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MISCELLANEOUS PAPER S-76-10

# VIBRATORY COMPACTION OF BITUMINOUS CONCRETE PAVEMENTS

by

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Final Report

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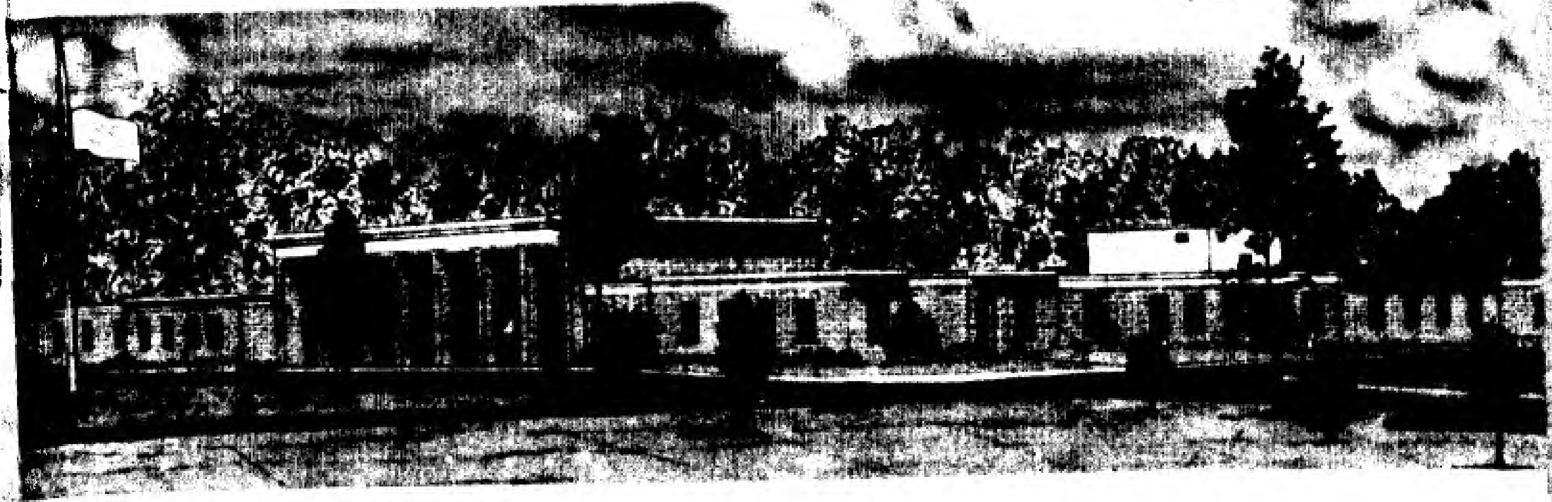

Prepared for Headquarters, U. S. Air Force
Washington, D. C. 20332

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

(14)

1. ~~REPORT NUMBER~~
WES ~~Miscellaneous~~ ~~Paper~~ S-76-10

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
(6) VIBRATORY COMPACTION OF BITUMINOUS CONCRETE PAVEMENTS.

5. ~~TYPE OF REPORT & PE~~RIOD COVERED
(9) Final report.

6. ~~PERFORMING ORG. RE~~PORT NUMBER

7. AUTHOR(s)
(10) Cecil D. Burns

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U. S. Army Engineer Waterways Experiment Station
Soils and Pavements Laboratory
P. O. Box 631, Vicksburg, Miss. 39180

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Headquarters, U. S. Air Force
Washington, D. C. 20332

12. ~~REPORT DATE~~
(11) June 1976

(12) 61p.

13. ~~NUMBER OF~~ PAGES
54

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

| | |
|---|---|
| Bituminous concretes | Rubberized tar |
| Flexible pavements | Vibratory compaction |
| Hot mix | Vibratory compactors |
| Overlays (pavements) | |

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study was conducted to evaluate the effectiveness of vibratory rollers in the compaction of hot-mix asphaltic concrete and rubberized-tar concrete to satisfy the needs of the Air Force. The study consisted of overlaying an existing heavy gear load test section at the U. S. Army Engineer Waterways Experiment Station, which consisted of rigid and flexible pavements, with asphaltic concrete and rubberized-tar concrete pavements. The overlay

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued).

pavements were compacted with two selected vibratory rollers, a Buffalo-Bomag BW210-A and a Dynapac CC-50A. A conventional steel-wheeled static roller and a pneumatic-tired static roller were also used for comparison. Variables included in the study were roller weight, frequency and amplitude of vibration, number of roller passes, type of roller (vibratory or static), type of foundation, and type and thickness of overlay pavements. The significant findings from this study are that (a) vibratory rollers of the type used are satisfactory for the compaction of high-quality bituminous concrete pavements, and (b) if properly used, they can provide densities meeting the requirements of the Air Force and the Corps of Engineers.

# PREFACE

The investigation reported herein was sponsored by the Headquarters, U. S. Air Force, Washington, D. C.

The investigation was conducted by personnel of the Soils and Pavements Laboratory (S&PL), U. S. Army Engineer Waterways Experiment Station (WES), under the general supervision of Messrs. James P. Sale and Richard G. Ahlvin, Chief and Assistant Chief, respectively, of S&PL. Personnel of S&PL actively engaged in the conduct of tests were Messrs. Carlton L. Rone, James D. Perkins, Jr., A. L. Sullivan III, and Cecil D. Burns. This report was prepared by Mr. Burns.

Director of WES during the conduct of the investigation and the preparation of this report was COL G. H. Hilt, CE. Technical Director was Mr. F. R. Brown.

# CONTENTS

## CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| inches | 25.4 | millimetres |
| feet | 0.3048 | metres |
| yards | 0.9144 | metres |
| miles (U. S. statute) per hour | 1.609344 | kilometres per hour |
| pounds (mass) | 0.4535924 | kilograms |
| kips (1000 lb mass) | 453.5924 | kilograms |
| tons (2000 lb mass) | 907.1847 | kilograms |
| pounds (mass) per cubic foot | 16.01846 | kilograms per cubic metre |
| pounds (force) | 4.448222 | newtons |
| pounds (force) per square inch | 6.894757 | kilopascals |
| pounds (force) per square inch per inch | 0.2714473 | kilopascals per millimetre |
| Fahrenheit degrees | 5/9 | Celsius degrees or Kelvins* |

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* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

# VIBRATORY COMPACTION OF BITUMINOUS CONCRETE PAVEMENTS

## PART I: INTRODUCTION

### Background

1. Current Corps of Engineers Guide Specifications for the construction of high-quality bituminous concrete pavements for airfields, heliports, and tank roads require that the paving mixtures be compacted with static steel-wheeled and heavy pneumatic-tired rollers to obtain an as-constructed density within the range of 98 to 100 percent of the laboratory design density. On recent Air Force projects, there has been increasing difficulty in obtaining heavy pneumatic-tired rolling because many paving contractors, who mainly do highway work for which they use vibratory rollers, do not have the necessary equipment. Therefore, the Air Force has permitted the substitution on some projects of vibratory rollers for heavy pneumatic-tired rollers, but with only limited success. The major emphasis of the Air Force in pavement work at present is in maintenance and upgrading of existing pavements, and these tasks are largely accomplished using thin overlays of hot-mix asphaltic concrete or rubberized-tar concrete paving mixtures.

### Purpose

2. The purpose of this study was to determine the performance of vibratory rollers in the compaction of asphaltic concrete and rubberized-tar concrete to satisfy the needs of the Air Force. Specifically, it was desired to determine the effects of roller weight, frequency and amplitude of vibration, travel speed, and number of roller passes on the degree of compaction obtained.

## Scope

3. The objectives of the study were accomplished by the following:

- a. Overlaying an existing heavy gear load test section at the U. S. Army Engineer Waterways Experiment Station (WES), which consisted of both rigid and flexible pavements, with asphaltic concrete and rubberized-tar concrete pavements.
- b. Developing laboratory mix designs for each of the paving mixtures used, and collecting construction control data during plant operations as the basis for evaluating in-place density values.
- c. Compacting the overlay pavements with two selected vibratory rollers and conventional steel-wheeled and pneumatic-tired static rollers.
- d. Determing density between passes of each of the rollers and at the completion of rolling operations.

This report describes the compaction rollers and the test section and presents test results, an analysis, and conclusions based on the test results.

# PART II: TEST EQUIPMENT, MATERIALS, AND TEST SECTION

## Compaction Rollers

4. Two vibratory rollers, a Buffalo-Bomag BW210-A and a Dynapac CC-50A, were selected for this study. These rollers are specially designed for the compaction of bituminous paving mixtures and are considered representative of the type vibratory rollers currently being used for this purpose. Comparative tests were also conducted with a conventional steel-wheeled tandem roller and a heavy pneumatic-tired roller. A description of each roller follows.

### Buffalo-Bomag BW210-A

5. The BW210-A roller (Figure 1) is manufactured and distributed by the Koehring Road Division, Springfield, Ohio. It is a self-propelled, single-vibrating-drum roller equipped with two steel drive wheels. Pertinent data on the roller are as follows:

- a. Vibratory drive:
  - (1) Hydraulic system: direct drive from engine.
  - (2) Dynamic force: 5,500 to 42,000 lb.*
  - (3) Frequency: 1,500 to 2,000 vibrations per minute (vpm).
- b. Dimensions and weights:
  - (1) Drum: 59 in. in diameter by 84 in. wide.
  - (2) Drive wheels: 56 in. in diameter by 26 in. wide.
  - (3) Total static weight of roller: 21,700 lb.
  - (4) Static weight of drum: 13,000 lb.
  - (5) Static weight per linear inch of drum: 155 lb.
  - (6) Total static weight at rear axle drive wheel: 8,700 lb.
  - (7) Static weight per linear inch on drive wheels: 167 lb.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

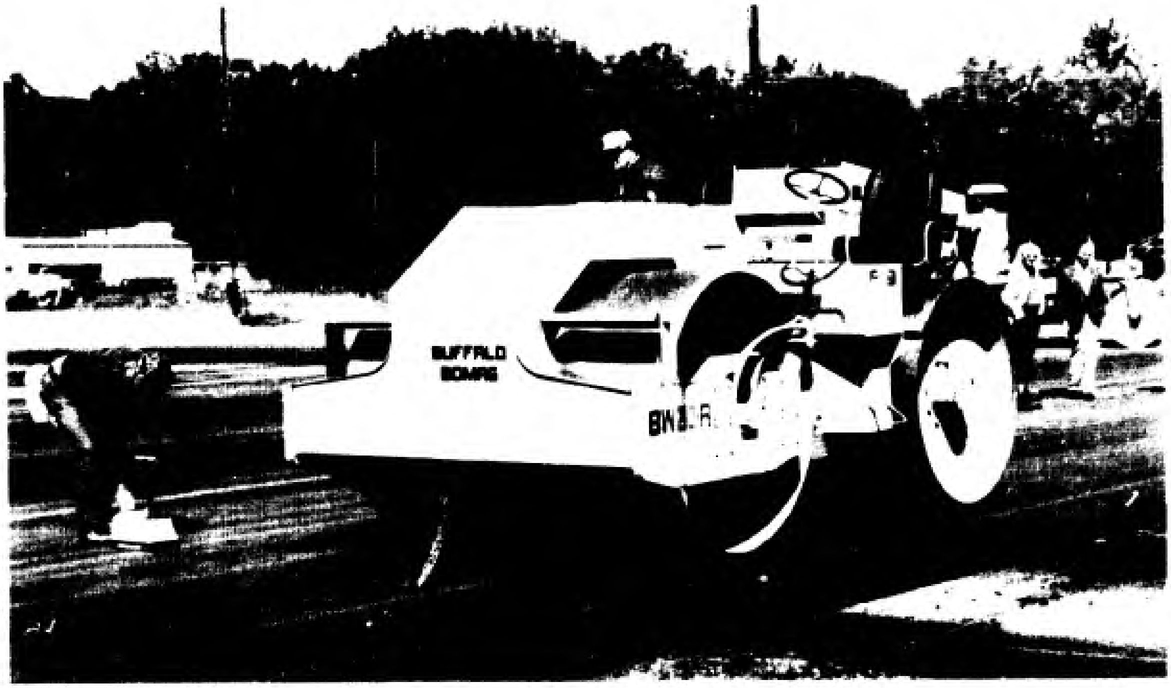

Figure 1. BW210-A vibratory roller

6. The roller contains a unique variable force mechanism which permits controlled variations in amplitude and dynamic force. This is accomplished by a fluid transfer between two opposing chambers. At a high force setting, a rotary control valve retains the mechanism's fluid content in the base chamber where its weight works in combination with steel eccentric weights. This setting yields the maximum eccentric weight and produces maximum amplitude and force for a given vibration frequency. As the rotary control valve is opened, fluid flows from the base chamber, where it has been working with the eccentric weights, to the opposing chamber. The control valve setting determines the amount of flow and, therefore, the total effective eccentric weight. Amplitude and force readings at various control valve settings are reported by the manufacturer to be as follows:

| Control Valve Setting | Amplitude in. | Dynamic Force at 2000 vpm lb | Total Applied Force at 2000 vpm lb |
|---|---|---|---|
| Maximum | 0.0487 | 42,000 | 55,000 |
| 3/4 | 0.0350 | 30,200 | 43,200 |
| 1/2 | 0.0237 | 20,400 | 33,400 |
| 1/4 | 0.0177 | 15,300 | 28,300 |
| 1/8 | 0.0157 | 13,500 | 26,500 |
| Minimum | 0.0116 | 10,000 | 23,000 |

Dynapac CC-50A

7. The CC-50A (Figure 2) is a self-propelled tandem roller. It is manufactured and distributed by Vibro-Plus Products Co., Stanhope, N. J. Weights and dimensions of this roller are as follows:

a. Drum: 60 in. in diameter by 84 in. wide.
b. Wheel base: 12 ft, 4 in.
c. Total static weight of roller: 32,500 lb.
d. Static weight at each drum: 16,250 lb.
e. Static weight per linear inch: 187 lb.

Vibratory forces per drum are shown in the following tabulation:

| Amplitude Range | Centrifugal Force, lb | Frequency vpm | Dynamic Force lb | Total Applied Force lb |
|---|---|---|---|---|
| High | 36,000 | 2,400 | 36,036 | 51,744 |
| Low | 18,000 | 2,400 | 17,976 | 33,684 |

Static rollers

8. The static rollers used in this study were a 25-ton, 7-wheel, self-propelled, pneumatic-tired roller with tires inflated to 90 psi and a Hyster G340A 10-ton, steel-wheeled tandem roller.

Figure 2. CC-50A vibratory roller

## Description of Test Section

### Existing pavements

9. An existing heavy gear load pavement test section at WES was used as the test site for this study. The basic section consisted of both rigid and flexible pavements which were originally designed, constructed, and tested to evaluate the effectiveness of stabilized base courses under both rigid and flexible pavements.* Sections of the

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* C. D. Burns et al., "Comparative Performance of Structural Layers in Pavement Systems; Design, Construction, and Behavior Under Traffic of Pavement Test Sections," Technical Report S-74-8, Vol I, Jun 1974, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

existing pavements are shown in Plate 1. The test section was approximately 300 ft long by 130 ft wide and consisted of a 50-ft width of rigid pavement and an 80-ft width of flexible pavement. Only 60 ft of the flexible pavement was designed and constructed for heavy gear load traffic. A 20-ft-wide strip of light-duty flexible pavement was constructed for a transition between the rigid and the heavy-duty flexible pavements.

10. The existing pavements had each been subjected to traffic in two 10-ft-wide lanes. This traffic resulted in deformation and cracking in all four lanes to the extent that they were considered unsatisfactory for further traffic. A typical view of a flexible pavement test item (this is item 3, lane 2, after 620 coverages) after it had been trafficked with a 240-kip twin-tandem assembly load is shown in Photo 1. Note the depressions and surface cracking of the pavement within the traffic lane. A typical view of a rigid pavement test item (item 4, lane 1, after 6360 coverages) after it had been trafficked with a 200-kip twin-tandem assembly load is shown in Photo 2. Even though the pavements were deformed and badly cracked in the traffic lanes, data from test pits following the traffic period showed that the strength of the stabilized bases and subgrade was generally higher at the end of traffic than when originally constructed. One exception to this, however, was item 1 of the rigid pavement which consisted of a 7-in. thickness of fibrous concrete over a 20-in.-thick membrane-encased soil layer (MESL) base. In this item, the membrane punctured near the end of traffic testing permitting water to enter the encased soil layer and decrease its strength.

11. This test section was considered ideal for the vibratory compaction study since it included both rigid and flexible pavements with both weak and strong foundations and was in such a deteriorated condition that an overlay would be required to restore the pavement for simulated aircraft operations.

12. In preparation for the overlay, all existing test pits in the test section area were filled with crushed stone or stable material and compacted to within 3 in. of the surface. The top 3 in. was filled

with hot-mix asphaltic concrete. A leveling course of hot-mix asphaltic concrete was also placed in the traffic lanes of the flexible pavement and in some depressed areas of the rigid pavement. This provided a relatively smooth surface for the overlay pavement, as shown in Photo 3.

### Overlay pavement

13. The test section was overlaid with asphaltic concrete and rubberized-tar concrete as shown in Plate 1. The type compaction roller and the settings and other variables used during compaction are also indicated in this plate.

## Asphaltic Concrete and Rubberized-Tar Concrete Mixes

### Materials

14. The aggregates used for both mixes were 1/2-in. maximum-size crushed limestone and sand filler. The limestone was purchased from Vulcan Materials Co., Birmingham, Ala., in two sizes, 1/2 in. to No. 4 and minus No. 4 screenings. The sand filler was obtained locally from a Mississippi River sandbar. Grading curves of the materials are shown in Plate 2.

15. The asphalt cement used in the asphaltic concrete mixture was an 85-100 penetration grade obtained from Southland Oil Co., Yazoo City, Miss. The rubberized-tar binder was obtained from Koppers Co., and was preblended at the Koppers plant in Heath, Ohio. The blended material was delivered to WES in a heated tank truck.

### Mix design

16. Laboratory mix designs were selected at WES. A combined aggregate gradation consisting of 40 percent coarse aggregate, 50 percent screenings, and 10 percent sand was used for both mixes. A combined grading curve and specification limits are shown in Plate 3. Laboratory mix design properties for the mixtures are shown in Plates 4 and 5. The optimum binder contents were determined to be 5.5 percent for the asphaltic concrete mixture and 6.4 percent for the rubberized-

tar concrete mixture.

17. The material properties and mix properties of the asphaltic concrete and rubberized-tar concrete met all requirements of Corps of Engineers Guide Specifications CE-807.22, "Bituminous Binder and Surface Courses for Airfields, Heliports, and Tank Roads (Central-Plant Hot-Mix)," and CE-807.25, "Rubberized-tar Concrete Pavements for Airfields and Heliports (Central-Plant Hot-Mix)," except that the percentage of filler (minus No. 200 mesh) slightly exceeded the specification limits.

## Mix Production

18. The bituminous mixtures were produced in a small, screenless, continuous-type mix plant (Figure 3) which is part of the asphalt plant at WES. The plant was calibrated prior to the start of paving to duplicate as near as possible the laboratory mix design. The aggregate gradation was controlled at the cold feed.

### Asphaltic concrete

19. The asphaltic concrete for the test section was mixed and placed during the period 16-18 September 1975. The mixing temperature of aggregate and asphalt was maintained at about 300 to 325°F. The mixture was discharged from the plant into dump trucks at a temperature of about 300°F and transported a distance of about 300 yd to the test site. Samples of the plant-mixed material were taken from the plant at intervals throughout the mixing period for control testing. Tests were made in the laboratory to check asphalt content, Marshall test properties, and aggregate gradation of the plant-mixed material. These data along with the laboratory mix design data are shown in Table 1.

### Rubberized-tar concrete

20. The rubberized-tar concrete was mixed and placed on 23 September 1975. The same mixing procedures were followed for the rubberized-tar concrete as for the asphaltic concrete, except that during mixing the aggregate temperature was maintained between 240 and 250°F and the binder material temperature between 210 and 230°F. The

paving mixture was discharged from the plant at a temperature between 225 and 240°F. Control samples were again taken from the plant and tested in the laboratory, and the results are shown in Table 1.

