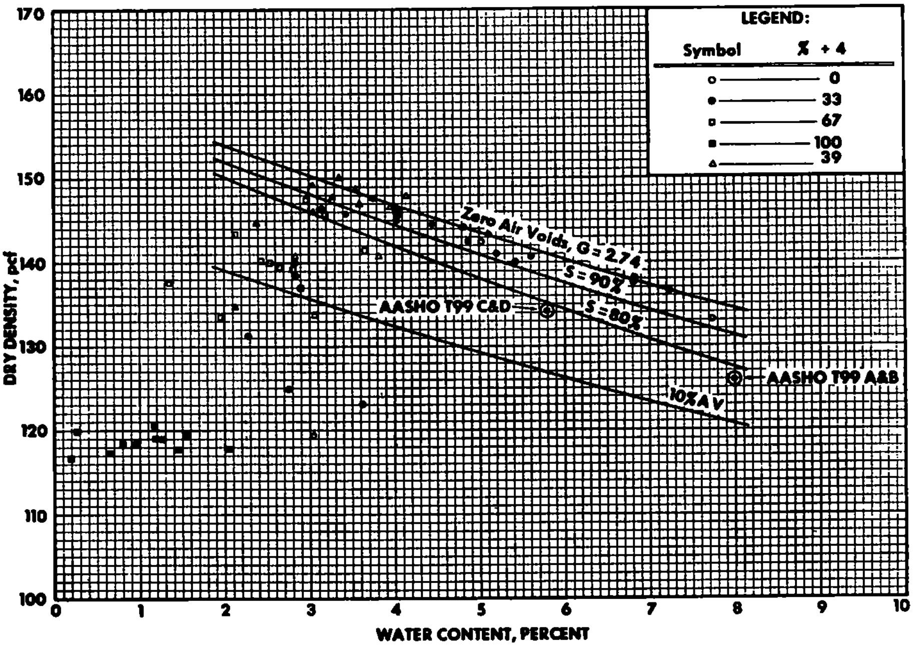

Figure 40. Laboratory compaction tests, sample 60-98.

the laboratory density of cohesionless materials and the correction methods previously discussed will not furnish realistic values of density. Recommendations from this study will advise testing coarse materials in apparatus similar to the vibratory table used in the study.

CONCLUSIONS

For the materials tested:

1. Laboratory vibratory compaction produces higher density than standard dynamic compaction and correlated well with field densities.
2. Current AASHO and ASTM standard compaction test methods give density values that can easily be exceeded by other laboratory methods and by field compaction.
3. Formulas that predict density increases caused by addition of plus No. 4 particles are likely to yield unrealistically high values, even though the formulas may be theoretically correct.

REFERENCES

1. Burmister, D.M., "Principles of Permeability Testing of Soils." ASTM Spec. Tech. Publ. 163 (1954).
2. Texas Highway Department, "Procedure THD-110." (1953).

