Corps
ers



MISCELLANEOUS PAPER GL-89-22

# THE EFFECTS OF THE CONSTRUCTION PROCESS ON SELECTED FRESH AND HARDENED PROPERTIES OF ROLLER-COMPACTED CONCRETE (RCC) PAVEMENTS

by

David W. Pittman

Geotechnical Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road
Vicksburg, Mississippi 39180-6199

September 1989
Final Report





Prepared for US Army Engineer Division, Europe
APO New York 09757-5301

GEOTECHNICAL LABORATORY

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

# REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

| | |
|---|---|
| 1a. REPORT SECURITY CLASSIFICATION: Unclassified | 1b. RESTRICTIVE MARKINGS |
| 2a. SECURITY CLASSIFICATION AUTHORITY | 3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited. |
| 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE | |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S): Miscellaneous Paper GL-89-22 | 5. MONITORING ORGANIZATION REPORT NUMBER(S) |
| 6a. NAME OF PERFORMING ORGANIZATION: USAEWES Geotechnical Laboratory; 6b. OFFICE SYMBOL (If applicable): CEWES-GP-T | 7a. NAME OF MONITORING ORGANIZATION |
| 6c. ADDRESS (City, State, and ZIP Code): 3909 Halls Ferry Road, Vicksburg, MS 39180-6199 | 7b. ADDRESS (City, State, and ZIP Code) |
| 8a. NAME OF FUNDING/SPONSORING ORGANIZATION: US Army Engineer Division, Europe; 8b. OFFICE SYMBOL (If applicable) | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER |
| 8c. ADDRESS (City, State, and ZIP Code): APO New York 09757-5301 | 10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO. |

11. TITLE (Include Security Classification)
The Effects of the Construction Process on Selected Fresh and Hardened Properties of Roller-Compacted Concrete (RCC) Pavements

12. PERSONAL AUTHOR(S)
Pittman, David W.

| 13a. TYPE OF REPORT | 13b. TIME COVERED | 14. DATE OF REPORT (Year, Month, Day) | 15. PAGE COUNT |
|---|---|---|---|
| Final report | FROM 1986 TO 1987 | September 1989 | 163 |

16. SUPPLEMENTARY NOTATION
See reverse.

| 17. COSATI CODES | | | 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) |
|---|---|---|---|
| FIELD | GROUP | SUB-GROUP | See reverse. |
| | | | |
| | | | |

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

In October 1986, a 16,500-sq-yd roller-compacted concrete (RCC) pavement tank hardstand was constructed at Harvey Barracks in Kitzingen, West Germany. This report discusses the effects of the construction process, particularly the laydown and compaction, on the strength, density, smoothness, and surface texture of the RCC pavement hardstand at Kitzingen.

The strength of the RCC was measured by conducting flexural and splitting tensile tests on beams and cylinders fabricated in the laboratory and extracted from the pavement. From the fabricated beams it was determined that the flexural strength decreases with decreasing density. The density of the RCC pavement was measured by conducting nuclear density gauge tests on the in situ RCC and by extracting cores from the pavement and determining the unit weight. It was determined that the density of the RCC pavement decreases close to an unconfined edge, that delayed compaction of joints results in decreased density, that the density decreases with pavement depth, (Continued)

| | |
|---|---|
| 20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS | 21. ABSTRACT SECURITY CLASSIFICATION: Unclassified |
| 22a. NAME OF RESPONSIBLE INDIVIDUAL | 22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL |

DD Form 1473, JUN 86 — Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

28

16. SUPPLEMENTARY NOTATION (Continued).

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. This report was also submitted to the Department of Civil Engineering, Mississippi State University, Starkville, MS, in partial fulfillment of the requirements for the degree of Master of Science.

18. SUBJECT TERMS (Continued).

| | | |
|---|---|---|
| Density | Roller-compacted concrete (RCC) | Zero-slump concrete |
| Durability | Smoothness | |
| Harvey Barracks | Strength | |
| Pavements | Surface texture | |

19. ABSTRACT (Continued).

and that the density increases with increasing roller passes.

From observation of the laydown and construction procedure and measurement of the longitudinal, transverse, and joint smoothness with a straightedge, it was determined that delayed compaction of the joints results in larger smoothness measurements, that maintaining paver continuity results in smaller longitudinal smoothness measurements, that stopping vibratory rollers on the fresh RCC surface results in larger longitudinal measurements, and that overlapping of vibratory roller passes results in larger transverse smoothness measurements.

From observation of the laydown and compaction procedure and the surface texture, it was determined that broadcasting of loose RCC over the pavement surface results in a coarser texture, that the RCC moisture content can affect the ability of the rollers to finish the surface, and that the rubber-tired roller is effective in tightening surface voids and fissures.

# PREFACE

This study was conducted by the Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES), During the period July 1986 through June 1987. The investigation was sponsored by the US Army Engineer Division (USAED), Europe.

The study was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, GL, and Mr. H. H. Ulery, Jr., Chief, Pavement Systems Division (PSD), GL. The study was conducted by Messrs. D. W. Pittman and R. T. Graham, PSD, GL; S. A. Ragan, M. K. Lloyd, and D. M. Walley, Concrete Technology Division, Structures Laboratory; and P. Ching, formerly of the Wurzburg Area Office, USAED, Europe. The report was prepared by Mr. Pittman as partial fulfillment of the requirements for the degree of Master of Science (Civil Engineering), Mississippi State University, Starkville, MS.

COL Larry B. Fulton, EN, is the Commander and Director of WES. The Technical Director is Dr. Robert W. Whalin.

## ACKNOWLEDGEMENTS

The work reported in this study was accomplished at the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. This study was developed within the Pavement Systems Division (PSD) of the Geotechnical Laboratory and conducted with the cooperation of the Concrete Technology Division (CTD) of the Structures Laboratory. Funding and support were provided by the Office, Chief of Engineers, US Army Corps of Engineers.

Appreciation is expressed to coworkers at the WES, in particular to Messrs. Steve Ragan, Michael Lloyd, and Donald Walley of the CTD, and Mr. Rogers Graham of the PSD; to Mr. Paul Ching, formerly of the Wurzburg Area Office, European Division, Corps of Engineers; and to Messrs. Wolfgang Schlage and Bernd Paar of Philipp Holzmann. Thanks are due to Dr. Robert M. Scholtes, Head of Civil Engineering Department, Mississippi State University, for chairing the thesis review committee; to Dr. Oswald Rendon-Herrero, for serving as my on-campus advisor and a member of the thesis review committee; and to Dr. George M. Hammitt III, for serving as my off-campus advisor and a member of the thesis review committee. Special thanks are due to Mr. David L. Cooksey and Dr. George M. Hammitt III for their constant support, motivation, and guidance; to the typists and draftsmen who patiently and professionally helped prepare this manuscript; and to my mother and father, for their support and inspiration.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES

# LIST OF FIGURES

LIST OF FIGURES

# CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| cubic yards | 0.7645549 | cubic metres |
| Fahrenheit degrees | 5/9 | Celsius degrees or kelvins* |
| feet | 0.3048 | metres |
| gallons (US liquid) | 3.785412 | cubic decimetres |
| inches | 2.54 | centimetres |
| pounds (force) per square inch | 6.894757 | kilopascals |
| pounds (force) per square foot | 47.88026 | pascals |
| pounds (mass) | 0.4535924 | kilograms |
| pounds (mass) per cubic foot | 16.01846 | kilograms per cubic metre |
| pounds (mass) per cubic yard | 0.5932 | kilograms per cubic metre |
| square yards | 0.8361274 | square metres |
| tons (force) | 8.896444 | kilonewtons |

* 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.

# SECTION I

## INTRODUCTION

Roller-compacted concrete (RCC) pavement employs a relatively new construction technique in which asphalt concrete paving methods are used to construct a portland cement concrete pavement. RCC paving involves placing a very stiff (zero-slump) concrete mixture with an asphalt paver and compacting it externally with a large vibratory roller. This paving technique allows the high-production placement of concrete pavement without the use of large slipform paving trains, forms, dowels, or steel reinforcement, and typically results in cost savings of 20 to 30 percent of conventional concrete pavements. These advantages are offset somewhat by a coarser surface texture and a rougher surface smoothness, especially at construction joints, than conventional concrete pavements. These characteristics have limited the use of RCC pavements to areas where heavy, low-speed traffic is the primary user of the pavement, such as port container terminals, intermodal shipping yards, secondary roads, and tank parking areas (hardstands).

The desired properties of adequate flexural strength, durability, smoothness, and surface texture of an RCC pavement are very sensitive to the construction process, including mixing, laydown, compaction, and curing. The effects of the construction process on the fresh and hardened properties of RCC became apparent during the construction of an RCC test section and hardstand in Kitzingen, West Germany.

In 1985, the U.S. Army, European Command, contacted the U.S. Army Engineer Waterways Experiment Station (WES) to help in the selection of an economical hardstand pavement alternative to "get the tanks out of the mud." The 16,500-square-yard tank hardstand was to be built at Harvey Barracks in Kitzingen, West Germany, a relatively harsh environment for any pavement (Figure 1). The German government would not approve the construction of a gravel hardstand because of the potential for contamination of the groundwater system with fuel or oil, and the hardstand had to be capable of withstanding the punishing action of tank traffic. RCC was selected from thirteen pavement alternatives as the best-suited and most economical means of serving this function.

During the construction of the Harvey Barracks hardstand, which was the first RCC pavement in West Germany, tests were conducted to


Figure 1. Location of Kitzingen, West Germany

evaluate the strength, density, and smoothness of the pavement. From these tests and from observation of the construction process by the writer, it was determined that variations in the laydown and compaction process affect the strength, density, smoothness, and surface texture of an RCC pavement. This thesis will present the plan of test used to evaluate these effects; the materials, mixture proportions, and geometry unique to the Harvey Barracks hardstand; the construction equipment and procedures used, including observations by the writer of the effects of the laydown and compaction on smoothness and surface texture; the results of the strength, density, and smoothness tests; and conclusions and recommendations based on the tests and observations made. Photographs of the construction equipment, the construction procedures and the effects of the construction process on the surface texture are provided to aid the reader in visualizing these points of discussion.

## A. OBJECTIVE

The objective of this study is to investigate the effects of the construction process, particularly the laydown and compaction, on the strength, density, smoothness, and surface texture of the RCC test section and hardstand at Kitzingen, West Germany.

## B. SCOPE

Results of the RCC mixture proportioning study, including the aggregate grading, hardness, and particle shape, and the RCC mixture proportions were examined. All elements of the test section and hardstand construction procedure, including the mixing, hauling, laydown, compaction, curing, and jointing, were investigated. The laboratory and field test data were compared to specification requirements. Specific tests included concrete moisture content; cylinder, core, and beam density and strength; in situ density and moisture content; and smoothness. Correlations were developed for roller passes versus nuclear gauge density, nuclear gauge density versus core density, and flexural strength versus fabricated beam density. Variations in the timing between lanes were investigated to examine the effects on the joint density between lanes. Observations of the laydown and rolling procedure and their effects on the smoothness and surface texture were made.

# SECTION II

# LITERATURE REVIEW

A review of the literature on RCC construction and material properties was conducted to determine what effects the construction process has on the strength, density, smoothness, and surface texture of RCC pavements. While RCC pavement construction is a relatively new process and the experiences at various construction projects may vary somewhat, some common factors were predominant in their influence on the fresh and hardened properties of RCC.

## A. STRENGTH

The strength of an RCC mixture is a very critical factor because it is the only property of the concrete that is used in the U.S. Army Corps of Engineers RCC thickness design procedure (Department of the Army 1988a). The strength of RCC pavement mixtures may be determined by using the flexural strength (American Society for Testing and Materials 1986a), compressive strength (American Society for Testing and Materials 1986b), or splitting tensile strength (American Society for Testing and Materials 1986c) tests on hardened concrete specimens at the required testing age. While the flexural strength is used in the Corps of Engineers design procedure, the compressive and/or splitting tensile strength is often correlated to the flexural strength because it is easier to extract cores than beams from the pavement and test them in the laboratory.

The strength of any portland cement concrete is a function of many variables, involving the materials used in the concrete, mixing and construction procedures, environmental factors, and even the method of testing or sample size. However, it is not the purpose of this thesis to provide an exhaustive investigation of these factors on the strength of RCC, but to present the key construction factor found in the literature that influences the strength of RCC, which is the degree of compaction or density.

It is well known that the degree of compaction, or relative density, of a given concrete mixture has a significant influence on the concrete strength. Neville (1986) states "the strength of concrete at a given age and cured at a prescribed temperature is assumed to depend primarily on two factors only: the water-cement ratio and the degree of compaction." Neville points out that a 5 percent increase in voids in concrete can reduce the strength by as much as 30 percent. This phenomenon appears to be as true for RCC as for conventional concrete (Pittman and Ragan 1986). Assuming that the water-cement ratio and mixture proportions for a given project remain reasonably constant, and given that the stiff consistency of a fresh RCC mixture makes it relatively difficult to fully consolidate, the degree of compaction obtained in the field is probably the single most important factor in achieving the required strength in an RCC pavement.

Rollings (1988a) sites test results from several projects that indicate that small decreases in density result in large decreases in compressive and flexural strength. Brett (1988) reports that test results from several RCC pavement projects in Australia indicate that a 5 percent reduction in relative density results in a 40 percent reduction in the compressive strength.

Rollings (1988b) points out that the performance of RCC pavements is adversely affected when adequate density is not achieved at the bottom of the lift. This becomes the weakest plane in the pavement section, and is where the highest stresses from loading develops. Abrams and Jacksha (1987) point out the effect of decreasing density with depth on the flexural strength of RCC. When a beam sawn from the RCC pavement at the Portland International Airport was inverted during testing to put the denser (top) portion of the beam on the bottom, the flexural strength was 75 pounds per square inch higher than beams that were not inverted.

B. DENSITY

The density of an RCC mixture, or the degree of compaction achieved, is influenced by many construction factors. These include: (1) the type of paver screed used, (2) the number of roller passes, (3) the time until initial compaction, and (4) the thickness of the lift.

Keifer (1988) reports that a heavy duty paver screed (which uses two or more tamper bars in addition to vibration to achieve 94 to 95 percent Modified Proctor density behind the paver) tends to compact the upper half of the lift to the extent that a "bridging" effect hinders the attainment of the required density in the lower half of the lift during rolling.

Keifer (1988) reports that at least four vibratory passes are required by the Corps, and then additional passes as needed, to obtain the required density. This pass level is generally accepted by most authors as the minimum necessary to achieve adequate density. Keifer reports that the Corps requires that the vibratory rolling be completed within 45 minutes of mixing the RCC, and that joints between lanes should be compacted within 60 minutes, to ensure that the RCC does not set up or dry out to the extent that the required density cannot be achieved.

Rollings (1988b) suggests that the maximum thickness that can be reliably compacted to the full depth is 6 to 9 inches; Hutchinson et al. (1987) suggests a maximum lift thickness of 12 inches; and Murphy (1987) reports that a 14-inch-thick lift would result in inadequate compaction at the base of the layer. Hess (1987) reports that the density of RCC decreases slightly with depth, even after final compaction.

C. SMOOTHNESS

The smoothness of a pavement surface refers to the evenness or flatness of the surface, which affects the ride quality and drainage characteristics of the surface. The U.S. Army Corps of Engineers procedure for determining the smoothness of an RCC pavement involves measuring the maximum deviation of the surface from a 10-foot straightedge. Bumps, depressions, or differential elevations across cracks or joints result in larger smoothness measurements and therefore a rougher ride quality. Some materials and construction factors that can effect the smoothness of an RCC pavement include: (1) the thickness of the lift, (2) the type of paver screed, (3) the operation of the paver, (4) the rolling operation, (5) the timeliness of the finish rolling, and (6) the presence of cold joints.

Palmer (1987) pointed out that the rolling of a 9-inch-thick lift of RCC produced a wavy surface, while a 6-inch-thick lift produced a flatter surface, due to the smaller amount of surface deflection needed to achieve adequate consolidation. Andersson (1987) was referring to this effect when he stated "the flatness of the surface depends primarily on the equipment used in relation to the thickness of the pavement."

The use of a "high-density" screed (with tamper bars) can also result in a smoother surface. Keifer (1988) observed that a screed with only vibratory compaction imparted very little density to the RCC, resulting in a higher percentage of settlement during rolling and making it difficult to meet straightedge tolerances. However, the high-density screed imparts more compaction to the RCC before rolling, improving the surface smoothness considerably.

The operation of the paver can have a major influence on the final smoothness achieved. Raczon (1988) points out that the three main operational factors that influence the smoothness achieved with an asphalt paver include: (1) the "angle of attack," (2) the head of material, and (3) the paver speed. The angle of attack refers to the angle of the bottom of the screed in relation to the grade, which determines the amount of material that will pass under the screed. This should be controlled manually by an experienced operator or by use of an electronic stringline grade control device. The head of material refers to the amount of material built up in front of the augers which distribute the material in front of the screed. The head should remain constant to ensure that a steady pressure is applied to the screed, thereby maintaining it at an even grade. The paver speed should be steady; slowing the paver speed causes the screed to rise and the material develops a higher density, while speeding up the paver increases the material demand, dropping the head of the material and reducing the amount of compaction. Johnson (1988) observed a similar phenomenon during RCC paving, pointing out that when the paver stops forward motion, the screed has a tendency to sag, and rises again when the forward motion proceeds, creating a wave in the pavement surface.

Pittman and Ragan (1986) note the influence of the rolling operation on the smoothness, recommending that the stopping points of successive vibratory roller passes be staggered to avoid depressions in the surface. They also warn that the vibratory roller should never stop on the pavement in the vibrating mode; rather, the vibrator should be turned on only after the roller is in motion and turned off several feet before the roller stops moving.

Hess (1987) reports that the roller marks may be left in the surface if the finish rolling with a smooth drum is not completed before the concrete sets. He also observed that cold longitudinal joints tend to have a high percentage of out-of-tolerance smoothness measurements transverse across the joint. However, when shorter lanes were paved to produce fresh longitudinal joints, the transverse joint measurements improved, but the frequent resetting of the paver resulted in poorer longitudinal smoothness.

## D. SURFACE TEXTURE

The surface texture refers to those characteristics of a pavement surface that influence the "skid resistance" or coefficient of friction between the pavement surface and a whatever comes in contact with it, such as an automobile tire. The "microtexture" of an RCC surface is determined by the presence of small voids or grittiness of extruding sand particles. The "macrotexture" is influenced by superficial cracks or tears in the surface, or by exposed coarse aggregate resulting from raveling of fines from the surface, scaling, or the presence of honeycombs exposed at the surface resulting from segregation of coarser aggregate from the mixture. A "tight" surface texture would have a minimum of voids, fissures, or exposed aggregate, while a "rough" or "coarse" surface texture would have more surface cracks or exposed coarse aggregate. The distinction is often made as a result of subjective observations, as there are no good tests for classifying surface texture.

From the literature, it was determined that the surface texture of RCC is affected by several construction factors, including: (1) the RCC moisture content, (2) the type of paver screed, (3) broadcasting of material over the surface before rolling, and (4) the rubber-tire roller operation.

Hess (1987) observed that when the RCC moisture content was slightly over optimum, the surface had a noticeable sheen, and surface shear cracks from the paver operation became wider and more apparent. However, the surface texture of the wetter mixture was easier to tighten with the rubber-tire roller, while a drier than optimum mixture was more difficult to tighten.

Keifer (1988) observed that a high-density screed has the disadvantage of causing numerous shallow tears in an RCC pavement surface that are difficult to close during rolling. Piggott (1987) observed that limiting the paver screed width tends to reduce segregation of the coarser aggregate at the edges of the lane.

Pittman and Ragan (1986) recommend that loose material not be broadcast (or spread with a shovel or rake) over the pavement surface before rolling, or a rough surface texture may result. They also recommend the use of a rubber-tire roller immediately after vibratory compaction to close surface voids and fissures.

Hutchinson et al. (1987) noted that excessive rolling of an RCC surface that has been wetted (due to raining or moist curing) can cause a very liquid slurry to be pumped to the surface, which has the potential for raveling or flaking under traffic.

# SECTION III

## PLAN OF TEST

To determine the effects of the laydown and compaction on the strength, density, smoothness, and surface texture, a plan of test was developed by the writer. This plan involved testing specific properties of the RCC, such as the flexural and splitting tensile strength and the density of the fresh and hardened materials, and also observing the paving and rolling operation to determine the effect on the smoothness and surface texture. Many of these tests were conducted as part of the quality control plan, whose results are provided in SECTION IX: TEST RESULTS. The following is a description of the tests conducted and observations made specifically to determine the effects of the laydown and compaction on the strength, density, smoothness, and surface texture.

### A. STRENGTH

During construction of the hardstand, six beams were fabricated by WES Concrete Technology Division (CTD) personnel in the laboratory (one per construction day) and tested for 28-day flexural strength. Due in part to the nonstandard fabrication technique used in manufacturing the beams (discussed in SECTION V: MATERIAL AND MIXTURE PROPORTIONING STUDY), a range in densities was obtained, which subsequently led to a wide range in flexural strengths obtained. Beams were also fabricated and sawed from the pavement during the test section construction to obtain a comparison of the laboratory and field flexural strengths.

B. DENSITY

During the test section construction, the in situ density of the RCC was determined with the nuclear density gauge after successive passes with the vibratory roller to determine the increase in density obtained. As part of the quality control operations, a nuclear gauge density reading was obtained at random intervals across the width of the paving lane and at incremental depths to detect changes in density across the width of the paving lane and with depth into the RCC lift. Six cores taken from the hardstand were trisected into upper, middle, and lower thirds to confirm any changes in density with pavement depth.

The time of the start and finish of each paving lane was documented to determine the average amount of time elapsed before compaction of the fresh joint between the lanes occurred. The average elapsed time between lanes was then compared to the average nuclear gauge density reading obtained at the joints for that day.

C. SMOOTHNESS

As part of the quality control testing during the test section and hardstand construction, smoothness measurements were made using a 13-foot-long straightedge in the longitudinal and transverse directions relative to the paving lane, and across joints between lanes. These measurements allowed a relative comparison of the smoothness achieved in each direction. By observation of the roller and paver operation, certain techniques were noticed by the writer which appeared to influence the magnitude of these measurements.

## D. SURFACE TEXTURE

No specific measurements were made to quantify changes in the surface texture due to the paving and rolling process; rather, observation of these processes were made by the writer to detect these changes. Based on his previous experience with RCC paving techniques and their effects on the surface texture of RCC, the writer noted changes in the texture as it appeared behind the paver, as changes in the RCC moisture content occurred, and the effect of the rubber-tire roller on the surface texture.

## SECTION IV

## COLLECTION OF DATA

Table 1 contains the type and frequency of testing used to determine the effects of the laydown and compaction on the strength, density, smoothness, and surface texture of RCC pavements. Each of the expected effects of the construction process on the properties of RCC, as discussed in the plan of test, is also given, as well as the personnel responsible for collecting the data. The actual data and test results are presented in Appendix D. It should be noted that all observations made in this thesis concerning the construction at Harvey Barracks are those of the writer.

TABLE 1. TYPE AND FREQUENCY OF TESTING AND DATA COLLECTION

| RCC Pavement Property | Construction Factor Influencing Property | Relationship Between Construction Factor and RCC Pavement Property | Type of Testing to Detect Influence | Frequency of Testing | Personnel Conducting Tests |
|---|---|---|---|---|---|
| Strength | Compaction | Variation in flexural strength with density | 28-day flexural strength of fabricated beams; measure density of beam | One per day (hardstand construction) | WES CTD (fabrication) and contractor quality control (QC) personnel (testing) |
| Density | Laydown and compaction | Variation in density across width of paving lane | Nuclear density gauge | One per 100 feet of paving lane | WES PSD and contractor QC personnel |
| | Laydown and compaction | Variation in joint density with delayed compaction | Nuclear density gauge; start and end time of each paving lane | One per 100 feet of joint; time each paving lane per day | WES PSD and contractor QC personnel; writer and Corps personnel |
| | Compaction | Variation in density with vibratory roller passes | Nuclear density gauge | Three readings per two vibratory passes | WES PSD personnel |
| | Compaction | Variation in density with pavement depth | Incremental nuclear density gauge readings; trisected core densities | One per 100 feet of paving lane; one core per day | Contractor QC personnel |
| Smoothness | Laydown and compaction | Effect of delayed compaction on joint smoothness | Straightedge testing across joint, and observation | One per 100 feet of joint | Writer (testing and observation) |
| | Laydown | Effect on paver continuity on longitudinal smoothness | Longitudinal straightedge testing and observation | One per 100 feet of of paving lane | Writer (testing and observation) |
| | Compaction | Effect of stopping vibratory roller on longitudinal smoothness | Longitudinal straightedge testing and observation | One per 100 feet of paving lane | Writer (testing and observation) |
| | Compaction | Effect of overlapping passes on transverse smoothness | Transverse straightedge testing and observation | One per 100 feet of paving lane | Writer (testing and observation) |
| Surface texture | Broadcasting (spreading loose RCC over surface) and compaction | Effect of broadcasting on surface texture | Observation | Per occurrence | Writer |

(Continued)

TABLE 1. (Concluded)

| RCC Pavement Property | Construction Factor Influencing Property | Relationship Between Construction Factor and RCC Pavement Property | Type of Testing to Detect Influence | Frequency of Testing | Personnel Conducting Tests |
|---|---|---|---|---|---|
| | RCC moisture content and compaction | Effect of RCC moisture content on surface texture | Observation | Per occurrence | Writer |
| | Laydown and compaction | Effect of paver screed and rubber-tire roller on surface texture | Observation | Each lane | Writer |

# SECTION V

## MATERIALS AND MIXTURE PROPORTIONING STUDY

In late spring 1986, a mixture proportioning study was conducted at the WES CTD on materials shipped from Kitzingen that were representative of those to be used during construction. The aggregates were provided in three sizes: crushed gravel, 3/4-inch to No. 4; crushed gravel, 3/8-inch to No. 50; and natural sand, No. 4 to No. 100. The sand was relatively clean, with approximately 1 percent by weight passing the No. 100 sieve. The combined grading fell well below the recommended grading band (Figure 2), which is very similar to that used in asphalt concrete. This aggregate grading tends to produce a concrete mixture that does not segregate easily, is stable under a vibratory roller, and provides a tight surface texture with minimal voids. The crushed gravel had an unusually high content (17 percent) of flat and

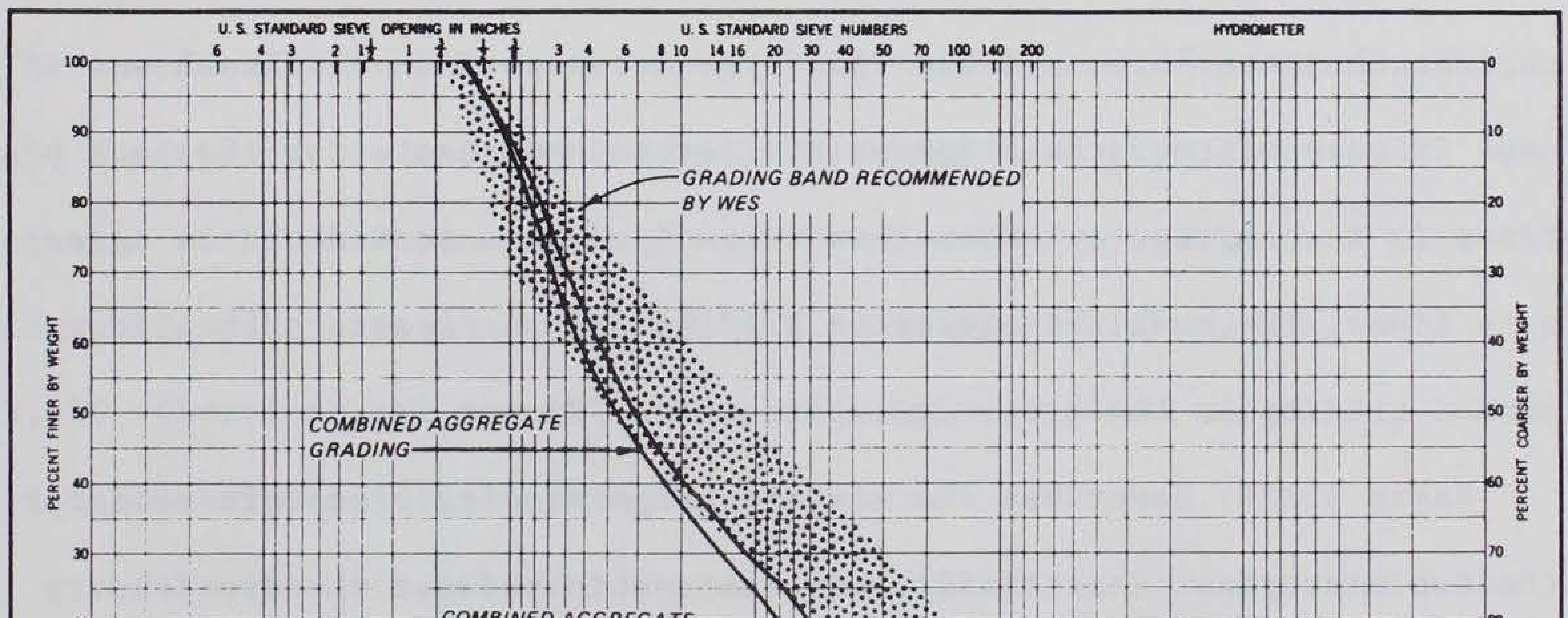



Figure 2. RCC Aggregate Grading

elongated particles (CRD-C 119) (U.S. Army Engineer Waterways Experiment Station 1986a) and Los Angeles Abrasion weight loss (25 percent) (CRD-C 117) (U.S. Army Engineer Waterways Experiment Station 1986b) although the materials were within specifications. The specifications allowed a maximum of 20 percent flat and elongated particles, and 40 percent weight loss in the Los Angeles Abrasion test. The relatively high Los Angeles Abrasion loss generated concern that the aggregate would break down during the mixing process, causing an increased water demand, while the high percentage of flat and elongated particles indicated that the aggregate might segregate readily from the concrete during placing and handling, causing unsightly and unsound rock pockets in the concrete. However, these potential problems did not manifest themselves when the construction began.

Two trial mixtures were prepared at the WES CTD, with different cement and flyash contents to provide a range of flexural strengths and surface characteristics (Table 2). A generous portion of flyash was used in both mixtures as a mineral filler to compensate for the lack of fines in the aggregate. When this extra flyash is considered as aggregate fines, the combined aggregate grading shifts closer to the recommended grading in the lower aggregate sizes (Figure 2).

Ragan (1988) describes the mixture proportioning procedure used for the two mixtures. Essentially, a relationship between the dry density and moisture content was developed using procedures described in ASTM D 1557 (American Society for Testing and Materials 1983) to determine the optimum moisture content at the maximum dry density for a specific compactive effort. This procedure was repeated over a range

TABLE 2. RCC MIXTURE PROPORTIONS

| Component | Mixture Proportions (lb/cu yd) Mix No. 1 | Mix No. 2 | Average Plant Yield Mix 1 |
|---|---|---|---|
| Cement | 467 | 539 | 466 |
| Flyash | 263 | 206 | 262 |
| Fine sand | 1,002 | 1,002 | 1,002 |
| Coarse sand | 1,243 | 1,243 | 1,243 |
| Coarse aggregate | 772 | 772 | 772 |
| Water | 215 | 218 | 226 |
| W/C+F | 0.29 | 0.29 | 0.31 |
| Moisture content | 5.7% | 5.8% | 6.0% |

* Total aggregate.

of cementitious material contents to develop mixtures with various water/cement ratios. Test specimens were then fabricated for each combination of optimum moisture content and cementitious material content. The specimens were fabricated by filling the beam molds in two layers, and the cylinders in three layers, and consolidating each layer for two minutes with a 150 pounds per square foot surcharge weight on a vibrating table with an amplitude of 0.0625 inch and a frequency of 3,600 vibrations per minute. The specimens were moist cured at 73 degrees F until the testing age.

A flexural strength of 800 pounds per square inch was given in the German specifications as the design concrete strength, and was assumed to be the result of center-point loading at 28-days. Since the flexural strength due to third-point loading (American Society for Testing and Materials 1986a) can be assumed to be about 80 to 90 percent of that obtained from center-point loading (Neville 1986), a flexural strength of 720 pounds per square inch at 28 days was assumed for the RCC mixture design.

# SECTION VI

## GEOMETRIC AND THICKNESS DESIGN

A plan of the 2,300 square yard test section and 16,500 square yard hardstand is given in Figure 3. The thickness of the pavement and base course were designed according to German standards, resulting in thicknesses of 7.1 inches and 12.6 inches, respectively. The hardstand is surrounded by a precast curb set in concrete, which provided good lateral support along the edge during compaction. The hardstand is divided by three drainage gutters running in the long direction of the rectangular hardstand, dictating the direction of the paving in the central portion (Day 2, 3, 4, and 5). The precast gutters were secured in place prior to paving by a 6-inch-wide concrete strip cast around the gutter. The edges of the hardstand adjacent to the gutters and curbs are tapered to a thickness of 8.9 inches. Four manholes are located between the gutters to provide access to the underground drainage system. An expansion joint was used between the RCC and all curbs, gutters, and manholes, and at the intersection of perpendicularly-placed paving lanes. The maximum cross slope is 2.5 percent.

