Development of Nuclear Density Tests for Hot Asphalt Pavement

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Development of a nondestructive test method for density measurements of hot asphalt concrete in the field using portable nuclear instrumentation is described. Also described are effects to utilize existing nuclear density probes designed for testing soil to measure the compacted density of hot asphalt pavement.

A prototype nuclear asphalt density probe was developed. After testing the prototype on test sections with densities from 110 to 144 pcf, a production model asphalt density probe was designed and built. Heat-resistant electronics allowed density tests to be performed on material ranging in temperature from cold to 300 F. Source type and strength, as well as source-to-detector geometry, were optimized so that depth of penetration was restricted to approximately 1¾ to 2 in., allowing testing of thin asphalt surface courses without base course influence. Comparison data and compaction growth curves from various roller patterns set in the field using the asphalt density probe are included. Test results were available within 2½ min after each roller pass.

•SINCE PROPER compaction of freshly laid hot asphalt concrete is very important in highway construction, it is equally important that field density tests be made as quickly and efficiently as possible. Present conventional test methods are excessively slow and tend to relegate test results to the postmortem class. By the time the specific gravity of a cooled asphalt concrete specimen has been determined, the section of pavement being tested has usually cooled to the point where additional compactive effort does little or no good should the test fail.

Recognizing this and the fact that there was no commercially available nuclear probe for density tests on hot asphalt, the Planning and Research Division of the Colorado Department of Highways agreed to purchase a prototype nuclear density probe from the Nuclear-Chicago Corp. The purpose of this new device was to determine the compacted density of freshly laid hot asphalt concrete surface courses in the field. Design criteria called for the probe to have an effective depth of measurement of 2 in.

The Materials Division was given the tasks of assisting in the development of the device from a practical usage standpoint and of correlating the nuclear results with existing conventional test methods. To expedite these two assignments, test sections of asphalt concrete were constructed at the Asphalt Paving Co. plant west of Denver near Golden, Colo. These test sections were constructed according to the following specifications:

Section A—¾-in. maximum size, 30 percent minus No. 4 sieve, 5.5 percent asphalt;
Section B—¾-in. maximum size, 60 percent minus No. 4 sieve, 6.0 percent asphalt; and
Section C—100 percent minus No. 4 sieve, 6.5 percent asphalt.

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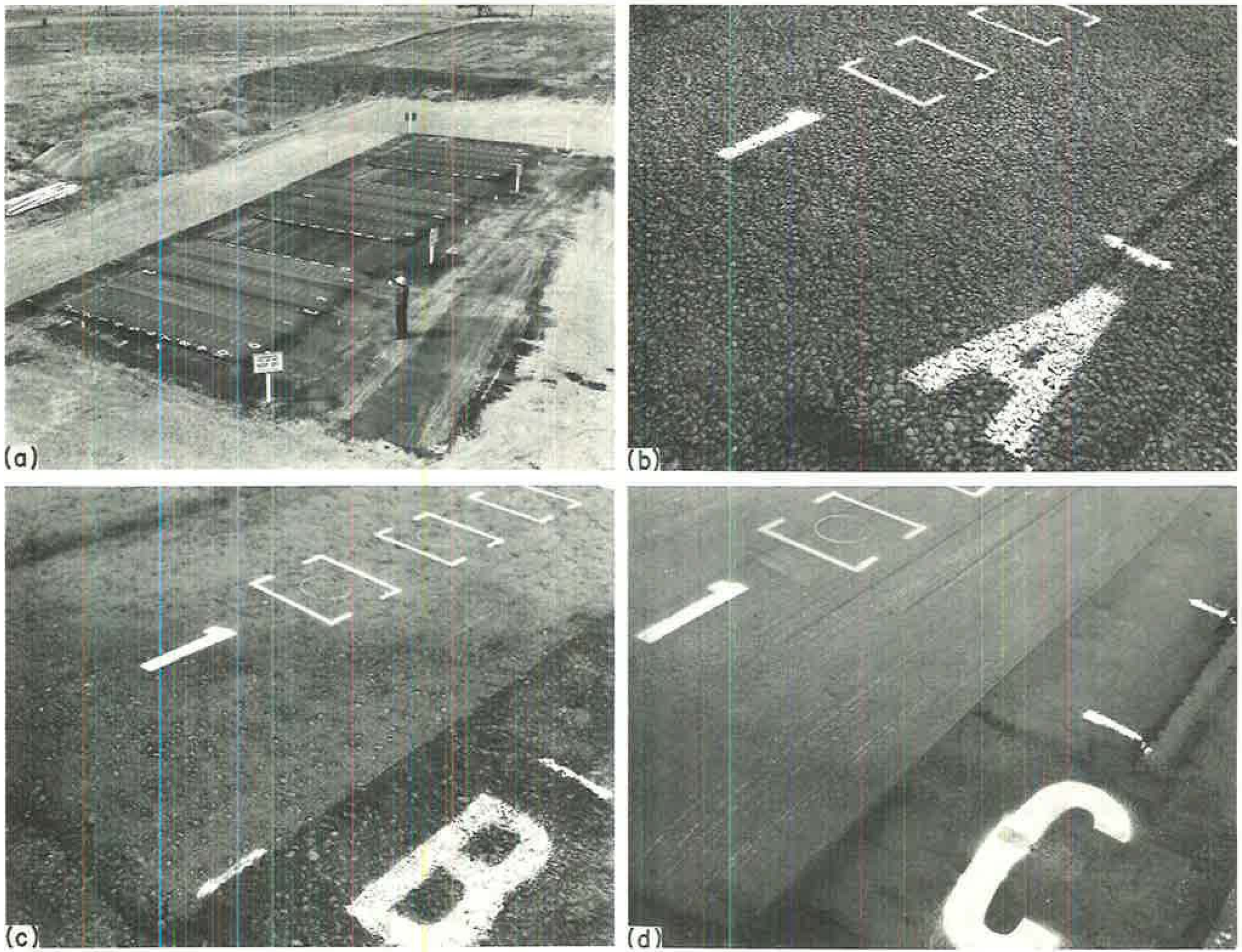