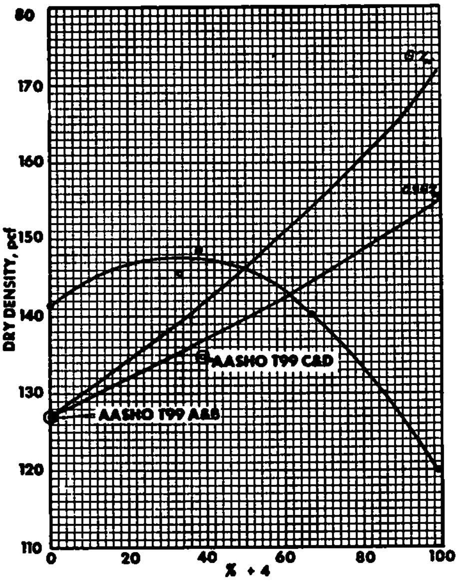

Figure 41. Density vs percent plus No. 4, sample 60-98

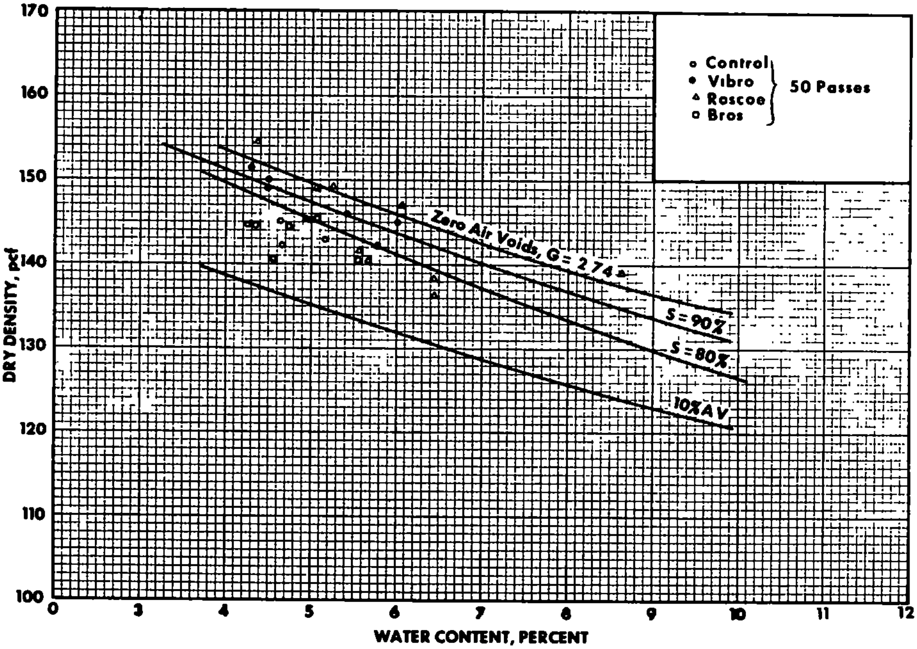

Figure 42. Field density test results, sample 60-98.

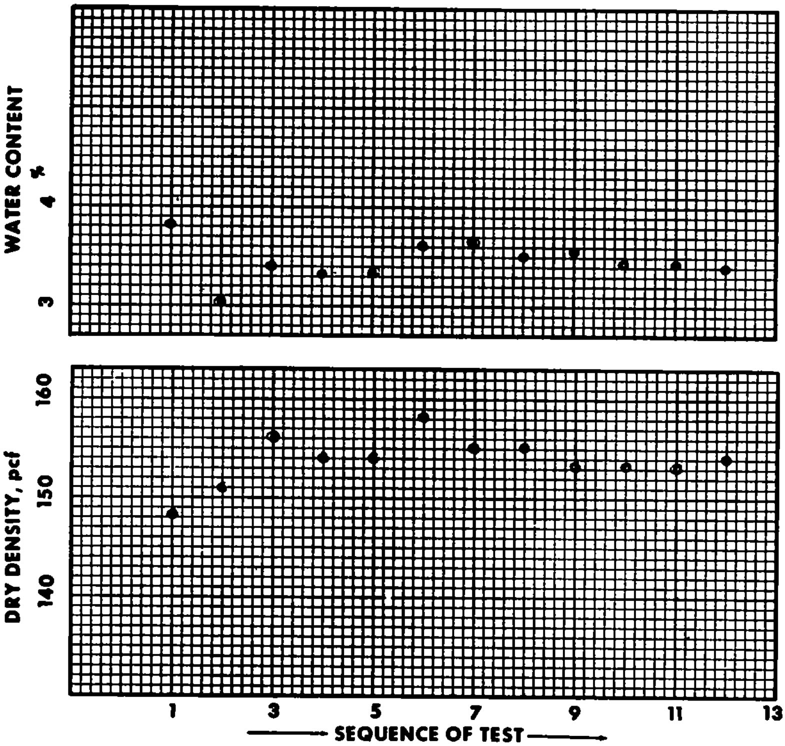

Figure 43. Control chart, sample 60-117.

3. Felt, E.J., "Laboratory Methods of Compacting Granular Soils." ASTM Spec. Tech. Publ. 239 (1958).
4. Pauls, J.T., and Goode, J.F., "Maximum Density of Noncohesive Soils and Aggregates." Procedures for Testing Soils, ASTM (1958).

Appendix

DENSITY CORRECTION FORMULA

$$D = \frac{D_f D_c}{P_f D_c + P_c D_f}$$

in which

D = corrected density, pcf;

D_f = AASHO T99 density, -4 fraction, pcf;

D_c = coarse density, (K) (62.4) (Bulk Sp. Grav.) pcf

in which

K is either 1.0 or 0.9 depending on the type of material;

P_f = fine fraction as a decimal; and

P_c = coarse fraction as a decimal.