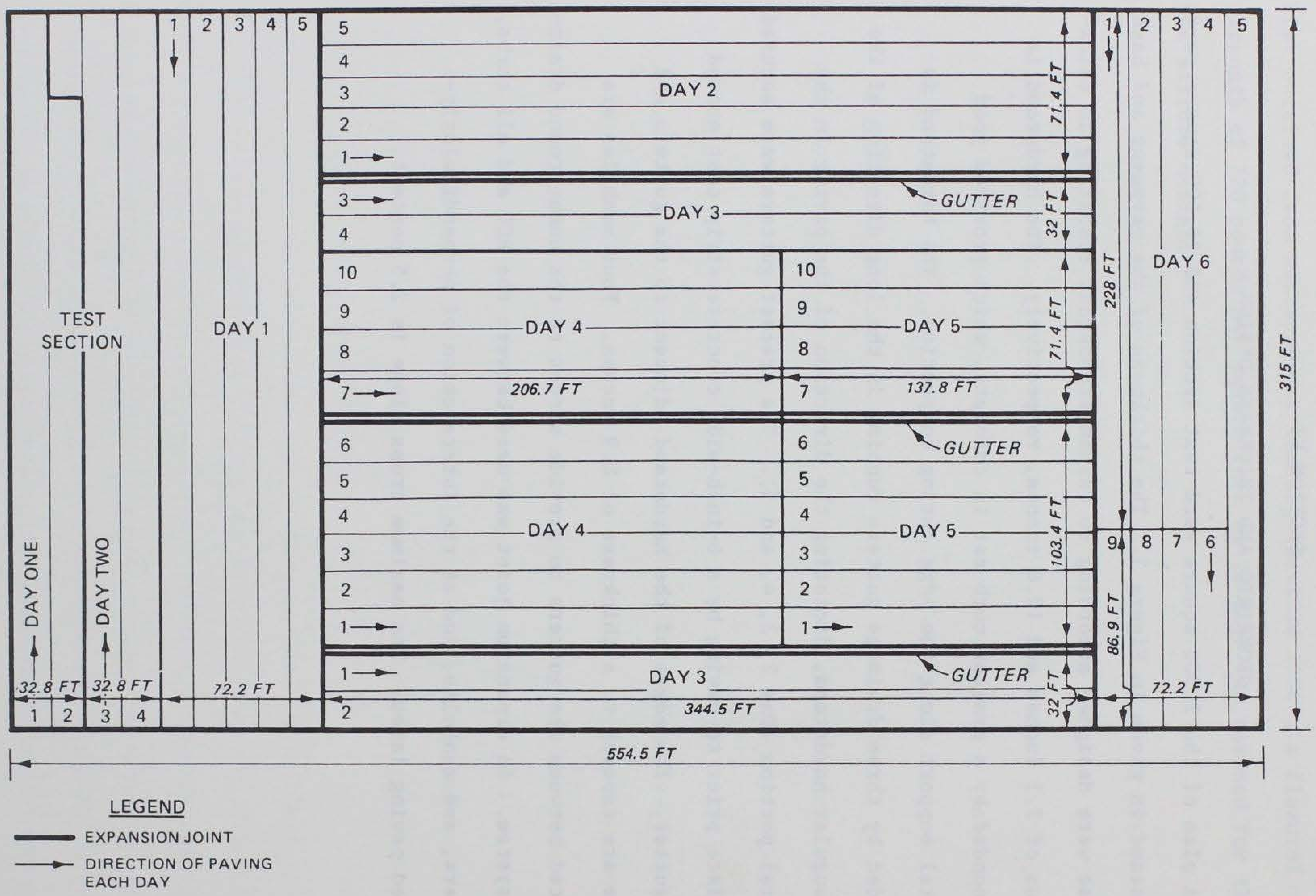



Figure 3. Orientation of Paving Lanes and Dimensions of Daily Placement

## SECTION VII

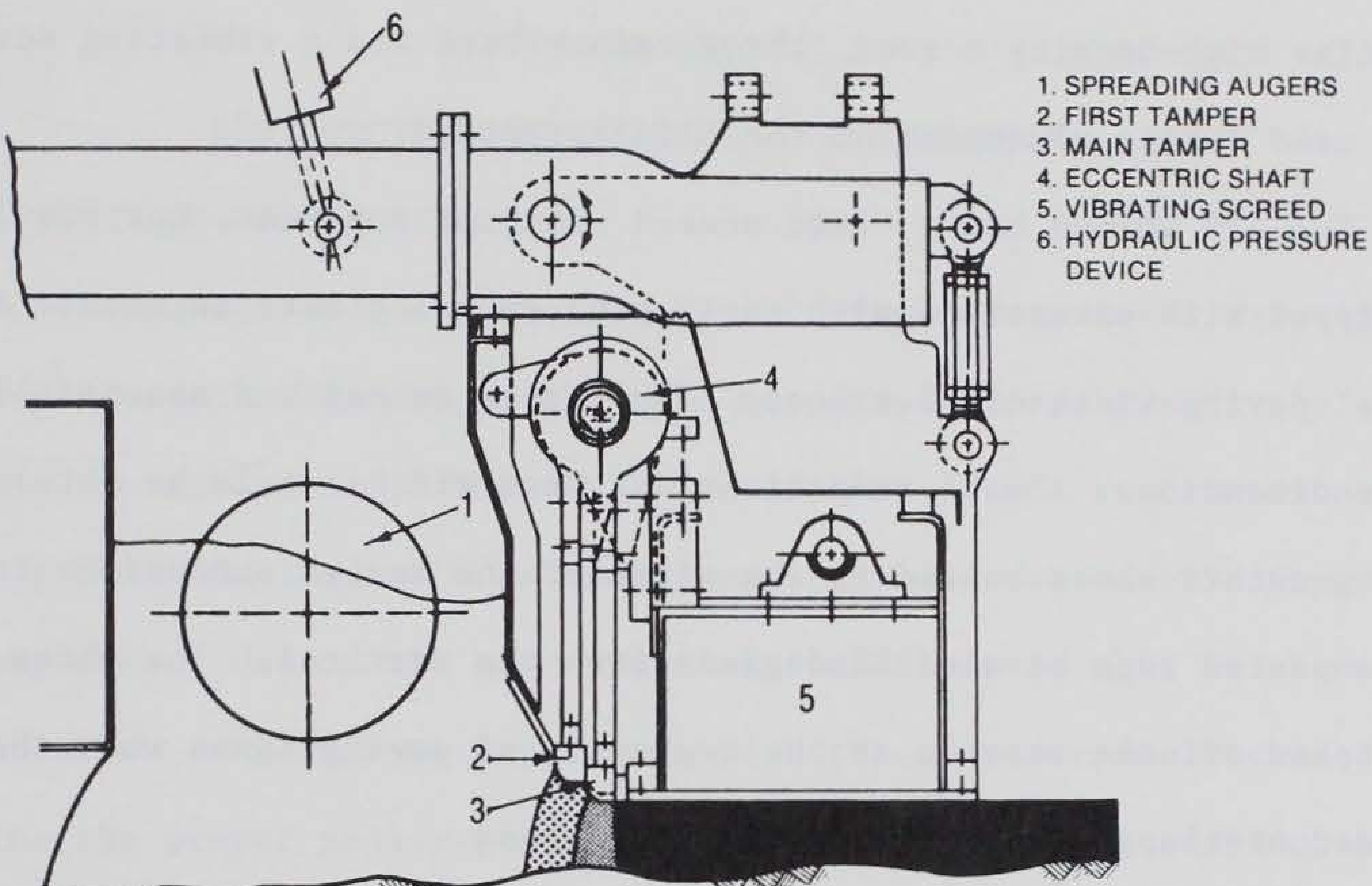
## CONSTRUCTION EQUIPMENT

A complete listing of the equipment used in the construction of the test section and the hardstand is given in Table 3. The mixing plant used in the production of the concrete was of the weigh-batch type, which allowed for accurate proportioning of the materials. The plant produced an average of about 65 cubic yards per hour, and was located about 15 minutes away from the paving site, although at times of heavy city traffic, the haul time would increase up to one hour. The 2.6 cubic yard mixing unit contained a single horizontal shaft to which paddles and spiral mixing blades were attached, and was of the type typically used for mixing conventional concrete in Germany. The mixer provided a very adequate mixing action to the stiff concrete, each batch being mixed an average of 50 to 60 seconds each. The RCC was hauled to the paving site with dump trucks of 13 to 16 cubic yard capacity.

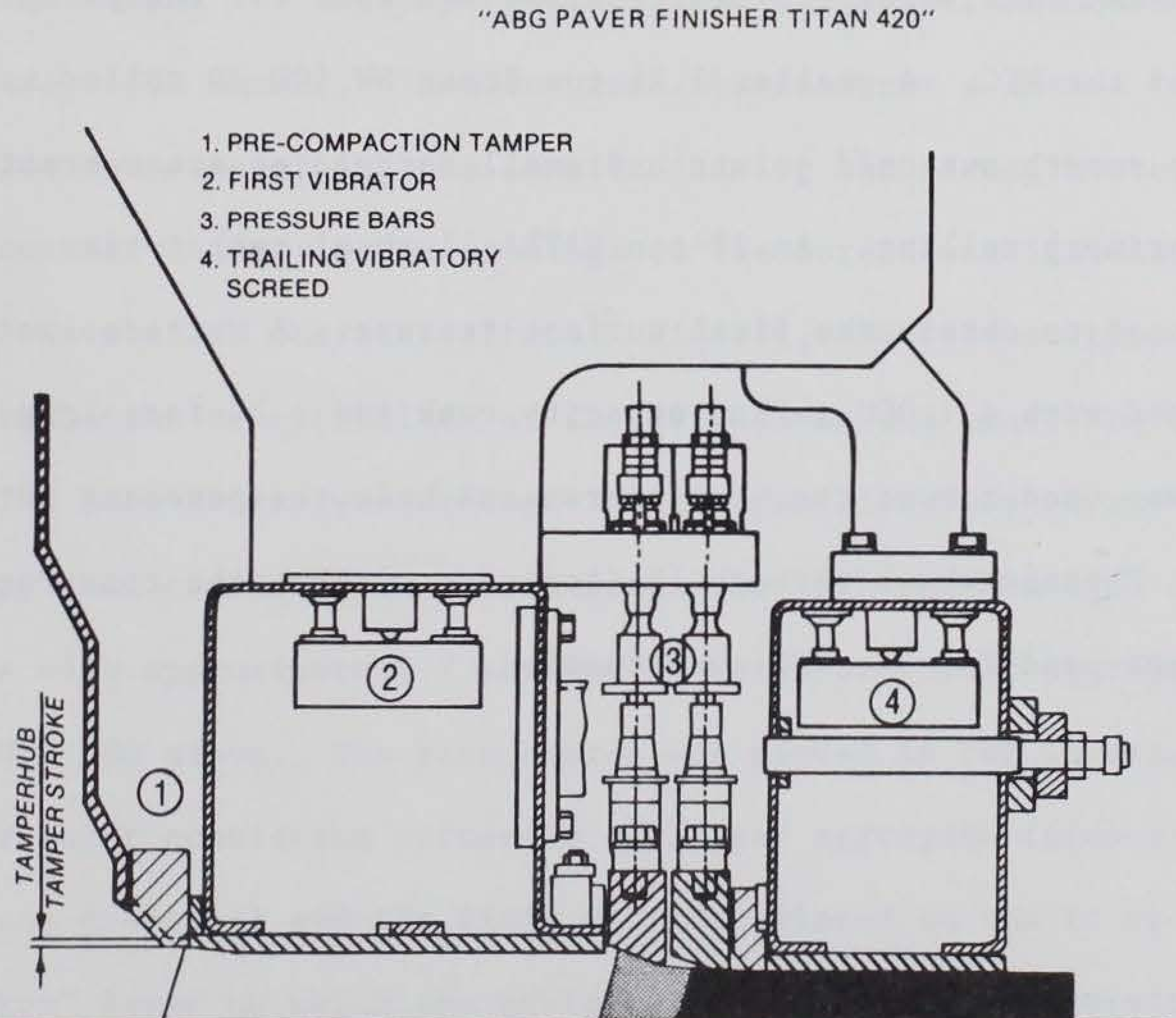
An ABG Titan 420 paver was used for paving the test section. The unique feature of this German-built machine is the "high-density" screed (Figure 4), which combines the effect of dual tamping bars with a vibrating screed to produce a very smooth surface behind the screed at a density of about 90 to 93 percent of the final density. This high density results in a smoother final surface than is typically achieved behind an ordinary paver, because the surface is not deflected as much during the rolling process, which causes the "wavy" surface sometimes associated with RCC pavements. A Vögele Super 1700 paver with a

TABLE 3. RCC PAVEMENT CONSTRUCTION EQUIPMENT

| Type | Features |
|---|---|
| 1. Concrete batch plant | European design with spiral blades<br>Production: 65 cu yd/hr |
| 2. Dump trucks | Dual axle<br>10 to 12 cu yd capacity<br>8 trucks used |
| 3. Paver | Test section:<br>ABG Titan 420<br>Tracked<br>16.4-ft-wide screed<br>Vibratory screed, 2 tamper bars |
| | Main hardstand:<br>Vögele<br>Tracked<br>16.4-ft-wide screed<br>Vibratory screed, 3 tamper bars |
| 4. Rollers | Vibratory:<br>HAMM dual-drum<br>Approximately 10 tons |
| | Rubber-tire:<br>HATRA<br>11 wheels<br>Approximately 18 tons |
| | Small roller:<br>BOMAG BW 100 AD<br>Dual-drum, vibratory<br>Approximately 4,500 lb |
| 5. Water truck | Mercedes Unimog-1200<br>Approximately 1,000 gal capacity<br>30-ft-long foldable water spray boom |




"ABG PAVER FINISHER TITAN 420"




"SCREED FOR HIGH-POWER COMPACTION FOR VOGELE ROAD PAVERS"

Figure 4. High-Density Paver Screeds:
ABG Titan 420 and Vögele Super 1700

similar high-density screed (three tamper bars and a vibrating screed) was used during placement of the main hardstand.

The ABG screed had a basic screed width of 9.8 feet, but was equipped with extensions with their own tampering bars to create a total paving width of 16.4 feet. The Vögele screed had essentially the same dimensions. Small reductions in these widths could be obtained by using cutoff shoes bolted to the sides of the screed extensions to form a compacted edge beveled 15 degrees from the vertical. The shoes could be taken off the screeds at the beginning of paving lanes when the screed overlapped the previously placed lane.

A 10-ton HAMM dual-drum vibratory roller was used for the primary compaction of the RCC. A smaller 2.25 ton Bomag BW 100 AD roller was used to help smooth out cold joints and small corrugated areas created during the primary rolling. An 18-ton HATRA 11-wheel rubber-tire roller was used to obtain the final surface texture. A Mercedes water truck equipped with a 1,000 gallon capacity tank and a 30-foot-long spray boom was used to wet the base course and keep the pavement surface moist. Photographs 1 through 12 (Appendix A) show the construction equipment used for the RCC construction.

# SECTION VIII

# TEST SECTION AND HARDSTAND CONSTRUCTION

## A. TEST SECTION CONSTRUCTION

A 2,300 square yard test section was constructed on 14-15 July 1986 at Harvey Barracks adjacent to the main hardstand site, effectively serving as an extension of the hardstand (Figure 3). A test section is typically built on large RCC pavement projects to serve several important functions. One of the most important functions is that it allows the contractor to gain some experience with the construction method, to determine the proper roller pattern to be used during construction, and to demonstrate his ability to place, haul, compact, and cure the RCC in an acceptable manner. It also gives the designer a chance to obtain samples for determining the in situ density and strength, to correlate the nuclear density gauge readings to the core densities, and to evaluate the surface characteristics. Finally, the test section served to determine the acceptability of the surface to the user, the U.S. Army.

The base course was defined in the specifications as an "anti-frost layer," and consisted of a well-graded, 2-inch maximum size crushed stone with approximately 7 percent by total weight of aggregate passing the No. 200 sieve. The base course was placed in two layers, with the lower layer consisting primarily of larger aggregate (presumably to enhance drainage) and the finer material placed on top to provide a "choker" layer on which the equipment could be easily operated. Photographs 13 through 15 (Appendix A) show the base course construction.

Mix 1 was used in the placement of the first two lanes of the test section (DAY ONE), and Mix 2 was used in the second two lanes (DAY TWO) (Figure 3). The first 100 feet of Lane 1 was used to adjust the moisture content of the concrete to where it appeared to compact best under the vibratory roller, and to determine the number of roller passes necessary to achieve the required density.

Once the number of roller passes was determined, the paving proceeded at a rate of about 3 feet per minute. The paver placed the fresh concrete at a height of about 8 inches to achieve the final compacted height of 7.1 inches, accounting for a 10 percent reduction in thickness due to rolling. Short skis riding on the surface of the curb or the previously placed lane guided the elevation of the screed on the inside of the paving lane, and a stringline was used to guide the screed on the outside.

As is characteristic of RCC pavement placed with the high-density screed, a smooth surface and dense compaction were achieved immediately behind the paver, but small superficial tears, perpendicular to the direction of paving and spaced about one inch apart, were left in the pavement surface. These tears typically close up during compaction with the rubber-tire roller, leaving at most a faint impression on the pavement surface.

The 10-ton vibratory roller followed immediately behind the paver, usually compacting the fresh concrete within 30 minutes after the addition of water at the plant. However, this time increased to as long as one hour if the haul truck was delayed or the paver broke down. The typical roller pattern was as follows: two vibratory passes were made within one foot of the free edge, followed by two passes along the fresh joint, and finally two passes in the center of the lane (two passes being one back-and-forth motion) (Figure 5). This pattern was repeated until a total of six vibratory passes or more were applied to the concrete. The rubber-tire roller then followed immediately with 4 to 8 passes on the surface, effectively tightening the surface texture.

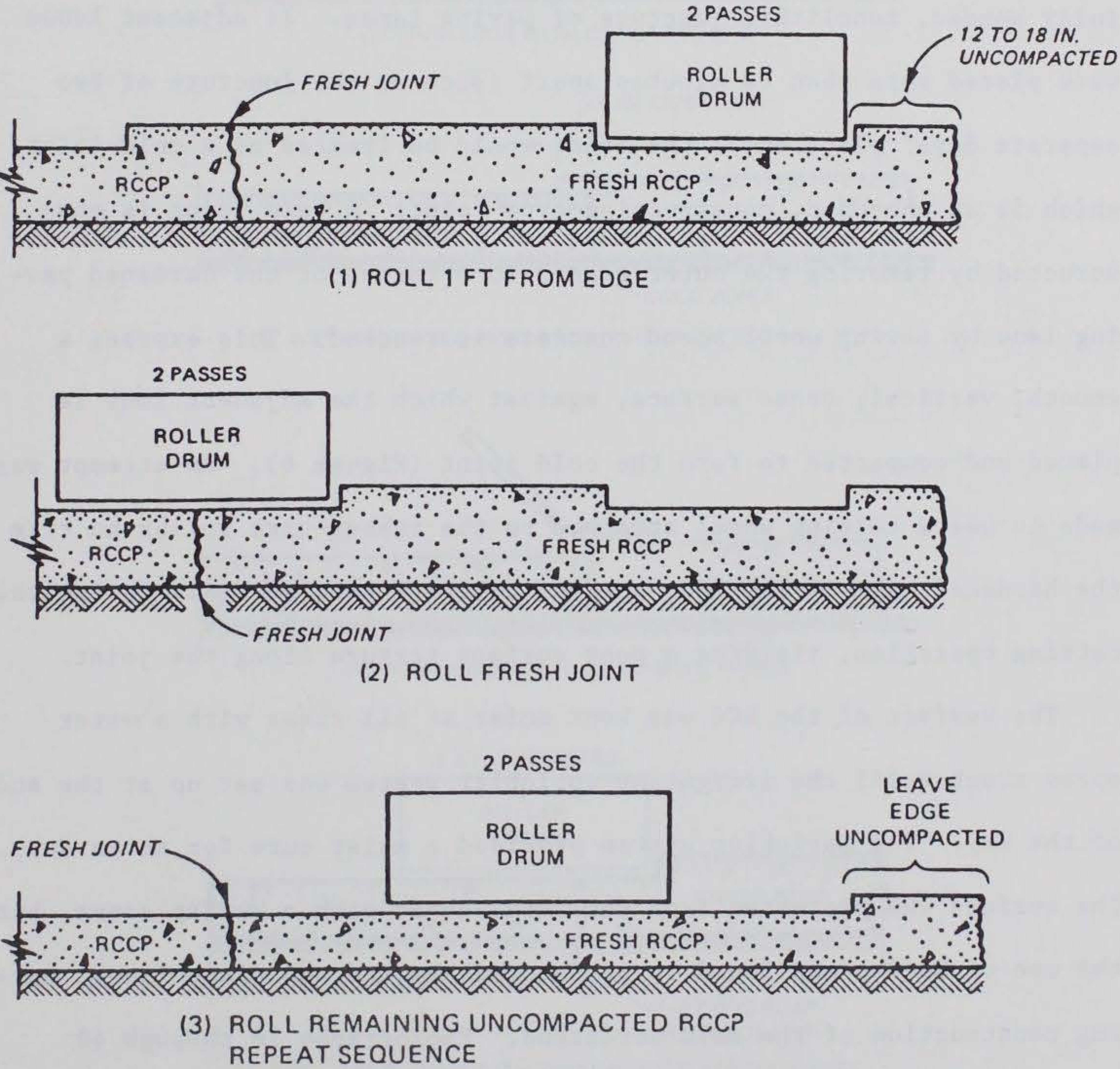



Figure 5. Roller Pattern: Fresh Joint Construction (from Pittman 1986)

At the end of the paving lane, the vibratory roller rolled off the end of the lane, creating a rounded ramp to the base course. This rounded end was cut off with a concrete saw to form a vertical face to pave against for the adjacent lanes, or to allow installation of the precast curbs along the perimeter of the hardstand.

The specifications required that adjacent lanes be placed and compacted together within 60 minutes to create a fresh joint, which is a fully bonded, monolithic juncture of paving lanes. If adjacent lanes were placed more than 60 minutes apart (such as the juncture of two separate days' placement), the joint would be treated as a cold joint, which is an unbonded, construction-type joint. A cold joint is constructed by removing the outer edge 3 to 6 inches of the hardened paving lane by sawing until sound concrete is reached. This exposes a smooth, vertical, dense surface, against which the adjacent lane is placed and compacted to form the cold joint (Figure 6). An attempt was made to use a cutting wheel attached to the rubber-tire roller to trim the hardened edge of the RCC, but the concrete raveled badly during the cutting operation, yielding a poor surface texture along the joint.

The surface of the RCC was kept moist at all times with a water spray truck until the irrigation sprinkler system was set up at the end of the day. The sprinkler system provided a moist cure for seven days. The surface was protected from the water spray with a burlap cover, but the use of burlap was found to be unnecessary and was discontinued during construction of the main hardstand. Photographs 16 through 43 (Appendix A) show the placement, compaction, and curing procedures used.

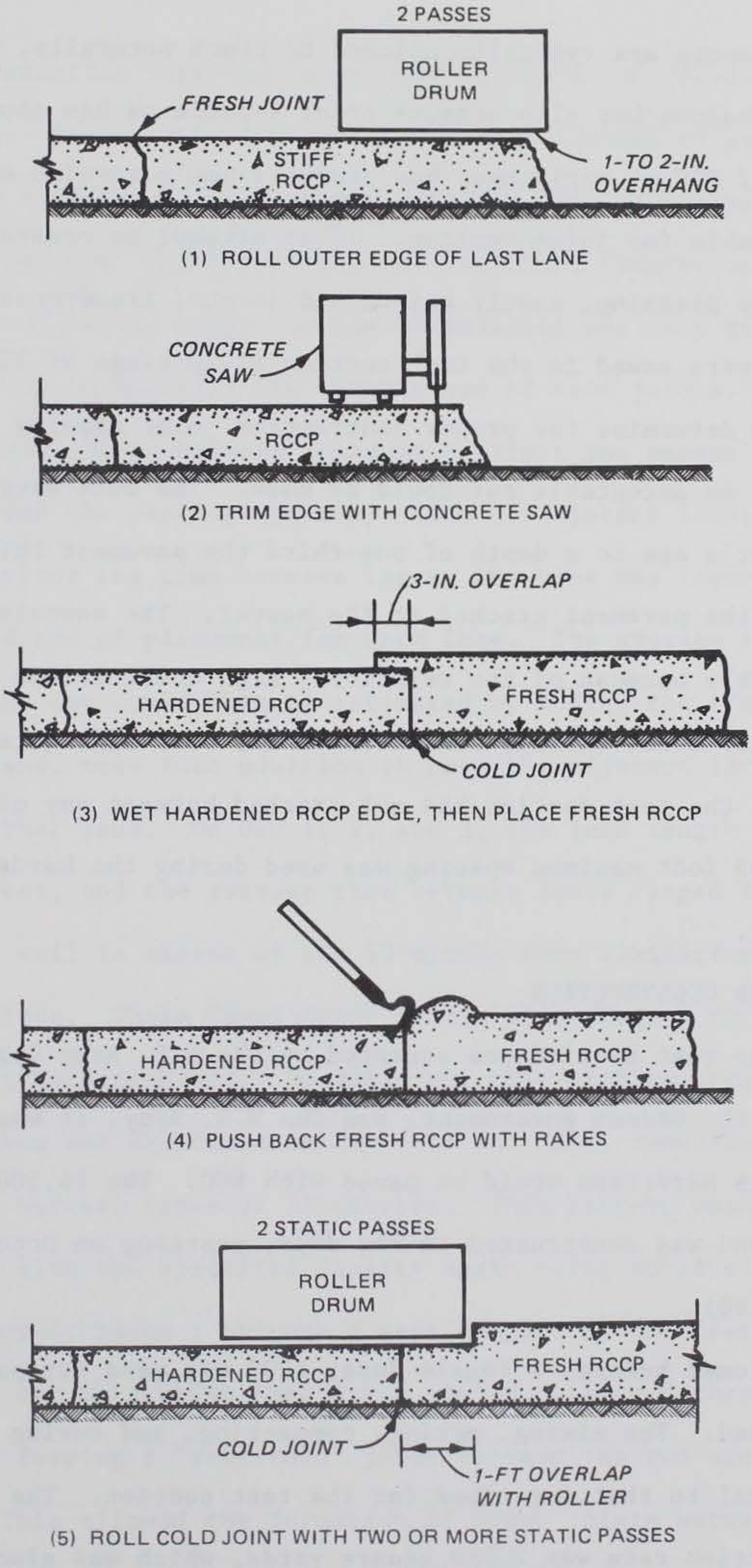



Figure 6. Roller Pattern: Cold Joint Construction (from Pittman 1986)

RCC pavements are typically allowed to crack naturally, mostly for economical reasons but also because prior experience has shown that sawcutting of RCC at early ages has produced badly raveled edges that are unacceptable for joint sealing. In an attempt to create aesthetically pleasing, easily maintained joints, transverse contraction joints were sawed in the test section at spacings of 33, 50, and 52.5 feet to determine the proper contraction joint spacing and to determine if an acceptable cut could be made. The cuts were made at 12 to 24 hour's age to a depth of one-third the pavement thickness to ensure that the pavement cracked at the sawcut. The sawcuts did not ravel, possibly because of the relatively high cementitious material content, early moist curing, and a relatively soft aggregate. At two month's age, the test section had not cracked between any of the sawcuts, so a 69 foot maximum spacing was used during the hardstand construction.

B. HARDSTAND CONSTRUCTION

After the test section was accepted by the U.S. Army Corps of Engineers, WES, the German government, and the U.S. Army, it was decided that the main hardstand would be paved with RCC. The 16,500 square yard hardstand was constructed in six days, starting on October 6, 1986 (Photograph 60).

As mentioned before, a Vögele Super 1700 was used for paving the main hardstand. The mixing, paving, compacting, and curing was virtually identical to that described for the test section. The average daily production rate was 2,750 square yards, which was almost five times the production rate the contractor estimate for fixed-form concrete paving. Herein lies the key to the cost savings of using RCC.

Figure 3 illustrates the laydown pattern used for the hardstand. The laydown pattern, which dictates the location, length, orientation, and sequence of paving lanes, should be selected not only to optimize production, but to minimize the occurrences of cold joints. The key to preventing cold joints between lanes is to limit the amount of time allowed between the placing and compaction of adjacent lanes. In an effort to monitor the time between lanes, the time was recorded for the beginning and end of placement for each lane. The average time between lanes for each day could then be estimated by adding the time to pave one-half a lane, move into position to pave the adjacent lane, and pave one-half of that lane. On Day 1, 2, and 3, the lane length ranged from 315 to 344 feet, and the average time between lanes ranged from 113 to 138 minutes, well in excess of the 60 minute time limitation specified for fresh joints. These "semi-cold" joints were subject to cracking at a later age (Photograph 63). To alleviate this problem, the length of the paving lane was shortened on Day 4 to 207 feet, resulting in an average time between lanes of 73 minutes. This pattern was repeated on Day 5 and 6, with the specified density again being achieved along the joint. On Day 6, Lanes 1 through 4 were stopped at 228 feet, and the rounded edge cut back while Lane 5 was placed. Lanes 6 through 9 were then placed, forming a "semi-cold" joint between the two areas of placement. This allowed the formation of fresh joints between adjacent lanes, while forming only one transverse cold joint.

The orientation of the paving lanes is usually influenced by the geometry of the hardstand; in this case, the ends (Day 1 and Day 6) of the hardstand were paved in the direction of the shortest dimension to minimize the time between lanes, and the central portion (Day 2 through 5) was paved in the direction of the longer dimension to be parallel with the already in-place trench drains. The sequence of the lanes for each day was such that the paving began on the low side of a sloped cross-section, to prevent the runoff water of the curing process from saturating or ponding on the base.

Transverse contraction joints were sawed in the RCC about 12 to 20 hours after the placement and compaction, to give the RCC sufficient time to harden (Photograph 47). If a greater period elapsed before sawing began, the RCC was prone to cracking ahead of the sawcut (Photograph 58). The contraction joints were spaced about 69 feet apart (Figure 7), and were sawed to a depth of about one-third the pavement thickness. The cold joints and contraction joints were later sealed with an asphaltic joint sealer (Photographs 64 and 65), although overfilling of the cold joints resulted in tearing of the joint sealer under tank traffic.

To avoid paving around the manholes, a unique solution was developed. The manholes were built up to the surface of the base course and covered with steel plates. The concrete was placed and compacted over the steel plates in the normal manner. The next day, a square section of the hardened RCC over the manhole was sawed, and lifted out with a forklift if the manhole was located at the edge of the last paving lane; otherwise, the RCC square was jackhammered and shoveled out. The

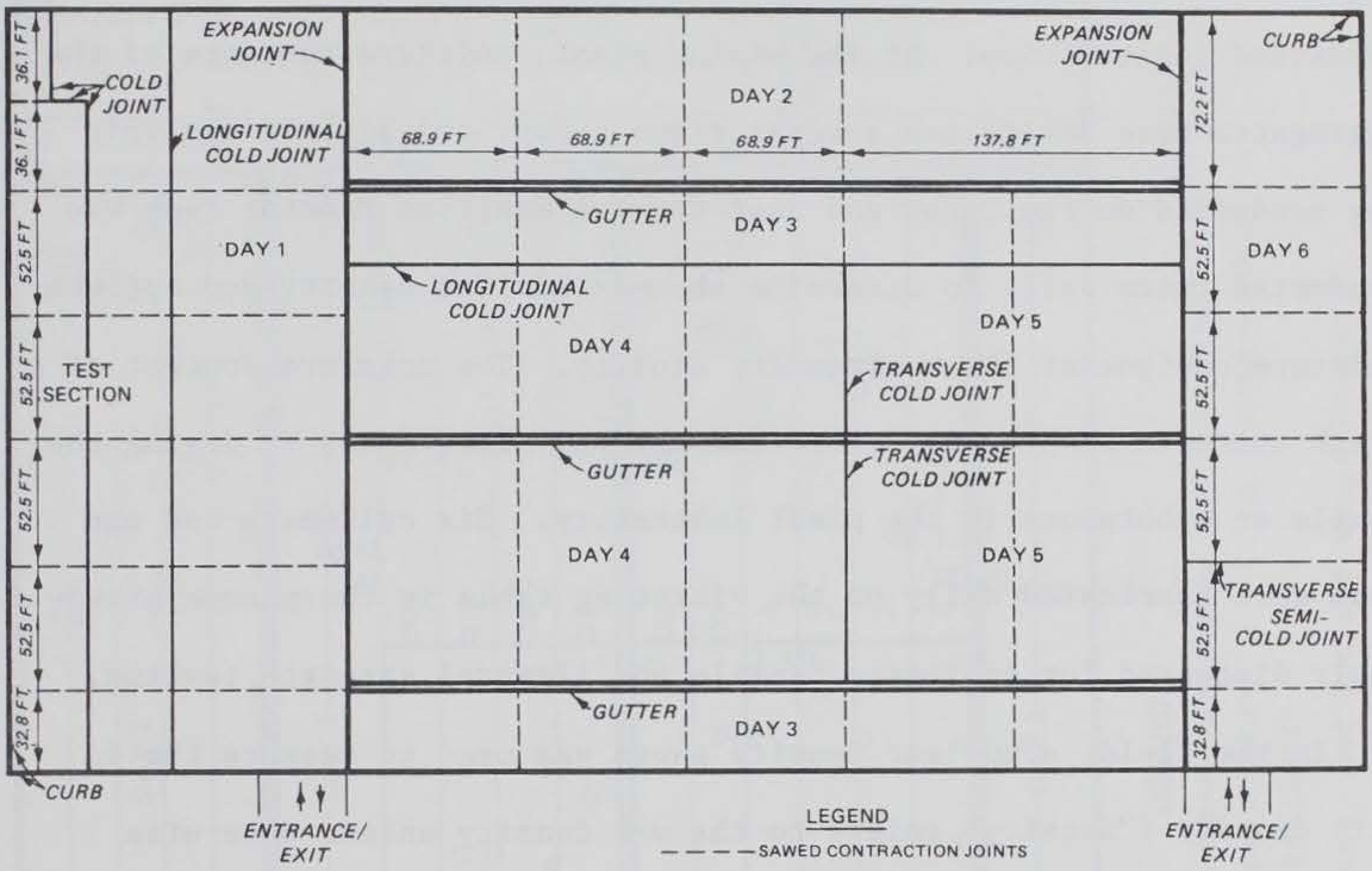



Figure 7. Location of Cold and Contraction Joints

manhole was then built up with concrete rings to the final elevation of the RCC surface, expansion material was attached to the vertical sides of the hole, and conventional concrete was used to fill in the space between the manhole and the RCC (Photographs 48 through 52).

Low spots formed in the surface from improper paving or rolling procedures were often filled with loose RCC and compacted. This practice was discouraged when it was discovered that the RCC "patches" were subject to debonding and wearing away after several days (Photograph 55). Broadcasting of loose material over the pavement surface during cold joint construction was also discouraged, because the resulting surface texture was often coarse and not durable under traffic.

A comprehensive quality control plan was implemented during the hardstand construction. At the mixing plant, moisture contents of the aggregates were determined several times a day, and a sieve analysis was conducted on the first and last day. A Modified Proctor test was conducted twice daily to determine the maximum wet density and optimum moisture content at the maximum dry density. The moisture content of a fresh concrete sample was determined several times a day by drying the sample on a hotplate in the plant laboratory. Six cylinders and one beam were fabricated daily on the vibrating table in the manner previously discussed for splitting tensile and flexural strength testing.

In the field, a nuclear density gauge was used to measure the in situ density ("density" refers to the wet density unless otherwise indicated) of the RCC immediately behind the vibratory roller at approximately 100 foot intervals at random points across the full width of the paving lane (Figure 8) (Photograph 44). At each location, density and moisture readings were taken at 2, 4, and 6 inch depths, although the 6-inch reading was used for control. Cores were taken from the RCC at random locations within each day's placement for density and splitting tensile tests (Figure 8) (Photographs 53 and 54). Smoothness tests were conducted on each paving lane at approximately 100 foot intervals across all joints, and in the longitudinal and transverse directions in the center of the lane (Figure 9) (Photographs 45 and 46).