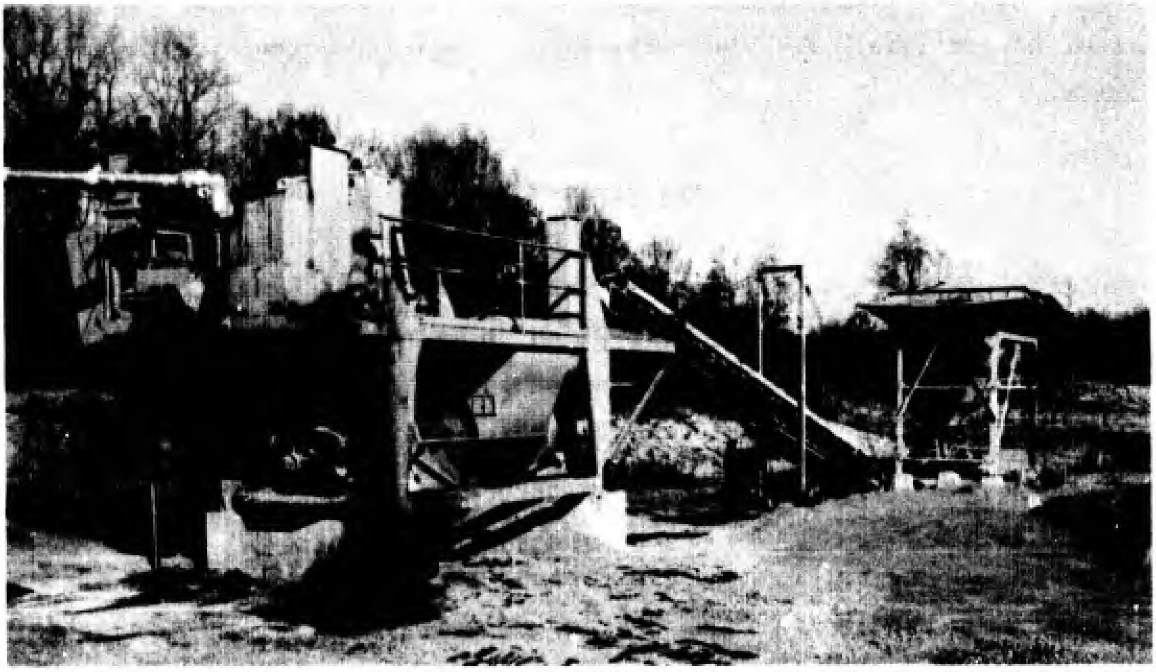


Figure 3. Asphalt plant

## Laydown Procedure

21. The bituminous mixtures were placed in 10-ft-wide paving lanes with the Barber-Green SA-41 asphalt finisher shown in Figure 4. A total of 31 paving lanes were placed. Lane 1 was 300 ft long and extended along the south edge of the existing rigid pavement (Plate 1). The remaining test lanes were approximately 120 ft long. They were placed perpendicular to lane 1 and extended over the heavy-duty rigid pavement and the light-duty and heavy-duty flexible pavements. The average overlay thickness was about 1-1/2 in., except for lanes 29-31 which were placed in thicker lifts to obtain information on the effect

of variation in lift thickness. Lanes 1-18, 29, and 30 were overlaid with asphaltic concrete, and lanes 19-28 and 31 were overlaid with rubberized-tar concrete.

Figure 4. Asphalt finisher

22. The plant production rate for both the asphaltic concrete and the rubberized-tar concrete was about 15 tons per hour, and approximately 45 min was required to mix enough material for a 120-ft lane 1-1/2 in. in thickness. Therefore, the hot-mix material was held in covered trucks until a sufficient quantity was mixed to place a complete lane. The asphalt finisher was operated at a speed of about 20

ft/min and required about 6 min to place a 120-ft-long paving lane.

## Compaction Rolling

23. The two vibratory rollers were operated by personnel from the equipment manufacturers. The static weight steel-wheeled and pneumatic-tired rollers were operated by WES personnel. In all cases, compaction rolling started immediately following the laydown of a test lane. The travel speed and vibration frequency and amplitude of the rollers were controlled to the values indicated in Plate 1.

### Rolling patterns

24. Vibratory rollers (lanes 1-16 and 20-31). The rolling pattern used was as follows: The vibratory roller was to overlap the previously placed lane, or free edge of the first lane, by about 6 in. and travel forward and backward in the same track for the full length of the test lane. It was then to shift to the opposite side of the lane, leaving about 3 or 4 in. of uncompacted material, and travel forward and backward in the same tracks. Since the paving lanes were 10 ft wide, and the drum width for both vibratory rollers was 84 in., this rolling pattern resulted in an overlap of roller passes in the interior portion of the lanes and produced twice the number of coverages in the center of the lanes as were obtained at the edges or joints between them.

25. Static rollers (lanes 17-19). The rolling pattern used was as follows: Two coverages of breakdown rolling were applied with the 10-ton, steel-wheeled tandem roller followed by 6 coverages of the 25-ton, pneumatic-tired roller and 2 coverages of final rolling with the steel-wheeled tandem roller.

### Compaction control

26. During the rolling operations, a Troxler nuclear gage (Figure 5) was used to measure density and to show the effect of roller passes on density. The test procedure was to take two 30-sec count readings at three predetermined locations in each test lane after each 2 passes of the roller. Compaction was continued with the vibratory

rollers until the nuclear count readings leveled out or indicated a decrease in density, at which time rolling was stopped.

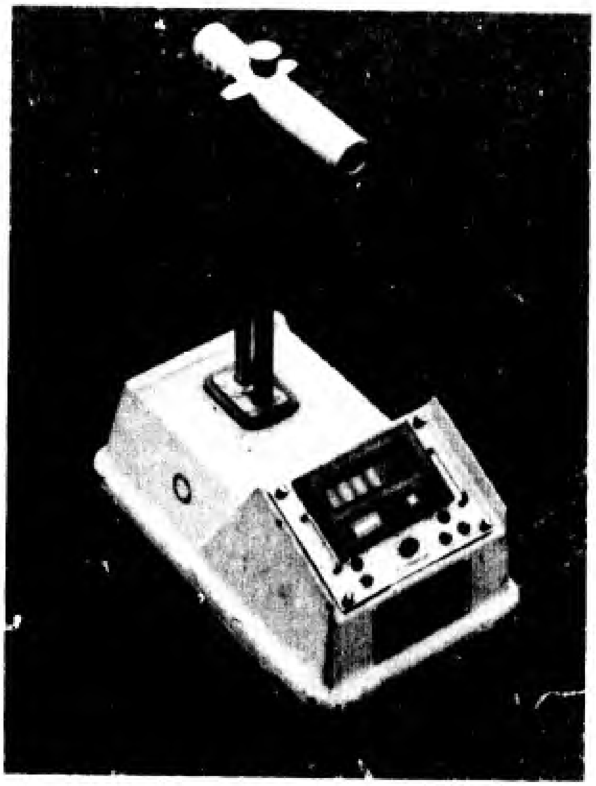


Figure 5. Troxler nuclear gage

Climatic conditions

27. The weather conditions during the placement and compaction of the asphaltic concrete overlay (16-18 September) were partly cloudy and mild with an ambient temperature of 65 to 80°F. The asphaltic concrete mat temperature at the start of rolling was 270 to 280°F. It was considerably cooler on 23 September during the placement and compaction of the rubberized-tar concrete, with an ambient temperature of 55 to 65°F and northerly winds of 10 to 20 mph. The temperature of the rubberized-tar concrete mat at the start of rolling was about 210°F.

### General observations

28. Both paving mixtures appeared quite stable under the rolling operations. There was no shoving or excessive displacement of mix under any of the rollers where the mix was placed over a firm foundation. Some checking and cracking of the asphaltic concrete did develop during compaction rolling with the BW210-A vibratory roller where the mix was placed over a weak foundation, as shown in Photo 4. This was caused by excessive deflection of the base pavement under the vibratory roller. In general, the surface texture of asphaltic concrete and rubberized-tar concrete pavements compacted by the vibratory rollers was very good, as shown in Photos 5 and 6, respectively.

## Sampling and Testing

29. After compaction, two or more 6-in.-diam core samples were cut from each lane at the same three locations that nuclear gage readings were obtained. These locations were at 56, 83, and 106 ft north of the test section baseline (Plate 1); i. e., one location each over the original heavy-duty rigid pavement, light-duty flexible pavement, and heavy-duty flexible pavement. These cores and the previously taken nuclear gage reading were all obtained near the center of the 10-ft-wide traffic lanes where the maximum number of roller passes was applied. Some additional cores were cut from joints between the lanes and from the overlay over the light-duty flexible pavement where a weak foundation existed.

30. Pavement thickness, density, and voids determinations were made on all pavement cores. In addition, extraction tests were conducted on the top and bottom portions of selected cores of the asphaltic concrete to determine if there was any migration of asphalt binder material to the surface of the pavement due to vibratory compaction.

# PART III: TEST RESULTS AND ANALYSIS

## Test Results

31. A summary of the basic test data is shown in Table 2. These data are mostly self-explanatory; however, further explanation of some of the data follows:

- a. The number of passes indicated for the vibratory rollers is the actual number of passes of the roller and, in the case of the BW210-A, which is a single-vibrating-drum roller, indicates the number of coverages of the vibrating drum. The CC-50A has dual vibrating drums and therefore applies 2 coverages of a vibrating drum over an area the width of the drum on each pass of the roller. Also, as previously discussed in paragraph 24, only half the number of passes applied over the interior portions of the lanes were applied over the joints between the lanes.
- b. The nuclear gage readings shown correspond to the actual laboratory density values determined from the pavement cores.
- c. The density values shown are average values determined from two 6-in.-diam core samples.
- d. The percent laboratory density is based on 75-blow Marshall compaction of samples of the plant-mixed material.

32. The results of the extraction tests on selected cores of the asphaltic concrete overlay are shown in Table 3. The uniformity of the asphalt content from top to bottom of the cores of the pavement indicates that there was no migration of the binder to the surface.

33. Density calibration curves for the Troxler nuclear gage developed for both overlay pavements are shown in Plates 6 and 7. These curves were developed by plotting the nuclear gage count ratio values, as determined at the end of compaction rolling, versus the density values, as determined from laboratory tests of pavement cores. These data show a variation in density of about ±2 pcf from the best-fit line through the data points. The data also indicate that the nuclear readings were not materially affected by the type of pavement upon which the overlay was placed, i. e. rigid or flexible. However, there was a

noticeable difference between the calibration curve for the asphaltic concrete (Plate 6) and that for the rubberized-tar concrete (Plate 7). A comparison of Troxler's calibration curve (furnished with the nuclear gage) with those developed for the asphaltic concrete and rubberized-tar concrete pavements in this study is shown in Plate 8.

## Analysis of Data

34. The basic data collected in this study have been plotted to show the effects of number of roller passes, vibration frequency and amplitude, travel speed, and type of foundation on the density obtained with the vibratory rollers. These effects are discussed in the following paragraphs.

### Effect of number of roller passes

35. Plots of density versus roller passes are shown in Plates 9-14. These density values are based on the nuclear count readings taken generally after every 2 passes of the rollers. The nuclear count readings were converted to count ratios, and the density values were then determined from the calibration curves shown in Plates 6 and 7. The values show a fairly consistent pattern with respect to the effect of the number of roller passes on density.

36. In lanes 2-11, which comprised a section of asphaltic concrete overlay compacted with the BW210-A at the travel speed, frequency, and amplitude indicated in Plates 9 and 10, the maximum density was generally obtained at 8 to 12 passes. It should be noted that in lane 10, the vibrator mechanism was shut down and the roller was operated as a static roller. As previously stated, the nuclear gage readings were taken primarily to determine when maximum density had been obtained and rolling could be stopped. Rolling was therefore discontinued after 8 to 12 passes.

37. In lanes 12-16 (Plates 11 and 12), which comprised a section of asphaltic concrete overlay compacted with the CC-50A, the maximum density was obtained at about 6 to 8 passes of the roller. As would be expected, the dual drums of this roller effectively reduced the

number of passes required to obtain maximum density. Note that in lane 16 (Plate 12) the CC-50A was operated as a static compactor.

38. In lanes 17 and 18 (Plate 12), which were asphaltic concrete overlay compacted with the static rollers, a conventional rolling pattern was used.

39. Plates 13 and 14 show density results obtained on rubberized-tar pavement compacted with the BW210-A and CC-50A rollers, respectively.

### Effect of vibration frequency

40. Plots showing the effect of frequency on compaction of the overlays are shown in Plate 15. These data are from traffic lanes 4, 5, 6, and 22, which were compacted with the BW210-A vibratory roller. As is indicated, the frequency was varied from 1500 to 2000 vpm on the asphaltic concrete overlay, but for the rubberized-tar concrete overlay, the roller was only operated at 2000 vpm. A travel speed of 1.5 mph and an amplitude setting of 1/4 were maintained. These data show that, for the asphaltic concrete overlay over flexible pavement, slightly better compaction was obtained at about 1750 vpm. There were no indications of surface rippling or undulations for the range of frequency settings used. There was little or no effect from varying the frequency over the rigid pavement. However, it should be noted for the asphaltic concrete overlay over the rigid pavement that the density values are lower than those indicated for the overlay over the flexible pavement. This difference is due to the fact that the overlay pavement was placed over a weak section of fibrous concrete. It can also be seen that the density developed at 2000 vpm in the rubberized-tar concrete overlay pavement was considerably higher than that in the asphaltic concrete pavement. The explanation for this difference is that the rubberized-tar concrete pavement was placed over a high-strength section of rigid pavement.

### Effect of amplitude

41. Plots showing percent laboratory density versus amplitude setting for the BW210-A roller are shown in Plate 16. These data indicate that for a given travel speed and vibration frequency the best compaction was obtained at the higher amplitude settings (one-half to maximum). This trend was evident for both the asphaltic concrete and

the rubberized-tar concrete pavements.

Effect of travel speed

42. The travel speed of both the BW210-A and the CC-50A rollers was varied from 1.5 to 3.0 mph. Plots showing the percent laboratory density versus travel speed for the BW210-A roller for both overlays over both rigid and flexible pavement are shown in Plate 17. From these data, it can be seen that better compaction was obtained at a travel speed of 3 mph than at 1.5 mph.

43. Similar data showing the effect of travel speed with the CC-50A roller are shown in Plate 18. The CC-50A has only two amplitude settings, high and low. The effect of amplitude setting at different travel speeds is also indicated in Plate 18. From these data, it can be seen that the best compaction with the CC-50A roller occurred at travel speeds of 2 to 3 mph and generally at the high amplitude setting.

Effect of type foundation

44. The density data shown in Table 2 at locations 106, 83, and 56 ft north of the baseline are, respectively, for the overlay pavements placed over high-strength, heavy-duty flexible pavement, light-duty flexible pavement, and rigid pavement (with the exception of lane 31, all of which was over high-strength flexible pavement). For lanes 3-7, the rigid pavement consisted of fibrous concrete over a MESL base, which was a rather low-strength wet foundation as previously discussed. For lanes 2 and 8-30, the rigid pavement was considered as a high-strength, heavy-duty pavement. This layout provided 24 lanes with which comparisons could be made of the density developed in thin overlays over high-strength rigid pavement and high-strength flexible pavement using the same compaction efforts.

45. A plot of percent density of the bituminous overlay over heavy-duty rigid pavement versus percent density of the overlay over heavy-duty flexible pavement is shown in Plot a of Plate 19. It can be seen that higher densities were developed in the overlay pavement constructed over the heavy-duty flexible pavement in 16 lanes and in that constructed over the heavy-duty rigid pavement in 7 lanes. A similar comparison for light-duty flexible pavement and heavy-duty flexible

pavement is shown in Plot b of Plate 19. In this case, higher densities were obtained in the overlay over the heavy-duty flexible pavement in 21 lanes and in the overlay over the light-duty flexible pavement in 8 lanes. A comparison for the light-duty flexible pavement and the heavy-duty rigid pavement is shown in Plot c of Plate 19. These data show that higher densities were developed in the overlay over the heavy-duty rigid pavement in 17 lanes and over the light-duty flexible pavement in 5 lanes.

46. The comparisons shown in Plate 19 reveal that better compaction was obtained in the overlay pavements over the heavy-duty flexible pavement foundation than was obtained over either the heavy-duty rigid pavement or the light-duty flexible pavement foundation. The lowest densities were developed over the light-duty flexible pavement. These trends hold for both static and vibratory compaction and indicate that the density obtained for a given compaction effort is related to the strength of the foundation layer, with higher densities being obtained over a higher strength foundation.

## Discussion and Summary of Test Results

47. For the asphaltic concrete overlay, a mean of 97.3 percent of laboratory density was obtained with all combinations of travel speed, vibratory frequency, and amplitude with both the BW210-A and the CC-50A vibratory rollers, except for the density in joints between paving lanes and in locations where the overlay was placed over a weak foundation. The standard deviation was 0.8. If the 1/4 amplitude compaction results are excluded, the mean density would be 97.7 and the standard deviation would remain 0.8. The actual densities developed in the joints and over the weak foundation material varied from 93 to 97 percent of laboratory density, as indicated in Table 2. The reason for the low densities in the joints was the roller pattern used in compacting the 10-ft-wide paving lanes. As previously discussed, only half as many roller passes were applied over the joints as over the interior portions of the lanes. and the mix chilled excessively along the uncompacted lane edge prior

to the placing and compacting of the adjacent lane. The low densities over the weak foundation material were due to excessive deflection of the pavement under compaction.

48. Somewhat better compaction was obtained with both vibratory rollers on the rubberized-tar concrete overlay than on the asphaltic concrete overlay. The actual densities developed in the rubberized-tar concrete overlay varied from about 97 to 100 percent of laboratory density, except for the joints between lanes where they were low for the same reasons as the asphaltic concrete. A mean density of 98.5 percent was obtained with all combinations of travel speed, vibration frequency, and amplitude with both the BW210-A and the CC-50A, except for the density in joints between the paving lanes. The standard deviation was 1.0.

49. Both vibratory rollers produced higher densities with the drum vibrating than they did when operated statically.

50. The densities developed with the static rollers varied from about 95 to 97 percent of laboratory density for both overlays as indicated for lanes 17, 18, and 19 in Table 2. These are lower densities than were obtained with vibratory rollers.

51. In general, higher densities were developed in the overlay pavements constructed over the heavy-duty flexible pavement than in the overlays placed over rigid pavement or light-duty flexible pavement.

## PART IV: CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

52. The following conclusions are believed warranted based on the data presented in this report:

- a. Vibratory rollers of the type used in this study are satisfactory for compaction of high-quality bituminous concrete pavements, and if properly used, they can provide densities meeting the requirements of the Corps of Engineers and the Air Force.
- b. The degree of compaction in bituminous pavements to be obtained with a given vibratory roller is dependent upon the number of roller passes, the vibrator frequency and amplitude, and the roller travel speed. In this study, the best results were obtained at roller speeds of 2 to 3 mph, at vibration frequencies of 1750 to 2400 vpm, and at the higher amplitude settings.
- c. For a given vibratory roller, the pavement density will increase with an increase in the number of roller passes up to a maximum density and with further rolling will tend to level off or in some cases actually decrease in density.
- d. Higher pavement densities can be obtained with the vibratory rollers used in this study in both types of overlay pavement than were obtained by compaction with the conventional steel-wheeled and pneumatic-tired rollers.
- e. The degree of compaction obtained with the vibratory rollers on both types of overlay pavement will be about the same for overlay thicknesses of 1-1/2 to 4 in.
- f. The degree of compaction obtained with either static or vibratory rollers in bituminous overlay pavements is influenced by the strength of the foundation layer. Higher densities will be obtained with a given compaction effort for mixes placed over higher strength foundations.
- g. The nuclear gage is valuable in compaction control for showing the effect of roller passes and other roller variables on density and thus for determining when rolling should be stopped.

### Recommendations

53. Based on the results of this study, it is recommended that

Corps of Engineers Guide Specifications CE-807.22, "Bituminous Binder and Surface Courses for Airfields, Heliports, and Tank Roads (Central-Plant Hot-Mix)," and CE-807.25, "Rubberized-Tar Concrete Pavements for Airfields and Heliports (Central-Plant Hot-Mix)," be revised to permit the use of vibratory rollers for compaction.

54. The vibratory rollers should meet the following requirements:

- a. Self-propelled, single or dual vibrating drums, and steel drive wheels, as applicable.
- b. Drum diameter of not less than 54 in.
- c. Vibration frequency of at least 1500 vpm.
- d. Static drum load of at least 150 lb per linear in.
- e. Variable amplitude.

55. Compaction of bituminous concrete mixtures should be controlled using a nuclear density device and density growth curves.

56. The practical density range obtained with vibratory rollers on bituminous concrete should be 98 ± 1 percent of the density of a specimen of the same mixture compacted in the laboratory using the 75-blow Marshall effort.