Figure 1. Asphalt test sections for nuclear testing program: (a) overall view; (b) closeup view of coarse-graded section; (c) closeup view of medium-graded section; and (d) closeup view of fine-graded section.

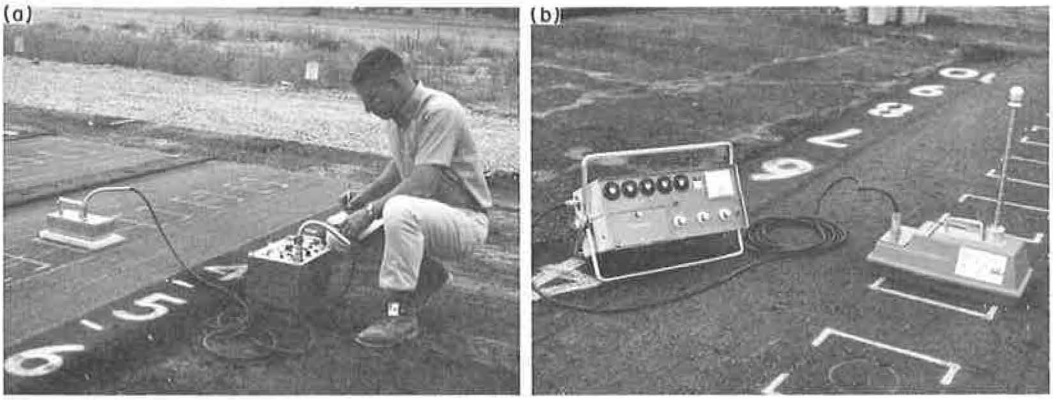

Figure 2. Density probes: (a) N-C Corp. P-22A on asbestos heat shield; and (b) Troxler being used on test sections.

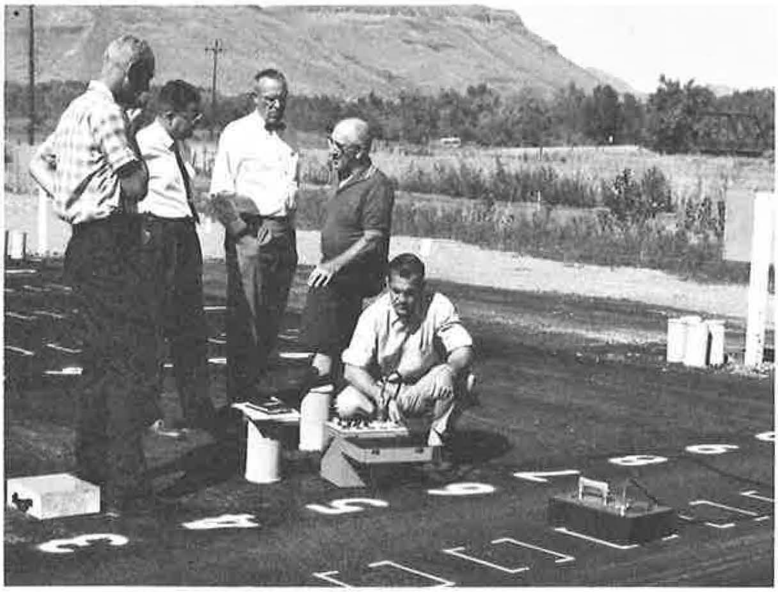

Figure 3. E-1-X prototype being operated on section B.