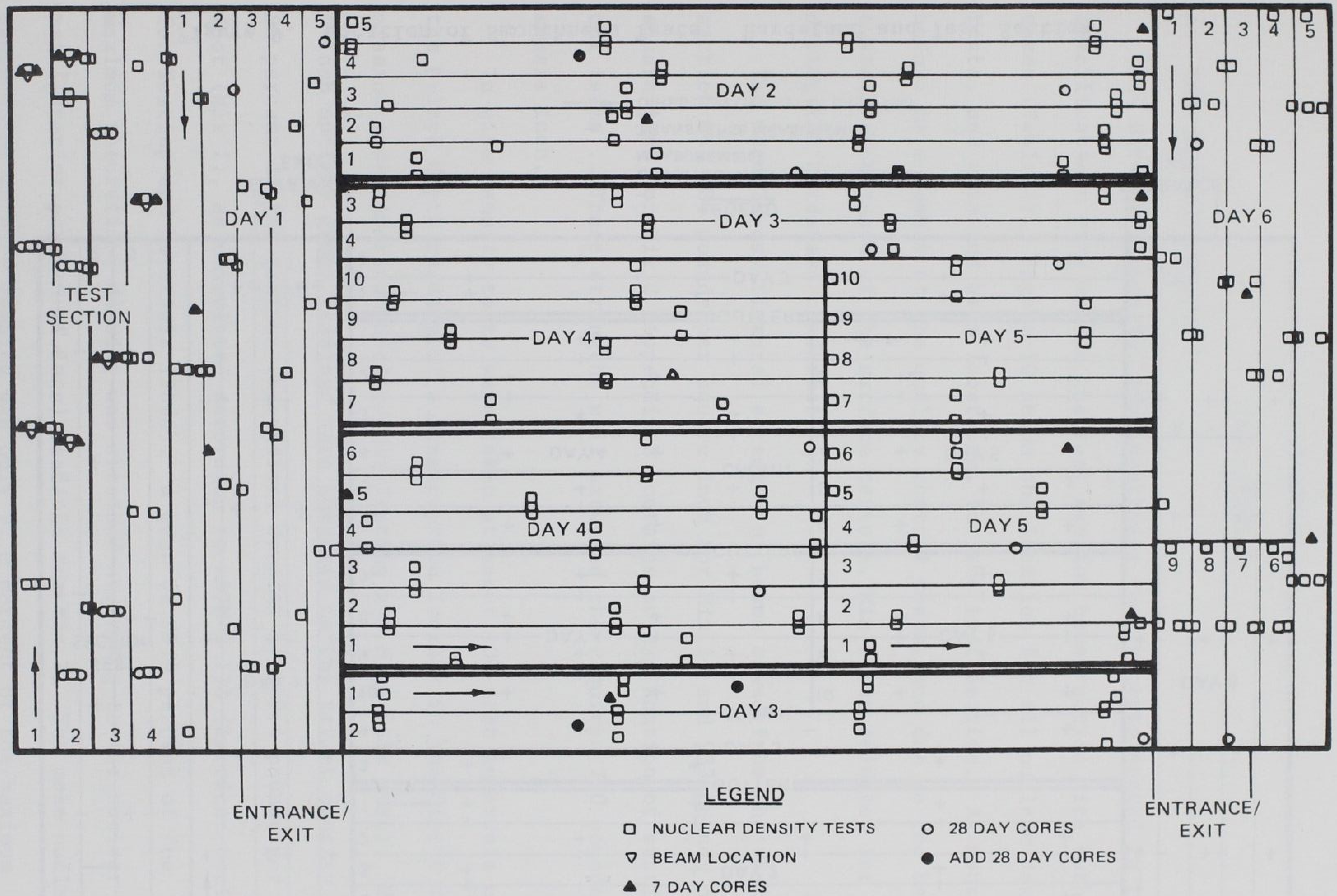



Figure 8. Location of Cores, Beams, and Nuclear Gauge Tests: Hardstand and Test Section

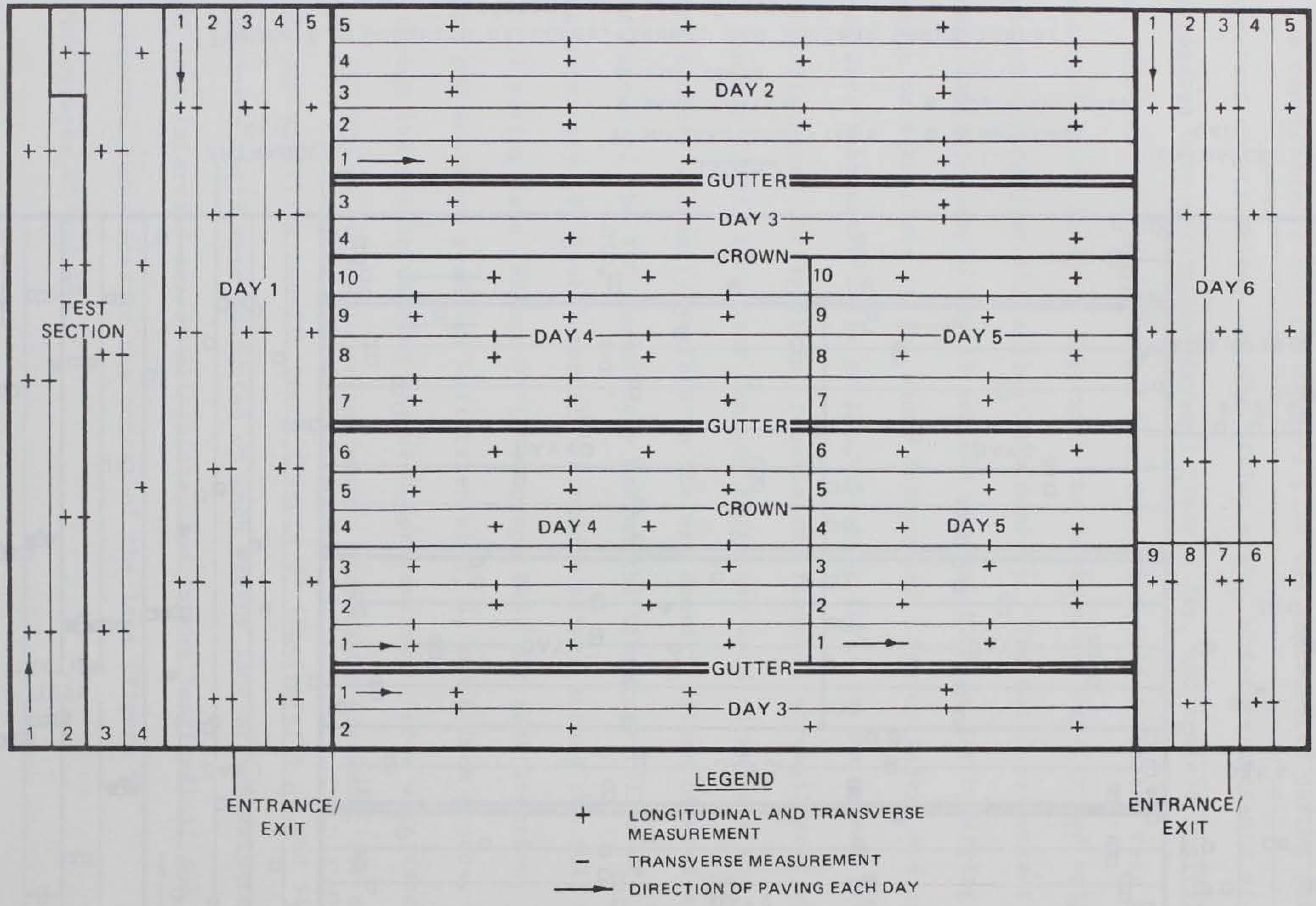



Figure 9. Location of Smoothness Tests: Hardstand and Test Section

# SECTION IX

# TEST RESULTS

## A. TEST SECTION RESULTS

All strength, density, and smoothness requirements stated in the specifications were met in the test section construction with both mixtures (Table 4). Figure 10 shows the location for all nuclear density tests, and core and beam locations, for the test section. As mentioned before as a result of the quality control tests, and due to the better overall appearance of the surface texture, Mix 1 was selected for use during the hardstand construction.

The mean 28-day flexural strength of beams sawed from the test section was 783 pounds per square inch for Mix 1, and 933 pounds per square inch for Mix 2 (Appendix B contains an explanation of statistical terms). These strengths well exceeded the required 720 pounds per square inch.

In situ density tests were taken at about 100 foot intervals using the 6-inch depth reading of a single-probe Troxler in the direct transmission mode (American Society for Testing and Materials 1984). The 6-inch nuclear gauge readings were compared to the target density of 96 percent of the maximum theoretical density of 150.4 pounds per cubic foot (Mix 1), as calculated according to ASTM C 138 (American Society for Testing and Materials 1986d). A mean of 96.9 percent of the maximum theoretical density was obtained according to the nuclear gauge mat (interior portion of lane) readings for Mix 1. The mean nuclear gauge joint density reading was only 92.0 percent of the maximum theoretical. The mean density of 28-day-old cores extracted from the

TABLE 4. QUALITY CONTROL RESULTS: TEST SECTION

| Quality Control Test | Day One Mix 1 | Day Two Mix 2 | Specification Requirements |
|---|---|---|---|
| Strength (lb/sq in.) | | | |
| 28-day Flexural | | | |
| Fabricated beams | | | |
| Average | 1,106 | 1,131 | 720 |
| No. of Tests | 4 | 4 | |
| Standard deviation | 78.2 | 72.3 | |
| Sawed beams | | | |
| Average | 783 | 933 | 720 |
| No. of tests | 3 | 3 | |
| Standard deviation | 63.1 | 36.8 | |
| 7-day Splitting tensile | | | |
| Cores | | | |
| Average | 338 | 350 | 242 |
| No. of tests | 6 | 6 | |
| Standard deviation | 105 | 97.4 | |
| Cylinders | | | |
| Average | 306 | 355 | 242 |
| No. of tests | 4 | 4 | |
| Standard deviation | 94.2 | 72.3 | |
| 28-day Splitting tensile | | | |
| Cores | | | |
| Average | 401 | 409 | |
| No. of tests | 6 | 6 | |
| Standard deviation | 113 | 106 | |
| Cylinders | 424 | 417 | |
| No. of tests | 4 | 4 | |
| Standard deviation | 173 | 13.9 | |
| Density (lb/cu ft) | | | |
| 6-in. Nuclear gauge | | | |
| Mat | | | |
| Average | 145.7 | 147.2 | 144.4 |
| No. of tests | 9 | 15 | |
| Standard deviation | 1.52 | 1.66 | |

(Continued)

TABLE 4. (Concluded)

| Quality Control Test | Day One Mix 1 | Day Two Mix 2 | Specification Requirements |
|---|---|---|---|
| Joint | | | |
| Average | 138.4 | 142.5 | 144.4 |
| No. of tests | 4 | 2 | |
| Standard deviation | 3.19 | 0.42 | |
| Cores | | | |
| 7-day | | | |
| Average | 149.2 | 149.9 | 144.4 |
| No. of tests | 6 | 6 | |
| Standard deviation | 3.36 | 2.69 | |
| 28-day | | | |
| Average | 150 | 150.1 | 144.4 |
| No. of tests | 6 | 6 | |
| Standard deviation | 2.08 | 1.91 | |
| Cylinders | | | |
| 7-day | | | |
| Average | 144.0 | 142.5 | 144.4 |
| No. of tests | 4 | 4 | |
| Standard deviation | 3.25 | 3.7 | |
| 28-day | | | |
| Average | 144.7 | 145.1 | 144.4 |
| No. of tests | 4 | 4 | |
| Standard deviation | 4.69 | 1.61 | |
| Smoothness (in./13 ft) | | | |
| Longitudinal | | | |
| Average | 0.09 | 0.19 | 0.375 |
| No. of tests | 6 | 6 | |
| Standard deviation | 0.07 | 0.08 | |
| Transverse | | | |
| Average | 0.17 | 0.14 | 0.375 |
| No. of tests | 6 | 6 | |
| Standard deviation | 0.06 | 0.11 | |
| Joint | | | |
| Average | 0.22 | 0.31 | 0.375 |
| No. of tests | 6 | 3 | |
| Standard deviation | 0.10 | 0.03 | |

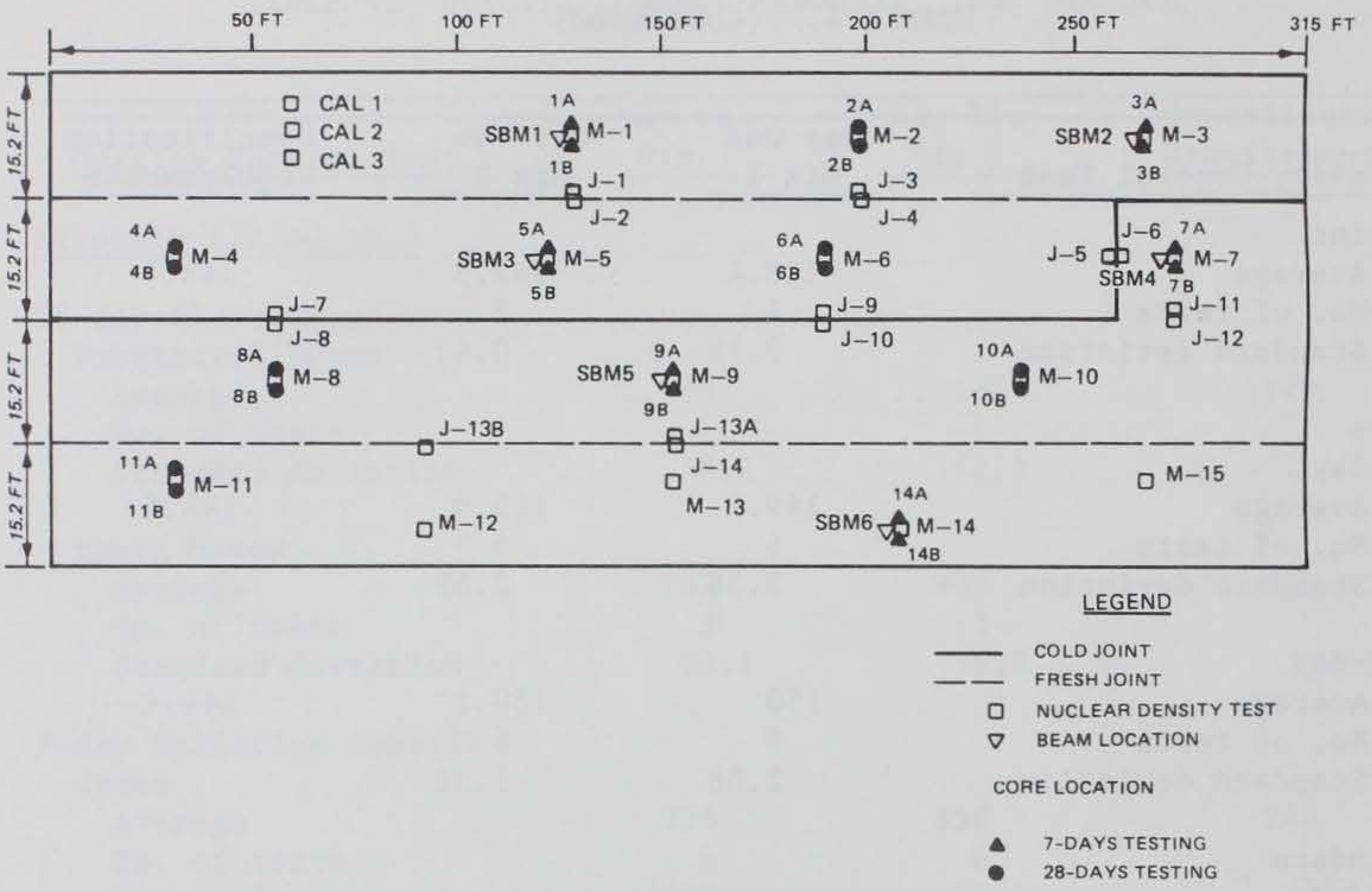



Figure 10. Location of Cores, Beams, and Nuclear Gauge Tests: Test Section

pavement was 99.7 percent of the maximum theoretical density of the RCC for Mix 1, and 99.8 percent for Mix 2. The density of the cores was measured by weighing the cores in air ($W_A$), then weighing them in water ($W_W$), and performing the following calculation:

$$\text{Density (lb/cu ft)} = \frac{W_A \text{ (lb)}}{W_A \text{ (lb)} - W_W \text{ (lb)}} \times 62.4 \text{ lb/cu ft}$$

Smoothness tests results of the test section in the longitudinal and transverse directions and across joints averaged 0.14, 0.15, and 0.25 inch deviations from a 13-foot-long straightedge, respectively.

These measurements were well within the specified limits of 0.375 inch deviation from a 10-foot straightedge.

Moisture content readings were also taken at each nuclear density test location. The moisture content readings of the nuclear gauge indicated that the RCC was being placed at a slightly drier moisture content than the optimum suggested by the Modified Proctor test (Table 5).

TABLE 5. DAILY RCC MOISTURE CONTENT: TEST SECTION

| Area Test | Modified Proctor Optimum Moisture Content | Mean Nuclear Gauge Reading |
|---|---|---|
| Day 1 (Mix 1) | 6.7 | 6.0 |
| Day 2 (Mix 2) | 6.7 | 6.2 |

The relationship between number of roller passes and full-depth density as measured with the nuclear density gauge (6-inch reading, direct transmission mode) was also obtained in the first portion of Lane 1 (Figure 11). Nuclear density gauge readings were taken close to the confined edge along the curb, in the center of the lane, and close to the free edge of the lane. A definite trend of decreasing density across the width of the paving lane from the confined edge to the free edge was noticed, emphasizing the need to pay careful attention to compaction of the joints. Since the target density was set at 144.4 pounds per cubic foot (96 percent of 150.4), six passes was selected as the required minimum number of vibratory passes for the test section and hardstand construction.

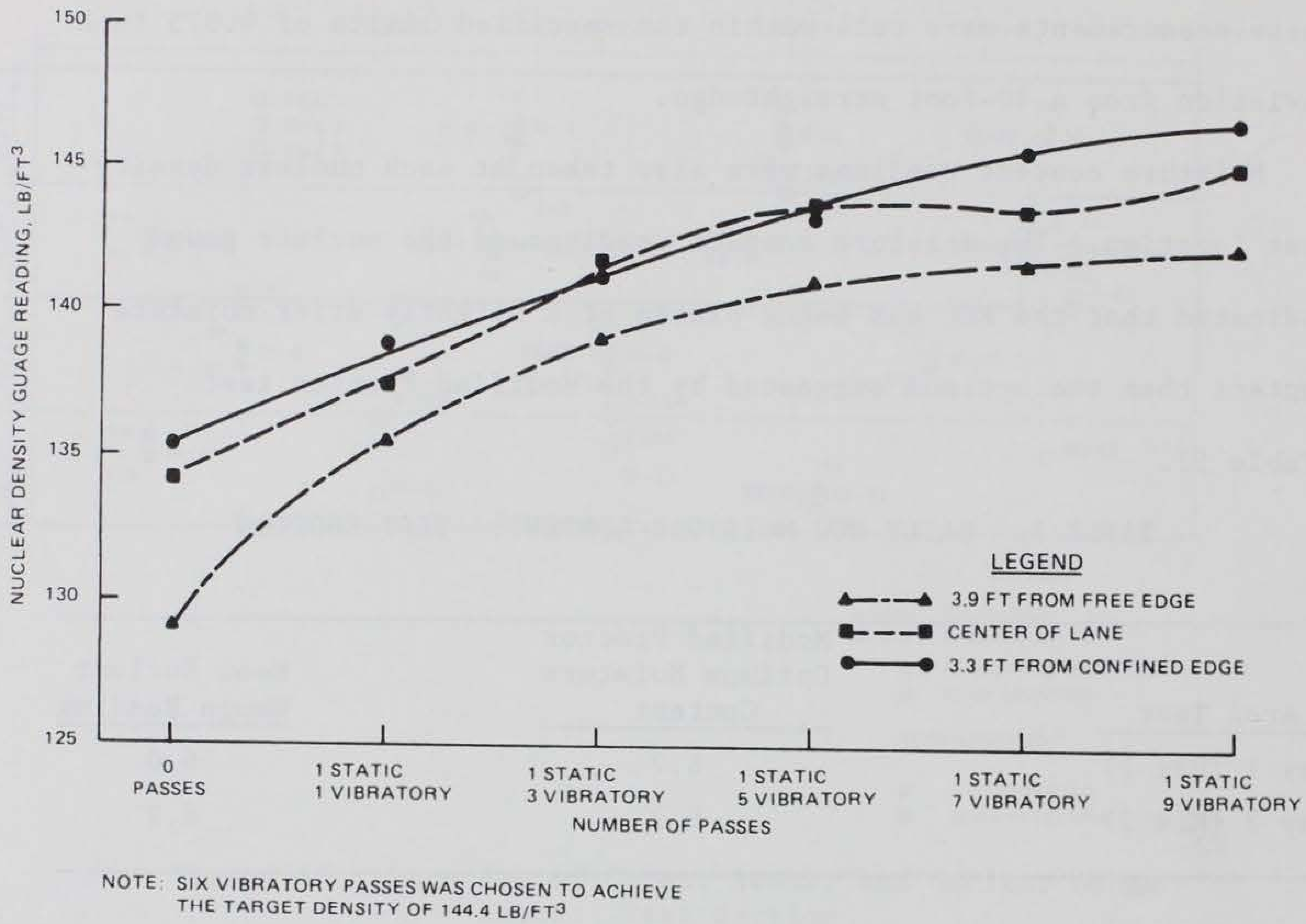



Figure 11. Roller Passes Versus RCC Density

Comparisons were also made between the strengths obtained from beams and cylinders fabricated in the laboratory and beams and cores taken from the test section. The beam and cylinder fabrication followed a non-standardized procedure of filling the beams molds with one layer of concrete and cylinders with five equal layers, and compacting each layer on a vibrating table with the help of a surcharge weight until the surface voids were filled with paste. The laboratory cylinders and beams were cured in a controlled temperature (73 degrees F) water bath until the proper age for testing was reached, and beams were taken from the test section in sufficient time to soak the specimen in a water bath for approximately 40 hours before testing. Generally, the strengths of the fabricated cylinders and beams were larger than the field cores and beams (Table 4). The average core splitting tensile strengths were within one standard deviation of the fabricated cylinder strengths for both mixes, at both 7 and 28 day's age. The fabricated beam flexural strengths were significantly higher, by several standard deviations, than the mean sawed beam strength.

The higher strengths associated with the fabricated specimens were not due to higher densities, however. Figure 12 shows the relationship between the core and cylinder densities and splitting tensile strength at 7 and 28 day's age for Mix 1 and Mix 2. The density of the cores averaged 4 percent higher than the cylinder densities. Also, the density of both the cores and cylinders tended to increase slightly with age, in addition to the increase in strength. This could be due

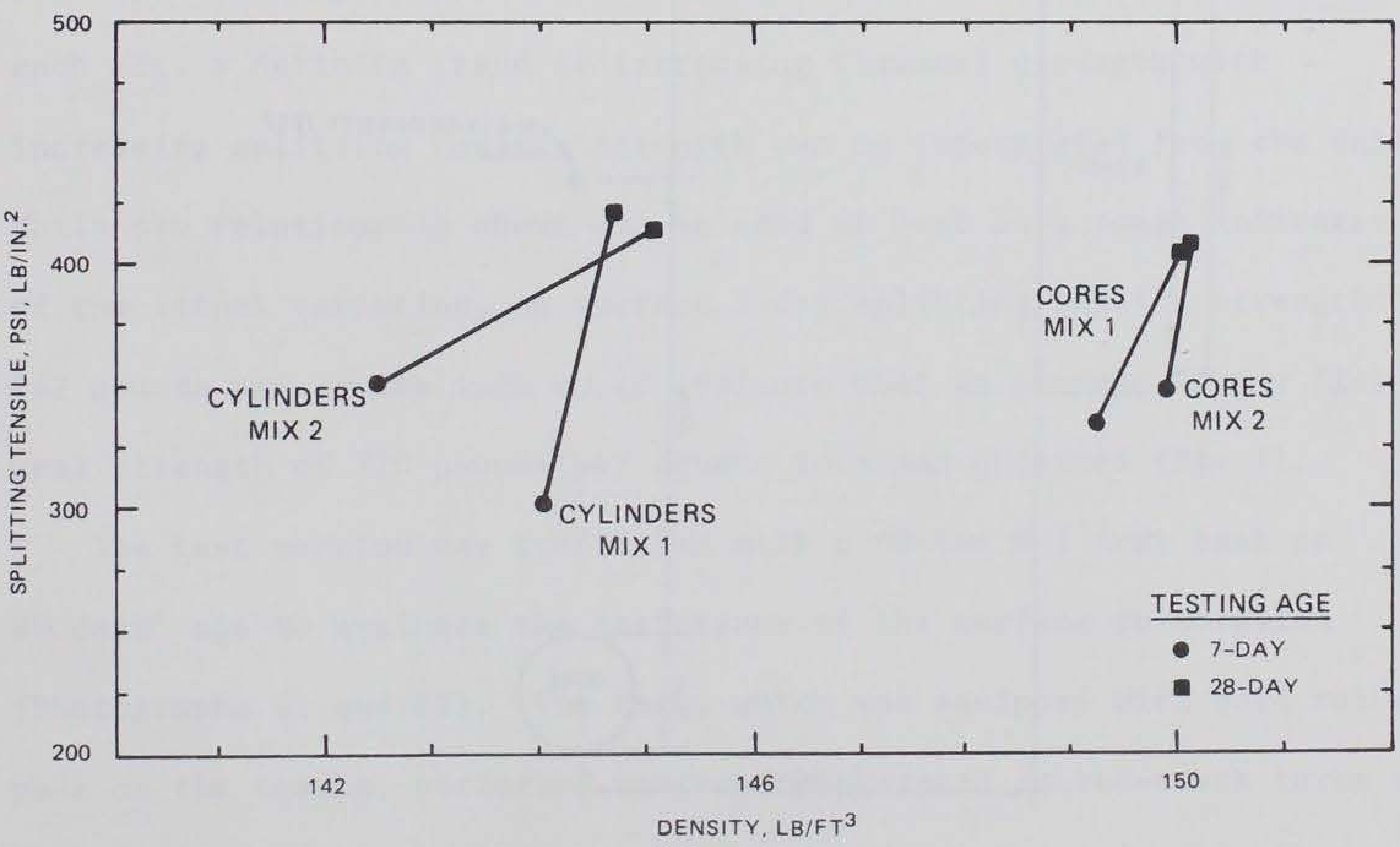



Figure 12. Splitting Tensile Strength Versus Density

to the hydration process mentioned by Andersson (1987). The higher cylinder strengths may be attributed to the continuous water-bath cure, while the higher core density may be attributed to the inability to obtain a good compactive effort with the cylinders on the vibrating table.

In the test section, six groups of cores, beams, and nuclear density gauge readings (Figure 13), and six more groups of only core and nuclear density gauge readings, were obtained from the test section to

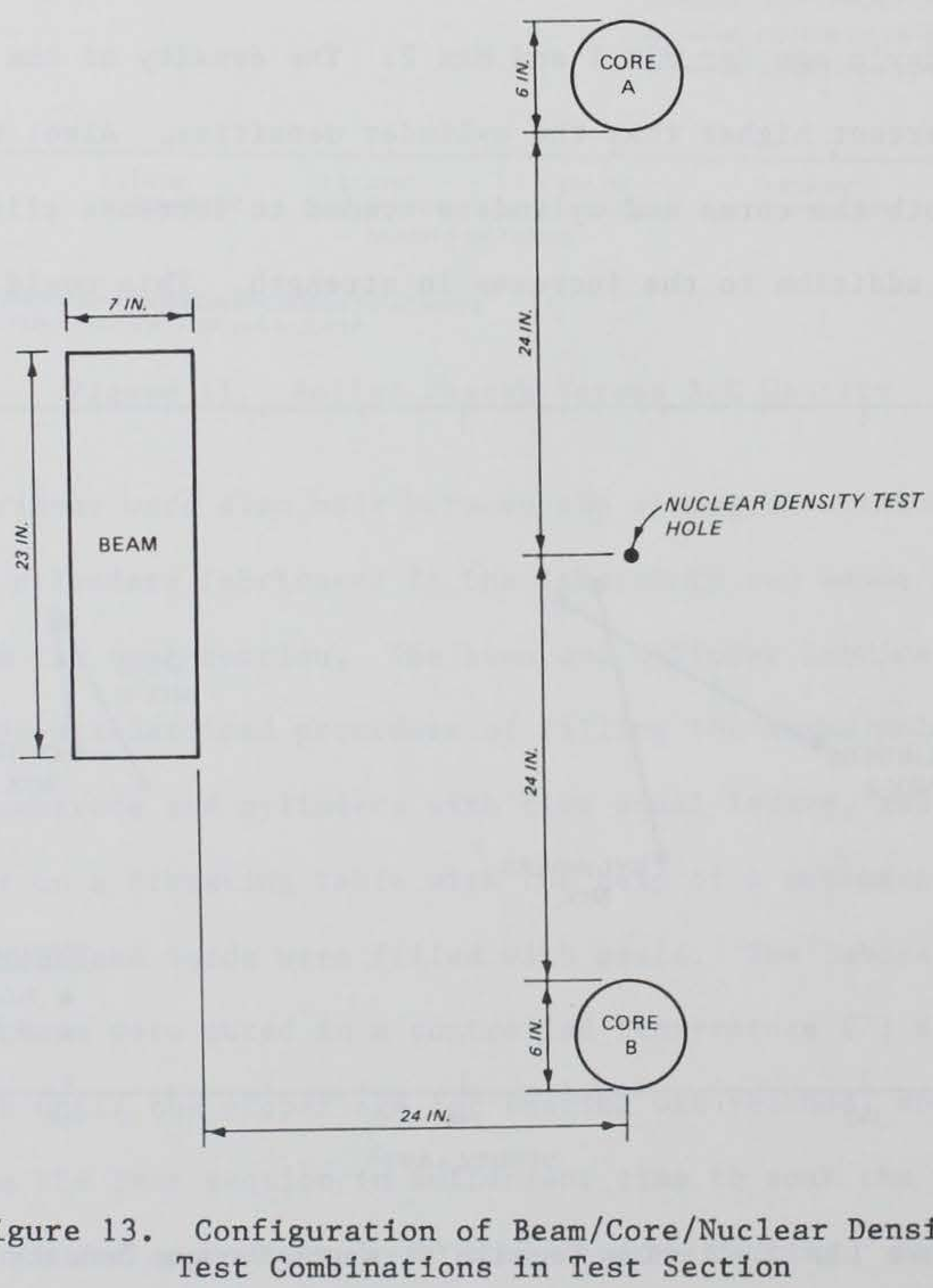



Figure 13. Configuration of Beam/Core/Nuclear Density Test Combinations in Test Section

investigate relationships between splitting tensile and flexural strength, and core density versus nuclear gauge density.

The nuclear density gauge readings were conducted in the direct transmission mode by inserting the single probe into a prefabricated hole to a 6-inch depth. The core densities were consistently higher than their companion nuclear density gauge readings, by an average difference of 3.1 pounds per cubic foot and 3.9 pounds per cubic foot for the 7-day and 28-day core densities (Mix 1 and Mix 2), respectively. This difference is not unexpected since it has been shown (Figure 9) that the density of the concrete cores increases slightly with age.

The core/beam sampling configuration also allowed a comparison of the mean 7-day splitting tensile strength of two cores to the 28-day flexural strength of an adjacent beam, for Mix 1 and Mix 2, (Figure 14). Although only three core/beam combinations were obtained for each mix, a definite trend of increasing flexural strength with increasing splitting tensile strength can be interpreted from the data. While the relationship shown may be used at best as a rough indicator of the actual variation, an average 7-day splitting tensile strength of 242 pounds per square inch would indicate that an average 28-day flexural strength of 720 pounds per square inch was obtained (Mix 1).

The test section was trafficked with a 60-ton M-1 Army tank at 80 days' age to evaluate the resistance of the surface to abrasion (Photographs 61 and 62). The tank, which was equipped with hard rubber pads on the tracks, performed numerous high-speed locked-track turns on the test section. No damage to the surface was observed, only skid marks left from the rubber pads wearing away.

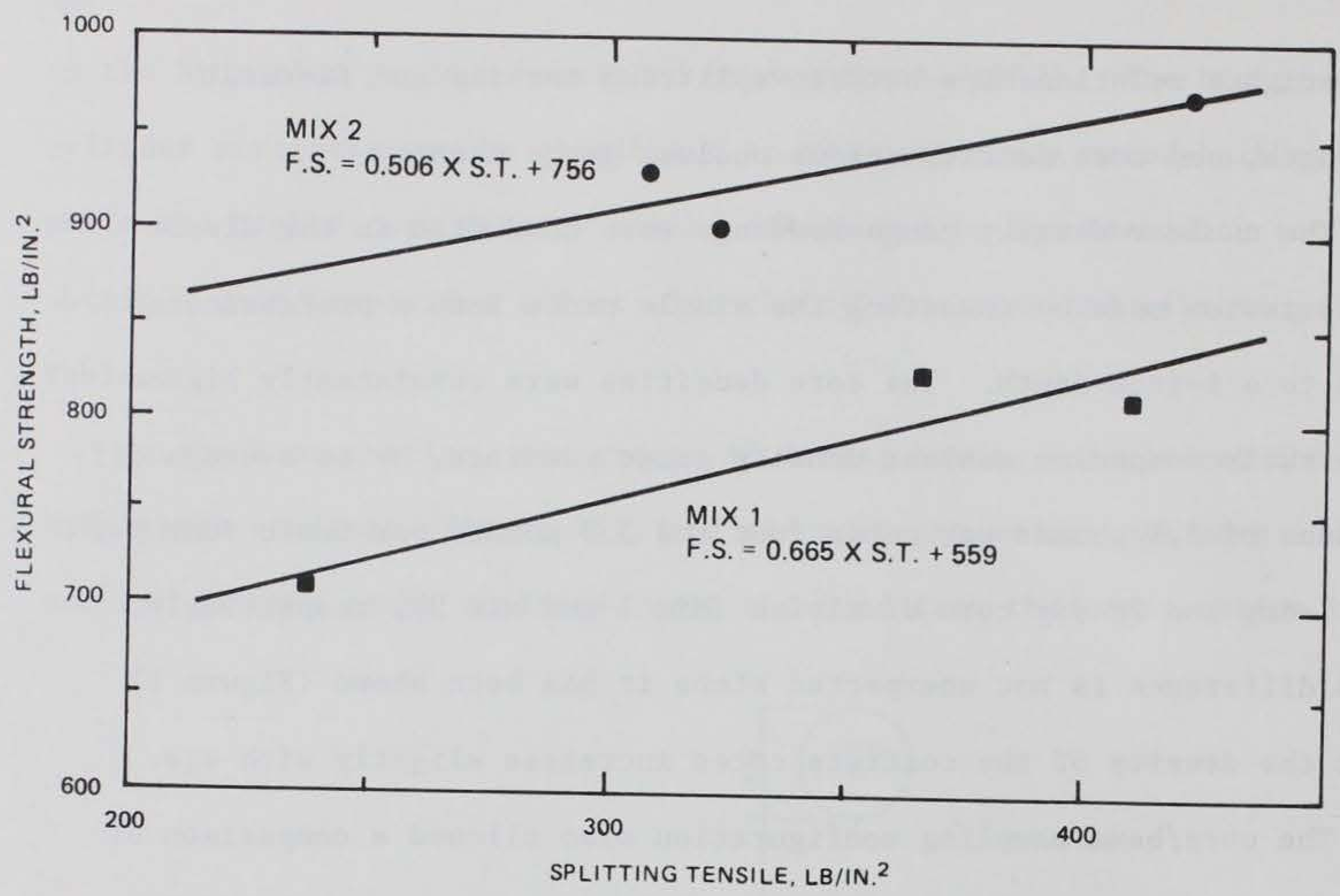



Figure 14. 28-Day Flexural Strength Versus 7-Day Splitting Tensile Strength

B. HARDSTAND RESULTS

Table 6 contains the results of the strength, density, and smoothness tests for the hardstands, and the corresponding specification requirements for each parameter. Generally, the test results indicate that most requirements stated in the specification were met.