## Table 1

**Summary of Mix Design and Plant Control Data (75-Blow Marshall Design)**

| Source of Sample | Binder Content percent | Density pcf | Percent Voids | | Stability lb | Flow $10^{-2}$ in. | Aggregate Gradation, Percent Passing Cited Sieve | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total Mix | Filled | | | 1/2 in. | 3/8 in. | No. 4 | No. 16 | No. 50 | No. 100 | No. 200 |
| **Asphaltic concrete** | | | | | | | | | | | | | |
| Lab mix design | 5.5 | 150.5 | 3.8 | 76.0 | 2400 | 12 | 100 | 90 | 64 | 37 | 18 | 12 | 7 |
| Plant-mixed and lab compacted samples | | | | | | | | | | | | | |
| No. 1 | 5.4 | 151.6 | 3.1 | 80.2 | 2353 | 15 | 100 | 90 | 63 | 36 | 16 | 10 | 7 |
| No. 2 | 5.6 | 151.6 | 2.9 | 82.2 | 2535 | 14 | 100 | 90 | 64 | 35 | 15 | 10 | 7 |
| No. 3 | 6.0 | 151.4 | 2.3 | 85.8 | 2071 | 17 | 100 | 92 | 68 | 40 | 18 | 12 | 8 |
| No. 4 | 5.6 | 151.8 | 2.7 | 83.1 | 2383 | 13 | 100 | 90 | 65 | 37 | 17 | 11 | 7 |
| No. 5 | 5.8 | 151.5 | 2.6 | 84.0 | 2257 | 17 | 100 | 91 | 68 | 41 | 20 | 13 | 8 |
| No. 6 | 5.8 | 151.2 | 2.8 | 83.0 | 2389 | 16 | 100 | 93 | 68 | 38 | 17 | 11 | 7 |
| No. 7 | 6.0 | 151.6 | 2.2 | 86.5 | 2341 | 16 | 100 | 93 | 69 | 40 | 19 | 12 | 8 |
| No. 8 | 5.6 | 151.7 | 2.7 | 82.9 | 2460 | 18 | 100 | 90 | 64 | 37 | 18 | 12 | 8 |
| **Rubberized-tar concrete** | | | | | | | | | | | | | |
| Lab mix design | 6.4 | 152.2 | 4.0 | 76.0 | 2825 | 15 | 100 | 90 | 64 | 37 | 18 | 12 | 7 |
| Plant-mixed and lab compacted samples | | | | | | | | | | | | | |
| No. 1 | 4.3 | 151.0 | 6.9 | 54.4 | 2717 | 13 | 100 | 92 | 68 | 41 | 21 | 13 | 8 |
| No. 2 | 5.4 | 152.3 | 5.0 | 67.9 | 3300 | 16 | 100 | 92 | 70 | 42 | 20 | 13 | 8 |
| No. 3 | 5.8 | 153.2 | 4.0 | 74.0 | 2605 | 23 | 100 | 86 | 67 | 38 | 18 | 12 | 7 |
| No. 4 | 5.8 | 153.0 | 4.2 | 73.1 | 2330 | 17 | 100 | 91 | 65 | 36 | 16 | 10 | 7 |

Table 2

Vibratory Compaction Study

Summary of Test Data

| Test Lane | Location | | Type Base Pavement | Compaction Roller Data | | | | Type Overlay Pavement | No. of Roller Passes | Field Density Data | | | | | Percent Laboratory Density | Percent Air Voids |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Station | Offset ft | | Type | Travel Speed mph | Amplitude Setting | Frequency vpm | | | Nuclear Gage Count | Nuclear Gage Count Ratio | Field Cores Core No. | Field Cores Thickness in. | Field Cores Density pcf | | |
| 1 | 1+25 | 15 | Rigid | BW210-A | 3.0 | 1/4 | 2000 | Asphaltic concrete | 10 | 177 | 1.226 | 21 & 22 | 1-3/8 | 145.6 | 96.0 | 6.4 |
| 1 | 1+75 | 15 | Rigid | CC-50A | 1.5 | Low | 2400 | Asphaltic concrete | 10 | 167 | 1.157 | 83 & 84 | 2.0 | 148.8 | 98.2 | 4.6 |
| 1 | 2+10 | 15 | Rigid | CC-50A | 2.0 | Low | 2400 | Asphaltic concrete | 10 | 168 | 1.165 | 85 & 86 | 1-7/8 | 146.9 | 97.0 | 5.5 |
| 1 | 2+75 | 15 | Rigid | CC-50A | 3.0 | Low | 2400 | Asphaltic concrete | 7 | 170 | 1.181 | 87 & 88 | 1-3/4 | 146.1 | 96.4 | 6.3 |
| 2 | 0+00 | 106N | Flexible | BW210-A | 3.0 | 1/4 | 2000 | Asphaltic concrete | 14 | 165 | 1.146 | 1 & 2 | 1-1/2 | 149.5 | 98.6 | 4.1 |
| | 0+00 | 83N | Flexible | BW210-A | 3.0 | 1/4 | 2000 | | 14 | 171 | 1.183 | 3 & 4 | 1-5/8 | 148.0 | 97.8 | 5.0 |
| | 0+00 | 56N | Rigid | BW210-A | 3.0 | 1/4 | 2000 | | 14 | 171 | 1.183 | 5 & 6 | 1-1/2 | 148.9 | 98.3 | 4.6 |
| 2 & 3 | Joint | 106N | Flexible | BW210-A | 3.0 | 1/4 | 2000 | Asphaltic concrete | 5 | -- | -- | 191 & 192 | 1-1/2 | 142.0 | 93.7 | 9.0 |
| 3 | 0+10 | 106N | Flexible | BW210-A | 3.0 | 1/4 | 2000 | Asphaltic concrete | 10 | 169 | 1.173 | 7 & 8 | 1-3/8 | 147.1 | 97.0 | 5.5 |
| | 0+10 | 83N | Flexible | BW210-A | 3.0 | 1/4 | 2000 | | 10 | 170 | 1.181 | 9 & 10 | 1-3/4 | 147.5 | 97.3 | 5.3 |
| | 0+10 | 56N | Rigid | BW210-A | 3.0 | 1/4 | 2000 | | 10 | 171 | 1.183 | 11 & 12 | 1-1/2 | 146.1 | 96.4 | 6.3 |
| 3 & 4 | Joint | 90N | Flexible | BW210-A | 1.5 | 1/4 | 2000 | Asphaltic concrete | 4 | -- | -- | 193 & 194 | 1-1/2 | 140.0 | 92.4 | 11.7 |
| 4 | 0+20 | 106N | Flexible | BW210-A | 1.5 | 1/4 | 2000 | Asphaltic concrete | 8 | 174 | 1.207 | 13 & 14 | 1-5/8 | 144.4 | 95.3 | 7.3 |
| | 0+20 | 83N | Flexible | BW210-A | 1.5 | 1/4 | 2000 | | 8 | 174 | 1.207 | 15 & 16 | 1-3/4 | 145.3 | 96.0 | 6.7 |
| | 0+20 | 65N* | Flexible | BW210-A | 1.5 | 1/4 | 2000 | | 8 | -- | -- | 222 | 1-1/2 | 144.1 | 95.1 | 7.5 |
| | 0+20 | 56N* | Rigid | BW210-A | 1.5 | 1/4 | 2000 | | 8 | 170 | 1.181 | 17 & 18 | 1-1/2 | 144.7 | 95.6 | 7.2 |
| | 0+20 | 22N | Rigid | BW210-A | 1.5 | 1/4 | 2000 | | 8 | -- | -- | 219 | 1-1/2 | 145.6 | 96.3 | 6.1 |
| 4 & 5 | Joint | 90N | Flexible | BW210-A | 1.5 | 1/4 | 2000 | Asphaltic concrete | 5 | -- | -- | 195 & 196 | 1-1/2 | 141.4 | 93.4 | 9.8 |
| 5 | 0+30 | 106N | Flexible | BW210-A | 1.5 | 1/4 | 2000 | Asphaltic concrete | 10 | 167 | 1.157 | 23 & 24 | 1-1/2 | 147.1 | 97.1 | 5.6 |
| | 0+30 | 83N | Flexible | BW210-A | 1.5 | 1/4 | 2000 | | 10 | 175 | 1.215 | 25 & 26 | 1-1/2 | 145.9 | 96.3 | 6.4 |
| | 0+30 | 65N* | Flexible | BW210-A | 1.5 | 1/4 | 2000 | | 10 | -- | -- | 223 | 1-3/8 | 141.3 | 93.0 | 11.7 |
| | 0+30 | 56N* | Rigid | BW210-A | 1.5 | 1/4 | 2000 | | 10 | -- | -- | 27 & 28 | 1-1/8 | 143.2 | 94.6 | 8.0 |
| | 0+30 | 35N* | Rigid | BW210-A | 1.5 | 1/4 | 2000 | | 10 | -- | -- | 29 & 30 | 1-1/4 | 144.0 | 95.0 | 7.6 |
| 6 | 0+40 | 106N | Flexible | BW210-A | 1.5 | 1/4 | 1750 | Asphaltic concrete | 10 | 171 | 1.183 | 31 & 32 | 2-1/16 | 148.7 | 98.2 | 4.6 |
| | 0+40 | 83N | Flexible | BW210-A | 1.5 | 1/4 | 1750 | | 10 | 170 | 1.181 | 33 & 34 | 2.0 | 148.0 | 97.7 | 5.0 |
| | 0+40 | 65N* | Flexible | BW210-A | 1.5 | 1/4 | 1750 | | 10 | -- | -- | 224 | 1-1/2 | 144.2 | 95.0 | 7.6 |
| | 0+40 | 56N* | Rigid | BW210-A | 1.5 | 1/4 | 1750 | | 10 | 171 | 1.183 | 35 & 36 | 1.0 | 144.7 | 95.5 | 7.1 |
| 7 | 0+50 | 106N | Flexible | BW210-A | 1.5 | 1/4 | 1500 | Asphaltic concrete | 12 | 167 | 1.157 | 37 & 38 | 1-7/8 | 147.2 | 97.2 | 5.5 |
| | 0+50 | 83N | Flexible | BW210-A | 1.5 | 1/4 | 1500 | | 12 | 166 | 1.149 | 39 & 40 | 1-7/8 | 147.4 | 97.3 | 5.3 |
| | 0+50 | 65N* | Flexible | BW210-A | 1.5 | 1/4 | 1500 | | 12 | -- | -- | 225 | 1-5/8 | 144.6 | 95.3 | 7.1 |
| | 0+50 | 56N* | Rigid | BW210-A | 1.5 | 1/4 | 1500 | | 12 | 170 | 1.181 | 41 & 42 | 1.0 | 144.8 | 95.4 | 7.2 |

(Continued)

Note: All data for pavement cores are average of two 6-in.-diam cores. Percent laboratory density is based on 75-blow Marshall compaction effort.
* Overlay over weak foundation.

(Sheet 1 of 4)

Table 2 (Continued)

| | Location | | | Compaction Roller Data | | | | | | Field Density Data | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Nuclear Gage | | Field Cores | | | | |
| Test Lane | Station | Offset ft | Type Base Pavement | Type | Travel Speed mph | Amplitude Setting | Frequency vpm | Type Overlay Pavement | No. of Roller Passes | Count | Count Ratio | Core No. | Thickness in. | Density pcf | Percent Laboratory Density | Percent Air Voids |
| 8 | 0+60 | 106N | Flexible | BW210-A | 1.5 | 1/2 | 2000 | Asphaltic concrete | 12 | 167 | 1.157 | 43 & 44 | 2-3/16 | 147.7 | 97.5 | 5.2 |
| | 0+60 | 83N | Flexible | BW210-A | 1.5 | 1/2 | 2000 | | 12 | 166 | 1.149 | 45 & 46 | 2-1/4 | 147.5 | 97.4 | 5.3 |
| | 0+60 | 56N | Rigid | BW210-A | 1.5 | 1/2 | 2000 | | 12 | 168 | 1.165 | 47 & 48 | 1-1/4 | 148.3 | 98.0 | 4.8 |
| 8 & 9 | Joint | 100N | Flexible | BW210-A | 1.5 | 1/2 | 2000 | Asphaltic concrete | 5 | -- | -- | 197 & 198 | 2.0 | 143.0 | 94.5 | 8.2 |
| 9 | 0+70 | 106N | Flexible | BW210-A | 1.5 | 3/4 | 2000 | Asphaltic concrete | 10 | 170 | 1.181 | 49 & 50 | 1-3/4 | 146.0 | 96.3 | 6.4 |
| | 0+70 | 83N | Flexible | BW210-A | 1.5 | 3/4 | 2000 | | 10 | 168 | 1.165 | 51 & 52 | 2-1/4 | 147.4 | 97.3 | 5.3 |
| | 0+70 | 56N | Rigid | BW210-A | 1.5 | 3/4 | 2000 | | 10 | 173 | 1.199 | 53 & 54 | 1-1/4 | 147.0 | 97.0 | 5.5 |
| 9 & 10 | Joint | 90N | Flexible | BW210-A | 1.5 | 3/4 | 2000 | Asphaltic concrete | 5 | -- | -- | 199 & 200 | 1-3/4 | 143.0 | 94.5 | 8.1 |
| 10 | 0+80 | 106N | Flexible | BW210-A | 1.5 | Static Weight Only | | Asphaltic concrete | 12 | 169 | 1.173 | 55 & 56 | 2-1/2 | 146.2 | 96.6 | 6.1 |
| | 0+80 | 56N | Rigid | BW210-A | 1.5 | | | | 12 | 177 | 1.226 | 57 & 58 | 2-1/8 | 146.2 | 96.6 | 6.1 |
| 11 | 0+90 | 106N | Flexible | BW210-A | 3.0 | 3/8 | 2000 | Asphaltic concrete | 10 | 169 | 1.173 | 59 & 60 | 2-1/4 | 147.6 | 97.4 | 5.3 |
| | 0+90 | 83N | Flexible | BW210-A | 3.0 | 3/8 | 2000 | | 10 | 166 | 1.149 | 61 & 62 | 2-1/4 | 149.1 | 98.4 | 4.4 |
| | 0+90 | 56N | Rigid | BW210-A | 3.0 | 3/8 | 2000 | | 10 | 173 | 1.199 | 63 & 64 | 1-1/2 | 147.2 | 97.2 | 5.5 |
| 11 & 12 | Joint | 50N | Rigid | CC-50A | 3.0 | Low | 2400 | Asphaltic concrete | 4 | -- | -- | 201 & 202 | 1-1/2 | 146.5 | 96.7 | 6.1 |
| 12 | 1+00 | 106N | Flexible | CC-50A | 3.0 | Low | 2400 | Asphaltic concrete | 8 | 168 | 1.165 | 65 & 66 | 2-1/8 | 147.5 | 97.4 | 5.3 |
| | 1+00 | 83N | Flexible | CC-50A | 3.0 | Low | 2400 | | 8 | 172 | 1.191 | 67 & 68 | 2-1/8 | 146.0 | 96.4 | 6.3 |
| | 1+00 | 56N | Rigid | CC-50A | 3.0 | Low | 2400 | | 8 | 171 | 1.183 | 69 & 70 | 1-1/2 | 146.4 | 96.7 | 6.1 |
| 13 | 1+10 | 106N | Flexible | CC-50A | 2.0 | Low | 2400 | Asphaltic concrete | 8 | 167 | 1.157 | 71 & 72 | 2-1/4 | 147.3 | 97.2 | 5.3 |
| | 1+10 | 83N | Flexible | CC-50A | 2.0 | Low | 2400 | | 8 | 169 | 1.173 | 73 & 74 | 2.0 | 149.2 | 98.5 | 6.3 |
| | 1+10 | 56N | Rigid | CC-50A | 2.0 | Low | 2400 | | 8 | 169 | 1.173 | 75 & 76 | 1.0 | 146.8 | 96.9 | 6.1 |
| 14 | 1+20 | 106N | Flexible | CC-50A | 1.5 | Low | 2400 | Asphaltic concrete | 10 | 168 | 1.165 | 77 & 78 | 2.0 | 147.5 | 97.3 | 5.3 |
| | 1+20 | 83N | Flexible | CC-50A | 1.5 | Low | 2400 | | 10 | 169 | 1.173 | 79 & 80 | 2.0 | 146.1 | 96.4 | 6.3 |
| | 1+20 | 56N | Rigid | CC-50A | 1.5 | Low | 2400 | | 10 | 173 | 1.199 | 81 & 82 | 1-3/8 | 146.8 | 96.9 | 5.8 |
| 14 & 15 | Joint | 50N | Rigid | CC-50A | 1.5 | High | 2400 | Asphaltic concrete | 4 | -- | -- | 204 & 205 | 1-1/2 | 141.0 | 93.1 | 11.6 |
| 15 | 1+30 | 106N | Flexible | CC-50A | 1.5 | High | 2400 | Asphaltic concrete | 6 | 171 | 1.183 | 89 & 90 | 1-1/4 | 148.2 | 98.0 | 4.7 |
| | 1+30 | 83N | Flexible | CC-50A | 1.5 | High | 2400 | | 6 | 175 | 1.215 | 91 & 92 | 1-3/8 | 148.8 | 98.6 | 4.1 |
| | 1+30 | 56N | Rigid | CC-50A | 1.5 | High | 2400 | | 6 | 167 | 1.157 | 93 & 94 | 1-1/4 | 150.5 | 99.3 | 3.4 |
| 16 | 1+40 | 106N | Flexible | CC-50A | 1.5 | Static Weight Only | | Asphaltic concrete | 8 | 175 | 1.215 | 95 & 96 | 2.0 | 144.5 | 95.4 | 7.2 |
| | 1+40 | 83N | Flexible | CC-50A | 1.5 | | | | 8 | 176 | 1.218 | 97 & 98 | 1-3/4 | 143.1 | 94.5 | 8.1 |
| | 1+40 | 56N | Rigid | CC-50A | 1.5 | | | | 8 | 177 | 1.226 | 99 & 100 | 1-1/4 | 143.8 | 94.9 | 7.7 |
| 17 | 1+50 | 106N | Flexible | SWPT** | 3.0 | -- | -- | Asphaltic concrete | 2-6-2 | 171 | 1.183 | 101 & 102 | 2.0 | 146.7 | 96.7 | 5.9 |
| | 1+50 | 83N | Flexible | SWPT** | 3.0 | -- | -- | | 2-6-2 | 172 | 1.191 | 103 & 104 | 1-3/4 | 143.5 | 94.7 | 8.0 |
| | 1+50 | 56N | Rigid | SWPT** | 3.0 | -- | -- | | 2-6-2 | 176 | 1.218 | 105 & 106 | 1-1/2 | 144.1 | 95.1 | 7.5 |
| 17 & 18 | Joint | 50N | Rigid | SWPT** | 3.0 | -- | -- | Asphaltic | 2-6-2 | -- | -- | 206 & 207 | 1-1/2 | 140.9 | 93.0 | 11.7 |

(Continued)

** Steel-wheeled and pneumatic-tired rollers.

(Sheet 2 of 4)