Each of these three sections measured 24 by 24 ft and were divided into four equal subsections (labeled 0, 1, 2, and 3). Subsection 0 had no compactive effort applied other than that of the vibrating screed at the rear of the SA-40 Barber-Greene paver. Subsections 1, 2, and 3 had roller passes applied that corresponded to these numbers. The roller used was a 10- to 14-ton Galion steel wheel tandem. Each of the subsections was then divided into 10 equal parts and indexed for testing as shown on Figure 1. This figure also includes closeup photos of each section illustrating the surface texture of the coarse, medium and fine mixes.

While waiting for the prototype to be developed, project personnel were instructed to log nuclear readings on the 120 indexed test sites using both the Nuclear-Chicago P-22 density probe with an asbestos heat shield (Marinite) (Fig. 2a) and the Troxler Model SC-120H surface density probe (Fig. 2b). The results of the tests using these two probes illustrated the need for developing a special probe for hot asphalt, since:

Figure 4. Polyethylene cover in place for weather protection.

Figure 5. Coring operation on test sections completed.

1. The slope of the calibration curve for the N-C Corp. P-22 was not steep enough to provide accurate readings;
2. The Troxler soil probe calibration curve had insufficient slope in the backscatter position, and
3. The Troxler soil probe could not be used in either the 1- or 2-in. position on hot asphalt because of the radiation hazard to the operator from wiping the source rod clean after each test.

The E-1-X prototype density probe was delivered to project personnel late in 1962 and nuclear readings were logged as weather would permit. Figure 3 shows the E-1-X being used on the test sections. A polyethylene cover was placed over the sections between test sequences involving the various nuclear devices so that moisture from rain or snow would not change the bulk density of the asphalt concrete (Fig. 4).

The E-1-X prototype consisted of a N-C Corp. P-22A with the six-tube detection system and the lower portion of the case removed. The remainder of the P-22 was placed in a relatively large case with appropriate lead shielding. The radioactive source of 3 millicuries (mc) of cesium 137 was changed to 2 mc of radium 226. A Transite heat shield was built into the bottom to protect the electronic components. The source-to-detector geometry had been selected experimentally by the N-C Corp. design engineers so that the effective depth of measurement under ordinary field conditions was held to approximately 2 in.

Field tests on asphalt concrete weighing 135 pcf and having a thickness of 2 in. showed that varying the underlying base material from 110 to 140 pcf had no appreciable

Figure 6. Specific gravity determinations in Central Laboratory.

effect on the count rate of the prototype. Laboratory tests on a specimen of asphalt concrete weighing 110 pcf indicated a difference of 2 pcf when varying the underlying base material from 119 to 152 pcf. These slight changes were considered tolerable at that stage of the prototype development.

A laboratory sample of asphalt concrete was heated to a temperature exceeding 250 F, and tests were performed on it while hot using the E-1-X prototype. No ill effects were noted because of the heat.

Coring of the 120 test sites within the test sections was accomplished subsequent to the logging of a total of 360 nuclear readings using the three probes previously mentioned. Figure 5 shows the test sections on completion of the coring. A Concore drill unit was employed using a 6-in. I.D. diamond-impregnated bit. The cores were wrapped in several feet of masking tape and placed in padded cartons. They were then transported to the CDH Central Laboratory and stored in a cool (unheated) room on a flat surface until the water from the coring operation had evaporated. Cores from the areas that had had no compactive effort applied were handled very carefully to prevent deformation of the sample.

Field trials involving the E-1-X showed that the new probe was quite sensitive to density after each roller pass. The electronic components were not affected by the heat of the mat, even though it exceeded 250 F.

A Dunagan apparatus was used to determine the specific gravity of the cores from the test sections. Standard procedure for Colorado Departments of Highways field personnel performing routine control tests was used. This method involves weighing of the uncoated specimen in air and in water and calculating the specific gravity (Fig. 6).

Representative core samples (eight from each section) were selected to be coated with paraffin to determine their density according to AASHO Test Method T-166-60. Table 1 gives the results using these two methods on cores from sections A, B, C, and E. (Section E is described later in this text.)