The average 28-day flexural strength of the fabricated beams (576 pounds per square inch) was less than the specified 720 pounds per square inch, and was the only parameter that did not meet specifications. The wide scatter in the fabricated beam strength can be attributed to the lack of compaction obtained in the fabrication process, with the lower densities resulting in lower flexural strength. The range in density and strength of the beams did allow a correlation to

TABLE 6. QUALITY CONTROL RESULTS: HARDSTAND

| Quality Control Test | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Total | Specification Requirements |
|---|---|---|---|---|---|---|---|---|
| Strength (lb/sq in.) | | | | | | | | |
| 28-day flexural | | | | | | | | |
| Fabricated beams | | | | | | | | |
| Average | 785 | 274 | 591 | 466 | 476 | 861 | 576 | 720 |
| No. of tests | 1 | 1 | 1 | 1 | 1 | 1 | 6 | |
| Standard deviation | -- | -- | -- | -- | -- | -- | 218 | |
| 7-day splitting tensile | | | | | | | | |
| Cores | | | | | | | | |
| Average | 289* | 284** | 325 | 378 | 361 | 408 | 341 | 242† |
| No. of tests | 2 | 2 | 2 | 2 | 2 | 2 | 12 | |
| Standard Deviation | 48.1 | 94.0 | 67.2 | 110 | 58.0 | 29.0 | 71.7 | |
| Cylinders | | | | | | | | |
| Average | 574 | 239 | 356 | 455 | 454 | 467 | 411 | |
| No. of tests | 1 | 2 | 2 | 2 | 2 | 2 | 11 | |
| Standard deviation | -- | 2.05 | 52.3 | 125.2 | 69.7 | 69.7 | 110 | |
| 28-day splitting tensile | | | | | | | | |
| Cores | | | | | | | | |
| Average | 430 | 459 | 502 | 512 | 469 | 508 | 482 | |
| No. of tests | 2 | 3 | 4 | 2 | 2 | 2 | 15 | |
| Standard deviation | 56.6 | 77.4 | 58.9 | 27.6 | 24.7 | 44.5 | 54.2 | |
| Cylinders | | | | | | | | |
| Average | 479 | 248 | 462 | 485 | 535 | 650 | 476 | |
| No. of tests | 2 | 4 | 4 | 4 | 4 | 4 | 22 | |
| Standard deviation | 52.3 | 53.9 | 40.6 | 50.7 | 122 | 43.3 | 141.2 | |
| Density (lb/cu ft) | | | | | | | | |
| 6-in. nuclear gauge | | | | | | | | |
| Mat | | | | | | | | |
| Average | 146.9 | 144.9 | 146.7 | 147.2 | 149.8 | 148.6 | 147.4 | 144.4 |
| No. of tests | 30 | 40 | 32 | 49 | 31 | 47 | 229 | |
| Standard deviation | 2.89 | 2.87 | 2.25 | 2.47 | 1.41 | 2.36 | 2.84 | |
| Joint | | | | | | | | |
| Average | 142.0 | 140.0 | 142.7 | 147.8 | 149.7 | 147.7 | 145.0 | 144.4 |
| No. of tests | 5 | 13 | 8 | 13 | 10 | 9 | 58 | |
| Standard deviation | 4.98 | 3.58 | 3.23 | 1.58 | 1.95 | 2.03 | 4.50 | |
| Cores | | | | | | | | |
| 7-day | | | | | | | | |
| Average | 149.9 | 144.4 | 149.3 | 148.7 | 148.8 | 150.4 | 148.6 | 144.4 |
| No. of tests | 2 | 2 | 2 | 2 | 2 | 2 | 12 | |
| Standard deviation | 2.40 | 2.60 | 1.84 | 3.39 | 2.47 | 0.21 | 2.71 | |
| 28-day | | | | | | | | |
| Average | 148.6 | 150.3 | 149.6 | 148.3 | 149.4 | 149.4 | 149.3 | 144.4 |
| No. of tests | 2 | 3 | 4 | 2 | 2 | 2 | 15 | |
| Standard deviation | 2.26 | 1.36 | 1.63 | 0.71 | 3.18 | 2.47 | 1.68 | |

(Continued)

* Testing for Day 1 samples conducted at 9 day's age.
** Testing for Day 2 samples conducted at 8 day's age.
† From correlation to 28-day flexural strength.

TABLE 6. (Concluded)

| Quality Control Test | Day 1 | 2 | 3 | 4 | 5 | 6 | Total | Specification Requirements |
|---|---|---|---|---|---|---|---|---|
| Density (Continued) | | | | | | | | |
| Cylinders | | | | | | | | |
| 7-day | | | | | | | | |
| Average | 150.2 | 141.0 | 145.2 | 149.0 | 148.3 | 149.6 | 146.9 | |
| No. of tests | 1 | 2 | 2 | 2 | 2 | 2 | 11 | |
| Standard deviation | -- | 0.85 | 1.06 | 1.41 | 2.12 | 0.78 | 3.49 | |
| 28-day | | | | | | | | |
| Average | 147.9 | 139.8 | 146.7 | 147.5 | 148 | 150 | 146.5 | |
| No. of tests | 2 | 4 | 4 | 4 | 4 | 4 | 22 | |
| Standard deviation | 0.42 | 0.93 | 0.42 | 0.65 | 2.61 | 0.84 | 3.57 | |
| Smoothness (in./13 ft) | | | | | | | | |
| Longitudinal | | | | | | | | |
| Average | 0.21 | 0.16 | 0.18 | 0.12 | 0.16 | 0.17 | 0.16 | 0.375 |
| No. of tests | 15 | 15 | 12 | 23 | 15 | 16 | 108 | |
| Standard deviation | 0.13 | 0.12 | 0.12 | 0.07 | 0.12 | 0.12 | 0.11 | |
| Transverse | | | | | | | | |
| Average | 0.22 | 0.23 | 0.19 | 0.27 | 0.31 | 0.37 | 0.25 | 0.375 |
| No. of tests | 15 | 15 | 12 | 21 | 15 | 16 | 106 | |
| Standard deviation | 0.14 | 0.17 | 0.09 | 0.09 | 0.09 | 0.22 | 0.15 | |
| Joint | | | | | | | | |
| Average | 0.20 | 0.50 | 0.40 | 0.20 | 0.27 | 0.22 | 0.28 | 0.375 |
| No. of tests | 9 | 12 | 4 | 15 | 6 | 13 | 69 | |
| Standard deviation | 0.15 | 0.31 | 0.27 | 0.12 | 0.10 | 0.10 | 0.20 | |

show the effect of density on flexural strength (Figure 15). This correlation readily illustrates that a small change in density can have a dramatic effect on the flexural strength of RCC.

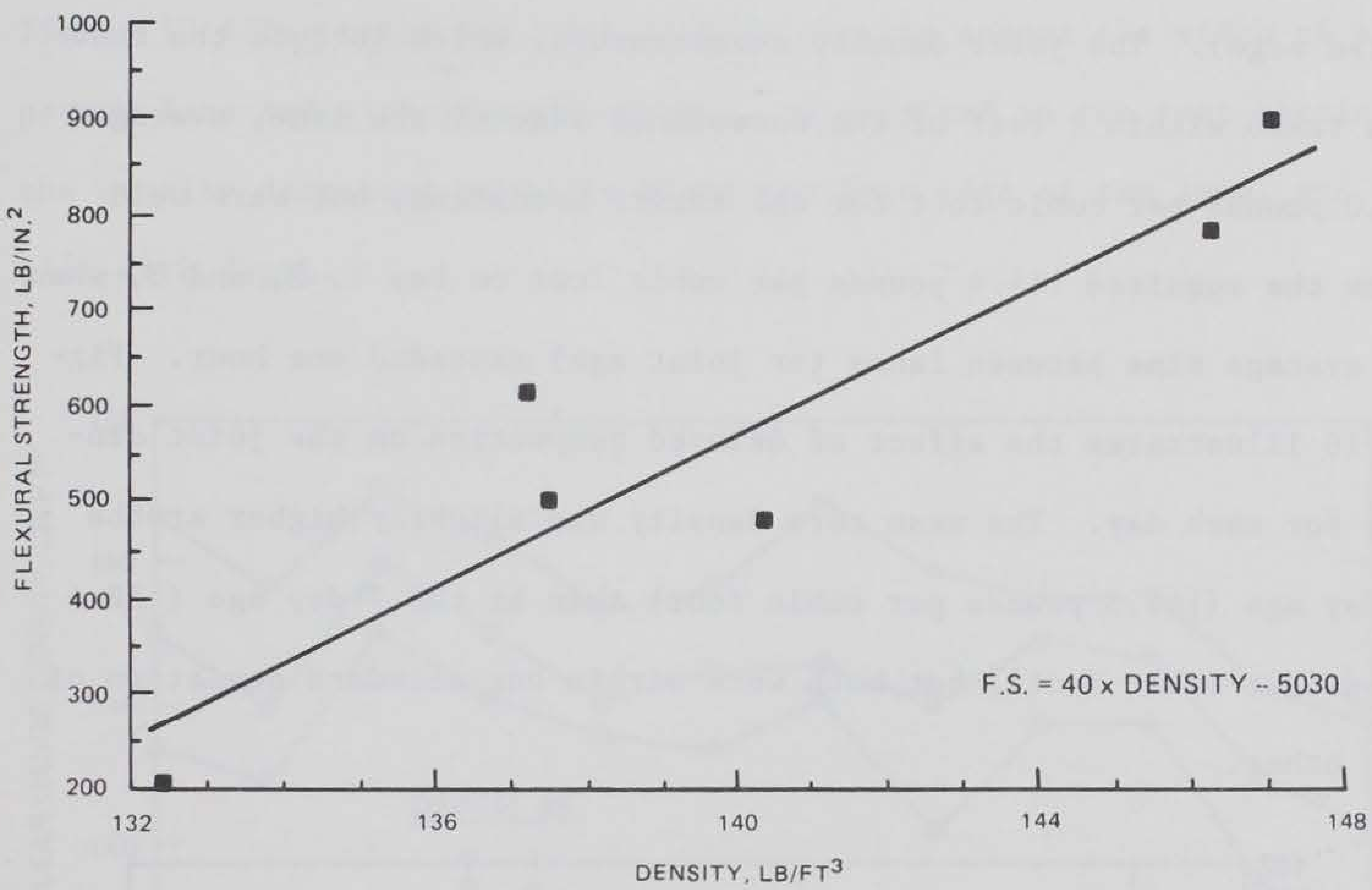



Figure 15. 28-Day Flexural Strength Versus Density

The average 7-day splitting tensile strength of cores taken from the pavement (341 pounds per square inch) well exceeded the 242 pounds per square inch requirement derived from the splitting tensile/flexural strength correlation from the test section results. The 7-day cylinder strengths averaged higher than the core strengths (but within one standard deviation), and the 28-day strengths of the cores and cylinders were approximately the same.

Table 6 contains the results of density measurements made with the nuclear density gauge (6-inch reading), and the unit weight of the cores taken from the hardstand and of cylinders fabricated during construction. A mean mat density of 147.4 pounds per cubic foot was obtained for 229 nuclear density tests taken during the construction ("mat" refers to the interior part of the lane, away from the unsupported edge). The joint density measurements, which include the readings taken within 2 feet of the unconfined edge of the lane, averaged 145.0 pounds per cubic foot for the entire hardstand, but were well below the required 144.4 pounds per cubic foot on Day 1, 2, and 3, when the average time between lanes (or joint age) exceeded one hour. Figure 16 illustrates the effect of delayed compaction on the joint density for each day. The mean core density was slightly higher at the 28-day age (149.3 pounds per cubic foot) than at the 7-day age (148.6 pounds per cubic foot), but both were within one standard deviation of each other.

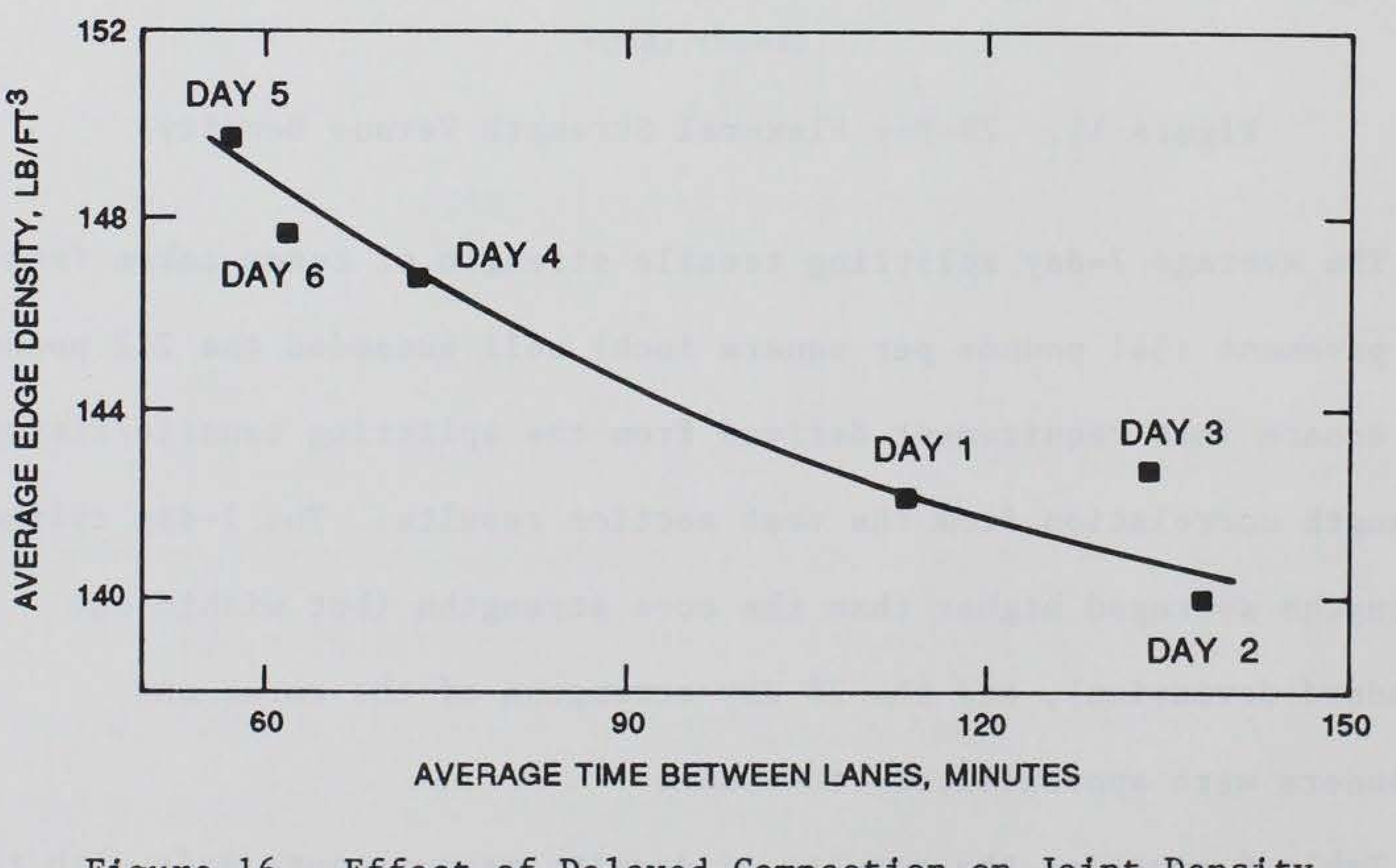



Figure 16. Effect of Delayed Compaction on Joint Density

At each nuclear gauge test location, the distance from the confined edge was recorded, and density readings were taken at 2, 4, and 6-inch depths. These readings were averaged for each depth and for each interval (approximately one-eleventh the lane width, or 1.5 feet). Figure 17 illustrates the variation in density across the width of the paving lane and with pavement depth. As detected in the test section, the density decreases markedly along the free edge of the lane, and also with depth.

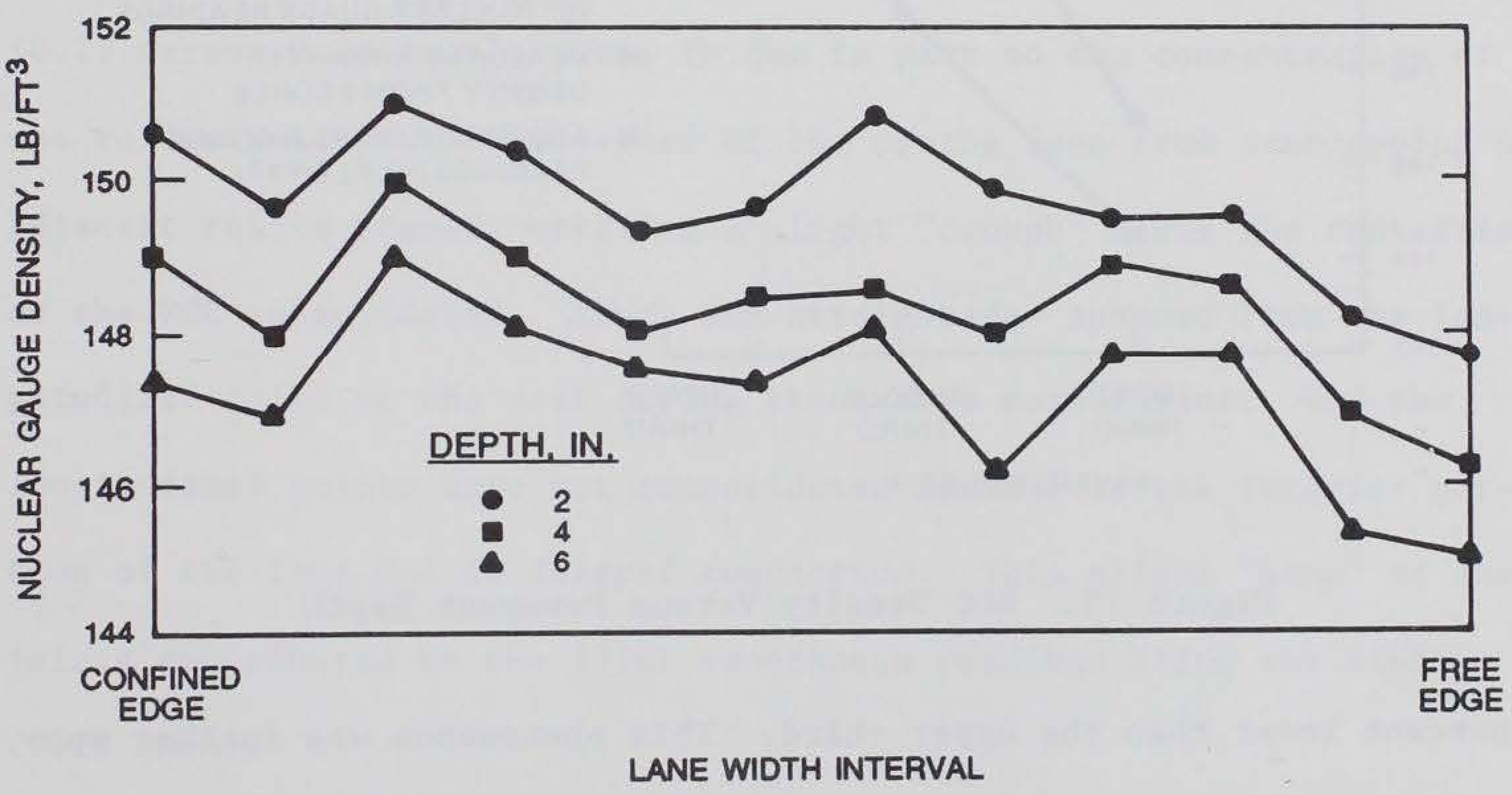



Figure 17. Variation of RCC Density with Lane Width and Pavement Depth

The decrease in density with depth was also indicated by sawing one core from each day's placement into thirds, obtaining the unit weight of the upper, middle, and lower thirds of the cores, and determining the mean density of the six cores for each increment of depth (Figure 18). The average density of the lower third of the cores was

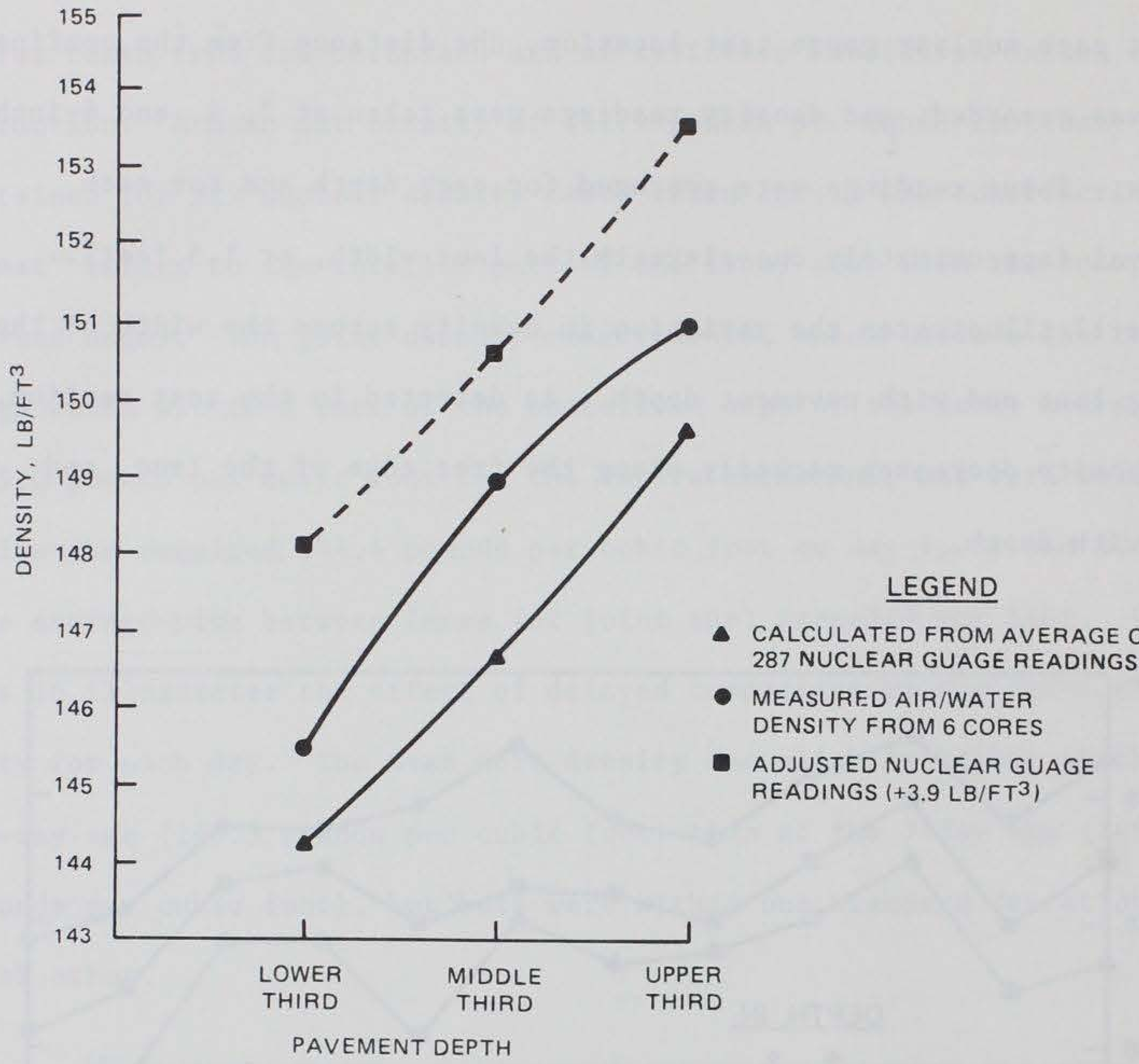



Figure 18. RCC Density Versus Pavement Depth

4 percent lower than the upper third. This phenomenon was further supported by the nuclear gauge readings, which, by using a simple algebraic algorithm, the density of the upper, middle, and lower 2-inch increment can be estimated (Appendix C illustrates the algorithm). Note that if the densities of the cores represented in Figure 12 are decreased by 4 percent, under the assumption that the area of least density of a core will dictate the maximum splitting tensile strength, the core and cylinder results correlate more closely.

The smoothness of the RCC pavement was determined by placing the 13-foot-long straightedge flat on the pavement surface, and measuring the maximum deviation of the pavement surface from the bottom of the straightedge. The averages of the longitudinal, transverse, and joint smoothness readings were well within the criteria of 0.375 inch for a 10-foot straightedge (a 10-foot straightedge was not available for conducting the tests, but the 13-foot-long straightedge would yield more conservative (larger) deviations on average). The transverse smoothness readings were typically higher than the longitudinal measurements (0.25 versus 0.16 inch). This is due in part to the concentration of the roller pattern in the center of the paving lane from overlapping of adjacent roller passes, creating a slight "trough" along the centerline as the RCC consolidated. Also, the straightedge spanned from one longitudinal joint to the next during transverse measurements, and the longitudinal joints were not consolidated as well as the interior portion of the lane due to delayed compaction. This slight "hump" at the joints contributed to the joint smoothness readings being the highest (0.28 inch).

Table 7 contains the daily average moisture content of the RCC, as measured with the nuclear density gauge (6-inch reading), and by drying a fresh sample of the RCC in the laboratory. The optimum moisture content from the Modified Proctor test was also determined twice daily on Day 2 through 6. The specifications required that the moisture content be controlled to obtain the maximum density in the field. The nuclear gauge moisture content readings are generally regarded to be too inaccurate to use for control applications and for determining the dry

TABLE 7. DAILY RCC MOISTURE CONTENT: HARDSTAND

| Test Area | Modified Proctor Optimum Moisture Content (Percent) | Mean Nuclear Gauge Reading (Percent) | Fresh Concrete Moisture Content By Drying (Percent) |
|---|---|---|---|
| Day 1 | -- | 5.8 | 6.0 |
| Day 2 | 5.2 | 5.8 | 6.0 |
| Day 3 | 6.0 | 5.6 | 5.8 |
| Day 4 | 6.1 | 5.9 | 6.0 |
| Day 5 | 6.2 | 6.0 | 6.3 |
| Day 6 | 6.6 | 6.3 | 6.2 |
| Hardstand Totals | | | |
| Mean | 6.0 | 5.9 | 6.1 |
| Standard deviation | 0.51 | 0.51 | 0.39 |
| No. of tests | 10 | 287 | 55 |

density of RCC (hence the use of the wet density instead of the dry density for control). However, the average nuclear gauge moisture reading (287 tests) of 5.9 percent agrees closely with the laboratory determined average of 6.1 percent (55 tests). The nuclear gauge moisture readings also followed the same daily fluctuations indicated by the laboratory measurements (Figure 19).

The optimum moisture content for compaction of the RCC varied between 5.8 and 6.3 percent, but ranged in extreme cases from 4.8 to 7.3 percent (according to the nuclear gauge). There appeared to be advantages and disadvantages associated with these extremes. When the RCC was relatively dry (i.e., moisture content less than 5.8 percent), the density at the lower portion of the lift (6-in. nuclear reading)

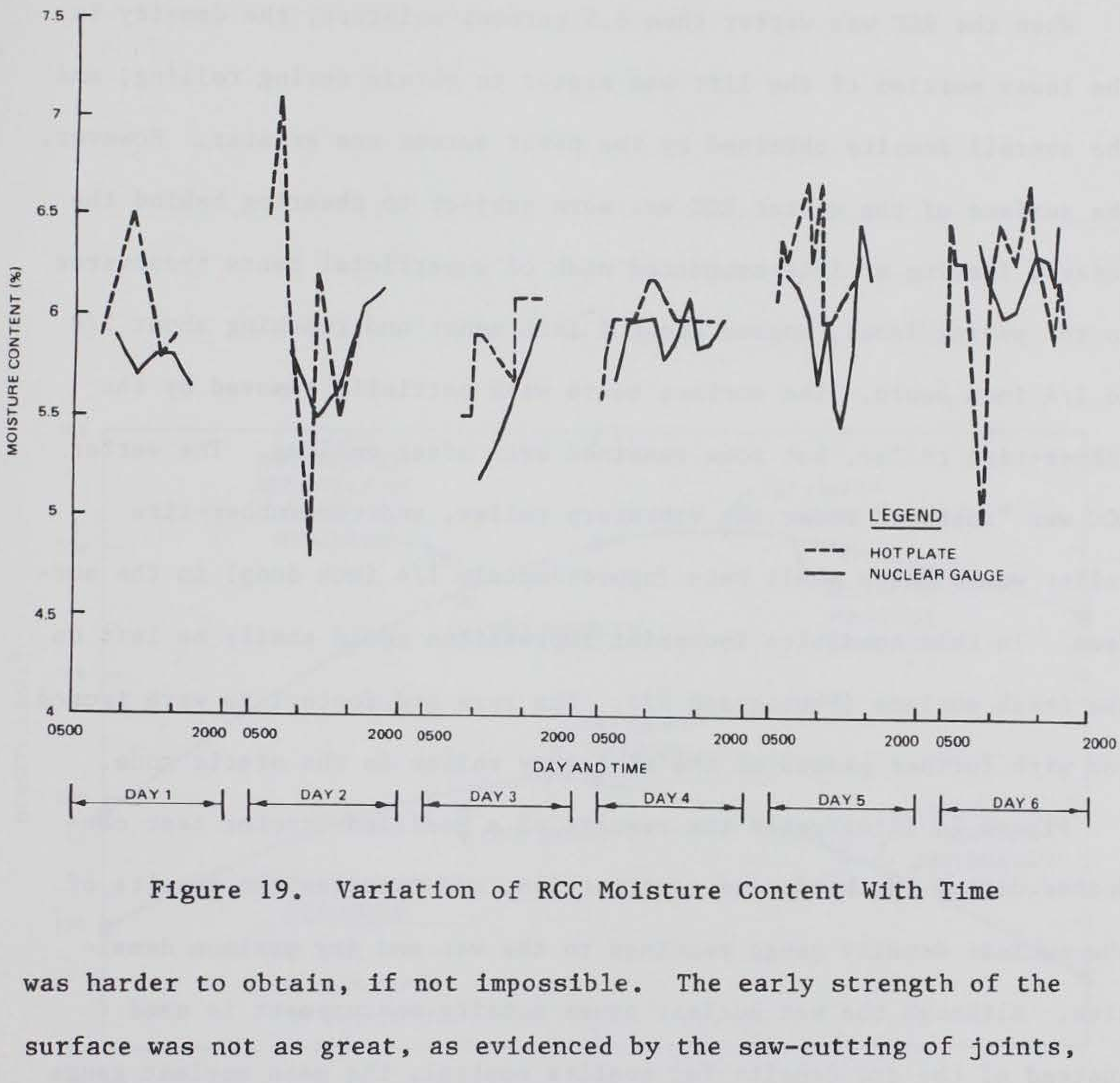



Figure 19. Variation of RCC Moisture Content With Time

was harder to obtain, if not impossible. The early strength of the surface was not as great, as evidenced by the saw-cutting of joints, which produced more raveled edges. The surface texture was coarse, but few surface tears formed behind the screed. However, with the drier RCC the surface was prone to "shearing" with the roller wheel during vibration, i.e., a shallow (1/4-inch-deep) portion of the surface would shear, and shift in the opposite direction of rolling. The surface was also more prone to the roller wheel "picking up" aggregate and/or cement paste in small pockets (Photograph 58).

When the RCC was wetter than 6.5 percent moisture, the density in the lower portion of the lift was easier to obtain during rolling, and the overall density obtained by the paver screed was greater. However, the surface of the wetter RCC was more subject to shearing behind the screed, leaving an interconnected mesh of superficial tears transverse to the paving lanes, spaced about 1 inch apart and reaching about 1/8 to 1/4 inch depth. The surface tears were partially removed by the rubber-tire roller, but some remained even after rolling. The wetter RCC was "rubbery" under the vibratory roller, and the rubber-tire roller would leave small ruts (approximately 1/4 inch deep) in the surface. In this condition footprint impressions could easily be left on the fresh surface (Photograph 52). The ruts and footprints were ironed out with further passes of the vibratory roller in the static mode.

Figure 20 illustrates the results of a Modified Proctor test conducted during the hardstand construction, and compares the results of the nuclear density gauge readings to the wet and dry maximum densities. Although the wet nuclear gauge density measurement is used instead of the dry density for quality control, the mean nuclear gauge dry density (287 tests) corresponds more closely to the Modified Proctor dry density.