Table 2 (Continued)

| | | | | Compaction Roller Data | | | | | | Field Density Data | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | | | | | | | Nuclear Gage | | Field Cores | | | | |
| Test Lane | Station | Offset ft | Type Base Pavement | Type | Travel Speed mph | Amplitude Setting | Frequency vpm | Type Overlay Pavement | No. of Roller Passes | Count | Count Ratio | Core No. | Thickness in. | Density pcf | Percent Laboratory Density | Percent Air Voids |
| 18 | 1+60 | 106N | Flexible | SWPT** | 3.0 | -- | -- | Asphaltic concrete | 2-6-2 | 172 | 1.191 | 107 & 108 | 2-3/4 | 145.6 | 96.1 | 6.5 |
| | 1+60 | 83N | Flexible | SWPT** | 3.0 | -- | -- | | 2-6-2 | 170 | 1.181 | 109 & 110 | 2.0 | 144.7 | 95.5 | 7.1 |
| | 1+60 | 56N | Rigid | SWPT** | 3.0 | -- | -- | | 2-6-2 | 172 | 1.191 | 111 & 112 | 1-3/8 | 145.3 | 95.9 | 6.4 |
| 19 | 1+70 | 106N | Flexible | SWPT** | 3.0 | -- | -- | Rubberized-tar concrete | 2-6-2 | 176 | 1.218 | 113 & 114 | 1-3/4 | 146.7 | 96.8 | 9.0 |
| | 1+70 | 83N | Flexible | SWPT** | 3.0 | -- | -- | | 2-6-2 | 172 | 1.191 | 115 & 116 | 1-1/2 | 146.7 | 96.8 | 9.0 |
| | 1+70 | 56N | Rigid | SWPT** | 3.0 | -- | -- | | 2-6-2 | 172 | 1.191 | 117 & 118 | 1-1/2 | 146.1 | 96.3 | 9.5 |
| 20 | 1+80 | 106N | Flexible | BW210-A | 3.0 | 1/4 | 2000 | Rubberized-tar concrete | 8 | 169 | 1.173 | 119 & 120 | 1-7/8 | 150.0 | 98.7 | 5.9 |
| | 1+80 | 83N | Flexible | BW210-A | 3.0 | 1/4 | 2000 | | 8 | 175 | 1.215 | 121 & 122 | 1-7/8 | 148.8 | 97.6 | 6.7 |
| | 1+80 | 56N | Rigid | BW210-A | 3.0 | 1/4 | 2000 | | 8 | 172 | 1.191 | 123 & 124 | 1-1/2 | 149.3 | 98.0 | 6.4 |
| 20 & 21 | Joint | 90N | Flexible | BW210-A | 2.0 | 1/4 | 2000 | Rubberized-tar concrete | 3 | -- | -- | 210 & 211 | 1-3/4 | 141.2 | 92.6 | 11.5 |
| 21 | 1+90 | 106N | Flexible | BW210-A | 2.0 | 1/4 | 2000 | Rubberized-tar concrete | 6 | 169 | 1.173 | 125 & 126 | 1-5/8 | 149.6 | 98.1 | 6.2 |
| | 1+90 | 83N | Flexible | BW210-A | 2.0 | 1/4 | 2000 | | 6 | 168 | 1.165 | 127 & 128 | 1-1/2 | 148.5 | 97.5 | 7.0 |
| | 1+90 | 56N | Rigid | BW210-A | 2.0 | 1/4 | 2000 | | 6 | 168 | 1.165 | 129 & 130 | 1-1/2 | 150.2 | 98.5 | 5.8 |
| 22 | 2+00 | 106N | Flexible | BW210-A | 1.5 | 1/4 | 2000 | Rubberized-tar concrete | 8 | 171 | 1.183 | 131 & 132 | 1-1/2 | 147.2 | 96.5 | 7.8 |
| | 2+00 | 83N | Flexible | BW210-A | 1.5 | 1/4 | 2000 | | 8 | 169 | 1.173 | 133 & 134 | 1-1/2 | 147.8 | 96.9 | 7.4 |
| | 2+00 | 56N | Rigid | BW210-A | 1.5 | 1/4 | 2000 | | 8 | 167 | 1.157 | 135 & 136 | 1-1/8 | 148.9 | 97.6 | 7.7 |
| 23 | 2+10 | 106N | Flexible | BW210-A | 2.0 | Min. | 2000 | Rubberized-tar concrete | 10 | 164 | 1.138 | 137 & 138 | 1-1/2 | 149.8 | 98.2 | 6.2 |
| | 2+10 | 83N | Flexible | BW210-A | 2.0 | Min. | 2000 | | 10 | 169 | 1.173 | 139 & 140 | 1-1/2 | 148.1 | 97.1 | 6.6 |
| | 2+10 | 56N | Rigid | BW210-A | 2.0 | Min. | 2000 | | 10 | 167 | 1.157 | 141 & 142 | 1-1/4 | 148.2 | 97.2 | 6.5 |
| 23 & 24 | Joint | 50N | Rigid | BW210-A | 2.0 | Min. | 2000 | Rubberized-tar concrete | 5 | -- | -- | 213 & 213 | 1-1/2 | 140.0 | 91.8 | 12.3 |
| 24 | 2+20 | 106N | Flexible | BW210-A | 2.0 | Max. | 2000 | Rubberized-tar concrete | 10 | 164 | 1.138 | 143 & 144 | 1-3/4 | 151.0 | 99.0 | 5.3 |
| | 2+20 | 83N | Flexible | BW210-A | 2.0 | Max. | 2000 | | 10 | 167 | 1.157 | 145 & 146 | 1-1/2 | 151.2 | 99.1 | 5.2 |
| | 2+20 | 56N | Rigid | BW210-A | 2.0 | Max. | 2000 | | 10 | 169 | 1.173 | 147 & 148 | 1-1/4 | 149.1 | 97.8 | 6.0 |
| 25 | 2+30 | 106N | Flexible | CC-50A | 3.0 | Min. | 2400 | Rubberized-tar concrete | 8 | 167 | 1.157 | 149 & 150 | 1-1/4 | 151.0 | 99.0 | 5.3 |
| | 2+30 | 83N | Flexible | CC-50A | 3.0 | Min. | 2400 | | 8 | 168 | 1.165 | 151 & 152 | 1-1/4 | 148.7 | 97.5 | 6.8 |
| | 2+30 | 56N | Rigid | CC-50A | 3.0 | Min. | 2400 | | 8 | 166 | 1.149 | 153 & 154 | 1-1/4 | 152.8 | 100.2 | 4.2 |
| 25 & 26 | Joint | 50N | Rigid | CC-50A | 2.0 | Low | 2400 | Rubberized-tar concrete | 4 | -- | -- | 214 & 215 | 1-1/2 | 139.0 | 91.2 | 13.5 |
| 26 | 2+40 | 106N | Flexible | CC-50A | 2.0 | Low | 2400 | Rubberized-tar concrete | 8 | 163 | 1.130 | 155 & 156 | 1-1/2 | 152.5 | 100.0 | 4.4 |
| | 2+40 | 83N | Flexible | CC-50A | 2.0 | Low | 2400 | | 8 | 172 | 1.191 | 157 & 158 | 1-1/8 | 150.1 | 98.5 | 5.9 |
| | | 56N | Rigid | CC-50A | 2.0 | Low | 2400 | | 8 | 165 | 1.146 | 159 & 160 | 1-1/4 | 151.4 | 99.1 | 5.1 |
| 27 | 2+50 | 106N | Flexible | CC-50A | 3.0 | High | 2400 | Rubberized-tar concrete | 8 | 165 | 1.146 | 161 & 162 | 1-1/2 | 152.2 | 99.7 | 4.6 |
| | 2+50 | 83N | Flexible | CC-50A | 3.0 | High | 2400 | | 8 | 168 | 1.165 | 163 & 164 | 1-1/8 | 151.7 | 99.4 | 5.0 |
| | 2+50 | 56N | Rigid | CC-50A | 3.0 | High | 2400 | | 8 | 164 | 1.138 | 165 & 166 | 1-1/4 | 151.8 | 99.5 | 4.9 |

(Continued)

** Steel-wheeled and pneumatic-tired rollers.

(Sheet 3 of 4)

Table 2 (Concluded)

| Test Lane | Location |  | Type Base Pavement | Compaction Roller Data |  |  |  | Type Overlay Pavement | No. of Roller Passes | Field Density Data |  |  |  |  | Percent Laboratory Density | Percent Air Voids |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Station | Offset ft |  | Type | Travel Speed mph | Amplitude Setting | Frequency vpm |  |  | Nuclear Gage Count | Nuclear Gage Count Ratio | Field Cores Core No. | Field Cores Thickness in. | Field Cores Density pcf |  |  |
| 27 & 28 | Joint | 90N | Flexible | CC-50A | 2-3 | High | 2400 | Rubberized-tar concrete | 4 | -- | -- | 216 & 217 | 1-1/2 | 140.5 | 92.1 | 12.0 |
| 28 | 2+60 | 106N | Flexible | CC-50A | 2.0 | High | 2400 | Rubberized- | 6 | 165 | 1.130 | 167 & 168 | 1-1/2 | 152.6 | 100.1 | 4.4 |
|  | 2+60 | 83N | Flexible | CC-50A | 2.0 | High | 2400 | tar | 6 | 170 | 1.181 | 169 & 170 | 1-1/4 | 150.0 | 98.5 | 6.7 |
|  | 2+60 | 56N | Rigid | CC-50A | 2.0 | High | 2400 | concrete | 6 | 167 | 1.157 | 171 & 172 | 1-1/4 | 151.3 | 99.0 | 5.1 |
| 29 | 2+70 | 106N | Flexible | BW210-A | 2.0 | 7/16 | 2000 | Asphaltic concrete | 16 | 169 | 1.173 | 173 & 174 | 2-5/8 | 149.5 | 98.7 | 4.0 |
|  | 2+70 | 83N | Flexible | BW210-A | 2.0 | 7/16 | 2000 |  | 16 | 172 | 1.191 | 175 & 176 | 2-1/4 | 146.0 | 96.4 | 6.4 |
|  | 2+70 | 56N | Rigid | BW210-A | 2.0 | 7/16 | 2000 |  | 16 | 170 | 1.181 | 177 & 178 | 2-3/4 | 146.4 | 96.6 | 6.1 |
| 30 | 2+80 | 106N | Flexible | CC-50A | 2.0 | High | 2400 | Asphaltic concrete | 8 | 171 | 1.183 | 179 & 180 | 2-3/4 | 146.5 | 96.7 | 6.0 |
|  | 2+80 | 83N | Flexible | CC-50A | 2.0 | High | 2400 |  | 8 | 170 | 1.181 | 181 & 182 | 2-1/4 | 145.6 | 96.7 | 6.0 |
|  | 2+80 | 56N | Rigid | CC-50A | 2.0 | High | 2400 |  | 8 | 165 | 1.145 | 183 & 184 | 2-1/4 | 148.2 | 97.8 | 4.8 |
| 31 | 0+00-10 | 106N | Flexible | BW210-A | 2.0 | 3/4 | 2000 | Rubberized- | 8 | 168 | 1.165 | 185 & 186 | 3.0 | 150.5 | 98.7 | 5.7 |
|  | 0+00-10 | 83N | Flexible | BW210-A | 2.0 | 3/4 | 2000 | tar | 8 | 166 | 1.149 | 187 & 188 | 4.0 | 151.0 | 98.8 | 5.6 |
|  | 0+00-10 | 56N | Flexible | BW210-A | 2.0 | 3/4 | 2000 | concrete | 8 | 166 | 1.149 | 189 & 190 | 3.0 | 151.3 | 99.0 | 5.3 |

(Sheet 4 of 4)

## Table 3

## Summary of Extraction Test Results

| | Compaction Roller Data | | | | Extraction Data | | |
|---|---|---|---|---|---|---|---|
| | | | | | | Asphalt Content percent | |
| Test Lane | Type | Travel Speed mph | Amplitude Setting | Frequency vpm | Core Nos. | Top 3/8 in. | Bottom 3/8 in. |
| 2 | BW210-A | 3.0 | 1/4 | 2,000 | 1 & 2 | 5.6 | 5.6 |
| 7 | BW210-A | 1.5 | 1/4 | 1,500 | 37 & 38 | 5.8 | 5.8 |
| 8 | BW210-A | 1.5 | 1/2 | 2,000 | 43 & 44 | 5.8 | 5.8 |
| 9 | BW210-A | 1.5 | 3/4 | 2,000 | 49 & 50 | 5.8 | 5.8 |
| 12 | CC-50A | 3.0 | Low | 2,400 | 65 & 66 | 6.0 | 6.1 |
| 15 | CC-50A | 1.5 | High | 2,400 | 89 & 90 | 5.6 | 5.7 |
| 17 | SWPT* | | (Static) | | 101 & 102 | 5.4 | 5.4 |

* Steel-wheeled and pneumatic-tired rollers.

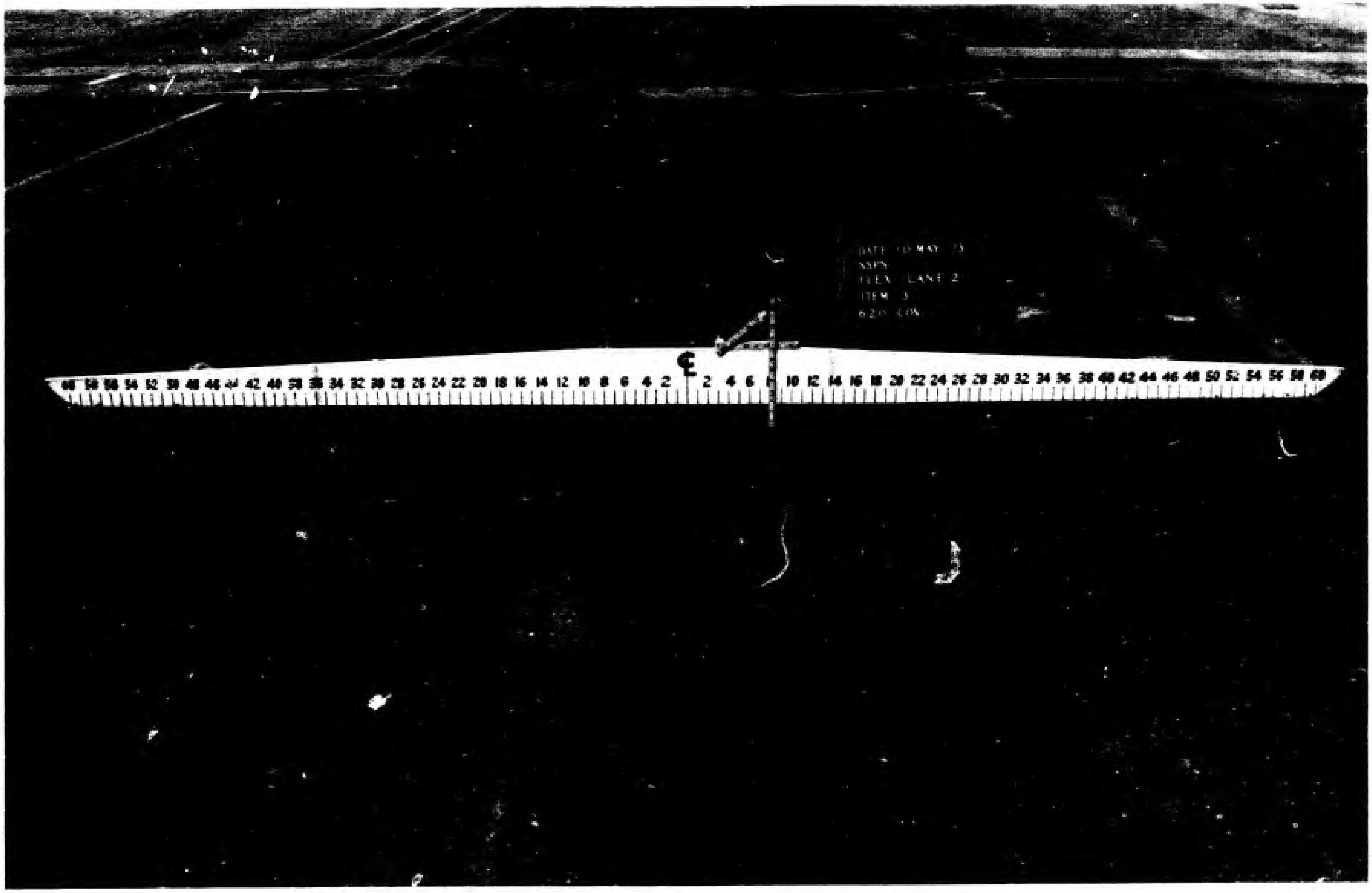


Photo 1. Typical view of flexible pavement prior to overlay

Photo 2. Typical view of rigid pavement prior to overlay

Photo 3. Overall view of test section after placing leveling course prior to overlay

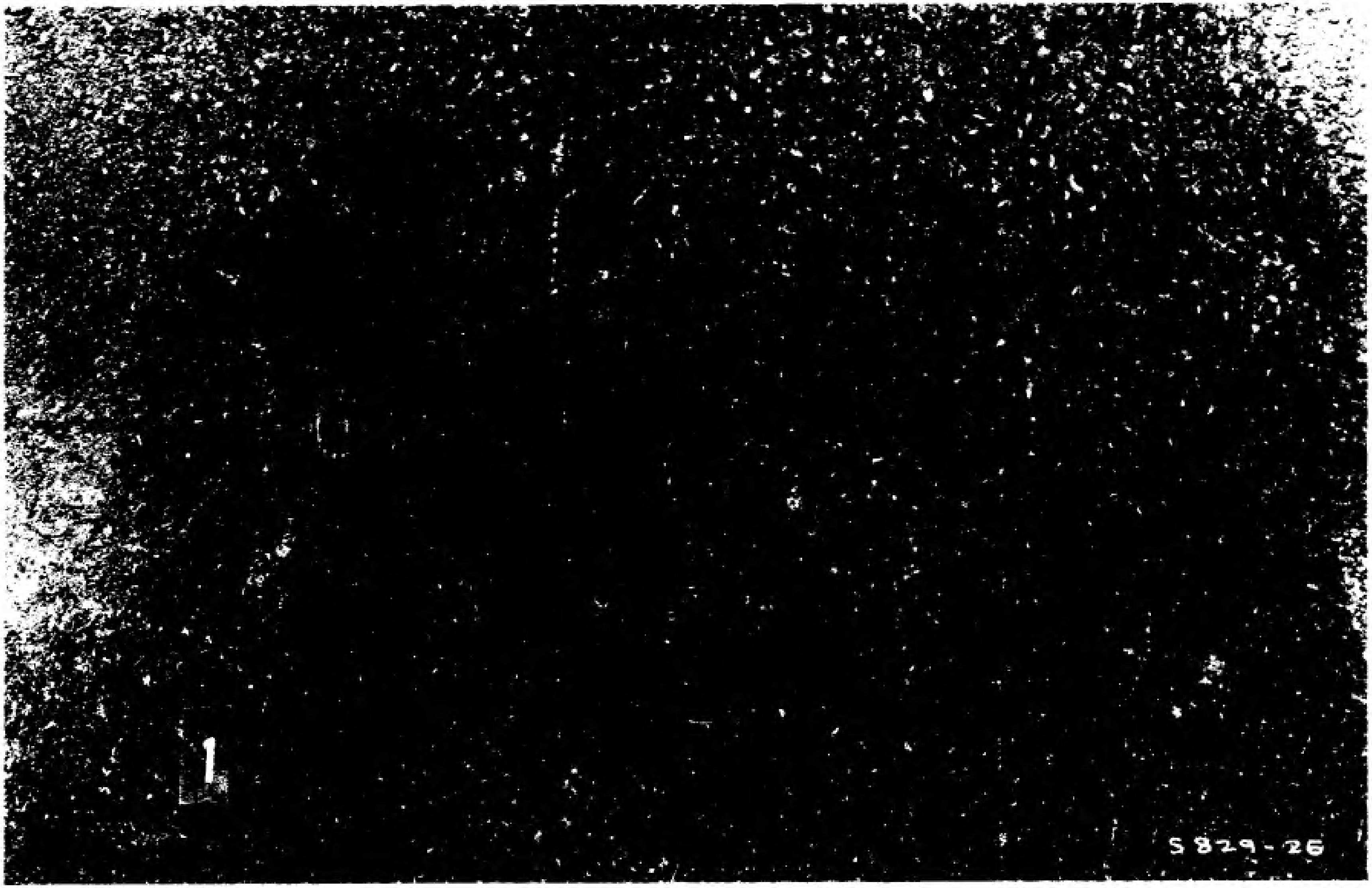


Photo 4. Asphaltic concrete overlay on weak foundation

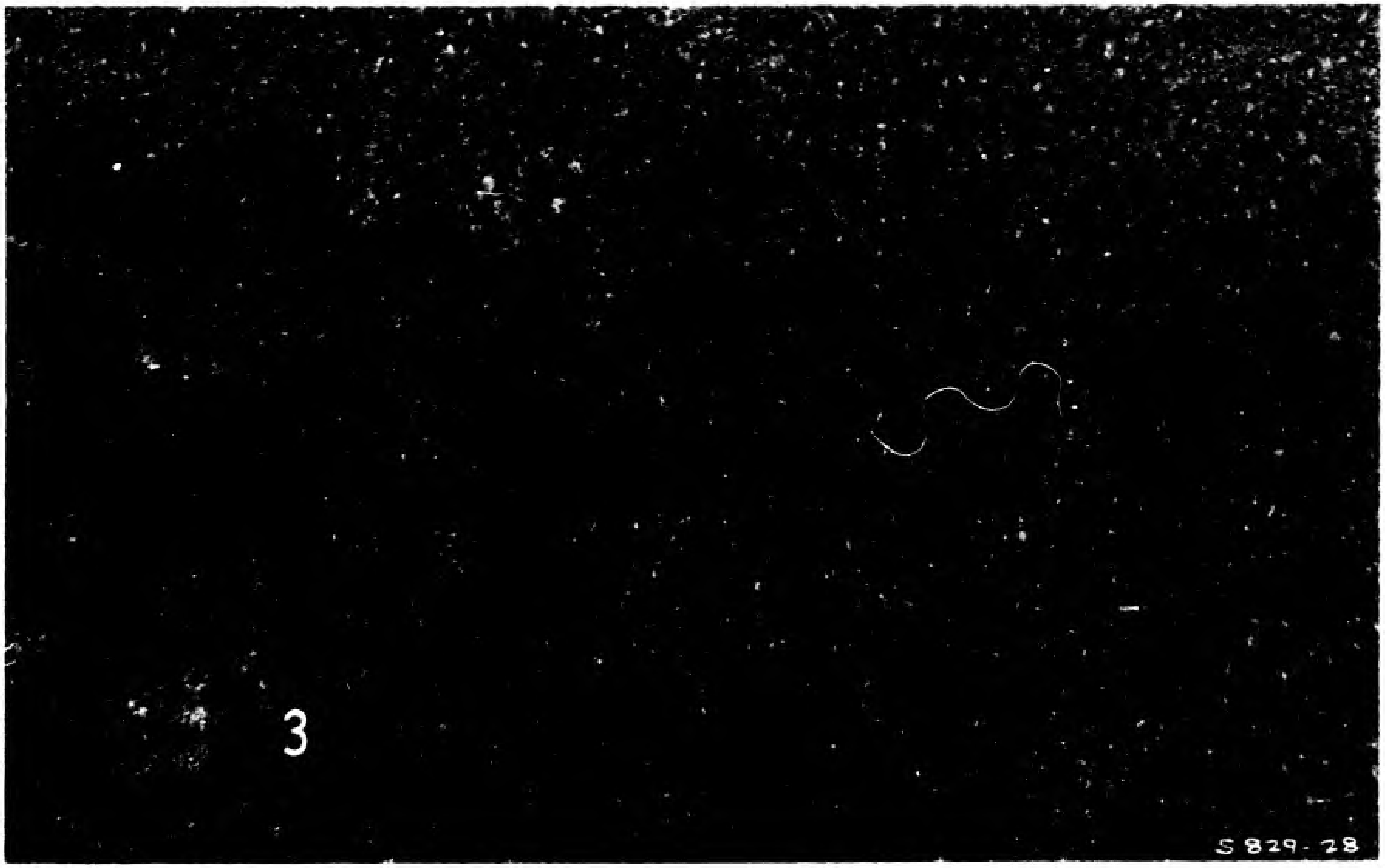


Photo 5. Surface texture of asphaltic concrete overlay (compacted with BW210-A roller)