Significant differences in the results of the two methods appear, especially when the more porous cores are tested. From past experience, project personnel have learned that the acceptance or the rejection of a new concept of testing by field forces is always based on correlation obtained with standard field procedure. Therefore, since project personnel entered into this research project with the intent of assisting in the development of procedures for the CDH field use of an asphalt density probe, they are of the

TABLE 1

SPECIFIC GRAVITY OF UNCOATED VS PARAFFIN-COATED[a] CORES

Core No.[b]	Density (pcf)		
	Uncoated	Coated	Diff.
A-0-3	137.7	133.3	4.4
A-0-8	139.6	—	—[c]
A-1-3	140.2	135.8	4.4
A-1-8	143.3	—	—[c]
A-2-3	142.0	137.1	4.9
A-2-8	142.0	137.1	4.9
A-3-3	142.0	137.1	4.3
A-3-8	141.4	136.4	5.0
B-0-3	127.7	124.0	3.7
B-0-8	127.7	122.7	5.0
B-1-3	131.5	128.3	3.2
B-1-8	131.5	129.6	1.9
B-2-3	130.2	127.7	2.5
B-2-8	130.2	129.0	1.2
B-3-3	132.1	129.6	2.5
B-3-8	132.7	131.5	1.2
C-0-3	105.7	105.3	0.4
C-0-8	107.8	106.5	1.3
C-1-3	110.9	109.6	1.3
C-1-8	110.2	109.6	0.6
C-2-3	114.0	112.1	1.9
C-2-8	111.5	110.9	0.6
C-3-3	116.5	115.3	1.2
C-3-8	112.1	112.1	0.0
E-0-1	136.4	126.5	9.9
E-0-2	136.4	126.5	9.9
E-2-1	139.6	135.8	3.8
E-2-2	139.6	135.8	3.8
E-4-1	140.8	136.4	4.4
E-4-2	138.9	135.8	3.1
E-6-1	140.2	137.1	3.1
E-6-2	140.2	135.8	4.4

[a]AASHO Test Method T-166-60.
[b]Cores from sections A, B, and C were dipped in paraffin; section E cores had paraffin painted on.
[c]Specimen broke up when dipped in hot paraffin.

opinion that the CDH field testing procedure (uncoated specimens) should be the comparison criterion.

Figure 7 illustrates the correlation between the E-1-X prototype and conventional density determinations according to the specific gravity of the uncoated specimens. This chart illustrates the following:

1. Using the N-C Corp. calibration curve that accompanied the E-1-X, the nuclear results will be excessively low.
2. Using the CDH calibration curve (based on a least squares analysis of the section B and C core densities on cores having a thickness of 1¾ in. or more), 87 percent of the tests are within ±3 pcf of a common curve.
3. The section B core data falling out of tolerance to the right of the CDH curve came from an uncompacted area. Since routine field tests for relative compaction will not be taken in an area such as this, the deviation shown is not as significant as would appear at first glance.
4. The nuclear readings were affected by the base course material when areas tested had a thickness of less than 1¾ in. This is close to the 2-in. depth of penetration for which the prototype was designed.
5. Data from the very coarse Section A (30 percent minus No. 4) indicate that the nuclear readings are significantly affected by the excessive surface air voids and a calibration curve is unobtainable for this section. This is of no great concern to project personnel because, although CDH standard specifications encompass this type of mat, it is never constructed in Colorado.

The Model E-1-X prototype was then sent back to the N-C Corp. with a list of suggestions for design modifications for the production model density probe. These suggestions included the following:

1. A high temperature, infinite counting time, thin-wall Geiger-Müller tube similar to that being developed by the Amperex Company should be considered as the detector;
2. A detector tube having a reasonably flat voltage plateau should be incorporated in the production model;
3. The screened vent should be eliminated; and
4. The case should be elongated to permit easier seating.

In June 1963, a production model of the asphalt density probe (designated Model 5846) was delivered to project personnel. This probe (Fig. 8) is compatible with the Model 2800A scaler used to operate the other N-C Corp. portable nuclear probes.