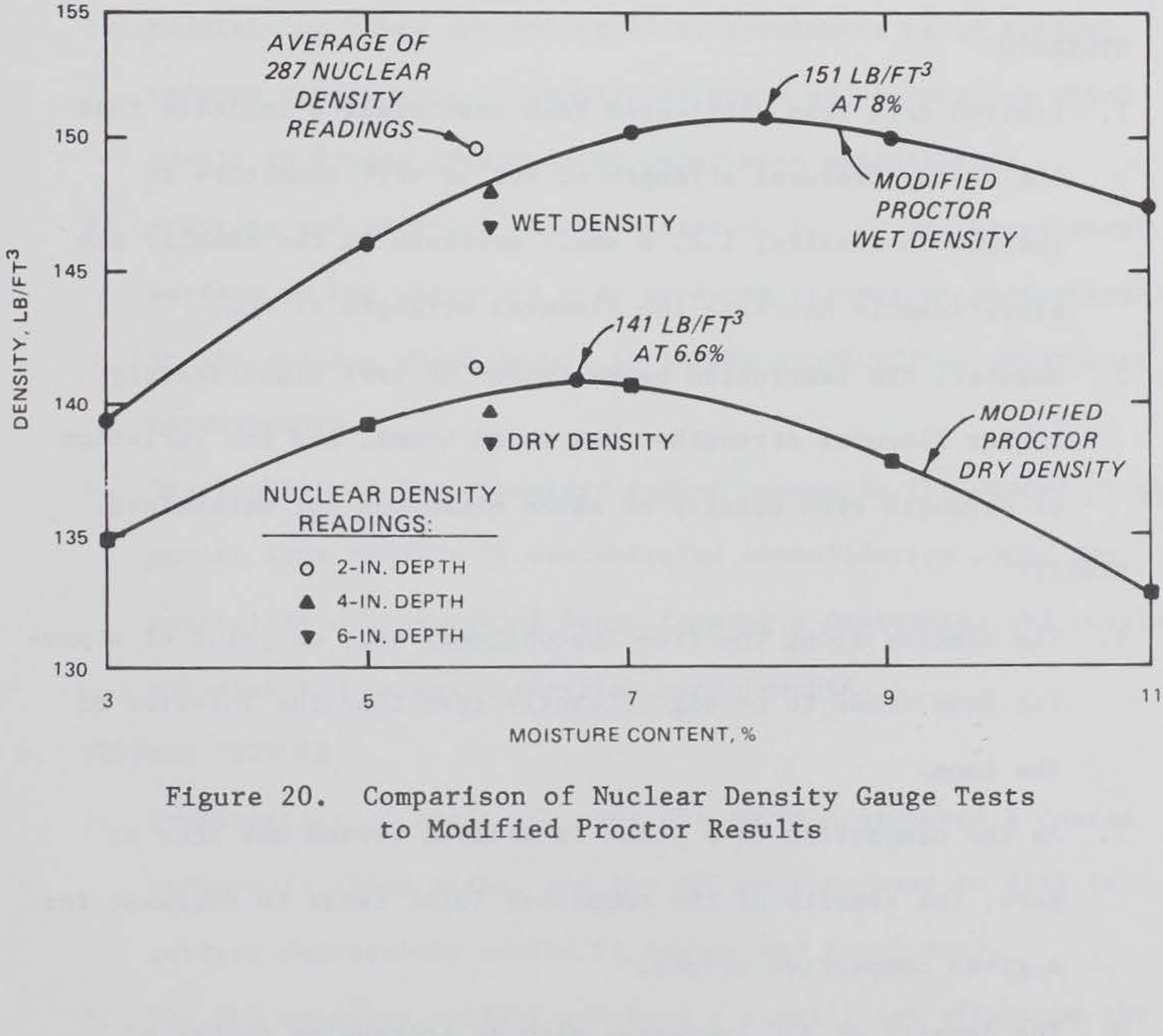



Figure 20. Comparison of Nuclear Density Gauge Tests to Modified Proctor Results

# SECTION X

# CONCLUSIONS

Based on the results of the test section tests, the quality control data, and observation of the construction procedures at Harvey Barracks, the following conclusions can be made on the effects of the construction process on the strength, density, smoothness, and surface texture of RCC:

A. STRENGTH

1. Limited data from fabricated beam test results indicate that the 28-day flexural strength of RCC is very sensitive to changes in density; i.e. a small decrease in the density can significantly decrease the flexural strength of RCC.
2. However, the fabricated beams tended to have significantly higher flexural strengths than sawed beams, and the variation of strength with density of sawed beams was not determined.

B. DENSITY

1. The density along the free (unconfined) edge or joint of a paving lane tends to be significantly less than the interior of the lane.
2. As the compaction of a joint is delayed beyond one hour or more, the density of the compacted joint tends to decrease for a given compactive effort.
3. The density of RCC increases with an increasing number of vibratory roller passes, with the increase in density diminishing after seven vibratory passes.

4. The in situ density of an RCC pavement slab tends to decrease with depth, which may be verified with incremental nuclear density gauge readings or by sectional core density measurements.

C. SMOOTHNESS

1. Delayed compaction of the joints tends to produce a "hump" along the joint that results in larger joint and transverse smoothness measurements.
2. Maintaining paver continuity (i.e. continuous paver motion) reduces occurrences of transverse bumps or depressions which result in larger longitudinal smoothness measurements.
3. Starting and stopping of the vibratory roller on the pavement surface in the vibratory mode produces transverse depressions in the surface which result in larger longitudinal smoothness measurements.
4. Overlapping of the vibratory roller passes in the center of the paving lane results in concentrated consolidation along the centerline of the paving lane, forming a depression and causing subsequently larger transverse measurements.

D. SURFACE TEXTURE

1. Broadcasting of loose RCC over the surface produced a coarse texture in those areas, and the RCC patches used to fill in surface depressions tended to debond and ravel away.
2. The RCC moisture content can have a significant effect on the surface texture. The fines in the drier RCC batches tended to "pick up" and stick to the roller drum during rolling, and the surface was subject to shearing under the roller drum. The

wetter RCC batches produced a tight surface texture, but roller marks and surface indentations (footprints) were difficult to remove.

3. The high-density screed did leave superficial surface tears parallel to the paver screed, but these were effectively removed by the kneading action of the rubber-tire roller.

# SECTION XI

# RECOMMENDATIONS

Based on the conclusions derived from the test section and quality control data, and from observations made during construction of the RCC hardstand at Harvey Barracks, the following recommendations are made regarding the effects of the construction process on the strength, density, smoothness, and surface texture of RCC pavements.

A. STRENGTH

1. To ensure that the design flexural strength is reached in all areas of an RCC pavement, the required minimum density should be achieved in all areas of the pavement, especially at the joints.
2. Standardized beam and cylinder fabrication procedures should be developed that accurately represent the strength and density of an RCC pavement, so that mixture proportions can be developed with confidence before the test section construction.
3. Correlations between 7-day splitting tensile and 28-day flexural strength of RCC should be obtained in a test section if the 7-day core strength will be used for control.

B. DENSITY

1. The free edge of a paving lane should be removed until RCC of adequate density is reached during the construction of longitudinal cold joints.
2. The length of the paving lane should be limited by the amount of time required to place and compact the adjacent lane and subsequent fresh joint between the lanes to the required

density. This maximum length of paving lane may be determined during the test section construction.

3. A minimum number of vibratory passes (probably four or more) should be applied to the fresh RCC to ensure that adequate density is achieved. This minimum number of passes may be determined during the test section construction.
4. Full-depth readings with the nuclear density gauge should be taken to ensure that adequate density is obtained throughout the depth of the paving lane. Incremental readings should be taken to detect changes in the RCC density with depth. The thickness of an RCC lift should be limited, or the number of vibratory passes increased, if the minimum required density is not achieved throughout the depth of the RCC.
5. The nuclear density gauge readings should be correlated to core densities during the test section construction so an appropriate correction factor can be applied to the readings during subsequent construction. The age of the cores used in the correlation should be constant to account for increasing density with age of the cores.
6. The RCC moisture content should be carefully controlled around the optimum to ensure that the required density is achieved for a given compactive effort.
7. The dry density readings of the nuclear density should be considered for control of the RCC density, since they may provide more accurate and less variable results than the wet density readings.

C. SMOOTHNESS

1. Compaction of the fresh joints should occur within specific time limitations to help prevent the occurrence of "humps" at the fresh joints. Every effort mentioned to maintaining joint density, such as limiting lane length and trimming cold joints, should be applied to improving joint smoothness also.
2. Careful, continuous operation of the paver should be maintained to help achieve good longitudinal smoothness. The paver hopper should not be allowed to empty, the paver should move at a constant speed, and the RCC should be kept above the auger level in the screed.
3. The vibratory roller should not be allowed to start or stop on the RCC surface in the vibratory mode; rather, the vibrator should be turned on only after the roller has started moving and should be turned off before the roller stops.
4. Consideration should be given to providing a "crown" in the paver screed to offset the extra consolidation achieved in the center of the lane from overlapping roller passes.

D. SURFACE TEXTURE

1. A minimum fines content should be maintained, by supplementation of flyash if necessary, to improve the workability characteristics of the RCC and to provide a tight surface texture.
2. Broadcasting of loose material over the RCC pavement surface before or during rolling should be prevented.
3. The RCC moisture content should be carefully controlled to prevent "picking up" of aggregate fines on the roller drum if the

RCC is too dry, or to minimize roller marks or surface indentations if the surface is too wet. Variations in the RCC moisture content of about one percent more or less than the optimum moisture content produced these changes.

4. A rubber-tire roller should be used to remove any surface tears or fissures left by the high-density screed or vibratory roller.

REFERENCES


1. Abrams, Jory M. and Jacksha, Jerry L., "An Airport Apron and a County Road," Concrete International: Design and Construction, Vol. 9, No. 2, February 1987, pp. 30-36.

2. American Society for Testing and Materials, "Standard Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10-pound Rammer and 18-inch Drop," Designation: D 1557-78, Annual Book of ASTM Standards, Vol. 4.08, Philadelphia, Pennsylvania, 1983.

3. American Society for Testing and Materials, "Standard Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)," Designation: D 2922-81, Annual Book of ASTM Standards, Vol. 4.08, Philadelphia, Pennsylvania, 1984.

4. American Society for Testing and Materials, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)," Designation: C 78-84, Annual Book of ASTM Standards, Vol. 4.02, Philadelphia, Pennsylvania, 1986a.

5. American Society for Testing and Materials, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens," Designation: C 30-86, Annual Book of ASTM Standards, Vol. 4.02, Philadelphia, Pennsylvania, 1986b.

6. American Society for Testing and Materials, "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," Designation: C 496-85, Annual Book of ASTM Standards, Vol. 4.02, Philadelphia, Pennsylvania, 1986c.

7. American Society for Testing and Materials, "Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete," Designation: C 138-81, Annual Book of ASTM Standards, Vol. 4.02, Philadelphia, Pennsylvania, 1986d.

8. Andersson, Ronny, "Swedish Experiences with RCC," Concrete International: Design and Construction, Vol. 9, No. 2, February 1987, pp. 18-24.

9. Brett, David M., "RCC Pavements in Tasmania, Australia," Roller Compacted Concrete II, Proceedings of the Conference sponsored by the Construction, Geotechnical Engineering, and Materials Engineering Divisions of the American Society of Civil Engineers, San Diego, California, February 29-March 2, 1988, pp. 369-379.

10. Department of the Army, U.S. Army Corps of Engineers, "Engineering and Design: Thickness Design of Roller-Compacted Concrete Pavements for Airfields, Roads, Streets, and Parking Areas," Engineering Technical Letter 1110-1-141, Washington, D.C., January 1988a.

11. Department of the Army, U.S. Army Corps of Engineers, "Roller Compacted Concrete (RCC) Pavement for Airfields, Roads, Streets, and Parking Lots," Corps of Engineers Guide Specification 02520, Washington, D.C., January 1988b.

12. Hess, John R., Roller Compacted Concrete Pavement for Tooele Army Depot, Utah, Master's Thesis, California State University, Sacramento, California, Spring 1987.

13. Hutchinson, Ronald L., Ragan, Steven A., and Pittman, David W., "Heavy-Duty Pavements," Concrete International: Design and Construction, Vol. 9, No. 2, February 1987, pp. 55-61.

14. Johnson, Robert R., "Visit to Fort Drum, New York, to Provide Technical Assistance during Construction of a Roller-Compacted Concrete Test Section," Memorandum For Record, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 13 July 1988.

15. Keifer, Oswin Jr., "Corps of Engineers Experience with RCC Pavements," Roller Compacted Concrete II, Proceedings of the Conference sponsored by the Construction, Geotechnical Engineering, and Materials Engineering Divisions of the American Society of Civil Engineers, San Diego, California, February 29-March 2, 1988, pp. 467-483.

16. Murphy, H. W., "Highway Construction in Queensland," Concrete International: Design and Construction, Vol. 9, No. 2, February 1987, pp. 42-48.

17. Neville, A. M., Properties of Concrete, 3rd Edition, Longman Scientific and Technical, Essex, England, 1986.

18. Palmer, William D., "One Tough Pavement," Concrete International: Design and Construction, Vol. 9, No. 2, February 1987, pp. 25-29.

19. Piggott, Robert W., "Ten Years of Heavy-Duty Pavement in Western Canada," Concrete International: Design and construction, Vol. 9, No. 2, February 1987, pp. 49-54.

20. Pittman, David W., "Construction of Roller-Compacted Concrete Pavements," Roller-Compacted Concrete Pavements and Concrete Construction, Transportation Research Record 1062, Transportation Research Board, Washington, D.C., 1986, pp. 13-19.

21. Pittman, David W., and Ragan, Steven A., A Guide for Design and Construction of Roller-Compacted Concrete Pavements, Miscellaneous Paper GL-86-39, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, November 1986.

22. Raczon, Frank, "Asphalt Paver Operation Targets Smooth Mats," Roads and Bridges, Vol. 26, No. 8, August 1988, pp. 52-56.

23. Ragan, Steven A., "Proportioning RCC Pavement Mixtures," Roller Compacted Concrete II, Proceedings of the Conference sponsored by the Construction, Geotechnical Engineering, and Materials Engineering Divisions of the American Society of Civil Engineers, San Diego, California, February 29-March 2, 1988, pp. 467-483.

24. Rollings, Raymond S., "Design and Construction of Roller Compacted Concrete Pavements," Proceedings, 14th Australian Road Research Board Conference, Canberra, Australia, August 1988a (to be published).

25. Rollings, Raymond S., "Design of Roller Compacted Concrete Pavements," Roller Compacted Concrete II, Proceedings of the Conference sponsored by the Construction, Geotechnical Engineering, and Materials Engineering Divisions of the American Society of Civil Engineers, San Diego, California, February 29-March 2, 1988b, pp. 467-483.

26. U.S. Army Engineer Waterways Experiment Station, "Method of Test for Flat and Elongated Particles in Coarse Aggregate," Designation CRD-C 119, Handbook for Concrete and Cement, Vicksburg, Mississippi, 1986a.

27. U.S. Army Engineer Waterways Experiment Station, "Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angles Machine," Designation CRD-C 117, Handbook for Concrete and Cement, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, (also ASTM Designation C 131-81), 1986b.

# APPENDIX A: PHOTOGRAPHS OF RCC PAVEMENT CONSTRUCTION

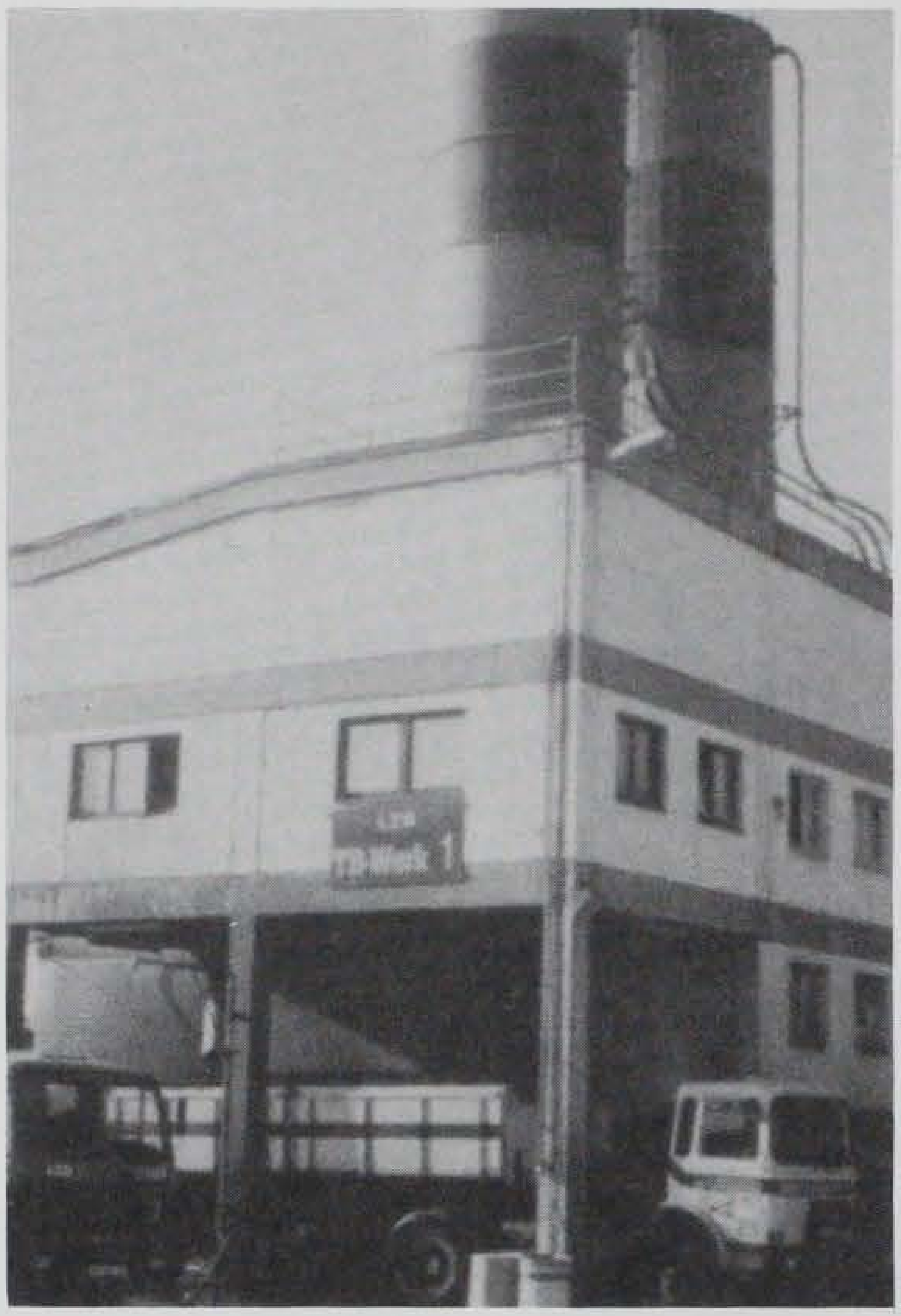


Photo 1. A stationary weigh-batch plant was used to mix the RCC

Photo 2. Freshly mixed RCC has the consistency of a wet gravel

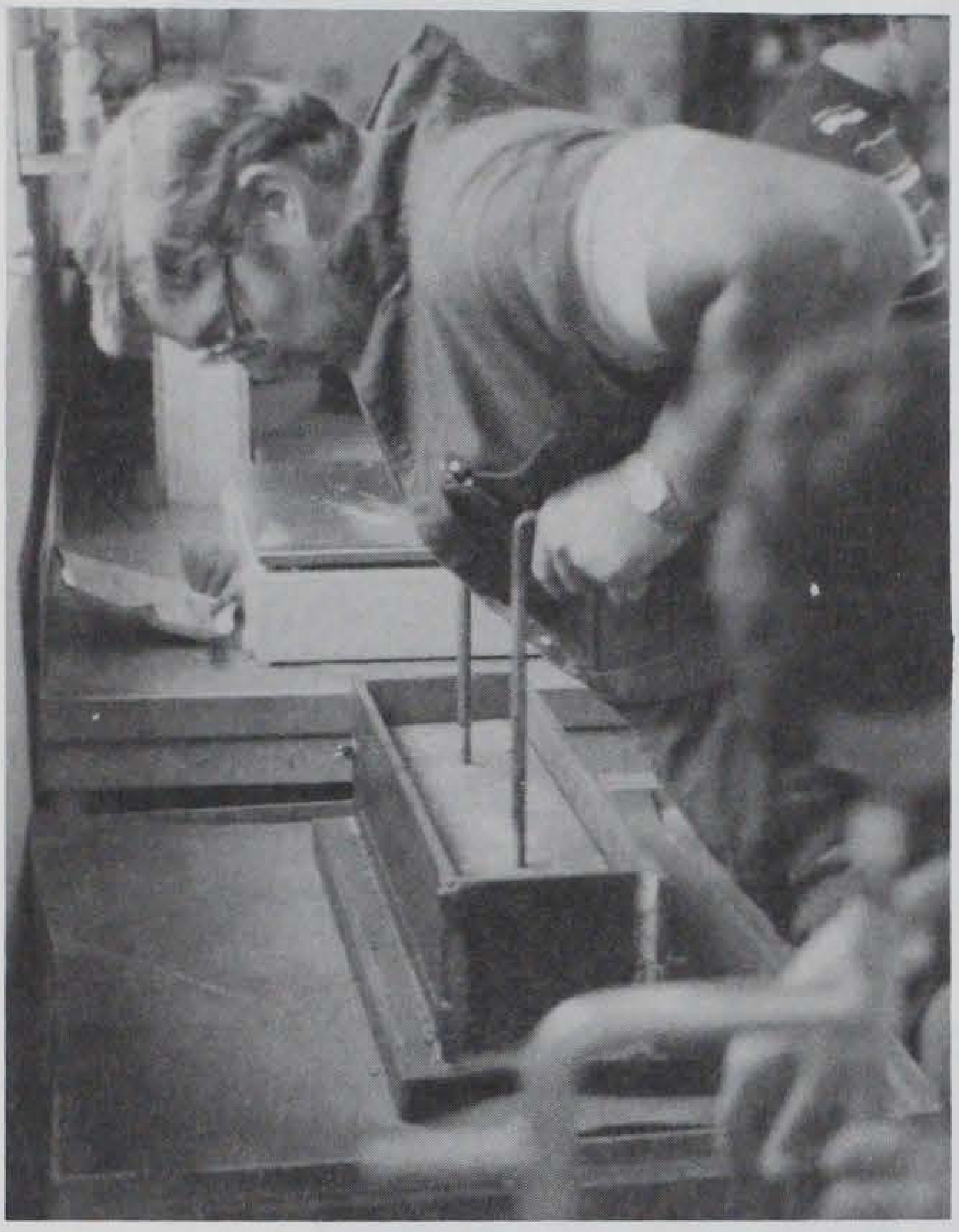


Photo 3. Beam samples were fabricated in two layers using a subcharge weight and a vibrating table

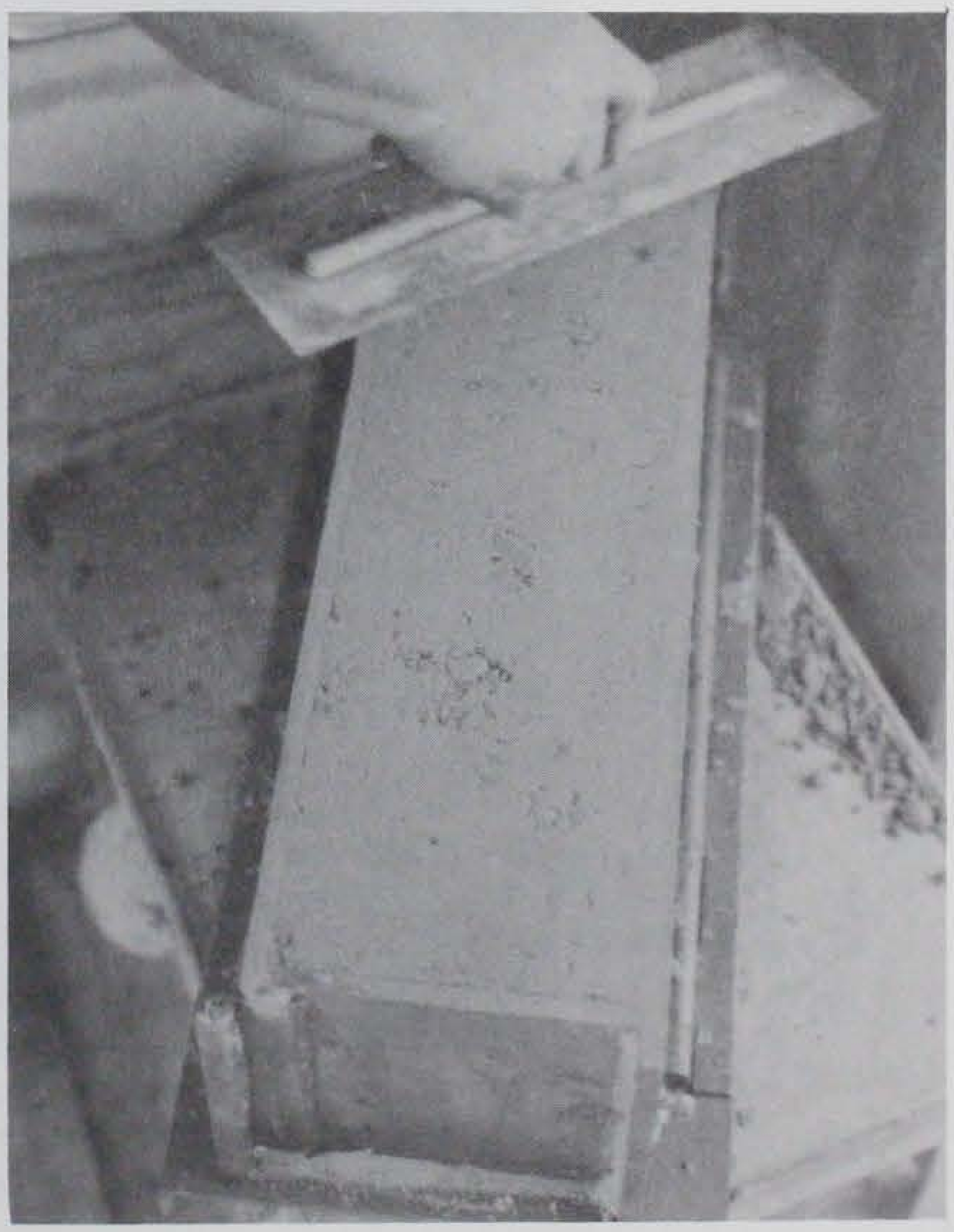


Photo 4. After vibrating the second layer, the beam was finished with a trowel

Photo 5. A finished RCC beam specimen

Photo 6. Modified Proctor tests were conducted on fresh RCC samples to determine the optimum moisture content

Photo 7. The proctor sample was weighed
to determine the density

Photo 8. An ABG Titan 420 paver was used to pave
the test section

Photo 9. A 10-ton dual drum vibratory roller was used for primary compaction

Photo 10. An 11-wheel rubber-tire roller was used to tighten the surface texture

Photo 11. A small vibratory roller was used to compact against the curbs and gutters

Photo 12. A water truck equipped with a spray boom was used to keep the RCC moist

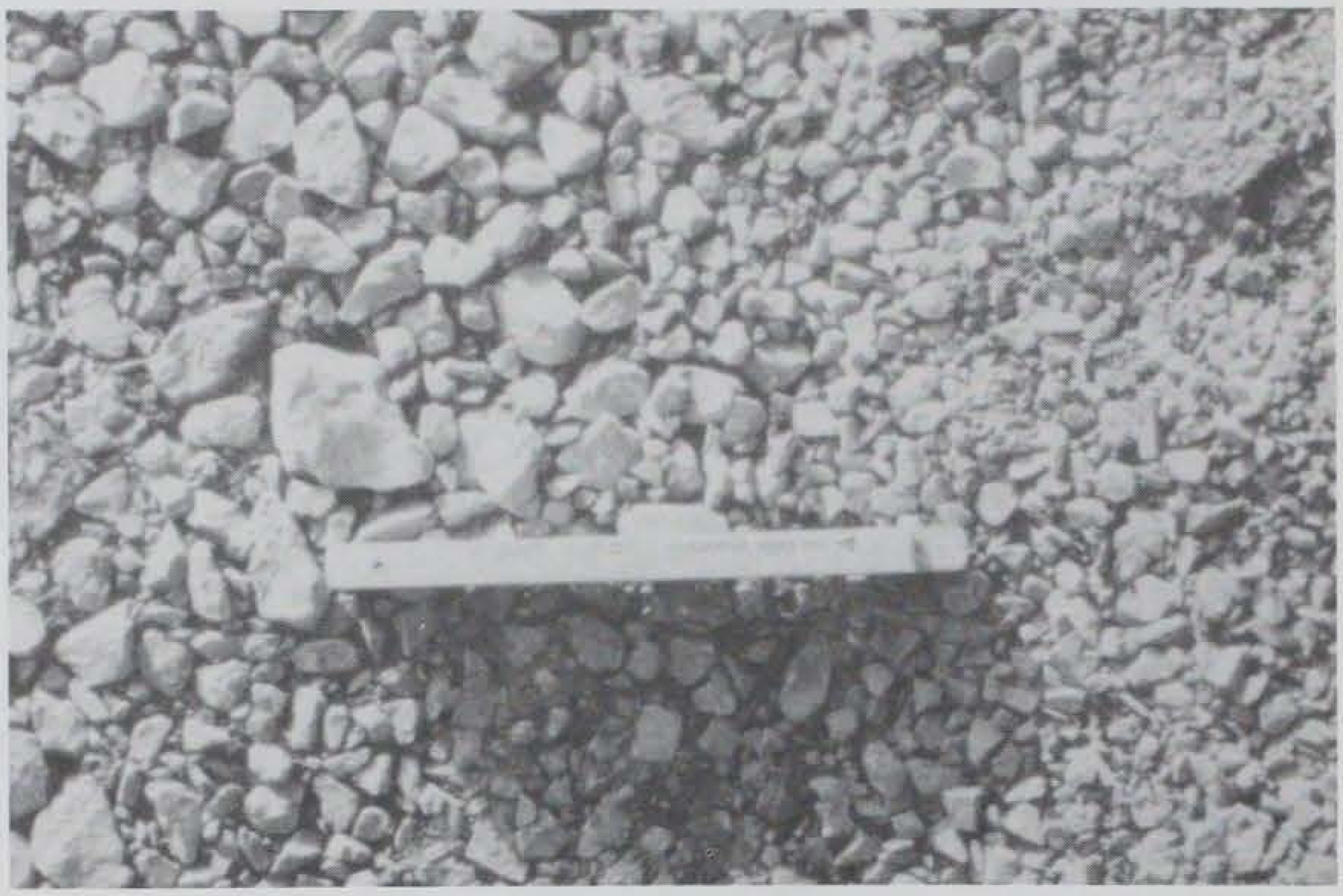


Photo 13. A well-graded crushed stone was used for the base course

Photo 14. The base course was spread to a 12 inch thickness with a motor grader

Photo 15. The coarser stone was spread first, and the smaller stone spread on top as a choker layer to make a firm working foundation

Photo 16. After the base course was completed, stringlines were set to guide the height of the paver screed

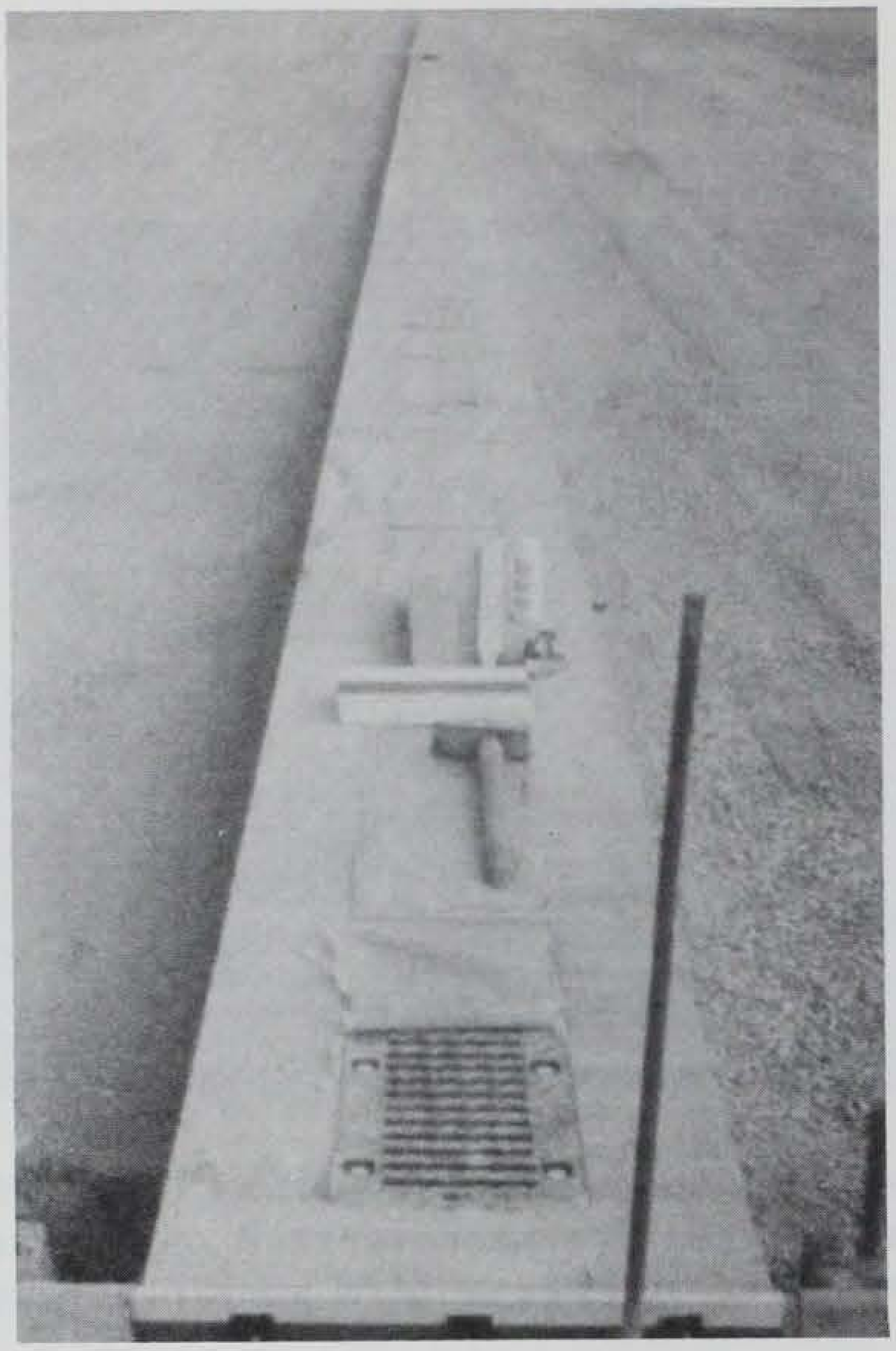


Photo 17. Long drainage gutters were secured in place with a 6-inch wide strip of concrete