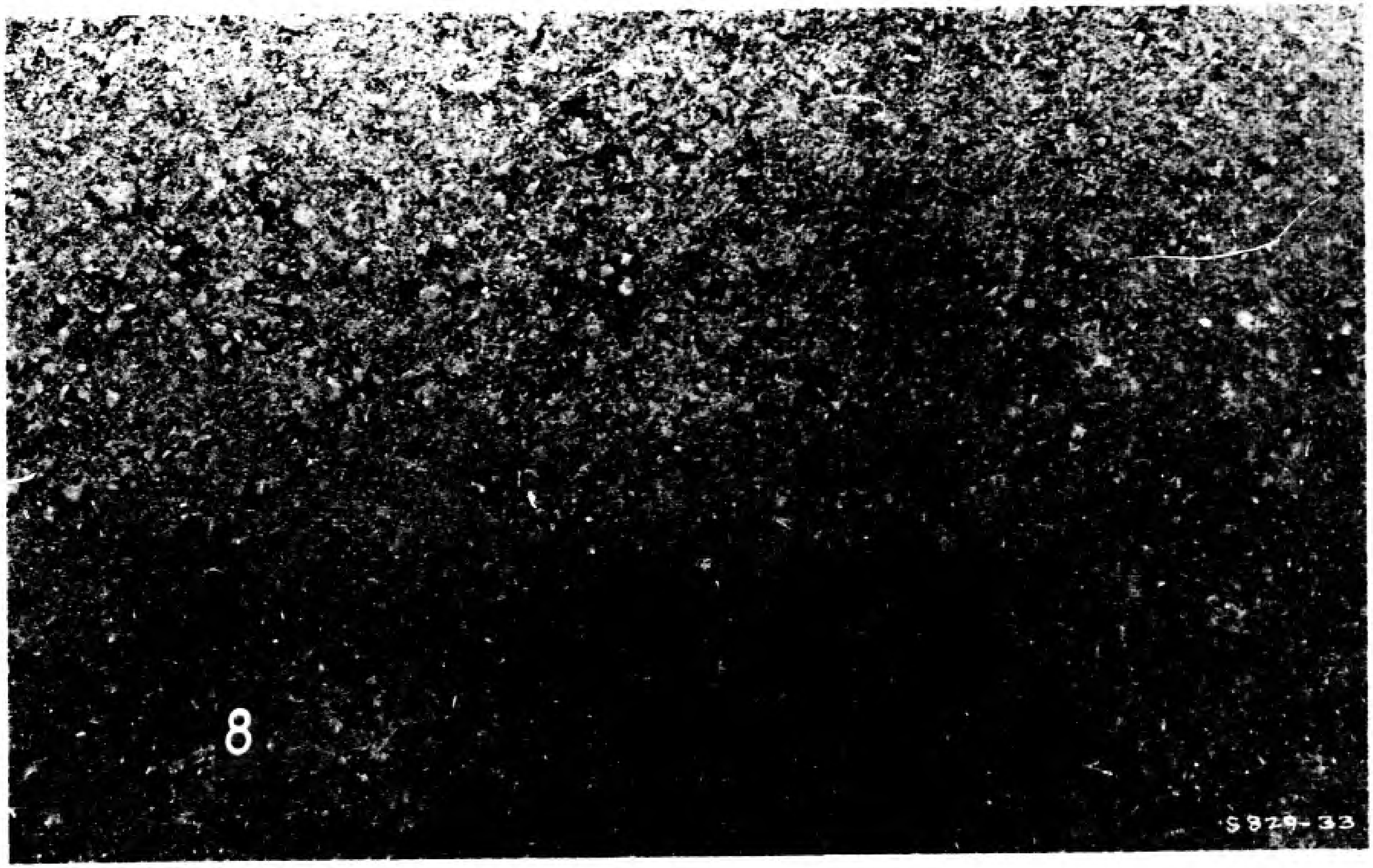
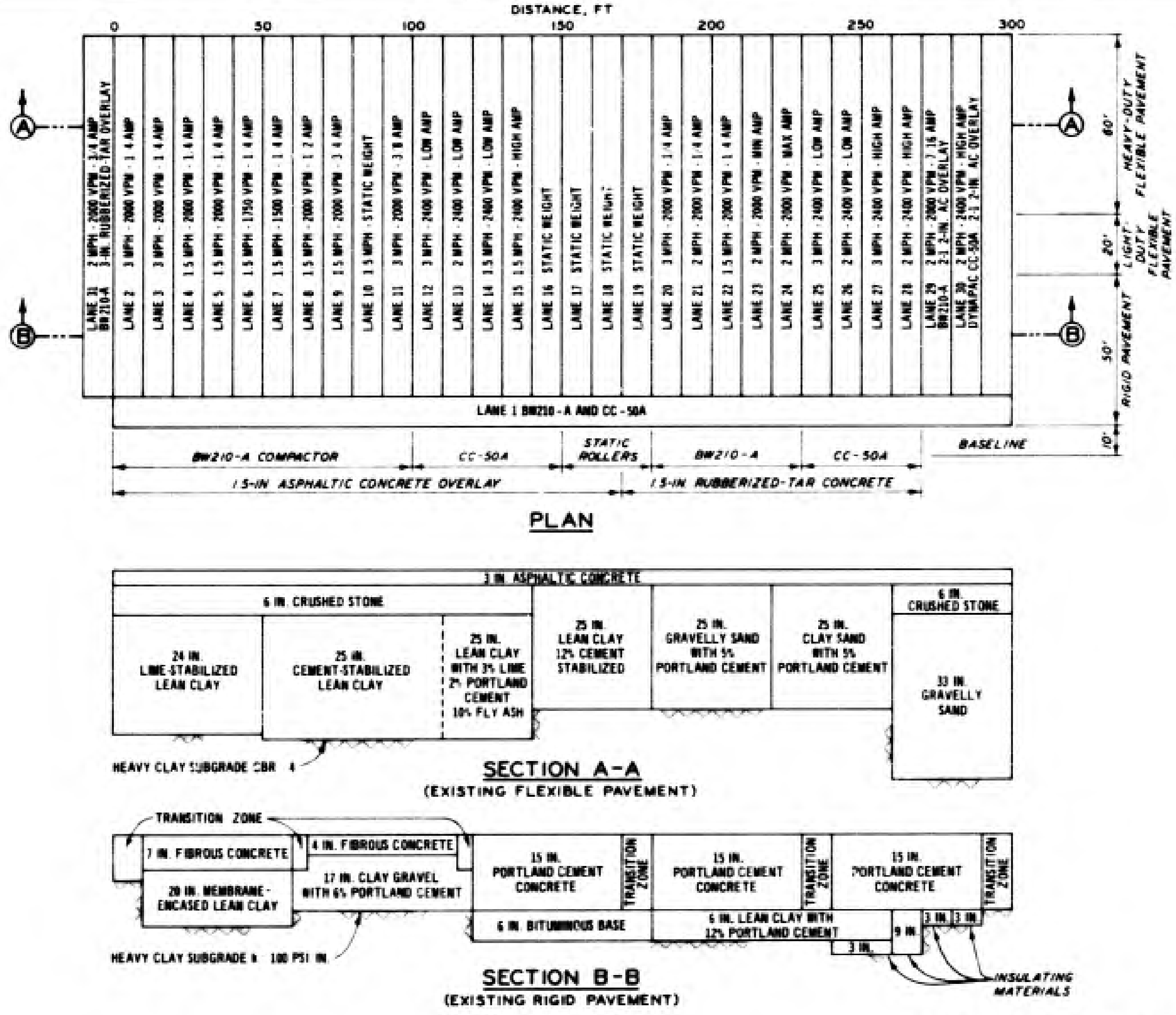
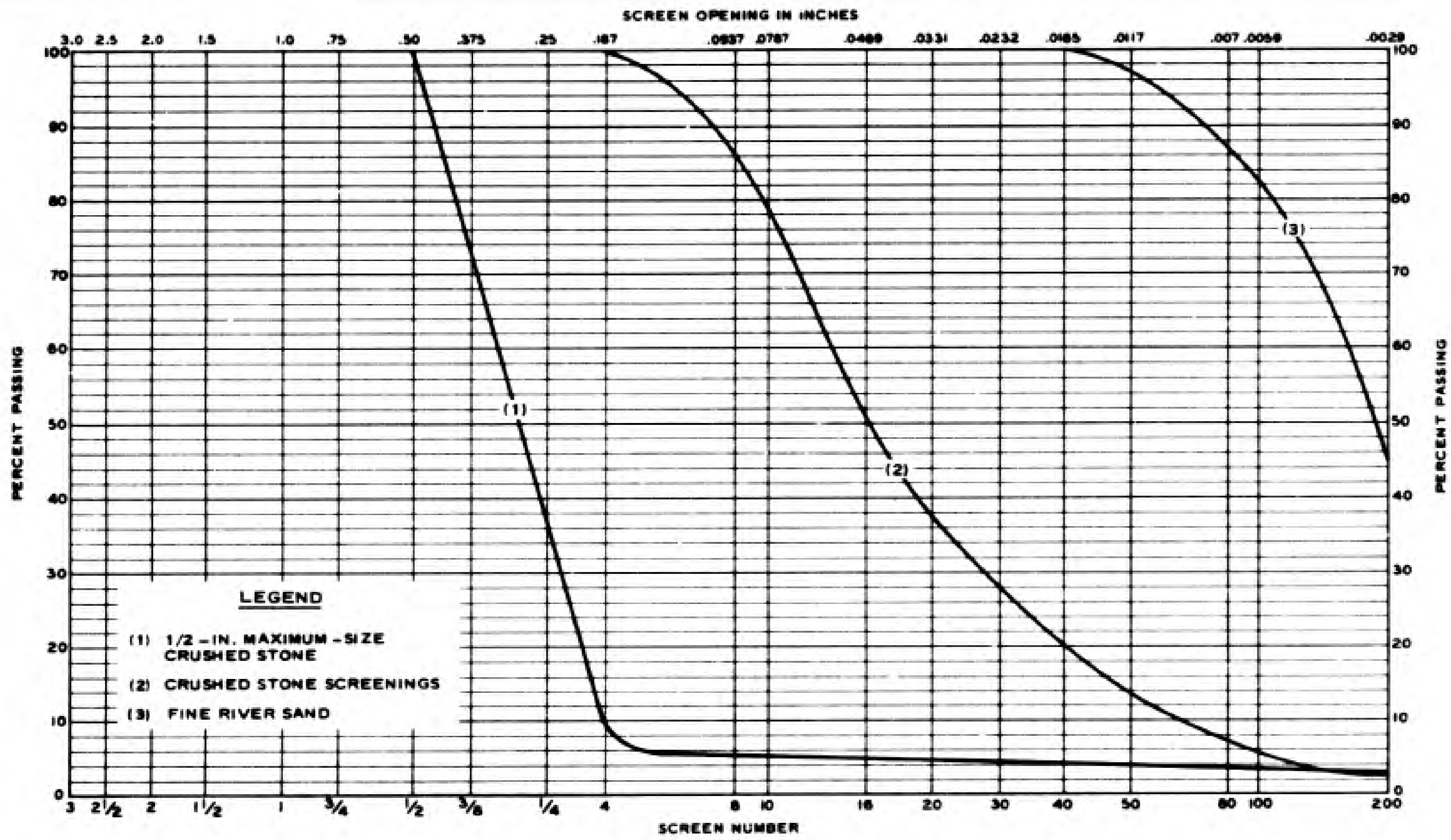


Photo 6. Surface texture of rubberized-tar concrete overlay
(compacted with CC-50A roller)