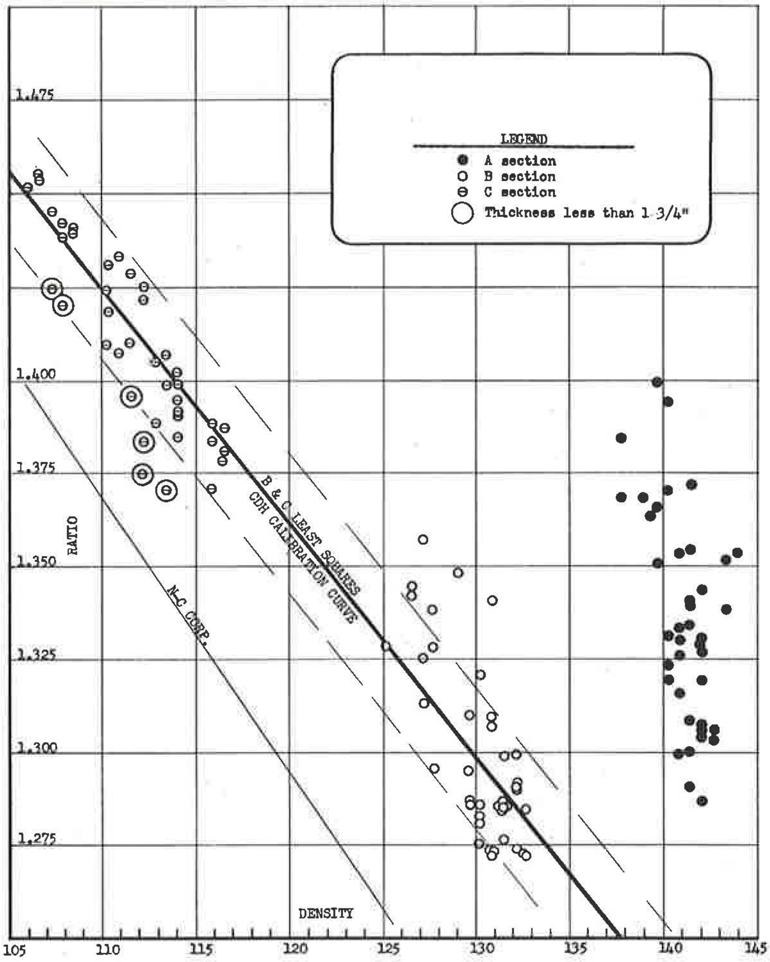

Figure 7. Correlation of conventional density determinations on sections A, B, and C with E-1-X prototype density probe determinations.

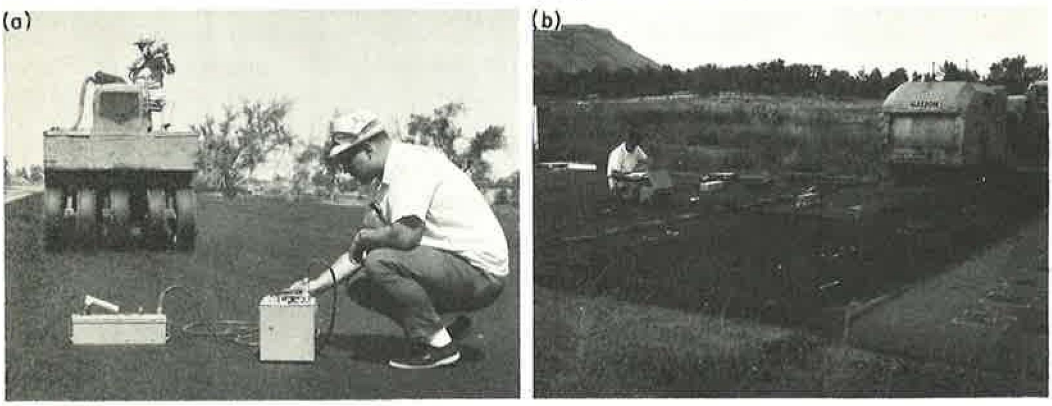

Figure 8. Model 5846 asphalt density probe: (a) being used in field trial; and (b) being operated on section E.

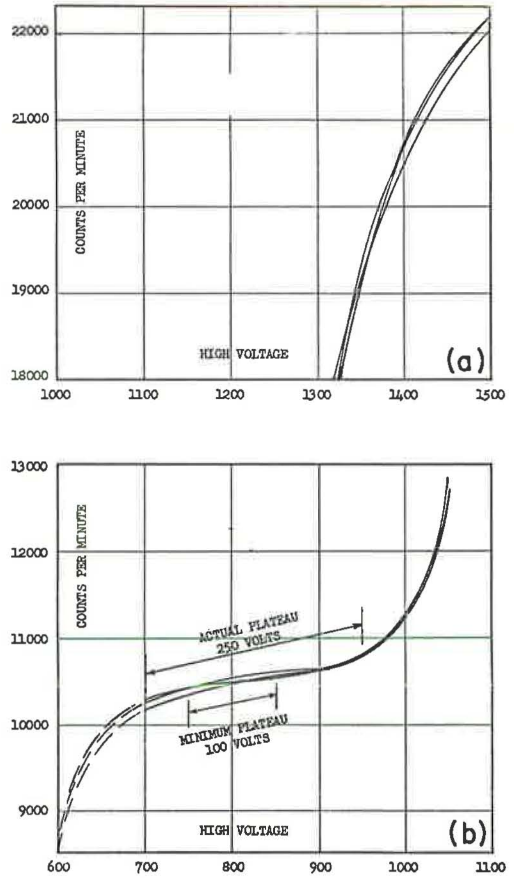

Figure 9. High-voltage plateaus: (a) E-1-X, and (b) Model 5486.