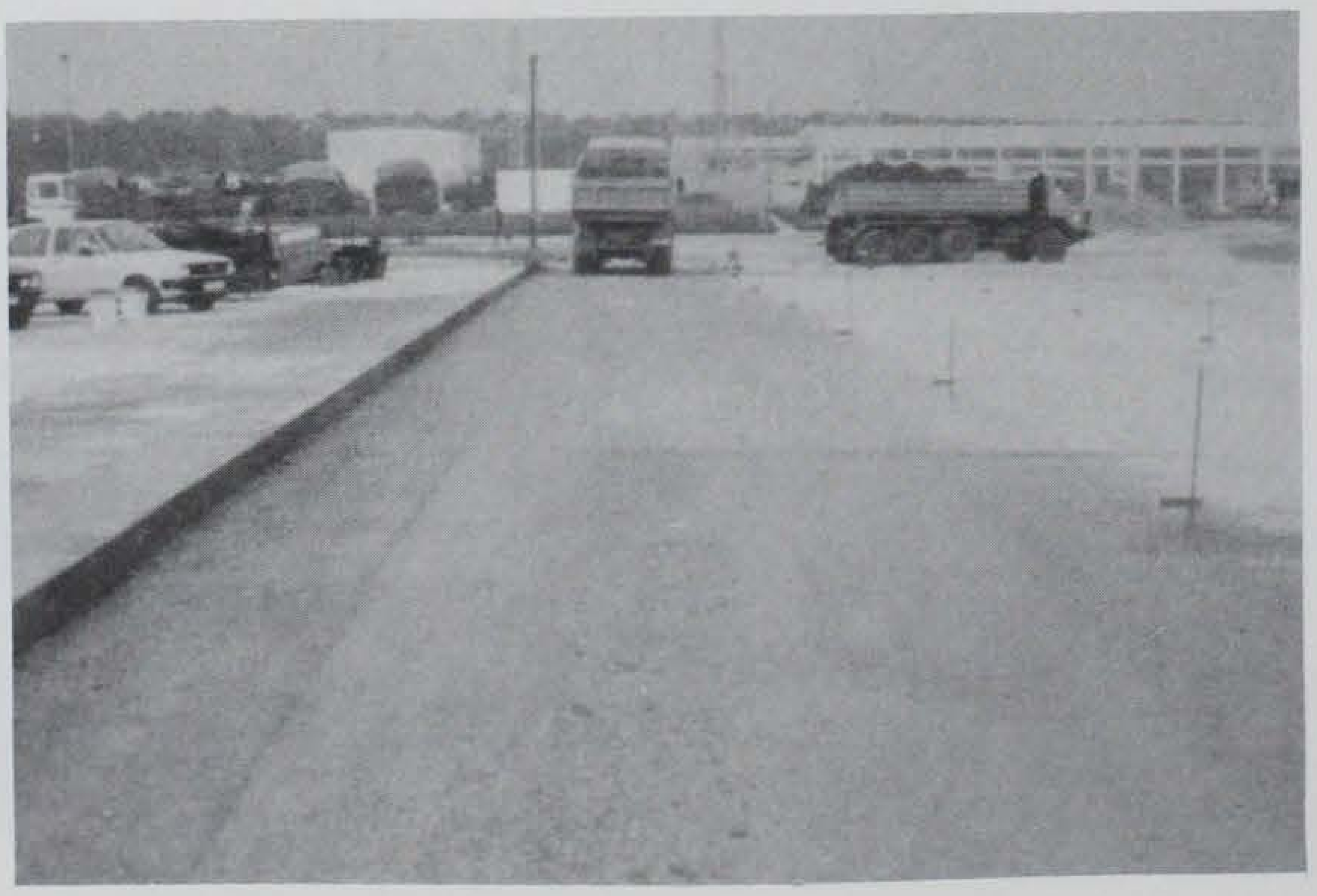


Photo 18. The base course was wet before the RCC was placed

Photo 19. Before paving began, the edge of the previously placed lane was trimmed with a concrete saw to form a vertical face to place against

Photo 20. The outer 6 inches to 1 foot along the longitudinal edge was also trimmed with a saw before the adjacent lane was placed

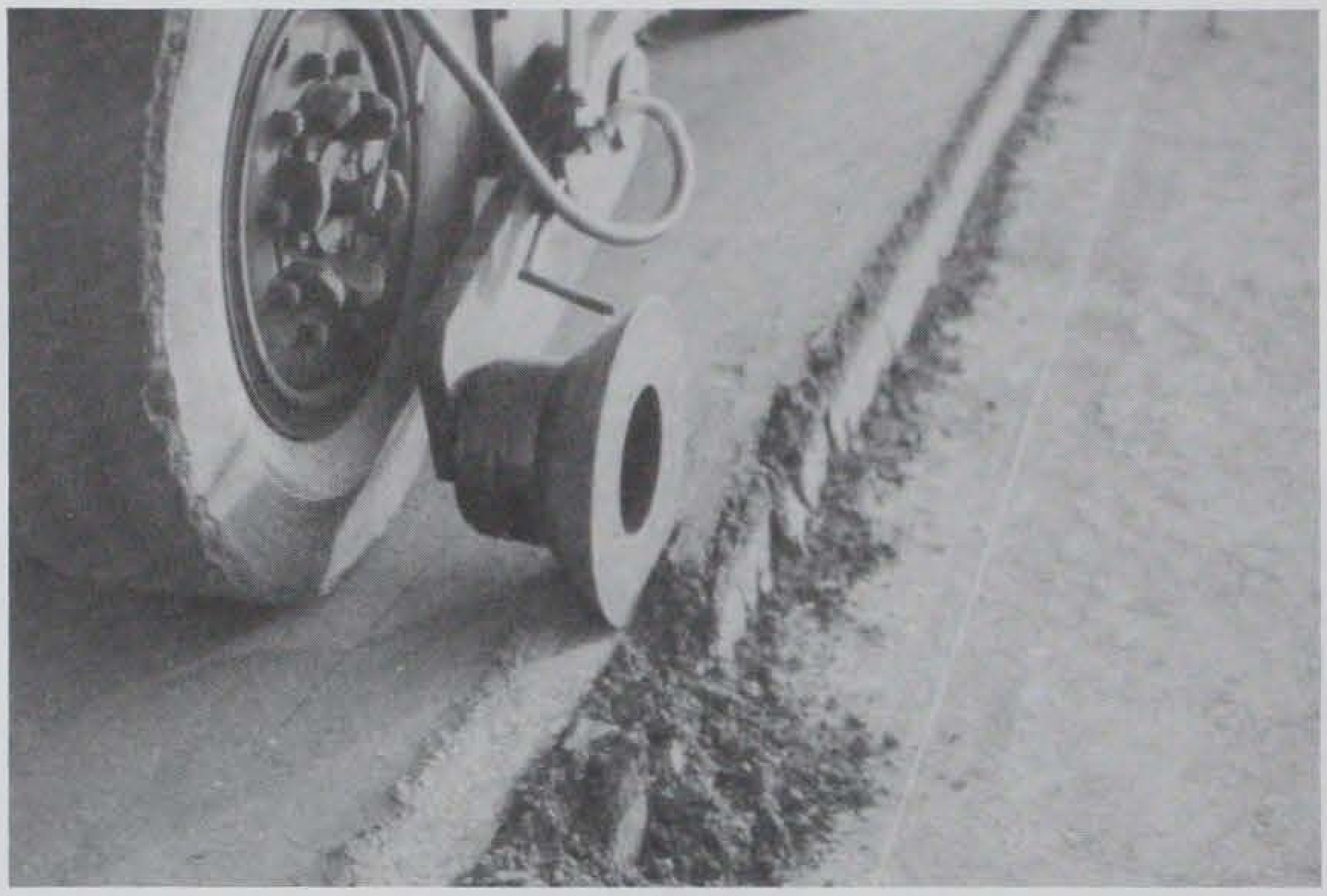


Photo 21. An asphalt cutting wheel was tried for trimming the edge, but it produced an unacceptable joint

Photo 22. To begin paving, the paver screed was positioned to overlap the previously placed lane (or curb along the perimeter) about 1 or 2 inches

Photo 23. As the paver pulled away from the cold joint, the excess RCC was carefully back with rakes and brooms...

Photo 24. ...to the joint interface

Photo 25. The cold joint was then rolled in the transverse direction with the smaller vibratory roller

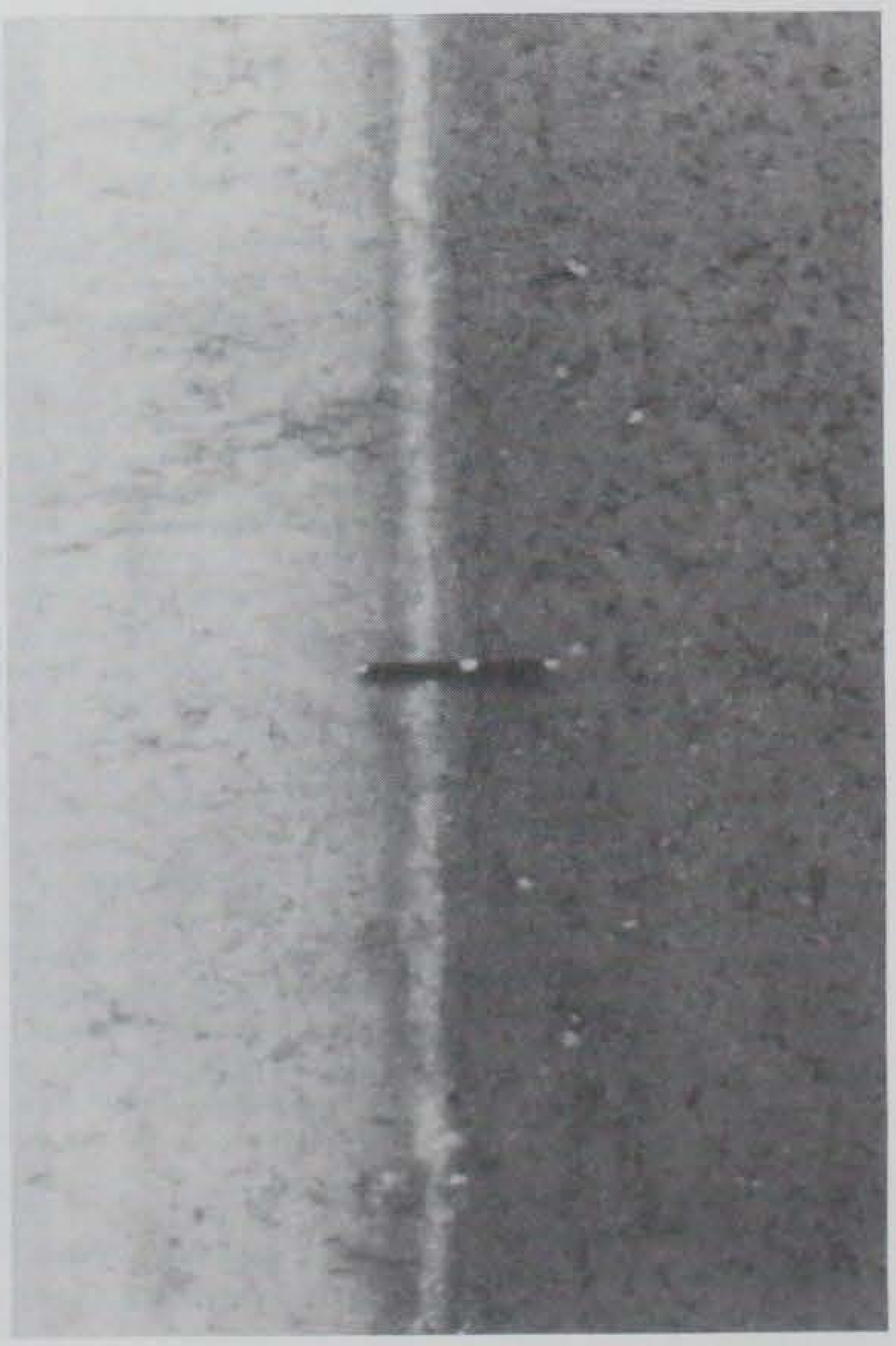


Photo 26. The finished cold joint

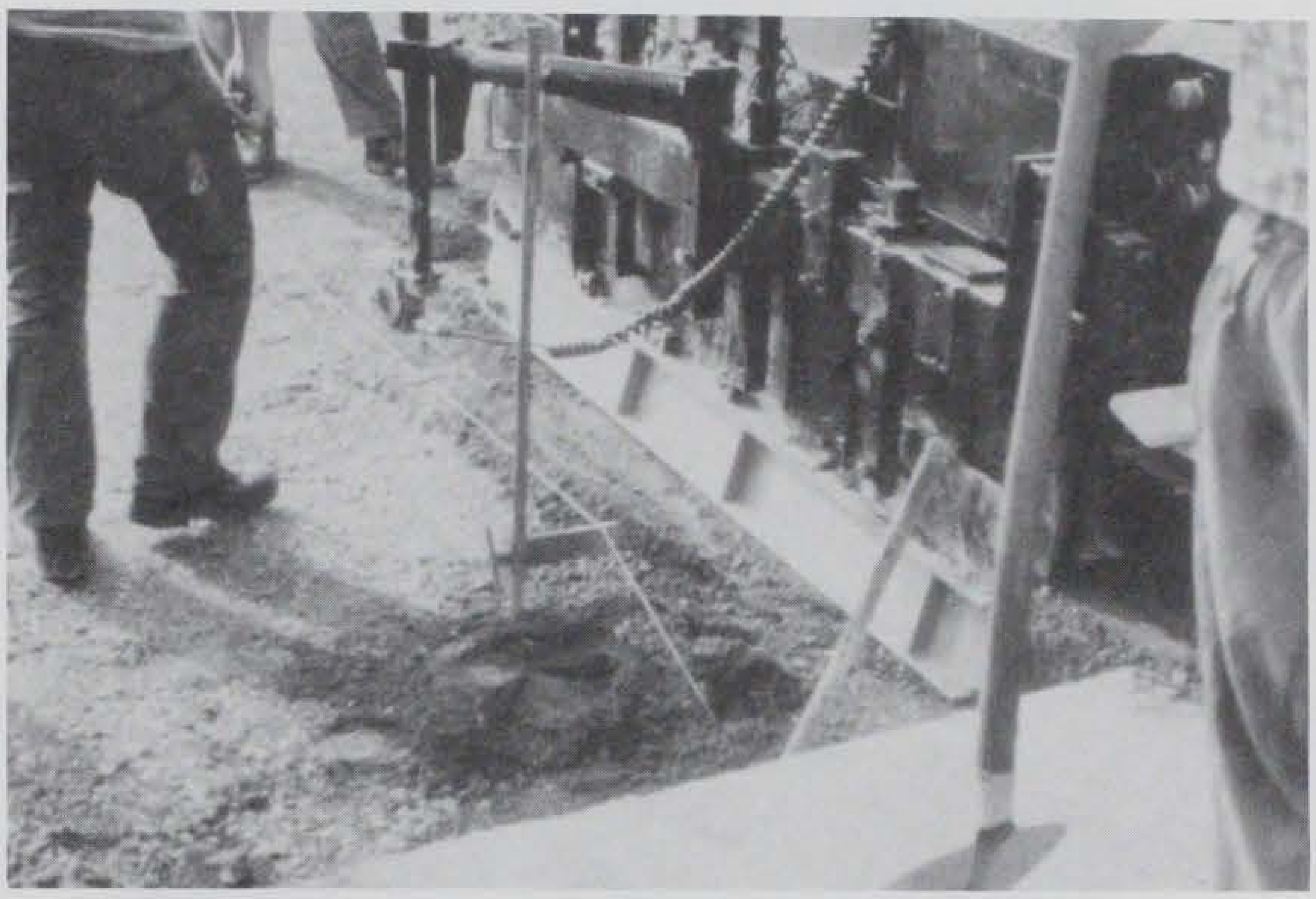


Photo 27. After pulling away from the joint, a shoe was attached to the screed to support the edge of the lane

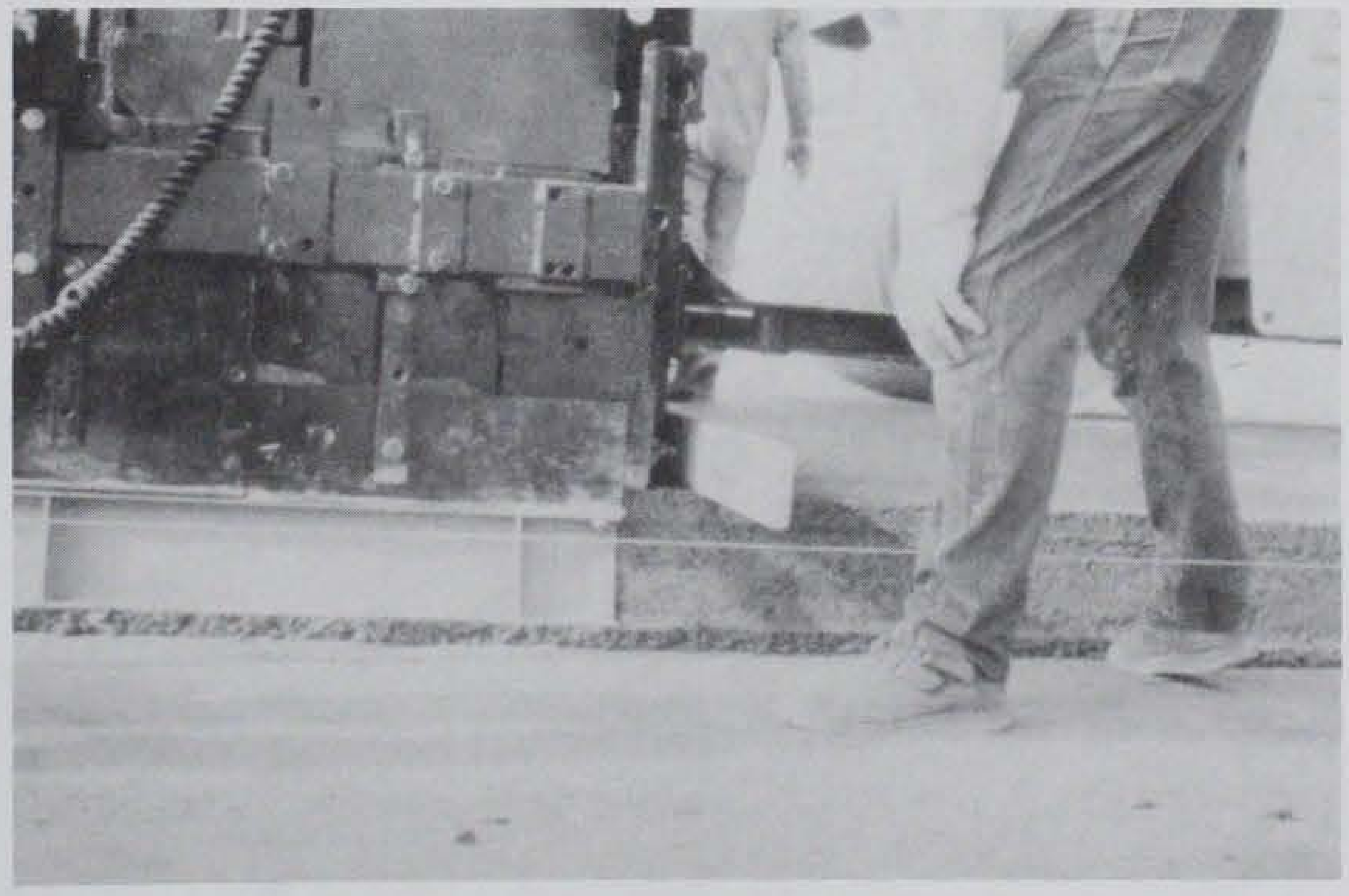


Photo 28. The height of the screed was set to about 10 percent over the required thickness to allow for compaction

Photo 29. Aggregate drag marks were created when large rocks were caught in the screed

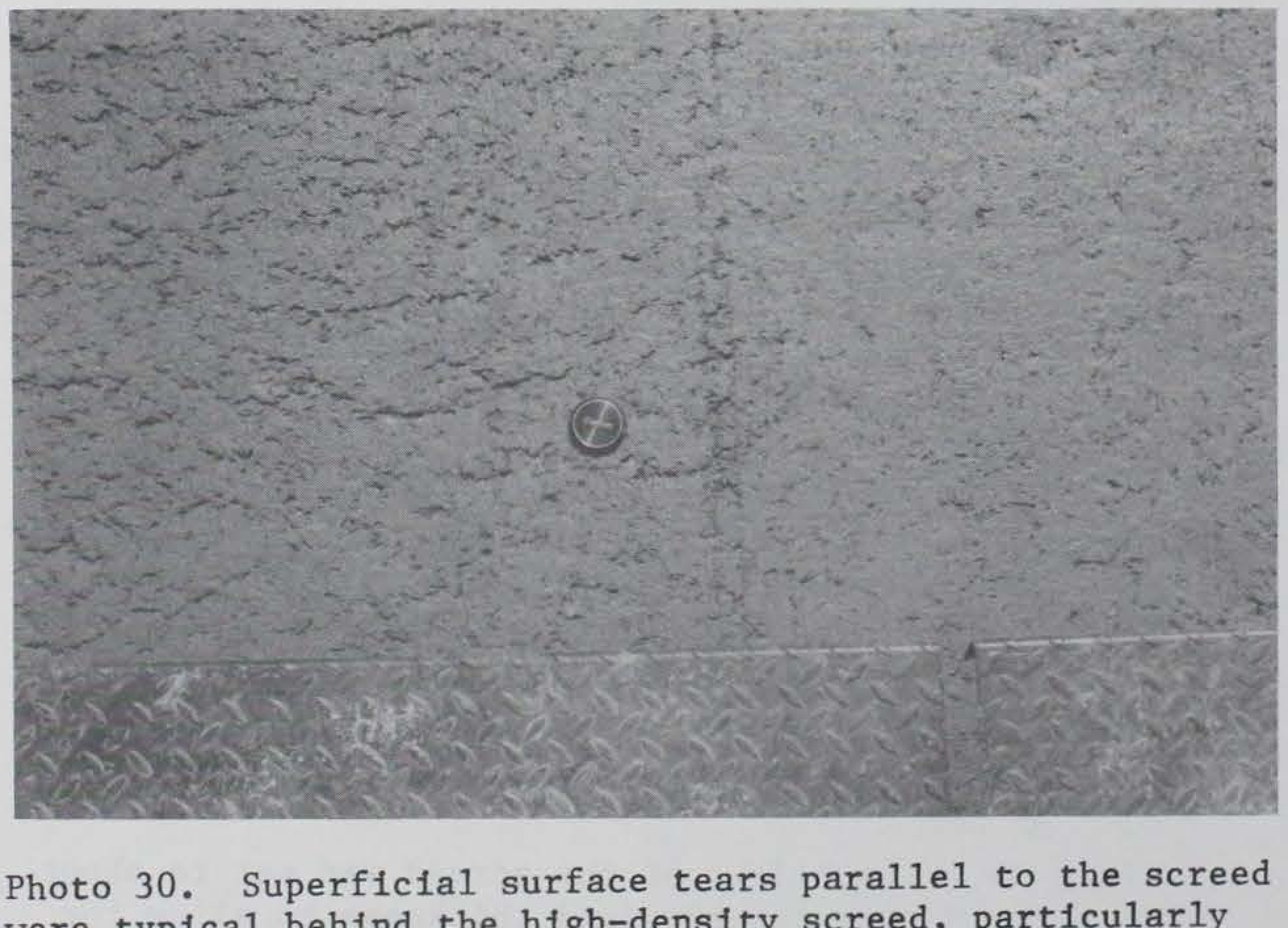


Photo 30. Superficial surface tears parallel to the screed were typical behind the high-density screed, particularly behind the screed extensions (left half of photograph)

Photo 31. As a quick field check of the consistency of the RCC, a sample was scooped up in both hands...

Photo 32. ...molded into a ball...

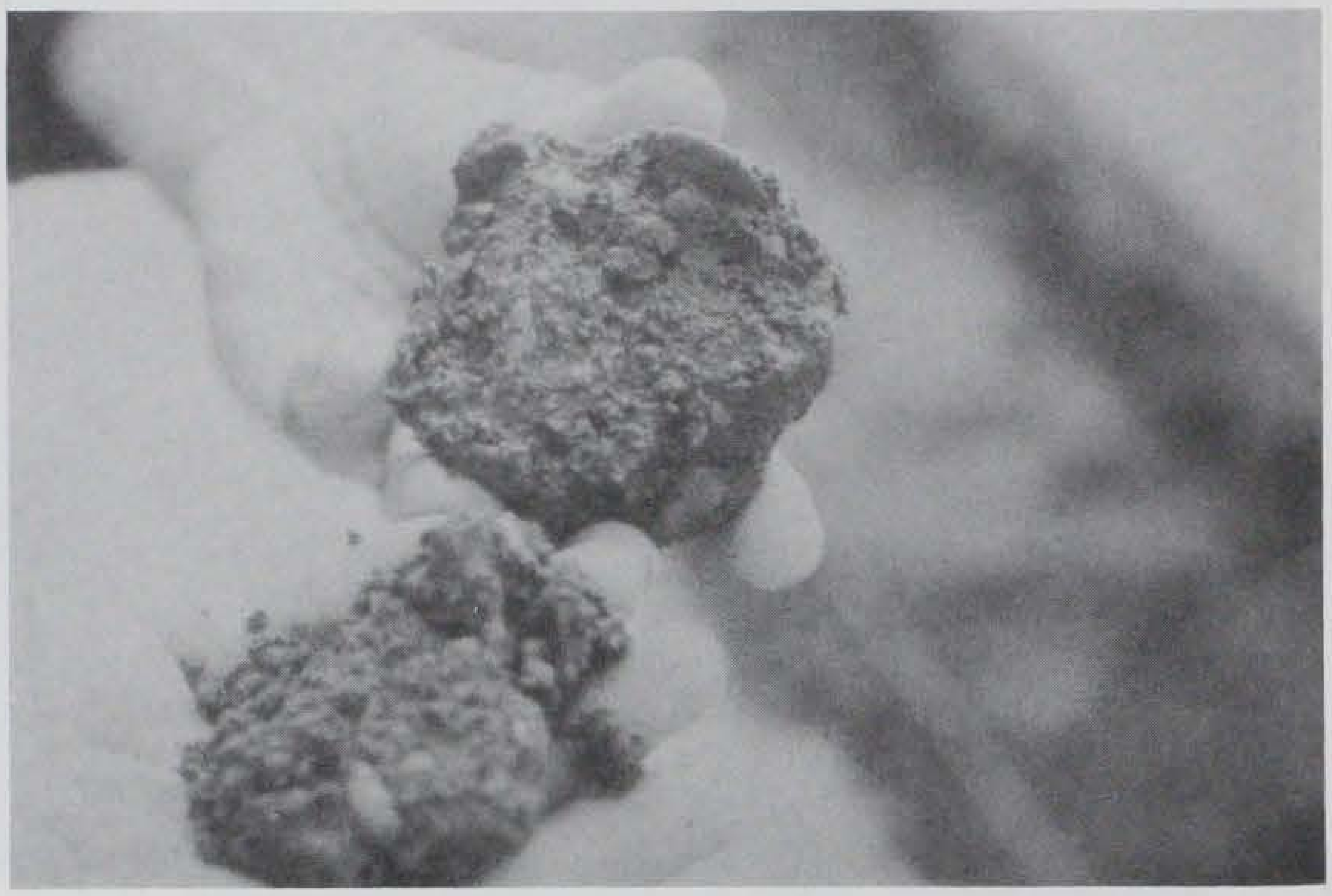


Photo 33. ...and broken in half. If it did not crumble or tend to stick together during breaking, the moisture content was close to ideal

Photo 34. The 10-ton vibratory roller followed immediately behind the paver for primary compaction

Photo 35. After six or more vibratory passes, the rubber-tire roller made six or more passes to tighten the surface texture

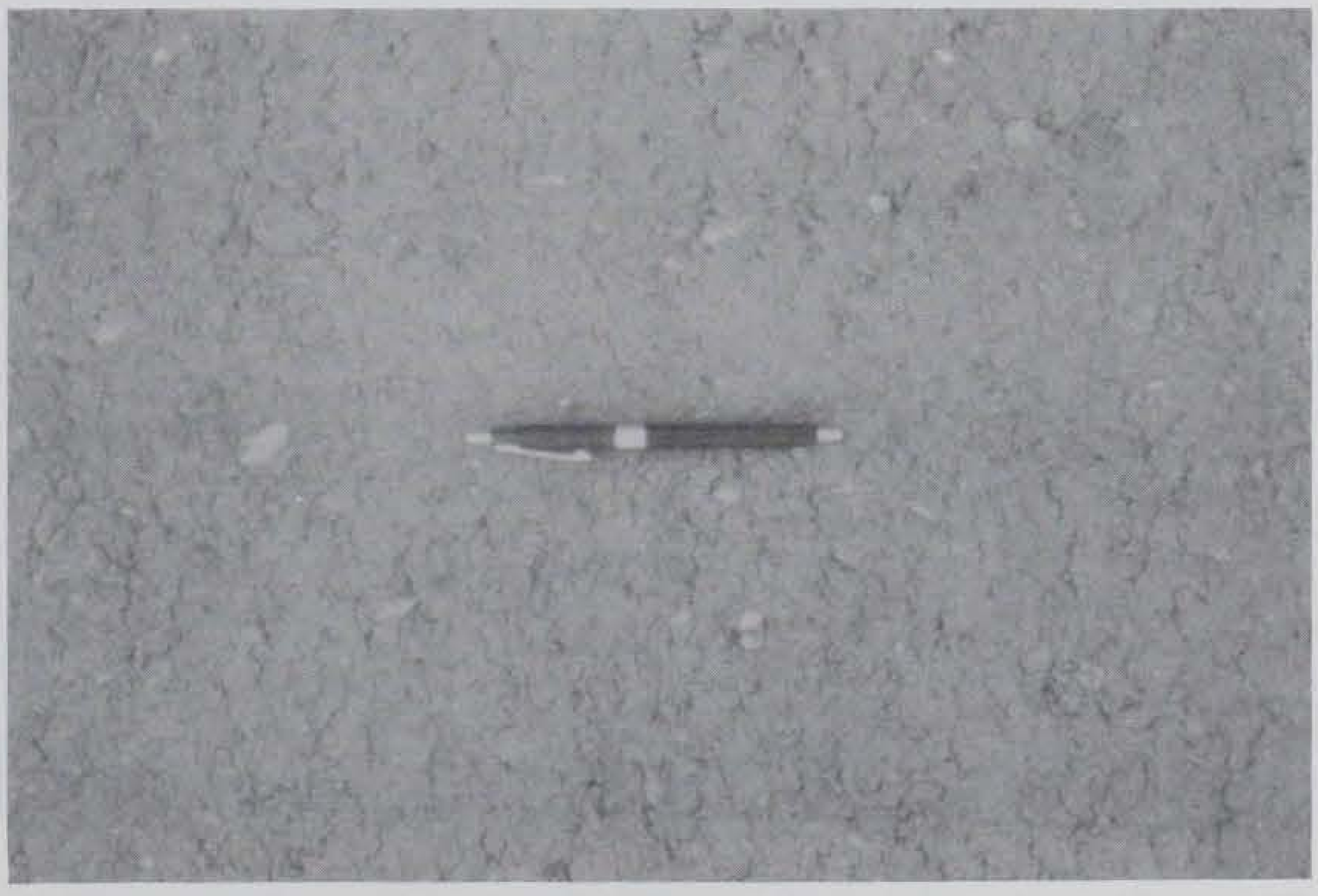


Photo 36. The surface texture above the pen has been tightened by two passes of the vibratory roller

Photo 37. The final surface texture of RCC is somewhat coarser than that of conventional concrete pavement

Photo 38. At the end of the lane, the rollers rolled off the end of the lane, which was then trimmed back before the next lane was placed

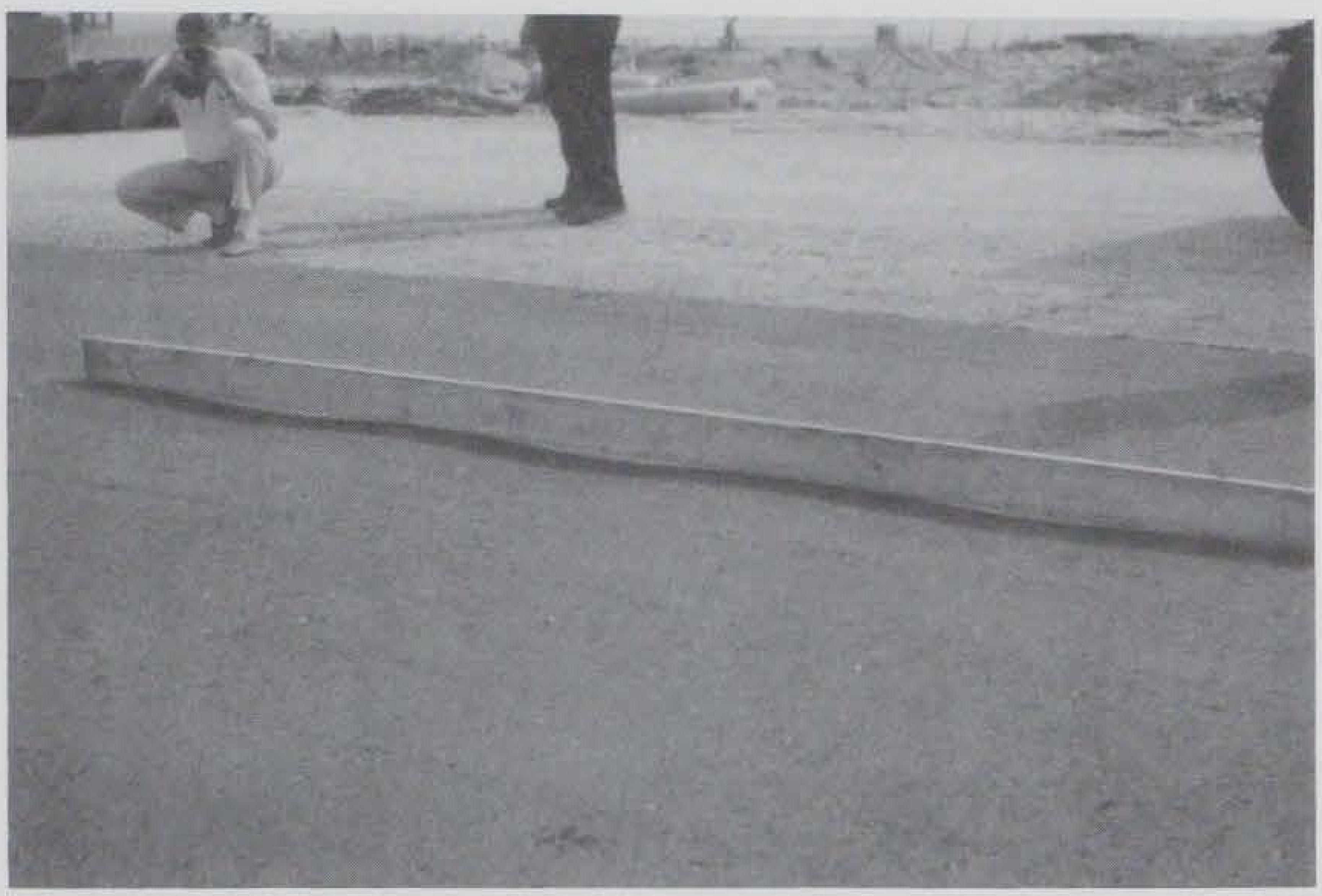


Photo 39. These transverse depressions were formed when the vibrator was left on as the roller stopped

Photo 40. The small vibratory roller was used in the transverse direction to iron out the bumps and depressions

Photo 41. The small vibratory roller was used against the curbs and gutters to protect the conventional concrete from damage caused by the large roller