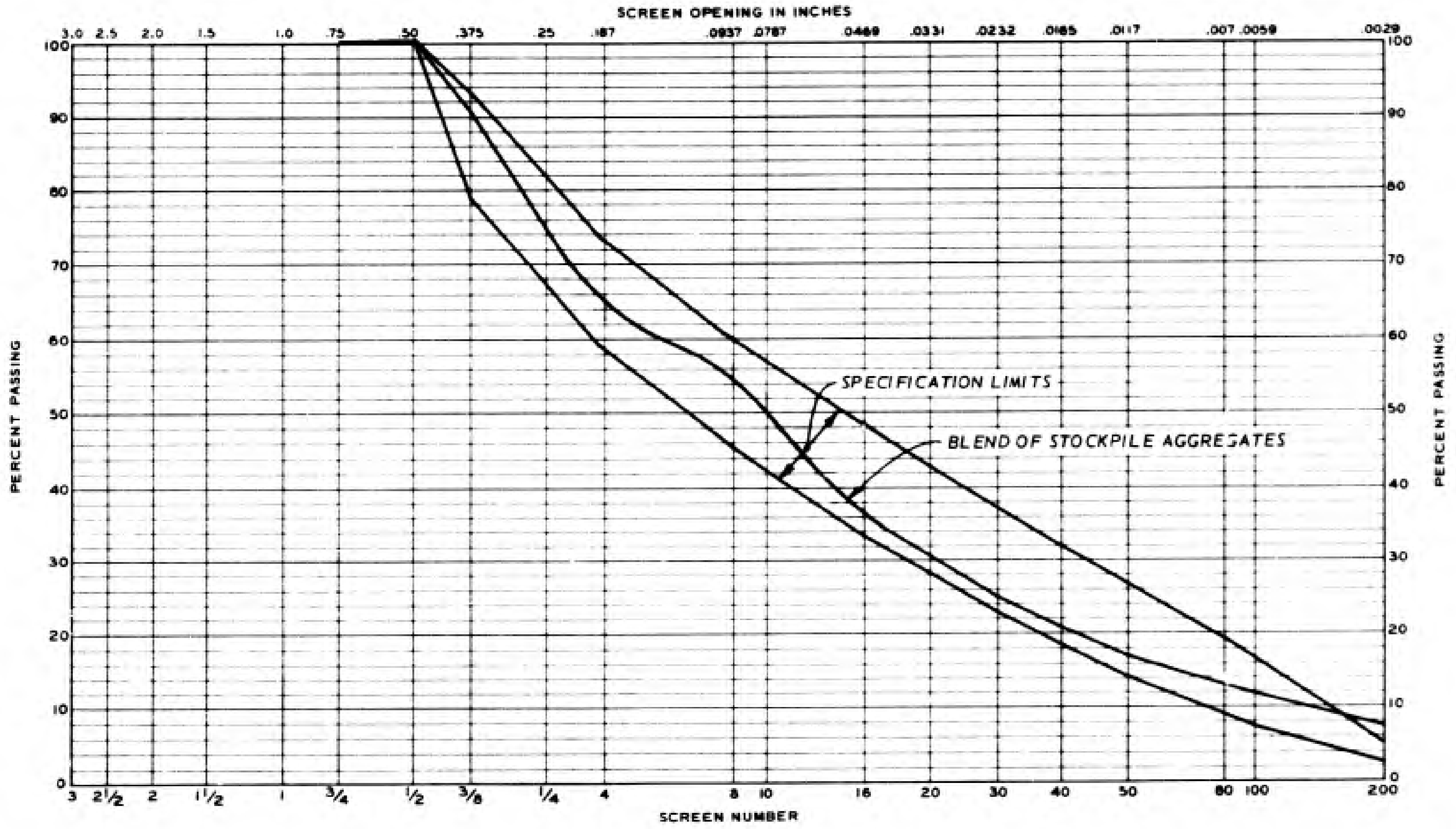
# LAYOUT FOR VIBRATORY COMPACTION STUDY

PLATE 1



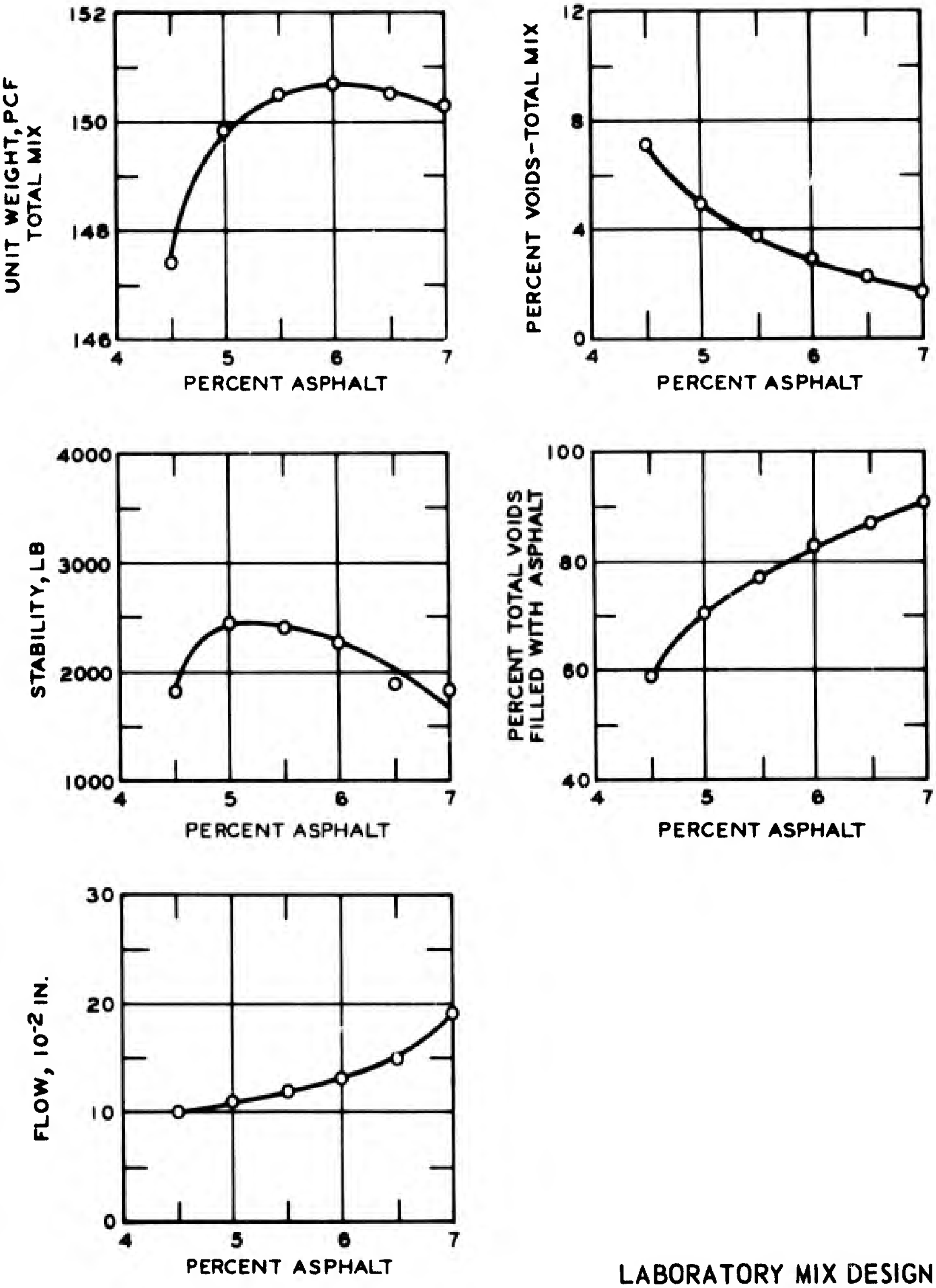
AGGREGATES USED IN PAVING MIXTURES

PLATE 2



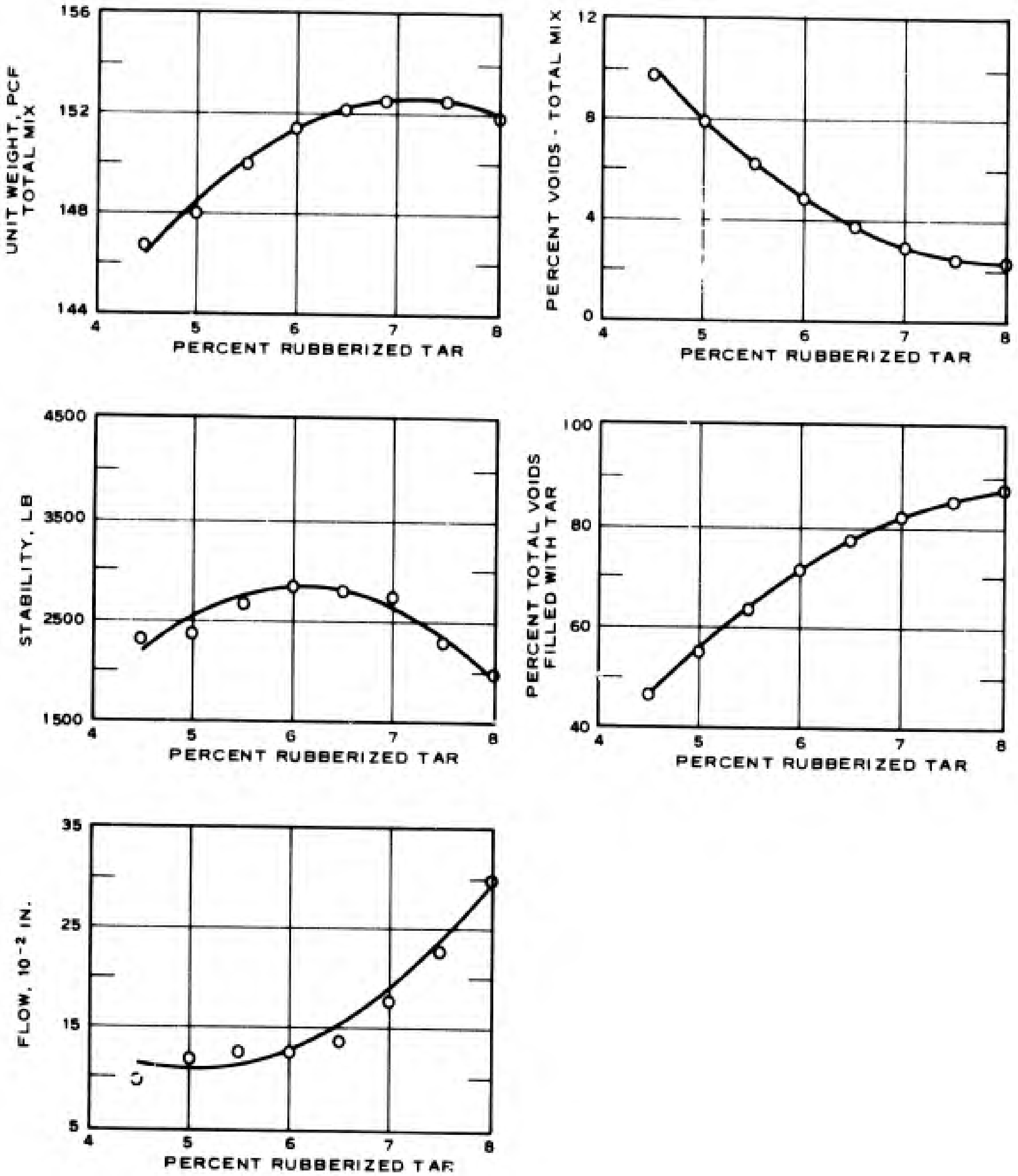
COMBINED AGGREGATE
GRADING CURVE

PLATE 3



LABORATORY MIX DESIGN
PROPERTIES
ASPHALTIC CONCRETE
75-BLOW MARSHALL

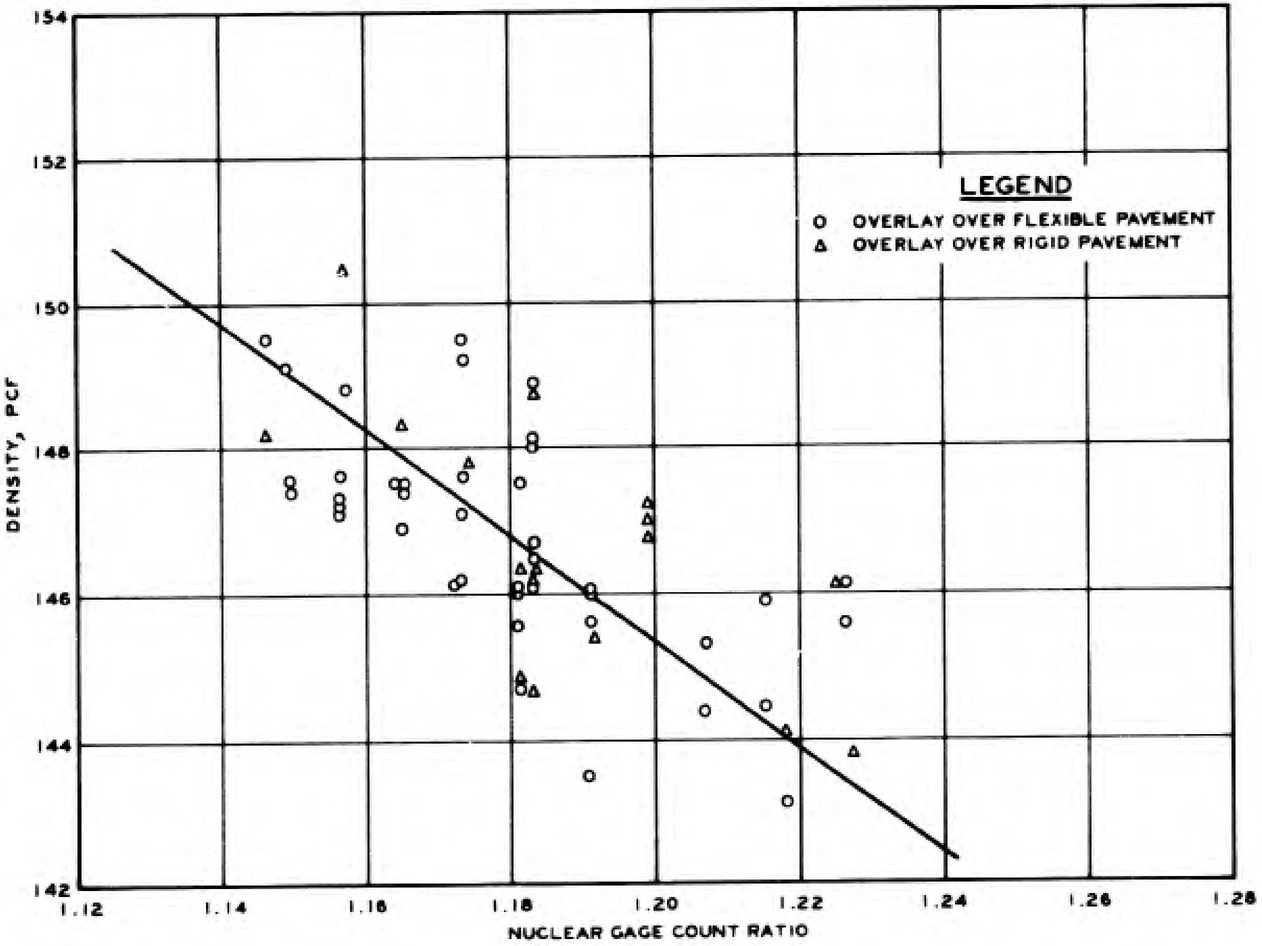
PLATE 4



**LABORATORY MIX DESIGN PROPERTIES**

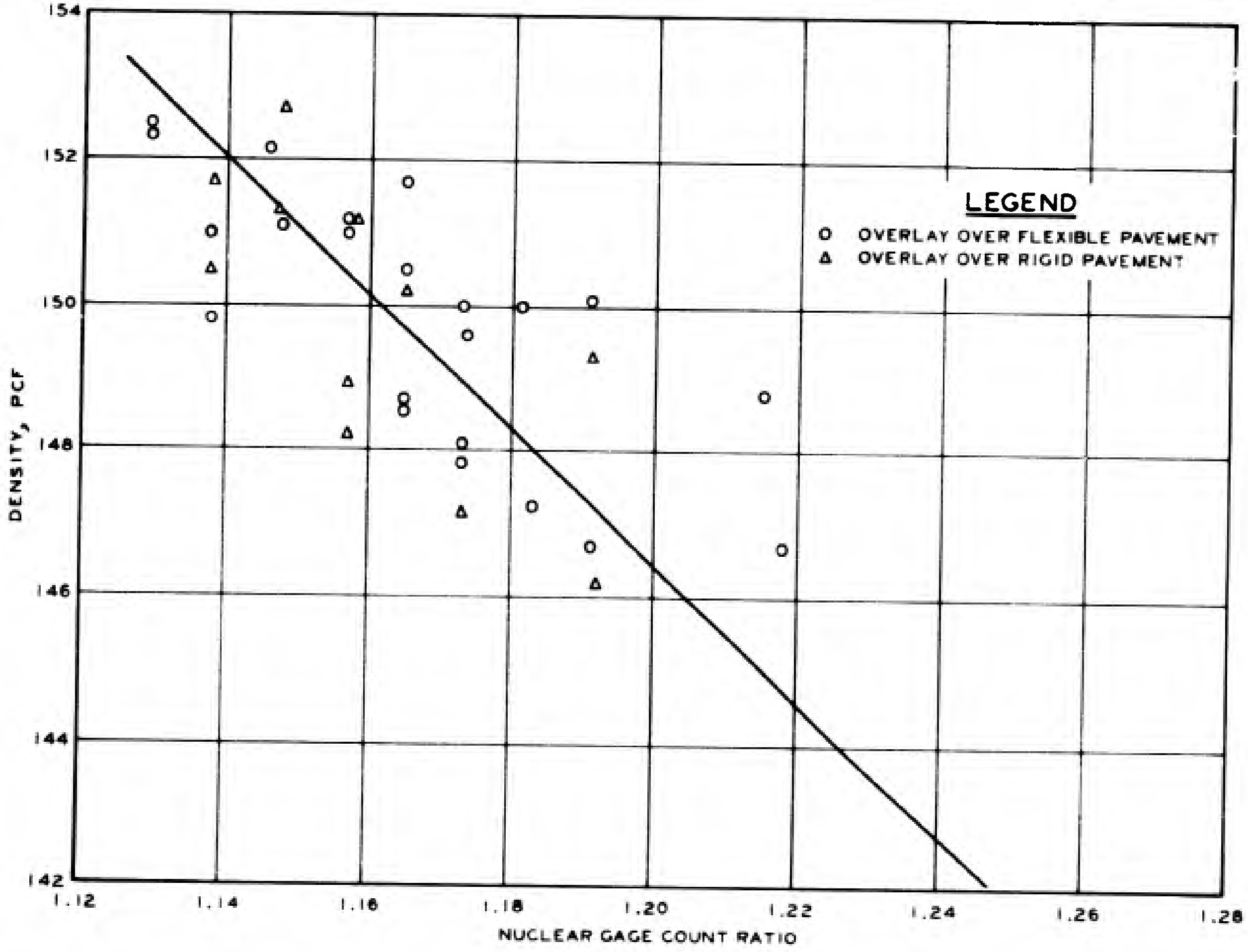
**RUBBERIZED-TAR CONCRETE**
**75 - BLOW MARSHALL**

PLATE 6



NOTE: DENSITY DETERMINED FROM
CORE SAMPLES CUT FROM
OVERLAY PAVEMENT.

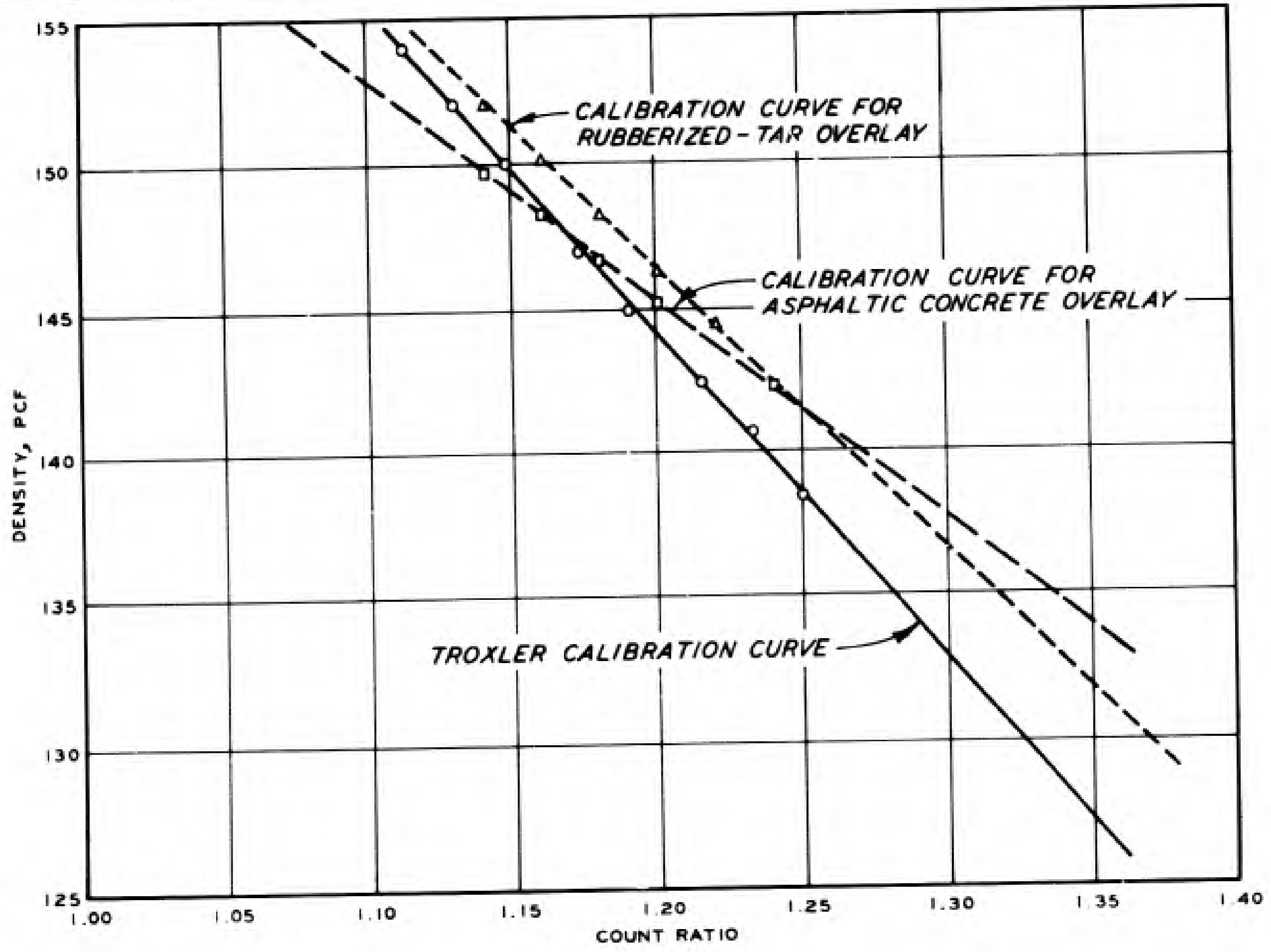
COUNT RATIO VERSUS DENSITY
1½-IN. ASPHALTIC
CONCRETE OVERLAY



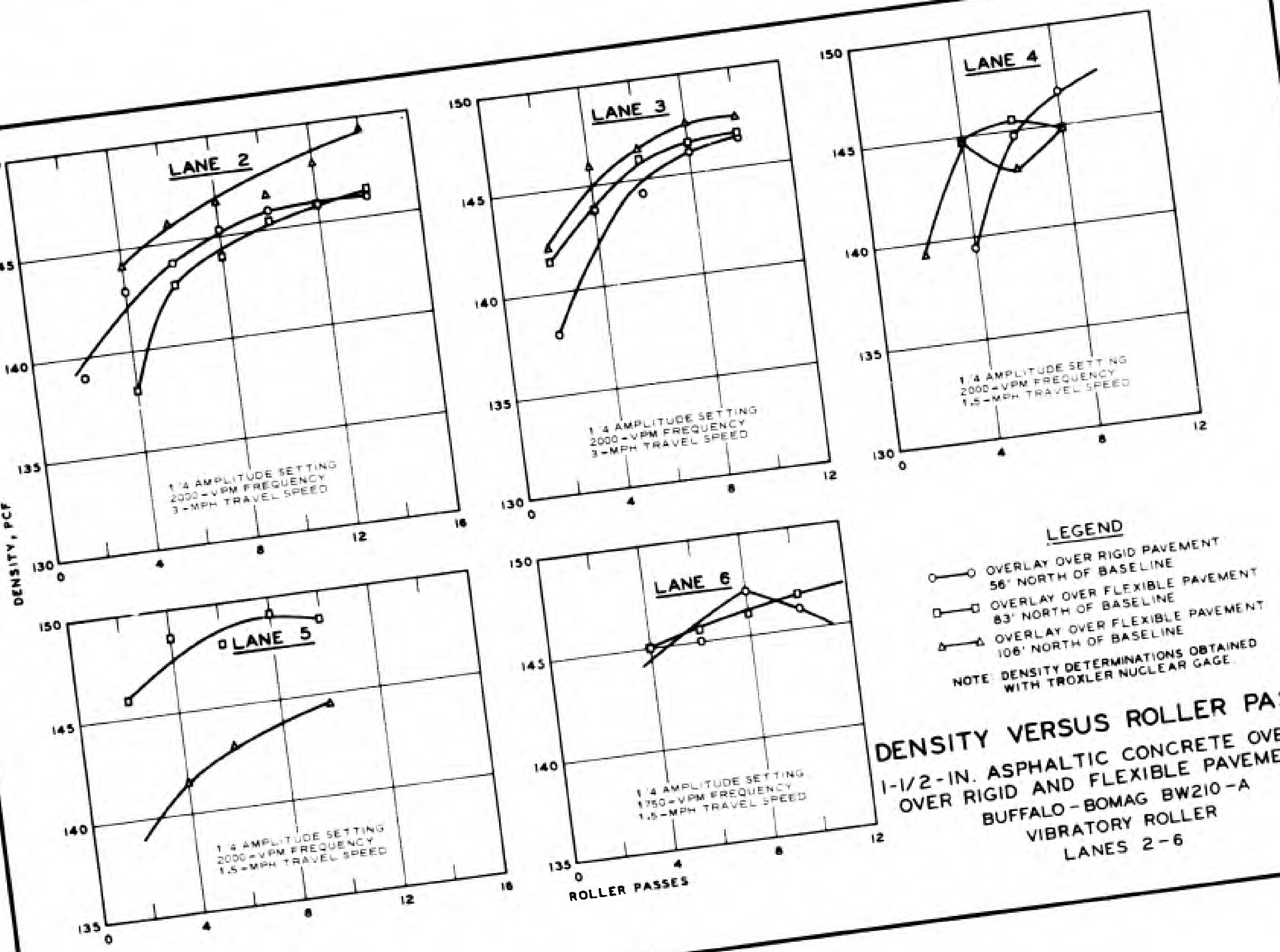
NOTE: DENSITY DETERMINED FROM
CORE SAMPLES CUT FROM
OVERLAY PAVEMENT.