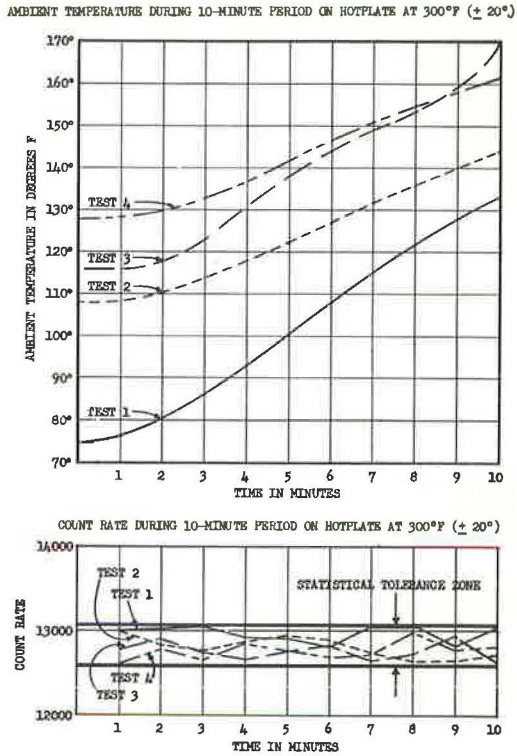

Figure 10. Model 5846 ambient temperature test results, series III.

The Model 5846 has incorporated into its design all the suggestions that CDH project personnel forwarded with the return of the E-1-X prototype. The first phase of laboratory tests involving the Model 5846 concerned the characteristics and the reproducibility of the high-voltage plateau of the new Amperex detector tube. Figure 9a illustrates the unacceptable curvilinear plateaus of the E-1-X. Figure 9b shows the excellent, reasonably flat high-voltage plateau of the Model 5846. The E-1-X has had this type of detector tube installed and now has a high-voltage plateau similar to that of the Model 5846.

The next phase of laboratory tests involving the Model 5846 pertained to a series of ambient temperature tests. Results of the last of a series of these tests, shown in Figure 10, indicate that this probe is not affected by heat up to 300 F originating from the material being tested.

The Model 5846 was operated on the test sections 1 ft to the east of the holes made by the core drill at the 120 test sites. Results of the tests were similar to the data shown in Figure 7. The data are available from the Colorado Department of Highways as a supplement to this paper.

The Model 5846 has been used in the field in Colorado to control the compaction of hot asphalt concrete surface courses. Figures 13+14 illustrate the field control results on hot asphalt on the Clifton-Cameo project. The new probe has also been used in Denver, Burlington, and on the Wolcott-North project to set roller patterns.

Acceptance of this new technique by both CDH and contractor personnel in the field has been good. CDH District VI (Denver) now has a Model 5846 probe that is being used for routine compaction control of hot asphalt and for setting roller patterns efficiently. CDH District III (Grand Junction) has a Model 5846 on order and plans to use it as an accessory to the density-moisture gages they now have in the field.