Photo 42. After all rolling was completed, the surface was kept moist the remainder of the day with the water truck

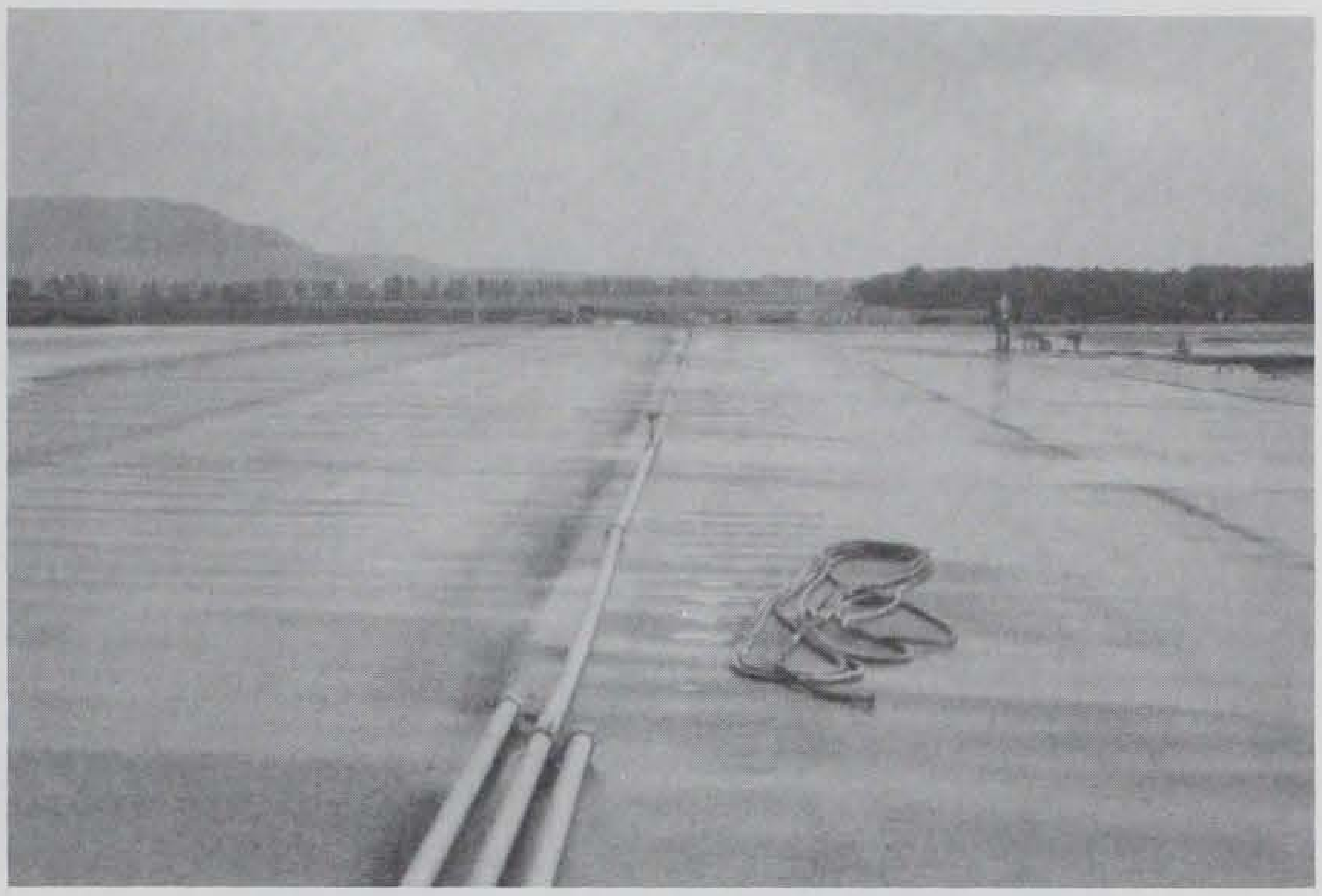


Photo 43. At the end of the day, an irrigation-type sprinkler system was set up to moist cure the RCC for seven days

Photo 44. The main quality control operation in the field was obtaining the in situ density with the nuclear density gauge immediately after rolling

Photo 45. Smoothness tests were conducted transverse and parallel to the lane, and across joints

Photo 46. A small calibrated wedge was used to measure the distance between the pavement surface and the straightedge

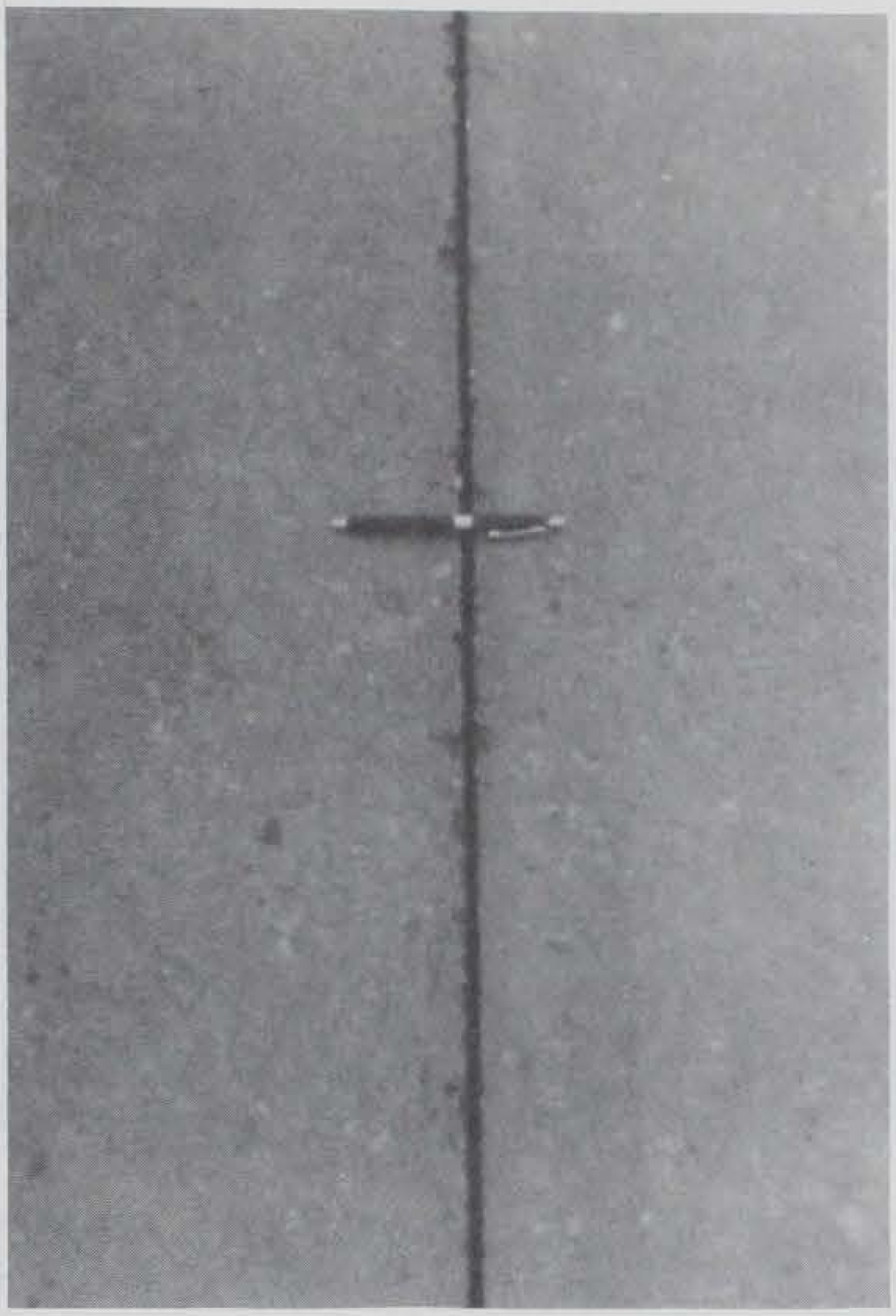


Photo 47. Transverse contraction joints were sawed at 69 foot spacings 12 to 20 hours after placement

Photo 48. To avoid paving around manholes, the manhole was built up to the level of the base course, and covered with a steel plate

Photo 49. The plate was paved over, and the next day a block of RCC was sawed over the plate

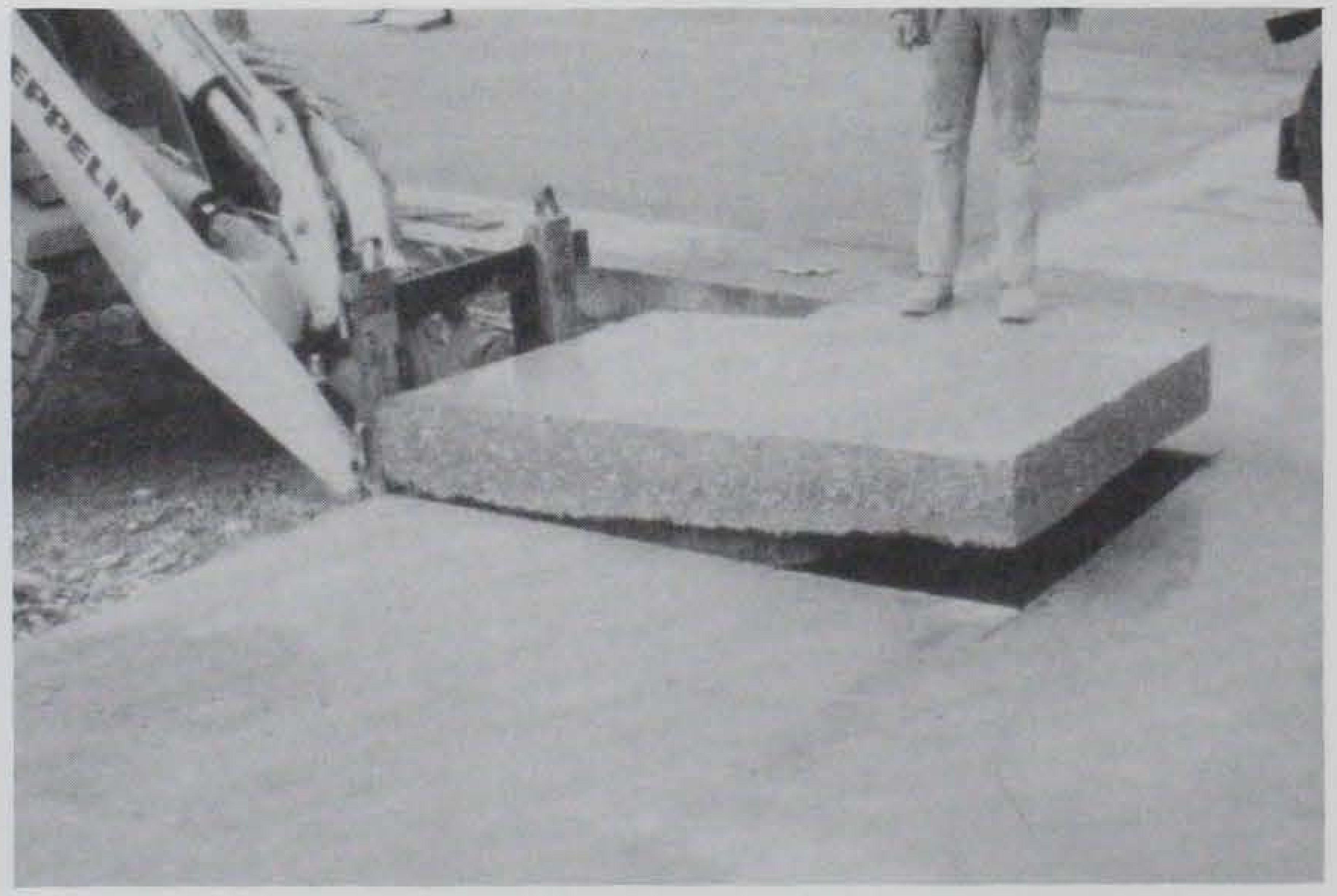


Photo 50. The block was removed by breaking it up with a jackhammer, or simply lifting it out with a forklift if it was at the edge of the lane

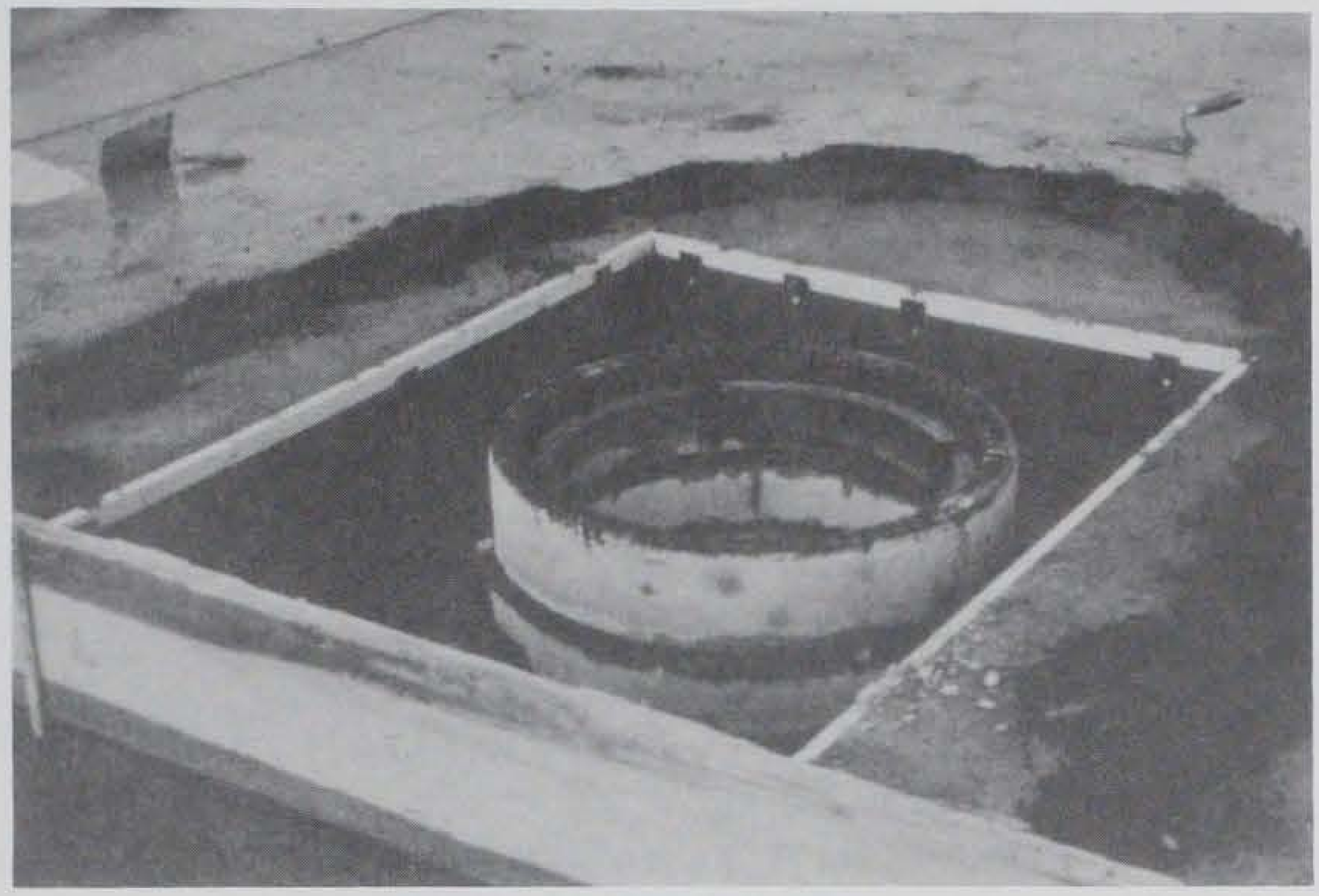


Photo 51. The plate was removed, the manhole built up to the pavement surface, and expansion material used to line the hole

Photo 52. The hole was then filled with conventional concrete to form the finished manhole


Photo 53. Cores were taken from the RCC for density and strength testing

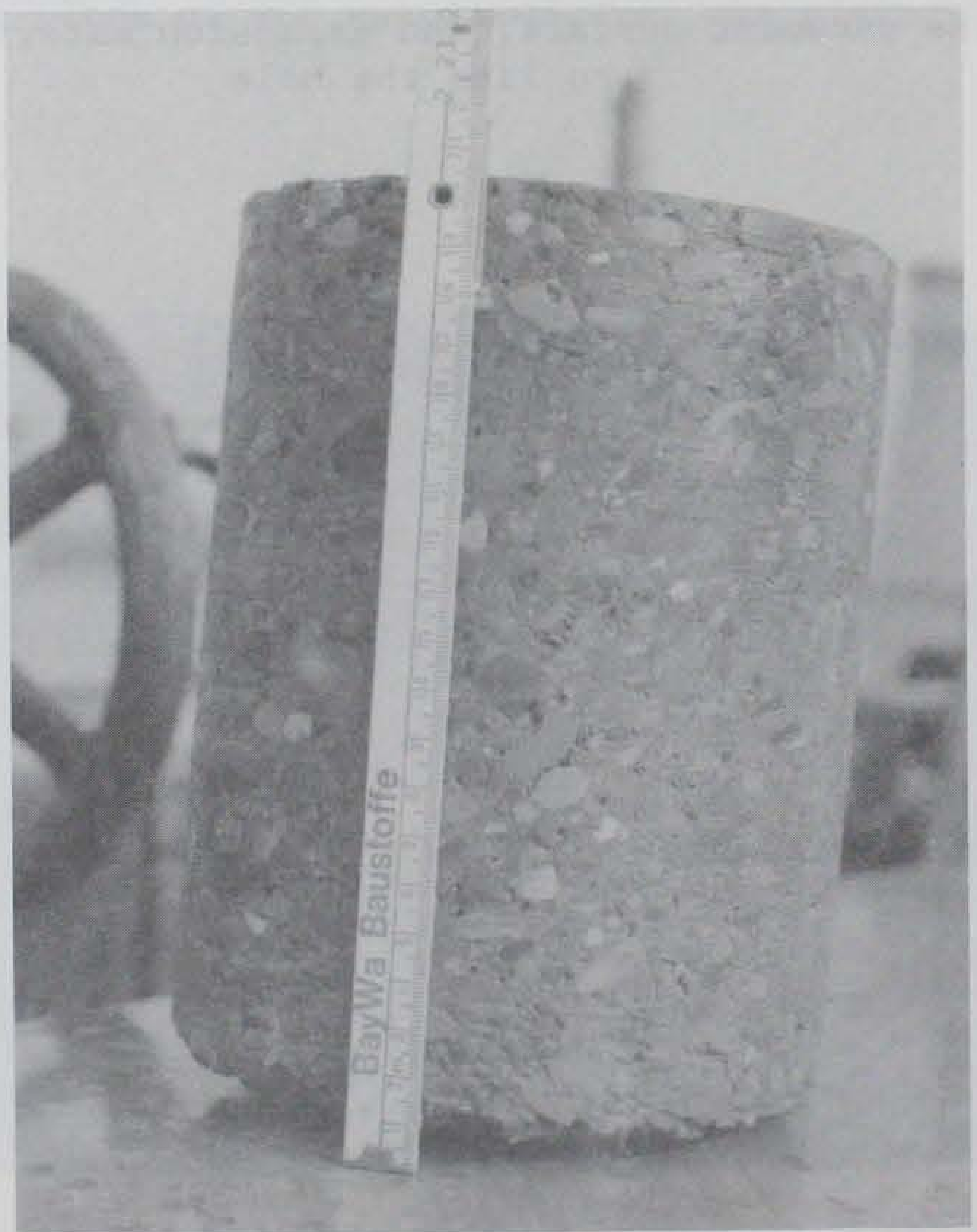



Photo 54. A closeup view of the core shows that good density was achieved throughout the thickness of the lift

Photo 55. Low spots were filled with loose RCC and compacted with the roller...

Photo 56. ...but these patches tended to ravel away with time, due to insufficient bonding

Photo 57. When the RCC was too wet for rolling, roller marks and even footprints were difficult to remove from the surface

Photo 58. This raveling was caused by the roller drum picking up aggregate and fines from a too-dry surface

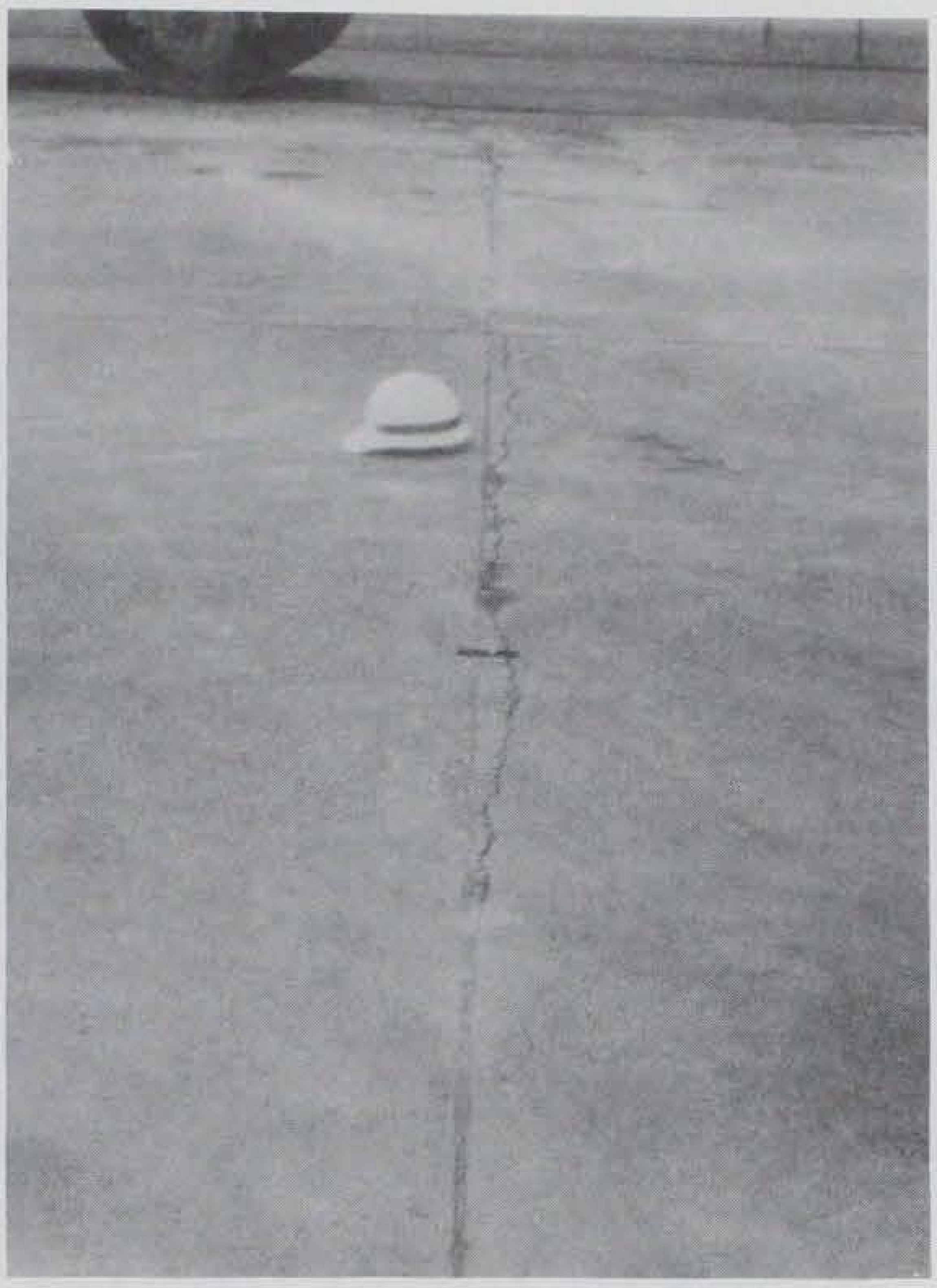


Photo 59. This crack formed ahead of the saw during cutting, indicating that the sawing occurred too late

Photo 60. The 16,500 square yard hardstand was completed in six days

Photo 61. To check the abrasive resistance of the surface a 60-ton tank performed locked-track turns on the test section at 80 days' age

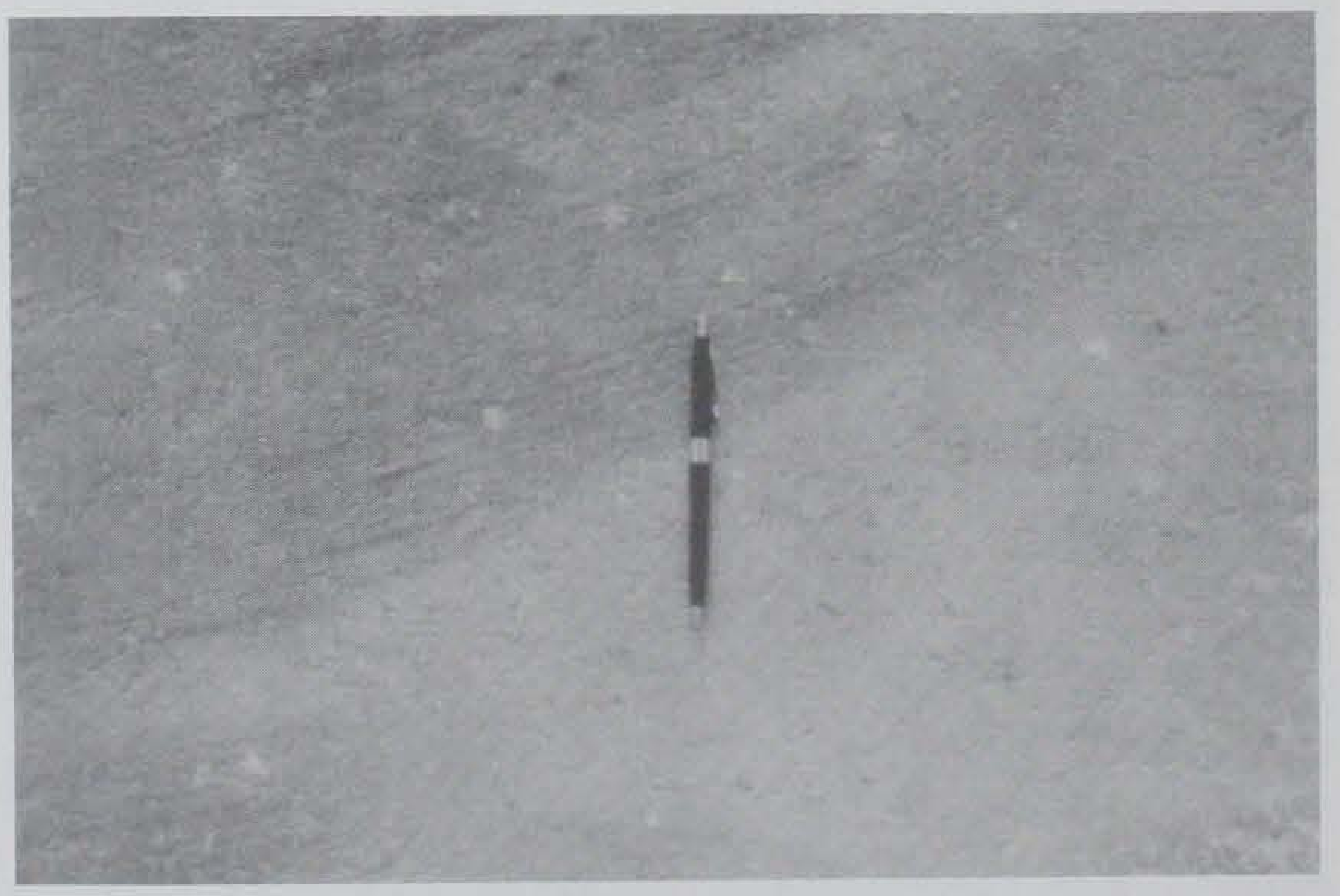


Photo 62. The surface remained intact after the tank turns, with only skid marks left from the rubber pads on the tracks

Photo 63. Tight cracks formed at the longitudinal joints when more than one hour elapsed between placement of adjacent lanes

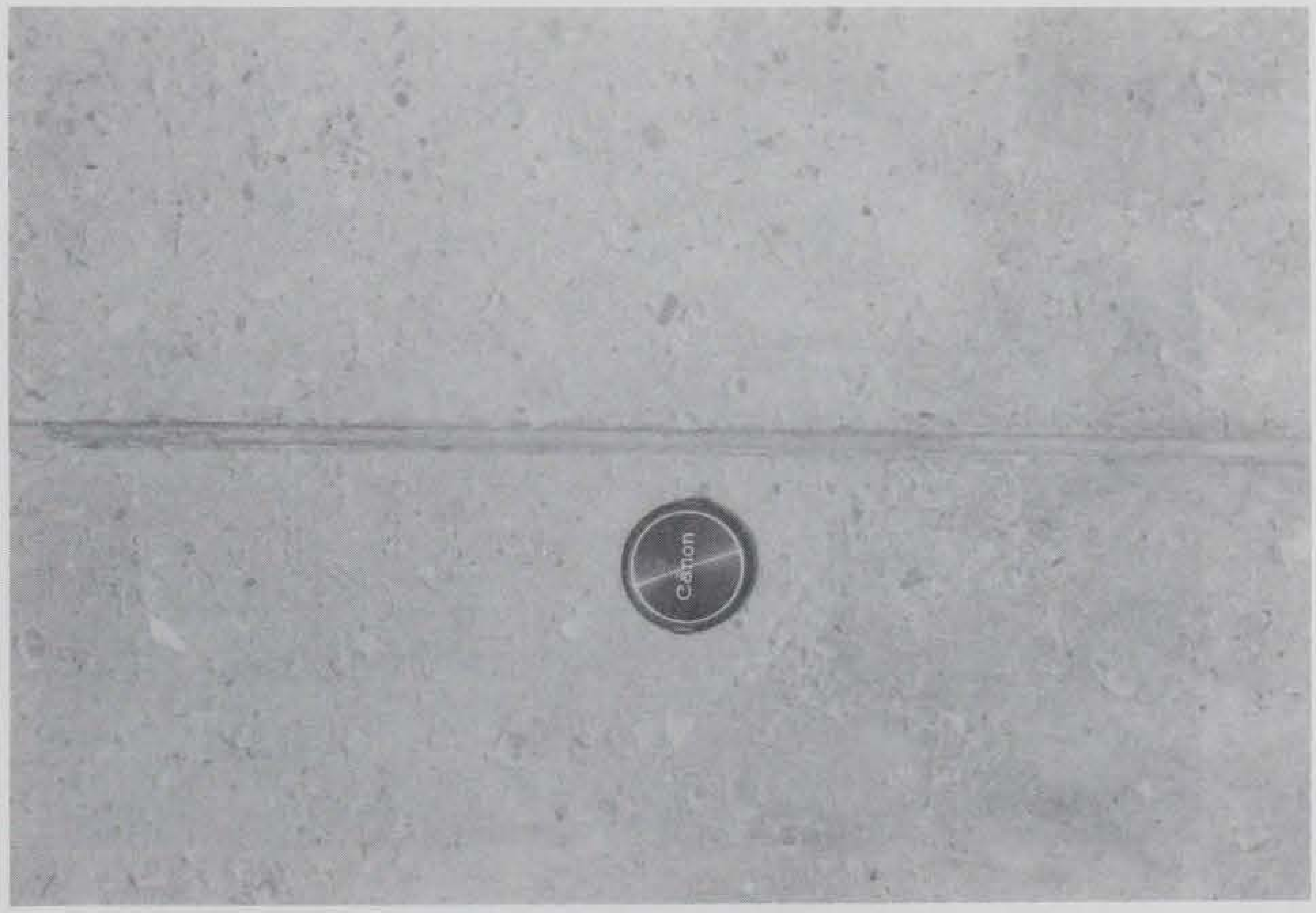


Photo 64. The transverse contraction joints and cold joints were sealed with an asphaltic joint sealer

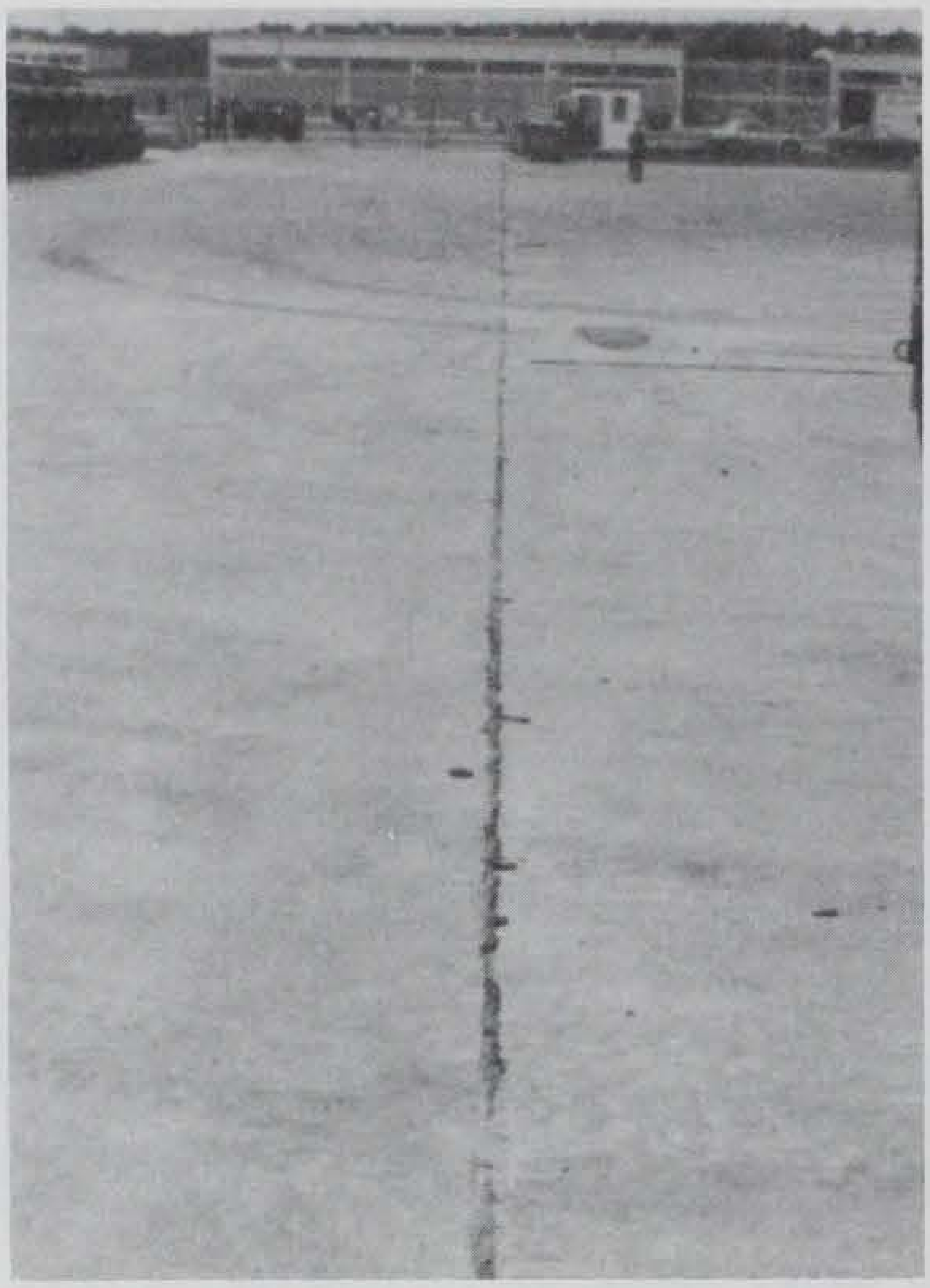


Photo 65. The cold joints were overfilled with joint sealer, causing extrusion of the sealer in hot weather and tearing of the sealer under tank traffic

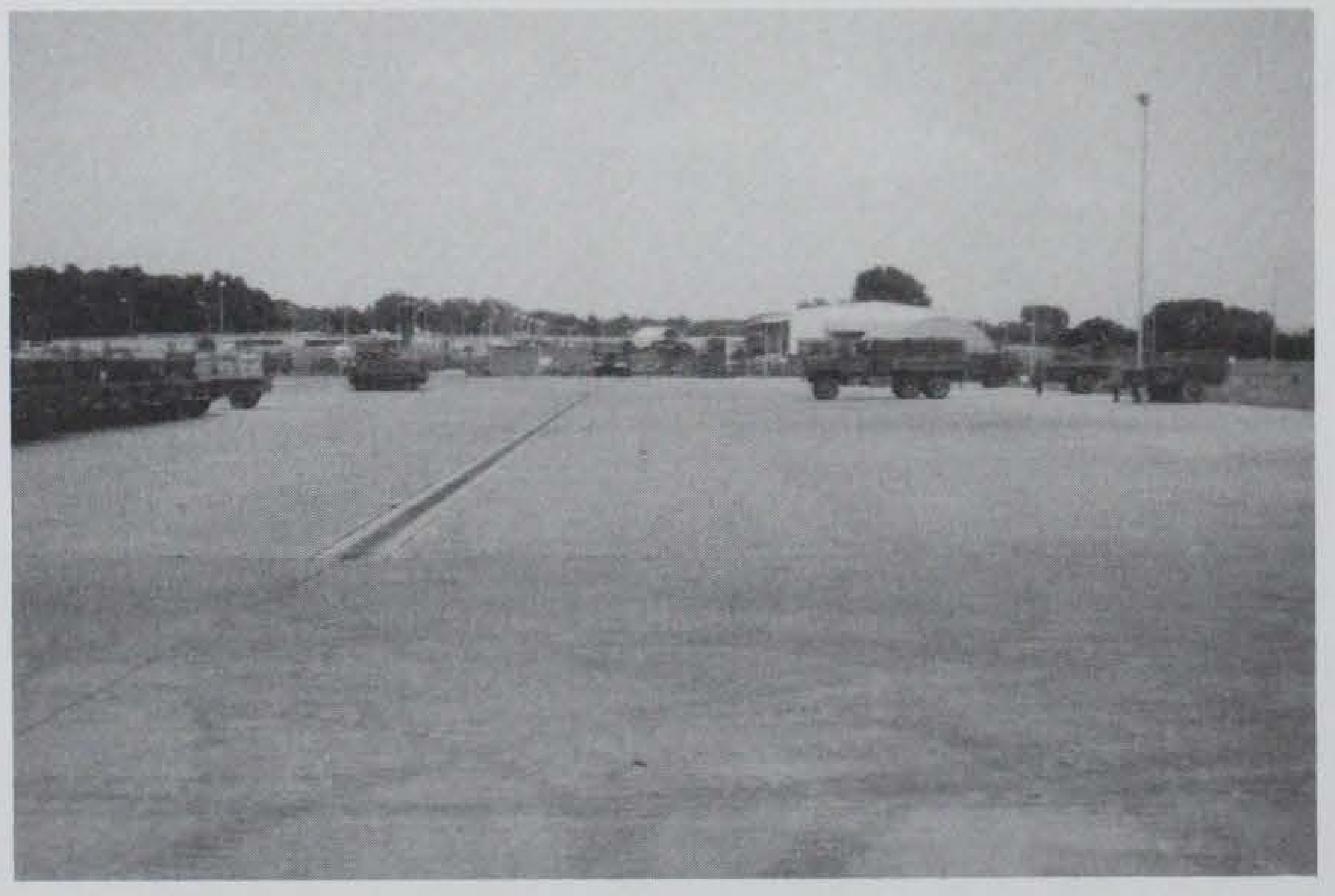


Photo 66. The completed RCC hardstand saved about 15 percent of the cost of a conventional concrete hardstand

# APPENDIX B: EXPLANATION OF STATISTICAL TERMS

The following is an explanation of statistical terms used in this thesis, taken from Probability and Statistics for Engineers by Irwin Miller and John E. Freund (second edition). The LOTUS 1-2-3 program was used on an IBM PC XT in the calculation of statistical parameters for this thesis.