COUNT RATIO VERSUS DENSITY
$1\text{-}\frac{1}{2}$-IN. RUBBERIZED-TAR
CONCRETE OVERLAY

PLATE 7



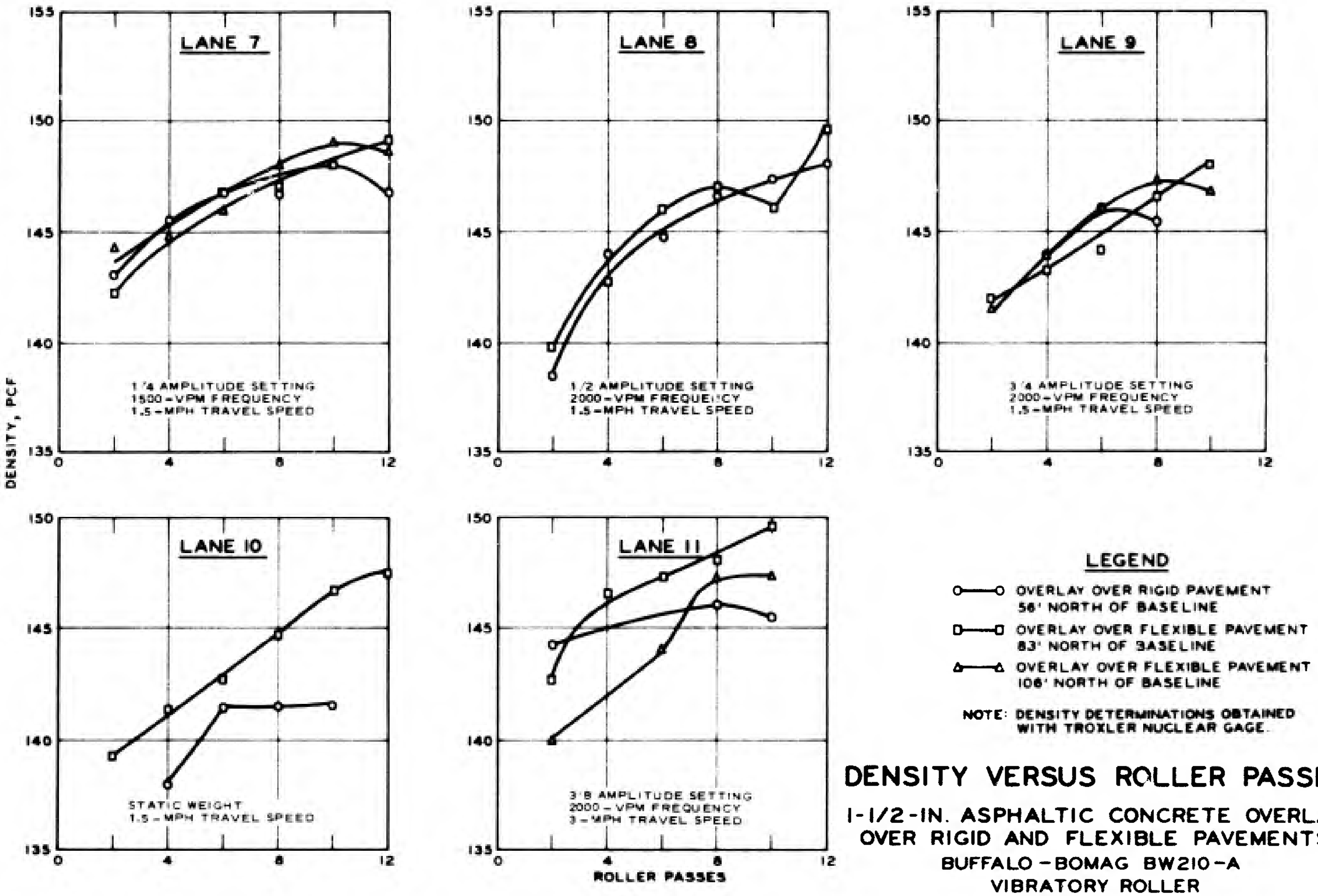
COUNT RATIO VERSUS DENSITY
COMPARISON OF CALIBRATION CURVES



DENSITY VERSUS ROLLER PASSES

1-1/2-IN. ASPHALTIC CONCRETE OVERLAY
OVER RIGID AND FLEXIBLE PAVEMENTS
BUFFALO-BOMAG BW210-A
VIBRATORY ROLLER
LANES 2-6

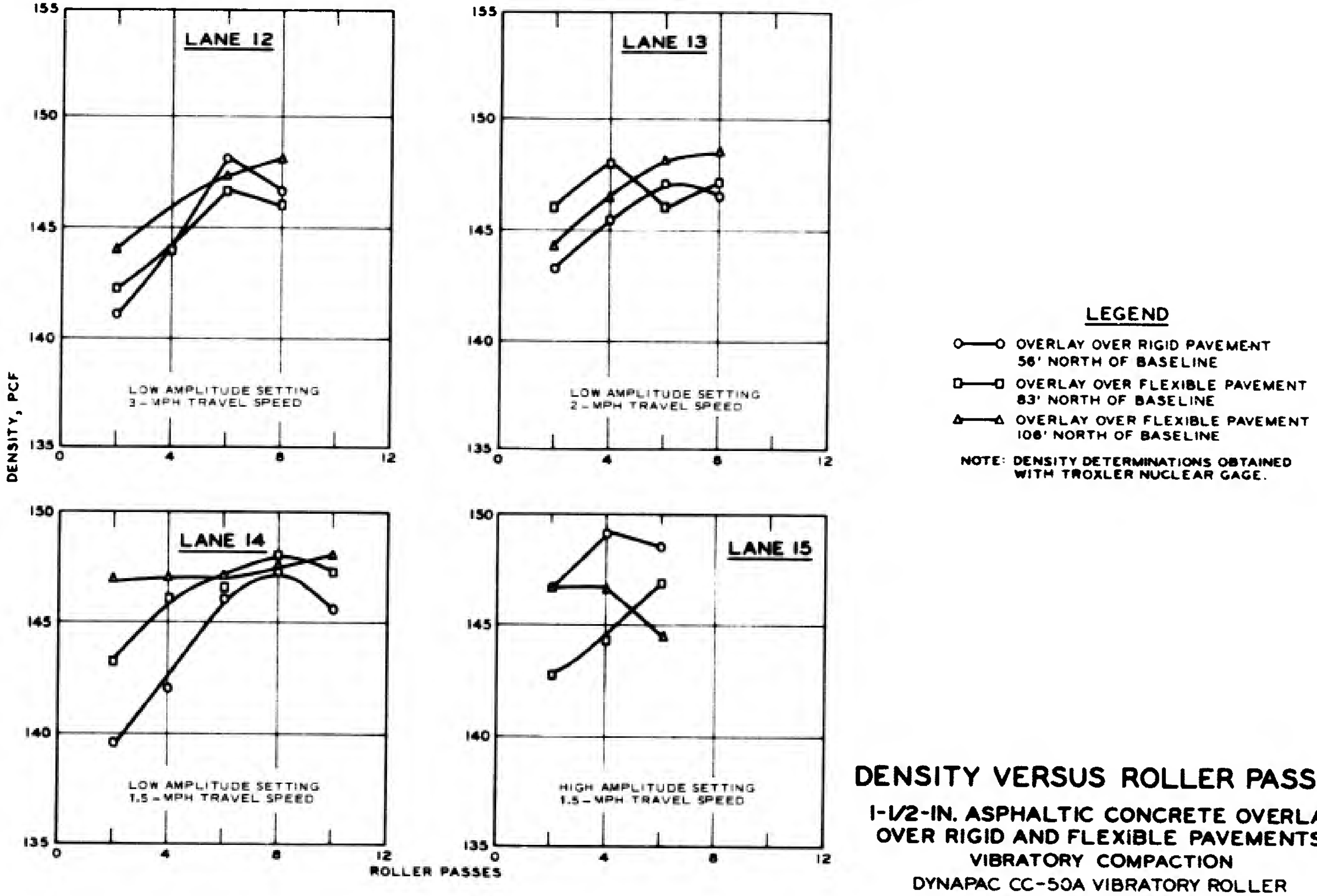
PLATE 9



NOTE: DENSITY DETERMINATIONS OBTAINED WITH TROXLER NUCLEAR GAGE.

## DENSITY VERSUS ROLLER PASSES

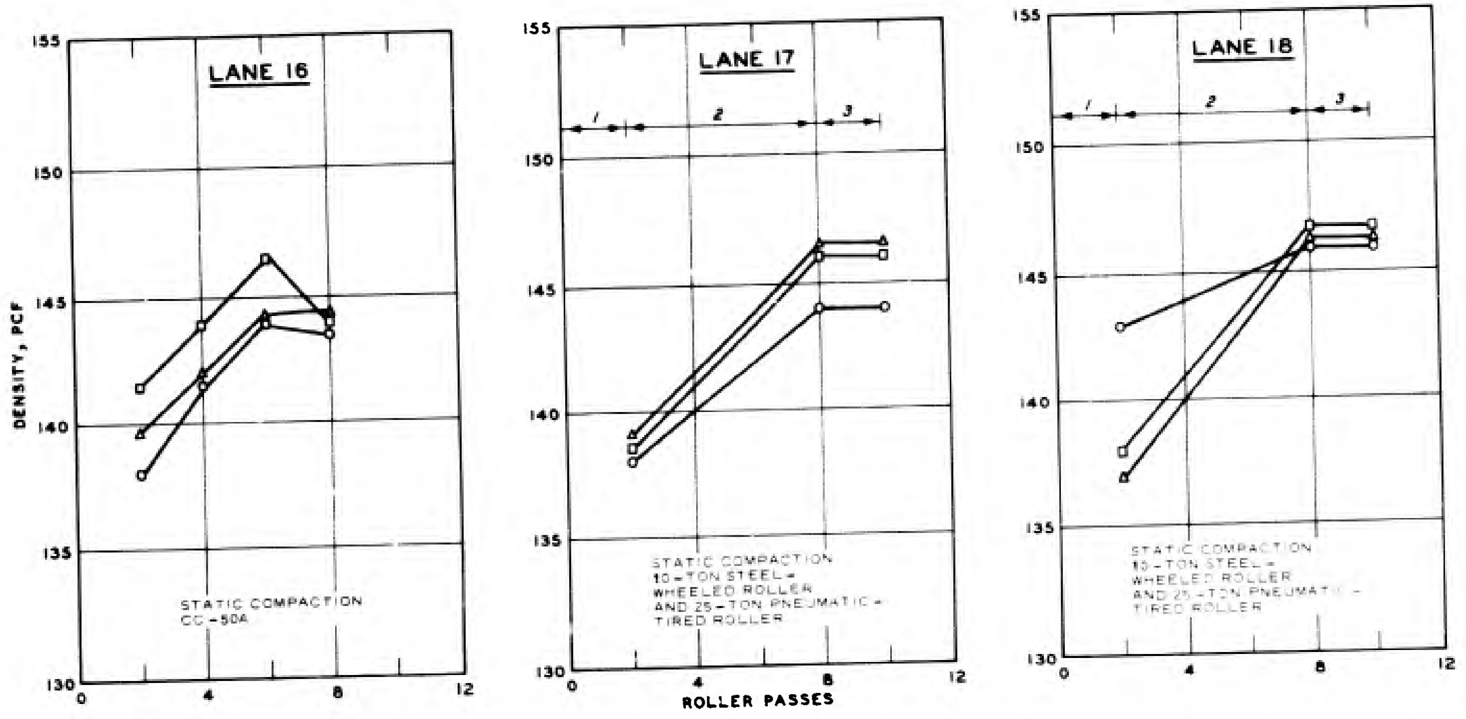
1-1/2-IN. ASPHALTIC CONCRETE OVERLAY
OVER RIGID AND FLEXIBLE PAVEMENTS
BUFFALO-BOMAG BW210-A
VIBRATORY ROLLER
LANES 7-11



DENSITY VERSUS ROLLER PASSES

1-1/2-IN. ASPHALTIC CONCRETE OVERLAY
OVER RIGID AND FLEXIBLE PAVEMENTS
VIBRATORY COMPACTION
DYNAPAC CC-50A VIBRATORY ROLLER
2400-VPM FREQUENCY

PLATE 11



LEGEND

○—○ OVERLAY OVER RIGID PAVEMENT
56' NORTH OF BASELINE

□—□ OVERLAY OVER FLEXIBLE PAVEMENT
83' NORTH OF BASELINE

△—△ OVERLAY OVER FLEXIBLE PAVEMENT
106' NORTH OF BASELINE

NOTE: DENSITY DETERMINATIONS OBTAINED WITH TROXLER NUCLEAR GAGE.

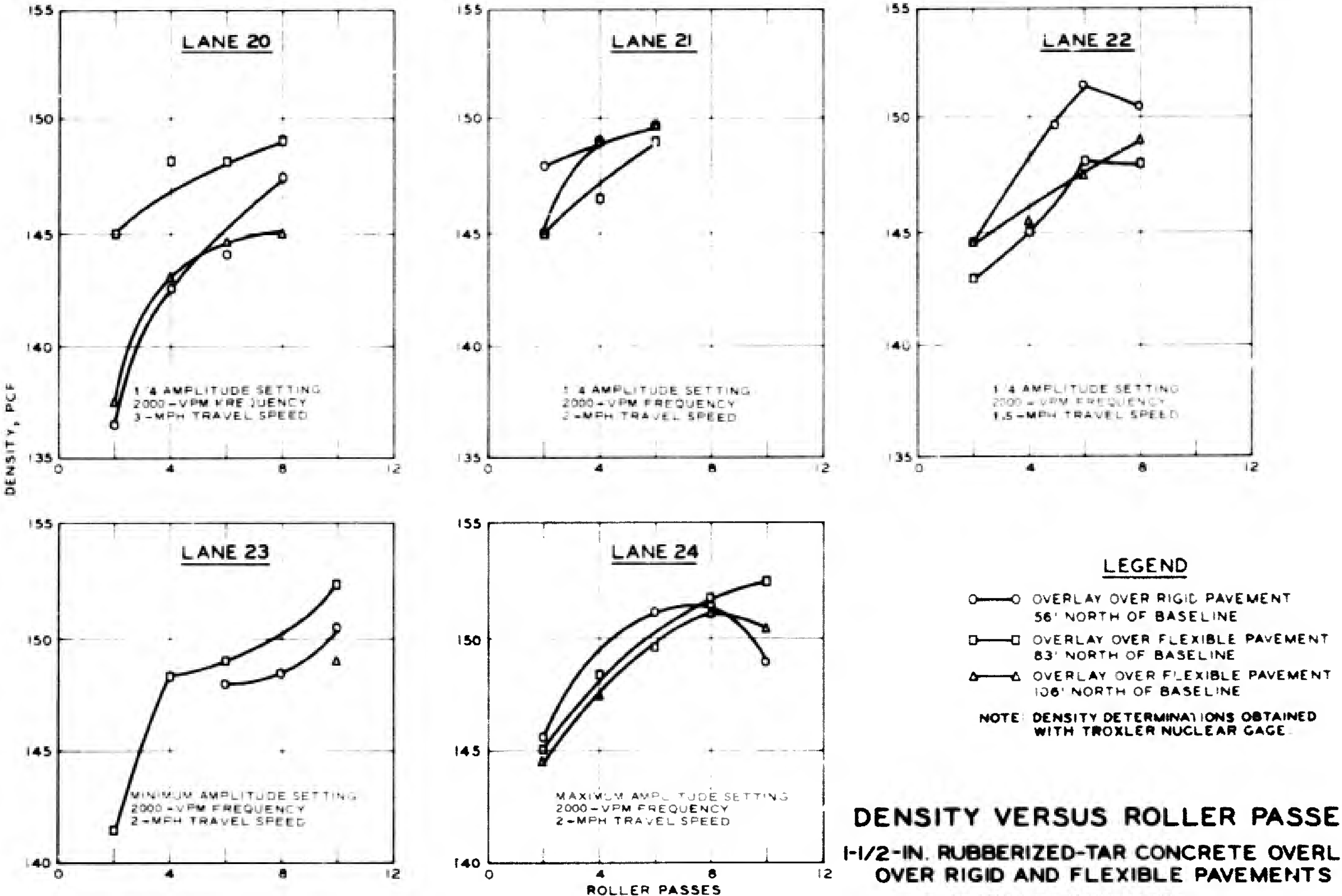
SEQUENCE OF COMPACTION IN LANES 17 AND 18 WAS

1. TWO COVERAGES WITH STEEL-WHEELED ROLLER
2. SIX COVERAGES WITH PNEUMATIC-TIRED ROLLER
3. TWO COVERAGES WITH STEEL-WHEELED ROLLER