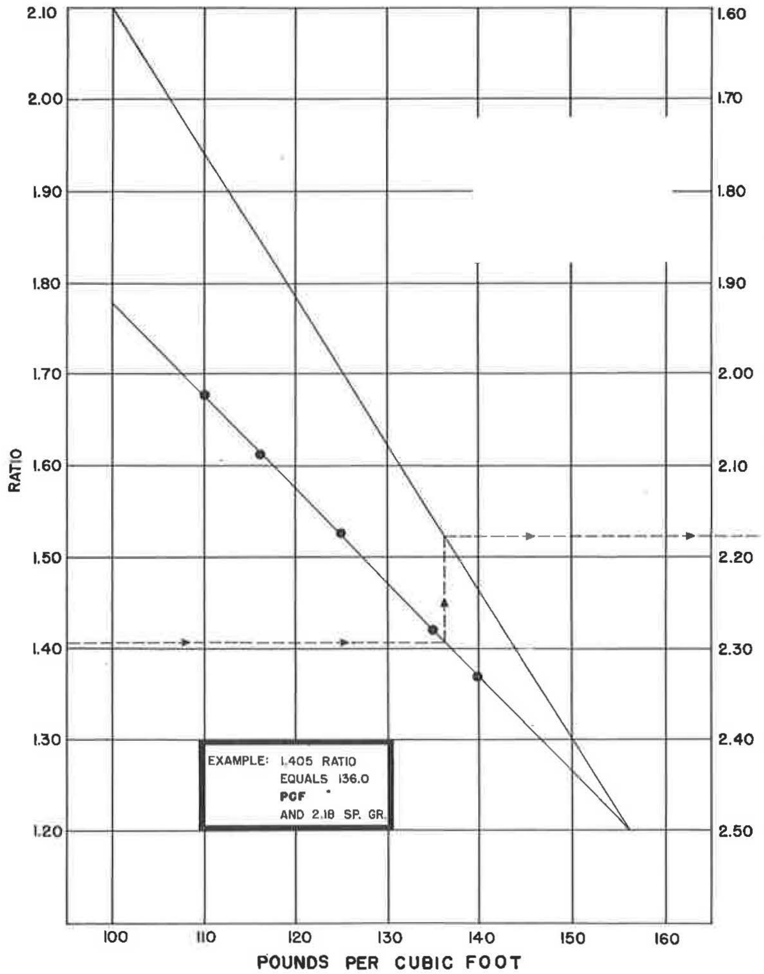

Figure 11. Model 5846 calibration and specific gravity conversion curves.

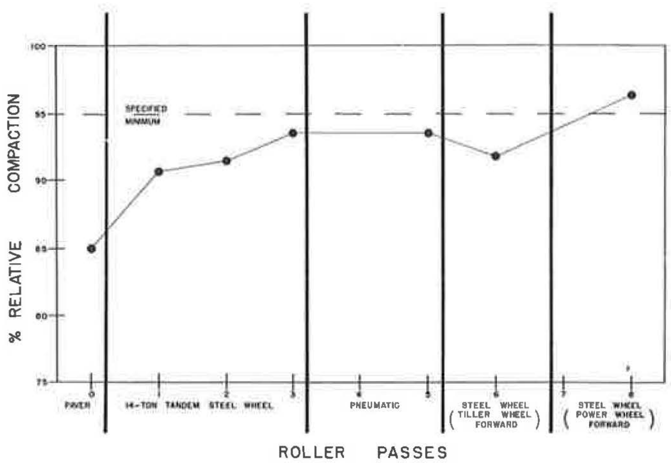

Figure 12. Compaction growth curve using Model 5846 nuclear density probe; Project I 70-4(26), E. 46th Ave.-Elizabeth St. to Jackson St. in Denver.

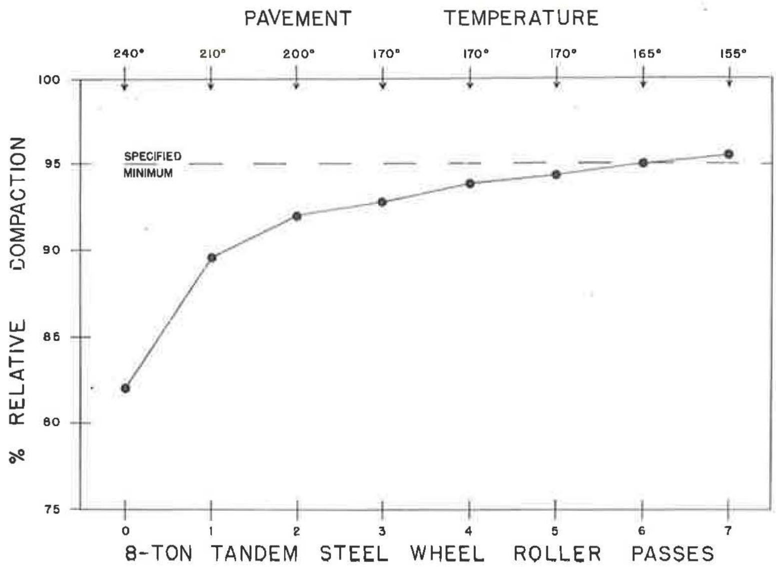

Figure 13. Compaction growth curve using Model 5846 nuclear density probe; Project I 70-1(7), Clifton-Cameo.

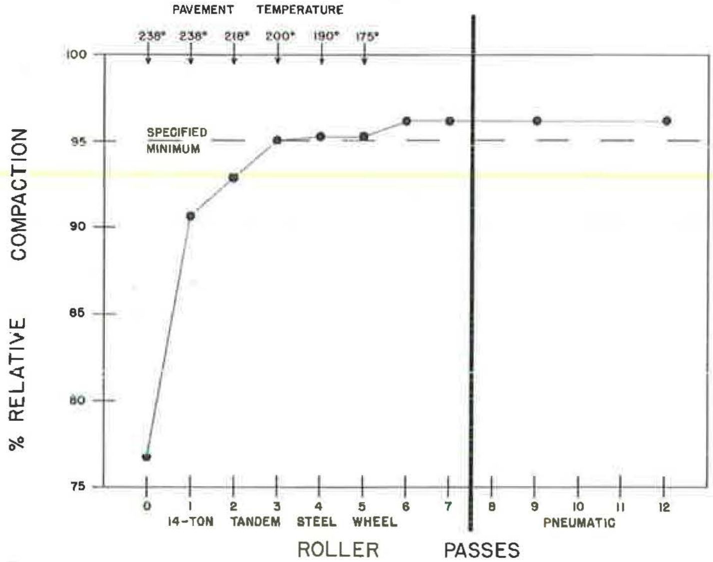

Figure 14. Compaction growth curve using Model 5846 nuclear density probe; Project I 70-1(7), Clifton-Cameo.

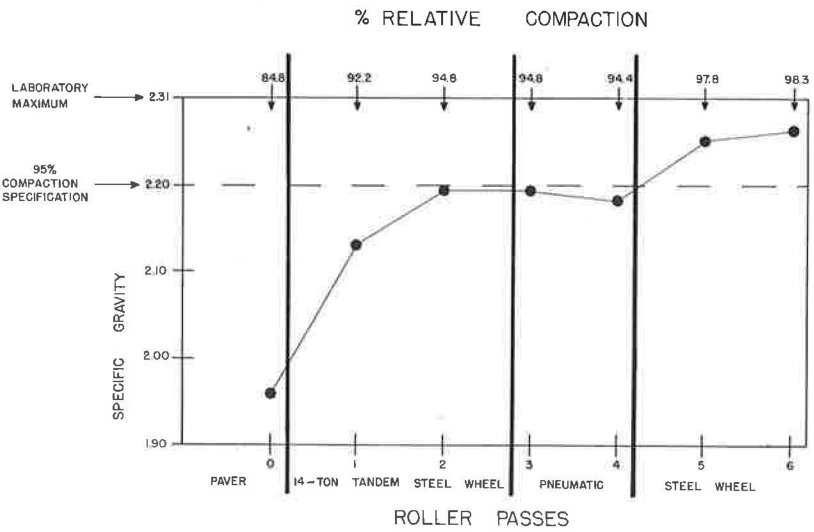

Figure 15. Compaction growth curve using Model 5846 nuclear density probe; Project U 012-2(9).

The Nuclear-Chicago Corp. has not supplied CDH project personnel with usable calibration curves for either the prototype or the Model 5846. The curves supplied were based on the company soil and concrete standards and were intended to be temporary, pending the completion of N-C Corp. asphalt standards of correct size, weight and uniformity.

CDH calibration standards compacted by hand in the Central Laboratory proved to be too small and nonuniform. Calibration standards being used at present were cut from the test sections with a diamond blade concrete saw. They measure 12 by 24 in. and are preserved in the Central Laboratory. Figure 11 shows the calibration curve for a Model 5846 based on these standards, as well as the specific gravity conversion curve for use in the field. The latter curve is useful because all data sent to the CDH field crews concerning laboratory maximum density for asphalt concrete are in terms of specific gravity.

To obtain a relatively high density area for a calibration standard, new sections of asphalt concrete (labeled D and E) were constructed in the space between the original three sections. Figure 8b shows Model 5846 being operated on section E. Specifications for these new sections were as follows:

Section D—¾-in. maximum size, 60 percent minus No. 4 sieve, 6.0 percent asphalt; and

Section E—¾-in. maximum size, 45 percent minus No. 4 sieve, 6.0 percent asphalt.

Roller passes on these sections varied from 0 to 12 passes of a 14-ton steel wheel roller. Maximum density obtained was 141 pcf and provided the necessary high density calibration standard.

Figures 12 through 15 show compaction growth curves developed in the field using the Model 5846 probe. These curves illustrate how readily a roller pattern may be established using the nuclear method, especially since each test takes less than 5 min to perform. These curves also show that pneumatic rolling has virtually no effect on pavement density after at least three passes of the steel wheel breakdown roller.

CONCLUSIONS

1. Nuclear density tests for hot asphalt surface courses are possible and practical during compaction.

2. Asphalt concrete temperatures up to 300 F may be tolerated during testing.

3. The effective zone of influence of the production model probe described in this paper has been arbitrarily set at 1¾ to 2 in. deep.

4. Nuclear results do not correlate well with conventional results on open-graded mixes having a significant amount of surface air voids.

5. Nuclear results correlate reasonably well with conventional results when testing the closer graded mixes used by the Colorado Department of Highways.

6. The nuclear method is preferable to the conventional method because (a) the complete nuclear density test is accomplished in less than 5 min, whereas the conventional test takes much longer; (b) the nuclear test is performed on the asphalt while it is still hot, thus allowing additional compactive effort to be applied while the asphalt is still hot should the test fail; (c) roller patterns are quickly set using the nuclear probe; (d) overrolling of asphalt pavements may readily be determined and corrected using the nuclear method, thus saving the contractor time and money should he be working under end-result specifications; and (e) the nuclear method is nondestructive.