## DENSITY VERSUS ROLLER PASSES

### 1-1/2-IN. ASPHALTIC CONCRETE OVERLAY OVER RIGID AND FLEXIBLE PAVEMENTS

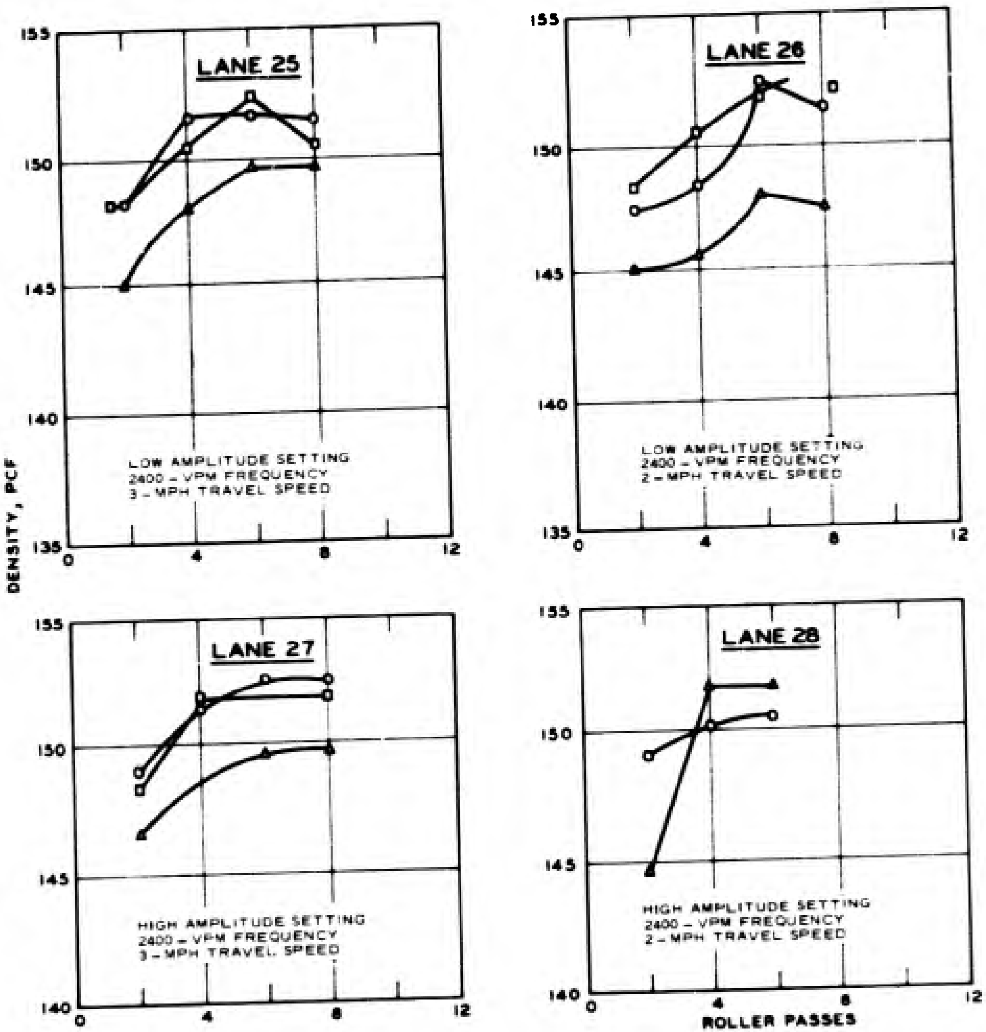
### STATIC COMPACTION



**DENSITY VERSUS ROLLER PASSES**

**1-1/2-IN. RUBBERIZED-TAR CONCRETE OVERLAY OVER RIGID AND FLEXIBLE PAVEMENTS**

BUFFALO-BOMAG BW210-A
VIBRATORY ROLLER



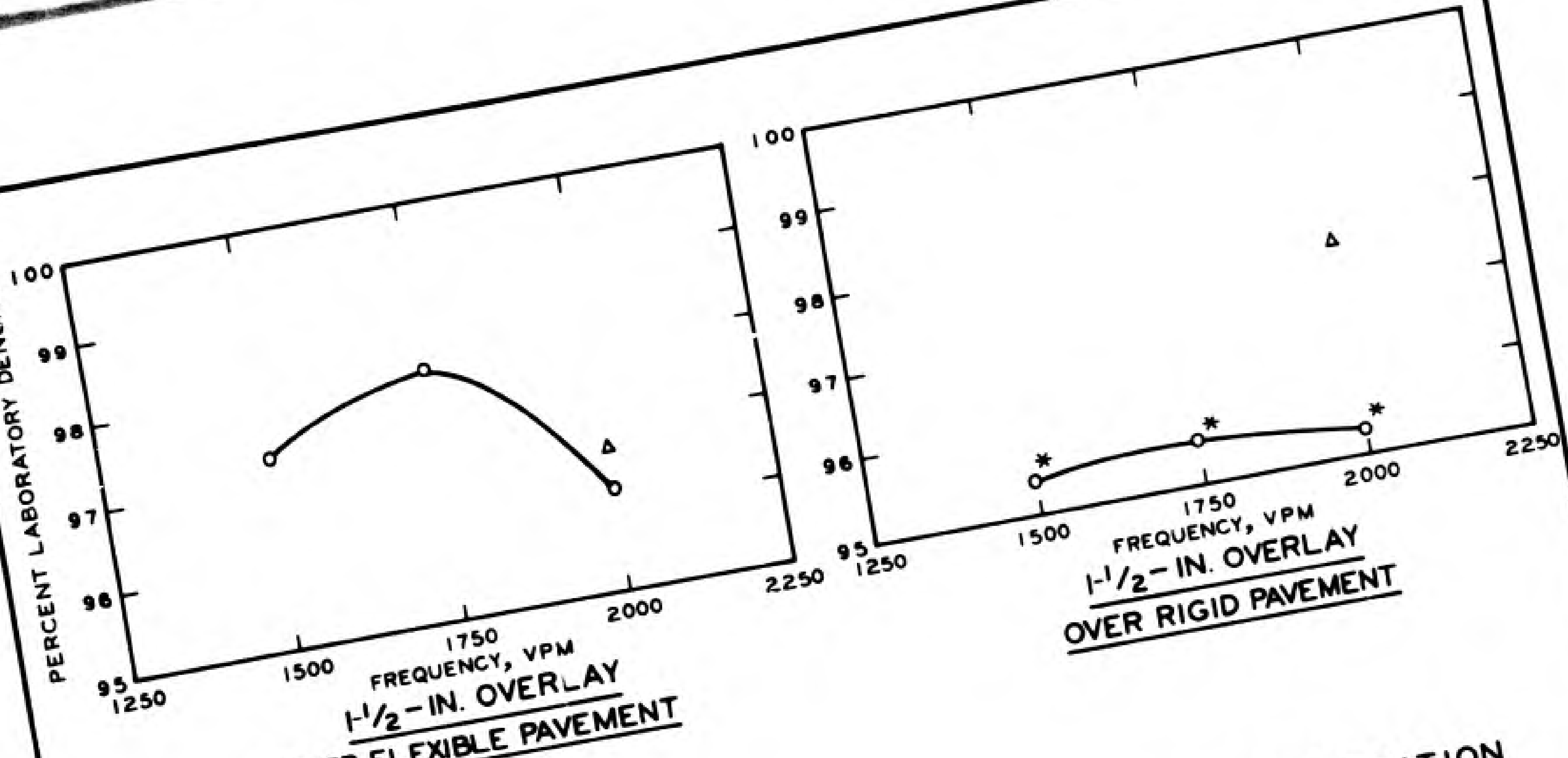
**LEGEND**

- ○—○ OVERLAY OVER RIGID PAVEMENT 56' NORTH OF BASELINE
- □—□ OVERLAY OVER FLEXIBLE PAVEMENT 83' NORTH OF BASELINE
- △—△ OVERLAY OVER FLEXIBLE PAVEMENT 108' NORTH OF BASELINE

NOTE: DENSITY DETERMINATIONS OBTAINED WITH TROXLER NUCLEAR GAGE.

DENSITY VERSUS ROLLER PASSES

1-1/2-IN. RUBBERIZED-TAR CONCRETE OVERLAY
OVER RIGID AND FLEXIBLE PAVEMENTS
DYNAPAC CC-50A
VIBRATORY ROLLER



1-1/2-IN. OVERLAY
OVER FLEXIBLE PAVEMENT

1-1/2-IN. OVERLAY
OVER RIGID PAVEMENT

LEGEND

o—o ASPHALTIC CONCRETE OVERLAY

Δ RUBBERIZED-TAR CONCRETE OVERLAY

NOTE: * BY DATA POINT INDICATES OVERLAY OVER WEAK SECTION OF FIBROUS CONCRETE.

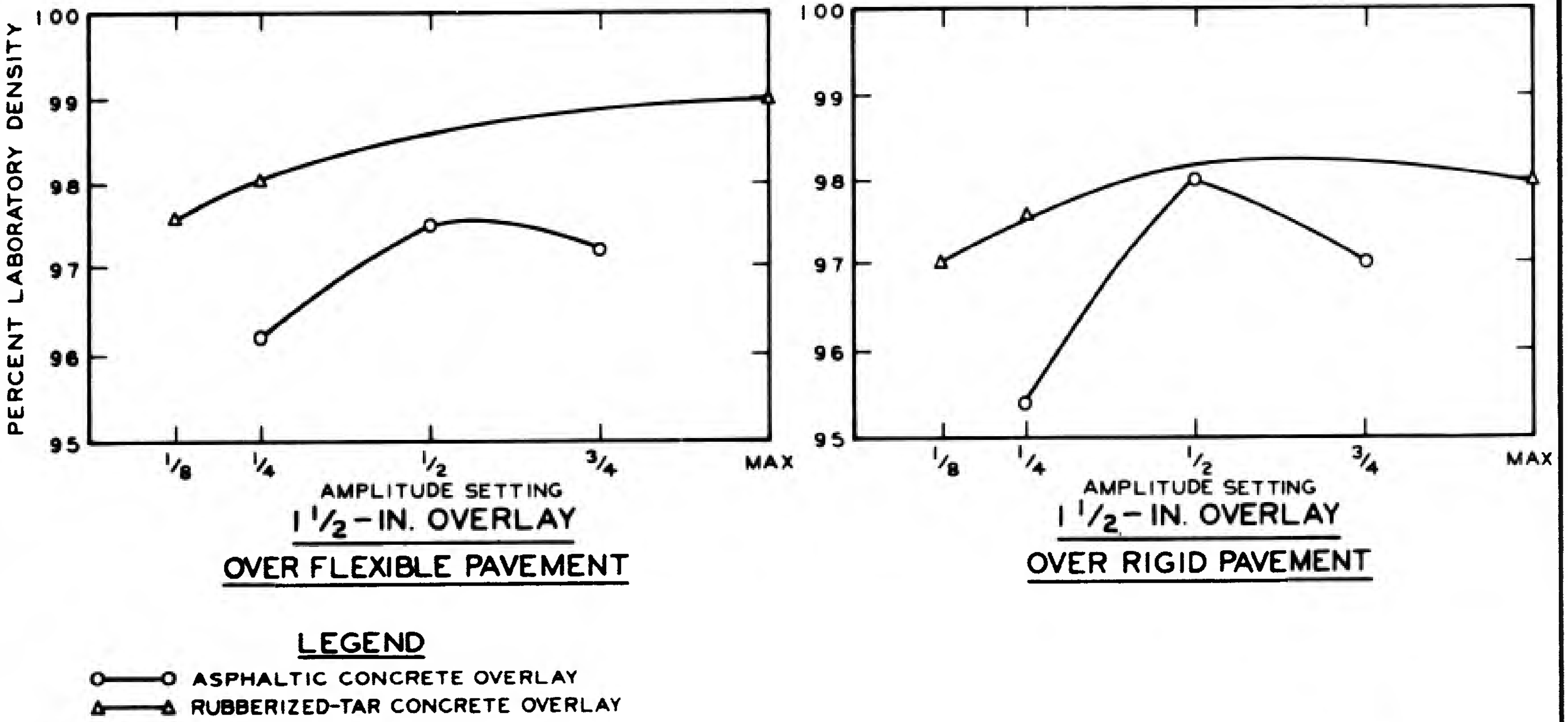
TRAVEL SPEED-1.5 MPH

AMPLITUDE SETTING-1/4

EFFECT OF VIBRATION
FREQUENCY ON
COMPACTION

BUFFALO-BOMAG BW210-A
VIBRATORY ROLLER

PLATE 15



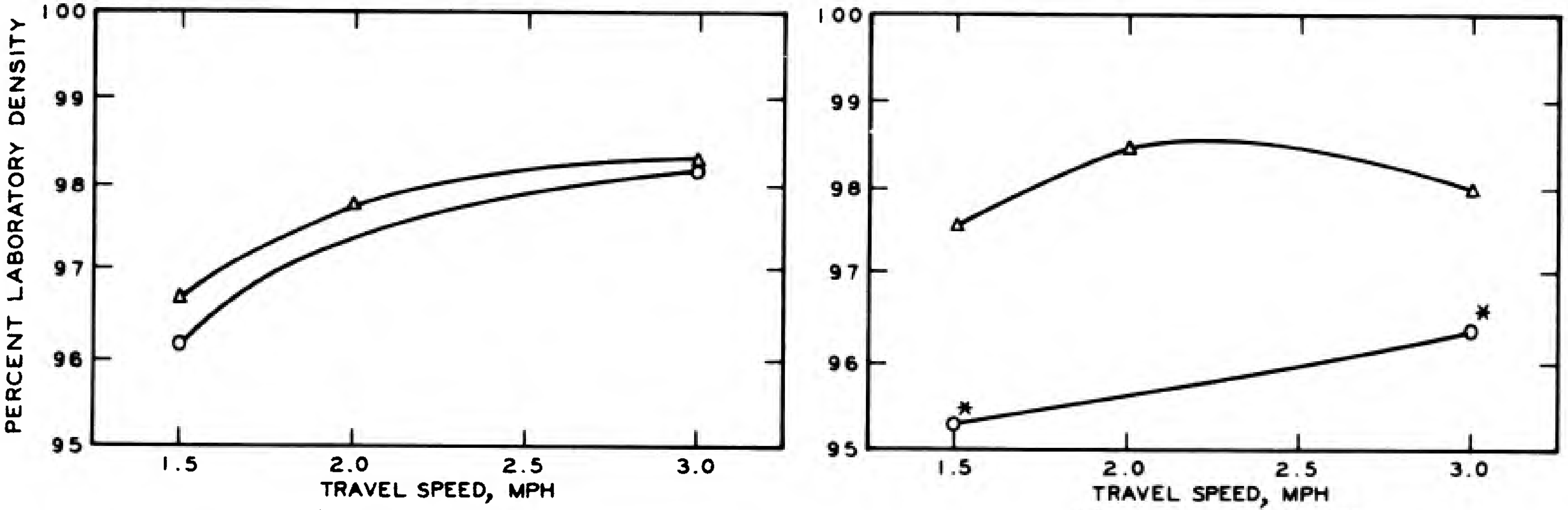
1 1/2-IN. OVERLAY OVER FLEXIBLE PAVEMENT

1 1/2-IN. OVERLAY OVER RIGID PAVEMENT

NOTE: TRAVEL SPEED – 1.5 MPH
FREQUENCY – 2000 VPM

**EFFECT OF AMPLITUDE
ON COMPACTION**
BUFFALO – BOMAG BW210 – A
VIBRATORY ROLLER

PLATE 16



1 1/2-IN. OVERLAY OVER FLEXIBLE PAVEMENT

1 1/2-IN. OVERLAY OVER RIGID PAVEMENT

LEGEND

○——○ ASPHALTIC CONCRETE OVERLAY
△——△ RUBBERIZED-TAR CONCRETE OVERLAY

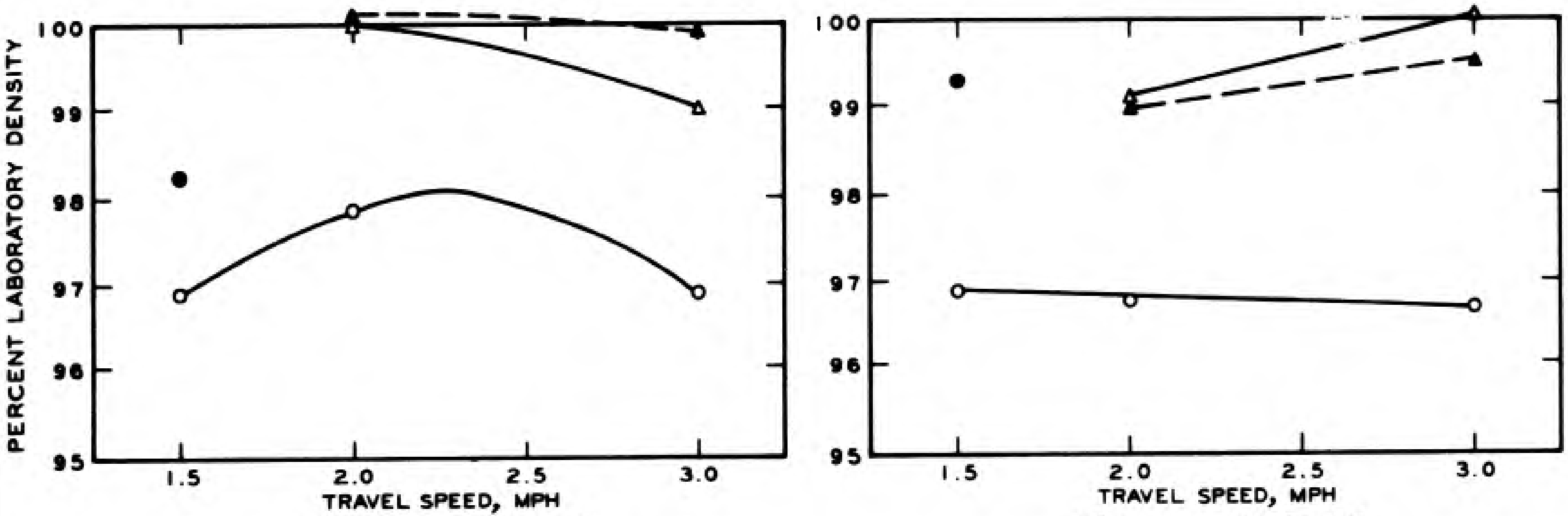
NOTE: * BY DATA POINT INDICATES OVERLAY OVER WEAK SECTION OF FIBROUS CONCRETE.

FREQUENCY-2000 VPM

AMPLITUDE SETTING-1/4

EFFECT OF TRAVEL SPEED ON COMPACTION

BUFFALO-BOMAG BW210-A VIBRATORY ROLLER



1-1/2-IN. OVERLAY
OVER FLEXIBLE PAVEMENT

1-1/2-IN. OVERLAY
OVER RIGID PAVEMENT

**LEGEND**

- o——o ASPHALTIC CONCRETE OVERLAY
- △——△ RUBBERIZED-TAR CONCRETE OVERLAY

NOTE: OPEN SYMBOLS DENOTE COMPACTION WITH LOW AMPLITUDE SETTING.

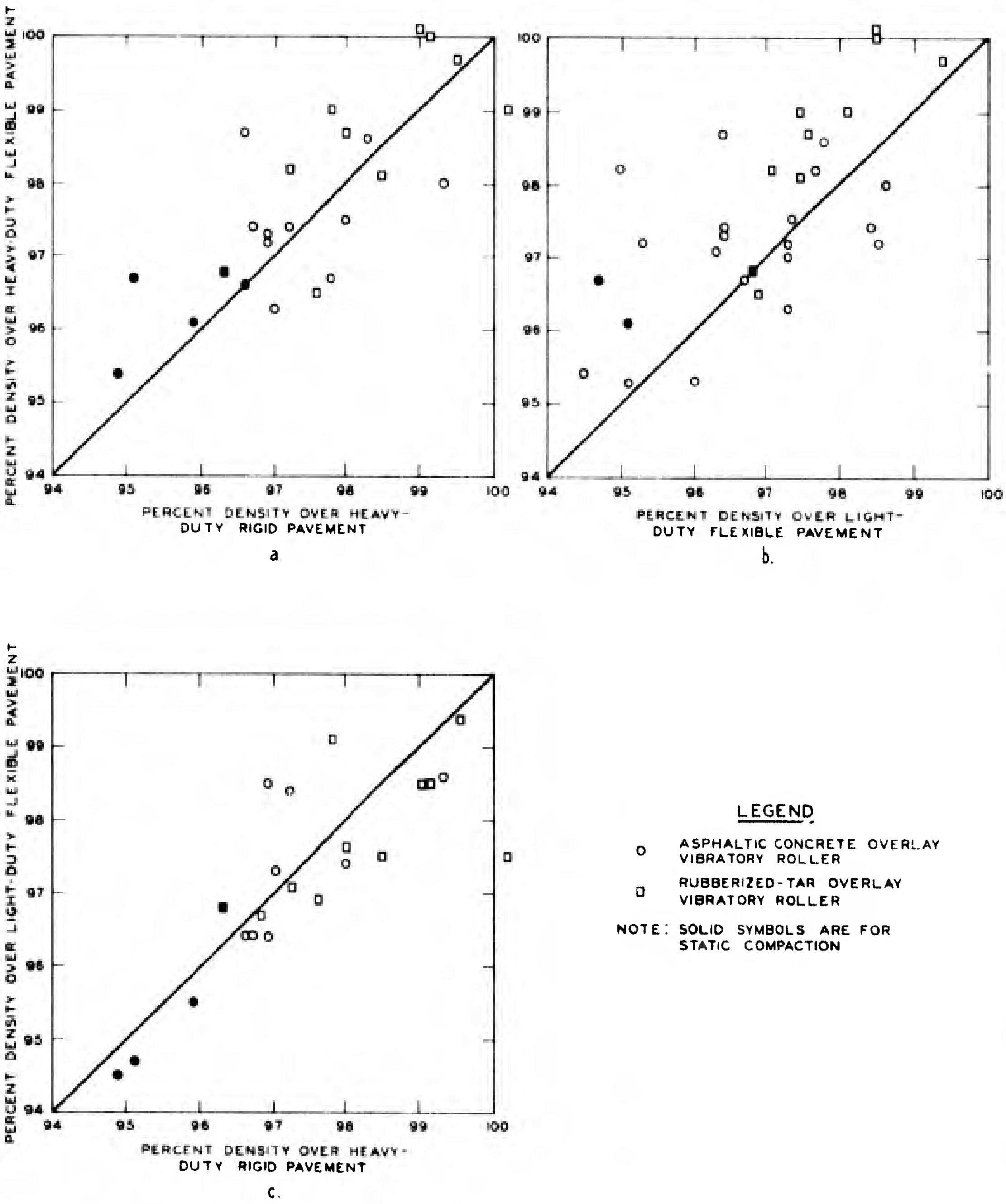
CLOSED SYMBOLS DENOTE COMPACTION WITH HIGH AMPLITUDE SETTING.

FREQUENCY-2400 VPM

EFFECT OF
TRAVEL SPEED AND AMPLITUDE
SETTING ON COMPACTION

DYNAPAC CC-50A
VIBRATORY ROLLER

PLATE 18



a

b.

c.

# EFFECT OF TYPE FOUNDATION ON COMPACTION

**In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.**

Burns, Cecil Dawson
Vibratory compaction of bituminous concrete pavements, by Cecil D. Burns. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.
1 v. (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Miscellaneous paper S-76-10)
Prepared for Headquarters, U. S. Air Force, Washington, D. C.

1. Bituminous concretes. 2. Flexible pavements. 3. Hot mix. 4. Overlays (Pavements). 5. Rubberized tar. 6. Vibratory compaction. 7. Vibratory compactors. I. U. S. Air Force. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper S-76-10)
TA7.W34m no.S-76-10