Mean. The mean of a sample or set of n measurements or observation, $x_1$ , $x_2$ , . . . ., $x_n$ , is defined by the formula

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

The term "average" is often used interchangeably with the term "mean," and for purposes of this thesis, will represent the same parameter.

Standard Deviation. The standard deviation of n observations $x_1$ , $x_2$ , . . . ., $x_n$ , is the square root of the variance, namely

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1}}$$

Coefficient of Variation. The coefficient of variation describes the standard deviation as a percentage of the mean, namely

$$CV = \frac{s}{\bar{x}} \times 100$$

<u>Linear Regression</u>. Linear regression is a method of determining the "best fit" line through a set of data pairs (x,y) by yielding an equation of the form

$$y = a + bx$$

where a is the intercept of the line at the ordinate (y axis) and b is the slope of the line. By using the criterion of least squares, in which the sum of the squares of the errors (i.e. difference between the actual y and the calculated y for a given x) is minimized, a and b can be determined by solving the set of equations

$$\sum_{i=1}^{n} y_i = a \times n + b \times \sum_{i=1}^{n} x_i$$

$$\sum_{i=1}^{n} x_i \times y_i = a \times \sum_{i=1}^{n} x_i + b \times \sum_{i=1}^{n} x_i^2$$

where n is the number of observations of (x,y). The term "correlation" may be interpreted in this thesis to mean the linear regression.

# APPENDIX C: CALCULATION OF DENSITY WITH INCREMENTAL DEPTH USING NUCLEAR DENSITY GAUGE READINGS

Let $n_2$ , $n_4$ , and $n_6$ represent the nuclear density gauge readings at 2, 4, and 6 inch depths, respectively. Assume that the $n_2$ reading represents the average density of the 0 and 2 inch increment, the $n_4$ reading represents the average density from 0 to 4 inches, and the $n_6$ reading represents the average density from 0 to 6 inches. Let $N_{0-2}$ , $N_{2-4}$ , and $N_{4-6}$ represent the density of the RCC at the 0 to 2 inch, 2 to 4 inch, and 4 to 6 inch increments, respectively. Then:

<u>0 to 2 inch incremental density ($N_{0-2}$)</u>

$$n_2 = N_{0-2}; \therefore N_{0-2} = n_2$$

<u>2 to 4 inch incremental density ($N_{2-4}$)</u>

$$n_4 = \frac{N_{0-2} + N_{2-4}}{2} ;$$

$$N_{2-4} = 2n_4 - N_{0-2} = 2n_4 - n_2$$

<u>4 to 6 inch incremental density ($N_{4-6}$)</u>

$$n_6 = \frac{N_{0-2} + N_{2-4} + N_{4-6}}{3}$$

$$\begin{aligned} N_{4-6} &= 3n_6 - N_{0-2} - N_{2-4} \\ &= 3n_6 - (n_2) - (2n_4 - n_2) \\ &= 3n_6 - 2n_4 \end{aligned}$$

Example:

Let $n_2$ = 148 pounds per cubic foot

$n_4$ = 146 pounds per cubic foot

$n_6$ = 144 pounds per cubic foot

Then: $N_{0-2}$ = <u>148 pounds per cubic foot</u>

$N_{2-4}$ = 2(146) - 148 = <u>144 pounds per cubic foot</u>

$N_{4-6}$ = 3(144) - 2(146) = <u>140 pounds per cubic foot</u>

# APPENDIX D: DATA

TABLE D-1. CORE, CYLINDER, AND BEAM STRENGTH AND DENSITY RESULTS: TEST SECTION

| Sample Number | Type Specimen | Mix Number | Age (days) | Density (lb/cu ft) | Strength (lb/sq in.) |
|---|---|---|---|---|---|
| 1A | Core | 1 | 7 | 150.4 | 299 |
| 1B | Core | 1 | 7 | 148.1 | 177 |
| 3A | Core | 1 | 7 | 152.1 | 471 |
| 3B | Core | 1 | 7 | 144.5 | 347 |
| 5A | Core | 1 | 7 | 153.4 | 429 |
| 5B | Core | 1 | 7 | 146.8 | 302 |
| 7A | Core | 2 | 7 | 147.5 | 408 |
| 7B | Core | 2 | 7 | 151.0 | 206 |
| 9A | Core | 2 | 7 | 154.2 | 493 |
| 9B | Core | 2 | 7 | 148.2 | 351 |
| 14A | Core | 2 | 7 | 151.0 | 348 |
| 14B | Core | 2 | 7 | 147.3 | 296 |
| 1T16C1 | Cylinder | 1 | 7 | 148.0 | 345 |
| 1T16C2 | Cylinder | 1 | 7 | 145.3 | 408 |
| 1T6C1 | Cylinder | 1 | 7 | 141.4 | 283 |
| 1T6C2 | Cylinder | 1 | 7 | 141.3 | 187 |
| 2T16C1 | Cylinder | 2 | 7 | 139.5 | 316 |
| 2T16C2 | Cylinder | 2 | 7 | 145.1 | 373 |
| 2T6C1 | Cylinder | 2 | 7 | 146.3 | 448 |
| 2T6C2 | Cylinder | 2 | 7 | 139.2 | 283 |
| 2A | Core | 1 | 28 | 149.1 | 522 |
| 2B | Core | 1 | 28 | 149.6 | 290 |
| 4A | Core | 1 | 28 | 149.0 | 276 |
| 4B | Core | 1 | 28 | 150.0 | 334 |
| 6A | Core | 1 | 28 | 154.0 | 493 |
| 6B | Core | 1 | 28 | 148.1 | 493 |
| 8A | Core | 2 | 28 | 153.5 | 319 |
| 8B | Core | 2 | 28 | 149.7 | 319 |
| 10A | Core | 2 | 28 | 151.1 | 479 |
| 10B | Core | 2 | 28 | 149.0 | 421 |
| 11A | Core | 2 | 28 | 148.1 | 334 |
| 11B | Core | 2 | 28 | 149.5 | 580 |
| 1T6C3 | Cylinder | 1 | 28 | 141.8 | 305 |
| 1T6C4 | Cylinder | 1 | 28 | 139.9 | 247 |
| 1T16C3 | Cylinder | 1 | 28 | 150.1 | 580 |
| 1T16C4 | Cylinder | 1 | 28 | 147.0 | 566 |
| 2T6C3 | Cylinder | 2 | 28 | 146.3 | 435 |
| 2T6C4 | Cylinder | 2 | 28 | 145.6 | 421 |
| 2T16C3 | Cylinder | 2 | 28 | 145.7 | 406 |
| 2T16C4 | Cylinder | 2 | 28 | 142.7 | 406 |

(Continued)

TABLE D-1. (Concluded)

| Sample Number | Type Specimen | Mix Number | Age (days) | Density (lb/cu ft) | Strength (lb/sq in.) |
|---|---|---|---|---|---|
| SB1 | Beam | 1 | 28 | -- | 711 |
| SB2 | Beam | 1 | 28 | -- | 812 |
| SB3 | Beam | 1 | 28 | -- | 827 |
| SB4 | Beam | 2 | 28 | -- | 928 |
| SB5 | Beam | 2 | 28 | -- | 972 |
| SB6 | Beam | 2 | 28 | -- | 899 |
| 1T16B1 | Fab Beam | 1 | 28 | -- | 1,088 |
| 1T16B2 | Fab Beam | 1 | 28 | -- | 1,117 |
| 1T6B1 | Fab Beam | 1 | 28 | -- | 1,015 |
| 1T6B2 | Fab Beam | 1 | 28 | -- | 1,204 |
| 2T6B1 | Fab Beam | 2 | 28 | -- | 1,175 |
| 2T6B2 | Fab Beam | 2 | 28 | -- | 1,204 |
| 2T16B1 | Fab Beam | 2 | 28 | -- | 1,044 |
| 2T16B2 | Fab Beam | 2 | 28 | -- | 1,102 |

TABLE D-2. SETTING OF ROLLER PATTERN: TEST SECTION

| Station (m) | Distance from Left Edge (m) | Depth of Reading (in.) | Wet Density (lb/cu ft) | Moisture Content (percent) | Total Number of Passes |
|---|---|---|---|---|---|
| 0+22 | 1 | 6 | 135.4 | 5.2 | 0 |
| 0+22 | 2.5 | 6 | 134.2 | 5.3 | 0 |
| 0+22 | 3.8 | 6 | 129.1 | 5.5 | 0 |
| 0+22 | 1 | 6 | 138.9 | 5.4 | 1 static, 1 vibratory |
| 0+22 | 2.5 | 6 | 137.5 | 5.6 | 1 static, 1 vibratory |
| 0+22 | 3.8 | 6 | 135.5 | 5.0 | 1 static, 1 vibratory |
| 0+22 | 1 | 6 | 141.2 | 5.5 | 1 static, 3 vibratory |
| 0+22 | 2.5 | 6 | 141.9 | 5.7 | 1 static, 3 vibratory |
| 0+22 | 3.8 | 6 | 139.1 | 5.1 | 1 static, 3 vibratory |
| 0+22 | 1 | 6 | 143.4 | 5.3 | 1 static, 5 vibratory |
| 0+22 | 2.5 | 6 | 143.9 | 5.6 | 1 static, 5 vibratory |
| 0+22 | 3.8 | 6 | 141.2 | 5.2 | 1 static, 5 vibratory |
| 0+22 | 1 | 6 | 145.7 | 5.7 | 1 static, 7 vibratory |
| 0+22 | 2.5 | 6 | 143.6 | 5.7 | 1 static, 7 vibratory |
| 0+22 | 3.8 | 6 | 141.7 | 5.7 | 1 static, 7 vibratory |
| 0+22 | 1 | 6 | 146.7 | 5.2 | 1 static, 9 vibratory |
| 0+22 | 2.5 | 6 | 145.2 | 5.4 | 1 static, 9 vibratory |
| 0+22 | 3.8 | 6 | 142.5 | 5.1 | 1 static, 9 vibratory |

TABLE D-3. NUCLEAR DENSITY GAUGE READINGS: TEST SECTION

| Lane Number | Test Number | 2 in. Reading (lb/cu ft) | Moisture Content (percent) | 4 in. Reading (lb/cu ft) | Moisture Content (percent) | 6 in. Reading (lb/cu ft) | Moisture Content (percent) |
|---|---|---|---|---|---|---|---|
| | | | | Day One | | | |
| 1 | M-1 | 145.4 | 5.9 | 146.9 | 5.7 | 147.3 | 5.6 |
| 1 | M-2 | 143.7 | 5.8 | 145.5 | 5.3 | 144.7 | 5.6 |
| 1 | M-3 | 146.2 | 5.7 | 146.2 | 5.8 | 144.1 | 5.7 |
| 2 | M-4 | 145.9 | 5.8 | 145.7 | 6.2 | 146.5 | 5.8 |
| 2 | M-5 | 144.1 | 6.1 | 144.2 | 6.2 | 145.2 | 6.1 |
| 2 | M-6 | 144.1 | 6.1 | 144.5 | 6.5 | 145.3 | 5.9 |
| 2 | J-2 | 147.1 | 6.0 | 147.8 | 6.1 | 147.4 | 6.4 |
| 2 | J-4 | 148.3 | 6.2 | 147.3 | 6.3 | 146.3 | 6.3 |
| 2 | J-5 | 146.3 | 6.6 | 146.0 | 6.2 | 145.6 | 5.9 |
| Average | | 145.68 | 6.02 | 146.01 | 6.03 | 145.82 | 5.92 |
| No. of Tests | | 9 | 9 | 9 | 9 | 9 | 9 |
| Std. Dev. | | 1.52 | 0.27 | 1.20 | 0.37 | 1.13 | 0.29 |
| 1 | J-1 | 142.6 | 6.4 | 141.3 | 6.5 | 138.9 | 6.3 |
| 1 | J-3 | 139.0 | 6.3 | 137.5 | 6.4 | 137.0 | 6.4 |
| 2 | J-7 | 136.1 | 5.6 | 136.2 | 5.6 | 134.9 | 5.5 |
| 2 | J-9 | 135.7 | 5.4 | 137.2 | 5.7 | 135.5 | 5.7 |

(Continued)

(Sheet 1 of 3)

TABLE D-3. (Continued)

| Lane Number | Test Number | 2 in. Reading (lb/cu ft) | Moisture Content (percent) | 4 in. Reading (lb/cu ft) | Moisture Content (percent) | 6 in. Reading (lb/cu ft) | Moisture Content (percent) |
|---|---|---|---|---|---|---|---|
| | | | | Day Two | | | |
| Average | | 138.35 | 5.93 | 138.05 | 6.05 | 136.58 | 5.98 |
| No. of Tests | | 4 | 4 | 4 | 4 | 4 | 4 |
| Std. Dev. | | 3.19 | 0.50 | 2.24 | 0.47 | 1.78 | 0.44 |
| End | | | | | | | |
| LN 2 | M-7 | 145.8 | 5.4 | 146.5 | 5.7 | 147.3 | 5.6 |
| 1 | M-8 | 144.6 | 5.7 | 145.5 | 5.8 | 144.3 | 6.4 |
| 1 | M-9 | 148.8 | 6.3 | 148.6 | 6.2 | 148.1 | 6.5 |
| 2 | J-6 | 148.4 | 5.8 | 149.3 | 5.8 | 148.3 | 6.2 |
| 1 | M-10 | 148.1 | 6.2 | 148.7 | 6.7 | 149.0 | 7.1 |
| 2 | M-11 | 147.4 | 5.7 | 146.9 | 6.0 | 146.9 | 5.9 |
| 2 | M-12 | 146.1 | 5.8 | 146.7 | 5.8 | 145.6 | 6.0 |
| 2 | M-13 | 149.8 | 6.5 | 150.1 | 6.1 | 149.2 | 6.1 |
| 2 | M-14 | 146.9 | 6.7 | 147.0 | 6.1 | 146.9 | 6.2 |
| 2 | M-15 | 144.9 | 5.8 | 144.3 | 5.8 | 144.1 | 5.5 |
| 1 | J-8 | 147.2 | 5.9 | 147.1 | 6.2 | 145.6 | 6.0 |
| 1 | J-10 | 147.3 | 6.3 | 148.0 | 6.2 | 148.2 | 6.6 |
| 1 | J-12 | 145.0 | 6.5 | 144.9 | 6.1 | 143.6 | 6.0 |
| 2 | J-138 | 148.4 | 6.1 | 148.2 | 5.8 | 147.5 | 6.2 |
| 2 | J-14 | 149.5 | 6.4 | 150.1 | 6.3 | 150.3 | 6.2 |

(Continued)

(Sheet 2 of 3)

TABLE D-3. (Concluded)

| Lane Number | Test Number | 2 in. Reading (lb/cu ft) | Moisture Content (percent) | 4 in. Reading (lb/cu ft) | Moisture Content (percent) | 6 in. Reading (lb/cu ft) | Moisture Content (percent) |
|---|---|---|---|---|---|---|---|
| | | | Day Two (Continued) | | | | |
| Average | | 147.21 | 6.07 | 147.46 | 6.04 | 146.99 | 6.17 |
| No. of Tests | | 15 | 15 | 15 | 15 | 15 | 15 |
| Std. Dev. | | 1.66 | 0.38 | 1.76 | 0.27 | 1.99 | 0.39 |
| End | | | | | | | |
| LN 2 | J-11 | 142.8 | 5.7 | 141.3 | 4.9 | 138.8 | 5.5 |
| 1 | J-13A | 142.2 | 5.8 | 144.0 | 5.9 | 141.9 | 6.0 |
| Average | | 142.50 | 5.75 | 142.65 | 5.40 | 140.35 | 5.75 |
| No. of Tests | | 2 | 2 | 2 | 2 | 2 | 2 |
| Std. Dev. | | 0.42 | 0.07 | 1.91 | 0.71 | 2.19 | 0.35 |

(Sheet 3 of 3)

TABLE D-4. NUCLEAR DENSITY GAUGE READINGS: HARDSTAND DAY 1

| Lane Number | Lane Interval | 2-in. Reading Density (lb/cu ft) | 2-in. Reading Moisture (percent) | 4-in. Reading Density (lb/cu ft) | 4-in. Reading Content (percent) | 6-in. Reading Reading (lb/cu ft) | 6-in. Reading Content (percent) |
|---|---|---|---|---|---|---|---|
| 1 | 4 | | | 150.1 | 6.5 | 150.3 | 6.5 |
| 1 | 1 | 147.8 | 5.5 | 145.5 | 6.2 | 143.8 | 6.3 |
| 1 | 10 | 146.3 | 6.2 | 144.8 | 6.4 | 143.1 | 5.9 |
| 1 | 7 | 152.3 | 6.0 | 150.1 | 6.0 | 147.6 | 5.1 |
| 1 | 10 | 144.6 | 5.9 | 143.0 | 5.5 | 141.0 | 5.3 |
| 1 | 1 | 148.9 | 4.6 | 146.6 | 5.1 | 143.8 | 5.3 |
| 1 | 1 | 150.2 | 5.7 | 148.6 | 5.1 | 147.8 | 6.2 |
| 1 | 6 | 149.8 | 5.4 | 148.2 | 5.5 | 147.0 | 6.6 |
| 2 | 7 | 152.1 | 5.3 | 149.3 | 5.7 | 147.3 | 6.2 |
| 2 | 11 | 135.3 | 5.2 | 134.4 | 5.2 | 134.4 | 5.2 |
| 2 | 0 | 152.6 | 5.6 | 152.0 | 5.9 | 148.3 | 5.4 |
| 2 | 6 | 152.0 | 5.9 | 150.8 | 6.0 | 149.8 | 6.2 |
| 2 | 8 | 151.4 | 6.1 | 150.3 | 6.2 | 149.8 | 6.0 |
| 2 | 0 | 153.5 | 5.9 | 152.0 | 5.0 | 149.1 | 5.4 |
| 3 | 2 | 151.9 | 6.4 | 155.3 | 5.8 | 150.3 | 5.7 |
| 3 | 10 | 143.9 | 6.4 | 141.6 | 5.8 | 138.5 | 6.1 |
| 3 | 0 | 151.1 | 5.6 | 151.1 | 6.0 | 147.2 | 5.8 |
| 3 | 10 | 150.2 | 6.1 | 148.2 | 6.3 | 148.5 | 5.5 |
| 3 | 11 | 144.9 | 5.5 | 142.7 | 5.8 | 140.5 | 5.5 |
| 3 | 0 | 149.6 | 5.8 | 148.8 | 5.7 | 142.2 | 6.0 |
| 3 | 3 | 150.4 | 5.5 | 150.0 | 5.8 | 148.8 | 6.2 |
| 3 | 0 | 152.5 | 6.2 | 149.4 | 5.8 | 146.8 | 5.3 |
| 3 | 11 | 146.0 | 6.5 | 144.5 | 6.0 | 142.7 | 6.1 |
| 4 | 9 | 147.7 | 5.7 | 148.3 | 5.6 | 148.7 | 6.0 |

(Continued)

TABLE D-4. (Concluded)

| Lane Number | Lane Interval | 2-in. Reading Density (lb/cu ft) | 2-in. Reading Moisture (percent) | 4-in. Reading Density (lb/cu ft) | 4-in. Reading Content (percent) | 6-in. Reading Reading (lb/cu ft) | 6-in. Reading Content (percent) |
|---|---|---|---|---|---|---|---|
| 4 | 0 | 149.0 | 6.5 | 147.6 | 5.2 | 145.5 | 5.6 |
| 4 | 5 | 150.5 | 5.8 | 148.9 | 6.3 | 148.6 | 6.3 |
| 4 | 0 | 149.6 | 5.8 | 148.1 | 6.1 | 144.8 | 5.6 |
| 4 | 9 | 150.5 | 6.2 | 149.1 | 6.2 | 147.7 | 5.4 |
| 4 | 0 | 150.6 | 5.3 | 148.9 | 5.3 | 146.4 | 6.0 |
| 5 | 6 | 152.4 | 5.9 | 151.5 | 6.1 | 148.5 | 5.3 |
| 5 | 0 | 145.8 | 4.9 | 147.5 | 6.2 | 146.3 | 5.1 |
| 5 | 2 | 150.6 | 5.8 | 149.0 | 6.3 | 148.6 | 6.2 |
| 5 | 11 | 146.7 | 5.1 | 146.8 | 5.9 | 145.8 | 5.7 |
| 5 | 5 | 150.8 | 5.9 | 150.2 | 6.6 | 150.0 | 6.0 |
| 5 | 11 | 148.3 | 6.3 | 147.3 | 5.6 | 146.9 | 5.6 |

TABLE D-5. NUCLEAR DENSITY GAUGE READINGS: HARDSTAND DAY 2

| Lane Number | Lane Interval | 2-in. Reading Density (lb/cu ft) | 2-in. Reading Moisture (percent) | 4-in. Reading Density (lb/cu ft) | 4-in. Reading Content (percent) | 6-in. Reading Reading (lb/cu ft) | 6-in. Reading Content (percent) |
|---|---|---|---|---|---|---|---|
| 1 | 8 | 149.4 | 6.5 | 148.8 | 7.1 | 147.6 | 5.6 |
| 1 | 0 | 151.6 | 6.3 | 150.4 | 6.1 | 150.6 | 5.8 |
| 1 | 11 | 147.8 | 6.1 | 144.3 | 6.1 | 141.9 | 5.8 |
| 1 | 10 | 149.5 | 6.5 | 147.9 | 6.5 | 147.0 | 6.2 |
| 1 | 0 | 150.1 | 5.5 | 147.9 | 6.1 | 146.8 | 6.3 |
| 1 | 1 | 147.0 | 5.9 | 146.2 | 6.0 | 147.0 | 5.9 |
| 1 | 0 | 149.6 | 5.2 | 147.0 | 6.5 | 147.0 | 5.5 |
| 1 | 11 | 144.8 | 5.8 | 143.5 | 5.9 | 142.2 | 6.0 |
| 1 | 7 | 148.6 | 5.9 | 143.9 | 5.6 | 141.5 | 6.1 |
| 1 | 0 | 144.9 | 4.9 | 142.5 | 5.4 | 140.2 | 5.3 |
| 1 | 11 | 137.3 | 4.8 | 134.9 | 5.2 | 134.0 | 5.7 |
| 1 | 4 | 146.8 | 4.7 | 145.0 | 6.7 | 143.3 | 5.3 |
| 1 | 0 | 145.0 | 5.8 | 143.1 | 5.4 | 141.8 | 6.0 |
| 2 | 5 | 144.2 | 5.9 | 143.7 | 5.5 | 142.5 | 5.7 |
| 2 | 0 | 147.3 | 5.5 | 148.3 | 5.5 | 145.1 | 5.6 |
| 2 | 9 | 147.6 | 5.5 | 146.0 | 5.0 | 144.5 | 5.2 |
| 2 | 0 | 145.8 | 5.6 | 144.5 | 5.2 | 142.3 | 5.8 |
| 2 | 11 | 136.3 | 5.2 | 135.7 | 5.0 | 135.6 | 5.2 |
| 2 | 2 | 145.6 | 5.8 | 144.5 | 5.2 | 141.8 | 5.7 |
| 2 | 0 | 147.8 | 4.9 | 145.8 | 4.8 | 144.0 | 5.1 |
| 2 | 11 | 143.1 | 5.4 | 141.8 | 4.9 | 141.9 | 5.5 |
| 2 | 4 | 145.8 | 6.1 | 144.1 | 5.1 | 141.7 | 5.1 |

(Continued)

(Sheet 1 of 3)

TABLE D-5. (Continued)

| Lane Number | Lane Interval | 2-in. Reading Density (lb/cu ft) | 2-in. Reading Moisture (percent) | 4-in. Reading Density (lb/cu ft) | 4-in. Reading Content (percent) | 6-in. Reading Reading (lb/cu ft) | 6-in. Reading Content (percent) |
|---|---|---|---|---|---|---|---|
| 2 | 0 | 151.3 | 5.0 | 150.0 | 5.1 | 145.0 | 6.3 |
| 2 | 11 | 143.2 | 5.0 | 141.3 | 5.6 | 139.0 | 5.1 |
| 3 | 1 | 146.1 | 5.6 | 145.1 | 5.7 | 142.7 | 5.8 |
| 3 | 7 | 144.5 | 5.5 | 142.8 | 5.2 | 141.8 | 5.4 |
| 3 | 0 | 147.2 | 5.0 | 145.0 | 5.8 | 143.0 | 5.0 |
| 3 | 11 | 138.7 | 4.8 | 136.8 | 5.4 | 135.1 | 4.9 |
| 3 | 10 | 147.3 | 5.1 | 145.6 | 6.3 | 144.3 | 5.9 |
| 3 | 0 | 149.5 | 5.5 | 149.3 | 5.8 | 144.4 | 6.0 |
| 3 | 11 | 142.2 | 5.2 | 141.6 | 5.5 | 138.5 | 5.6 |
| 3 | 6 | 145.2 | 5.8 | 143.6 | 5.6 | 142.2 | 6.0 |
| 3 | 0 | 146.8 | 5.3 | 146.0 | 5.4 | 143.0 | 6.0 |
| 3 | 11 | 144.1 | 5.3 | 143.3 | 4.9 | 141.8 | 5.9 |
| 4 | 8 | 143.4 | 5.2 | 144.8 | 5.7 | 142.3 | 5.5 |
| 4 | 11 | 142.5 | 5.0 | 142.1 | 5.5 | 140.3 | 5.4 |
| 4 | 3 | 147.1 | 6.1 | 145.0 | 5.3 | 144.9 | 5.2 |
| 4 | 0 | 146.8 | 5.3 | 144.3 | 5.1 | 139.7 | 5.4 |
| 4 | 2 | 151.5 | 6.6 | 150.0 | 6.8 | 149.5 | 6.7 |
| 4 | 0 | 151.2 | 6.7 | 151.6 | 6.6 | 148.5 | 6.3 |
| 4 | 11 | 142.7 | 5.7 | 140.7 | 5.8 | 139.1 | 6.1 |
| 4 | 8 | 149.4 | 5.8 | 148.9 | 6.6 | 147.2 | 6.9 |
| 4 | 0 | 151.0 | 6.3 | 149.1 | 6.5 | 147.6 | 6.6 |
| 4 | 11 | 148.8 | 6.0 | 147.6 | 5.7 | 146.4 | 6.4 |
| 4 | 11 | 146.5 | 6.3 | 144.1 | 6.1 | 143.7 | 5.8 |

(Continued)

(Sheet 2 of 3)

TABLE D-5. (Concluded)

| | | 2-in. Reading | | 4-in. Reading | | 6-in. Reading | |
|---|---|---|---|---|---|---|---|
| Lane Number | Lane Interval | Density (lb/cu ft) | Moisture (percent) | Density (lb/cu ft) | Content (percent) | Reading (lb/cu ft) | Content (percent) |
| 5 | 2 | 151.3 | 6.1 | 149.9 | 6.2 | 149.5 | 6.1 |
| 5 | 0 | 148.7 | 5.8 | 146.6 | 6.2 | 145.0 | 6.0 |
| 5 | 4 | 150.0 | 5.4 | 149.1 | 5.5 | 148.6 | 5.9 |
| 5 | 0 | 150.7 | 5.8 | 147.8 | 5.8 | 144.0 | 5.8 |
| 5 | 1 | 153.0 | 6.2 | 151.1 | 6.7 | 148.7 | 6.2 |
| 5 | 0 | 148.0 | 6.7 | 145.3 | 5.5 | 143.2 | 6.5 |
| 5 | 4 | 151.7 | 6.4 | 149.6 | 5.5 | 149.8 | 6.4 |
| 5 | 0 | 149.2 | 6.3 | 147.3 | 5.7 | 144.4 | 6.2 |

(Sheet 3 of 3)

TABLE D-6. NUCLEAR DENSITY GAUGE READINGS: HARDSTAND DAY 3

| | | 2-in. Reading | | 4-in. Reading | | 6-in. Reading | |
|---|---|---|---|---|---|---|---|
| Lane Number | Lane Interval | Density (lb/cu ft) | Moisture (percent) | Density (lb/cu ft) | Content (percent) | Reading (lb/cu ft) | Content (percent) |
| 1 | 7 | 147.8 | 5.0 | 147.0 | 5.0 | 144.4 | 5.2 |
| 1 | 0 | 151.3 | 5.0 | 150.1 | 5.0 | 148.1 | 5.1 |
| 1 | 11 | 143.0 | 4.4 | 140.8 | 4.5 | 139.0 | 3.9 |
| 1 | 3 | 151.6 | 4.7 | 149.9 | 5.6 | 146.5 | 5.1 |
| 1 | 0 | 151.0 | 5.5 | 147.7 | 5.3 | 148.3 | 5.4 |
| 1 | 11 | 145.0 | 4.7 | 142.8 | 5.1 | 142.0 | 4.8 |
| 1 | 5 | 149.5 | 5.3 | 148.0 | 5.5 | 146.6 | 6.0 |
| 1 | 0 | 152.5 | 5.3 | 150.3 | 4.8 | 149.5 | 5.2 |
| 1 | 11 | 142.7 | 4.7 | 142.2 | 5.2 | 140.8 | 5.0 |
| 1 | 10 | 151.6 | 5.6 | 149.1 | 6.4 | 146.9 | 5.8 |
| 1 | 0 | 150.1 | 5.0 | 148.5 | 5.3 | 146.1 | 5.6 |
| 1 | 11 | 147.1 | 5.7 | 147.2 | 4.8 | 144.6 | 5.3 |
| 2 | 4 | 146.6 | 5.3 | 145.0 | 5.5 | 145.1 | 5.7 |
| 2 | 0 | 145.1 | 4.1 | 141.2 | 4.9 | 140.3 | 5.3 |
| 2 | 3 | 151.1 | 5.9 | 149.9 | 5.8 | 148.0 | 5.5 |
| 2 | 0 | 144.9 | 5.0 | 141.3 | 5.8 | 140.5 | 5.7 |
| 2 | 5 | 149.7 | 5.2 | 148.2 | 5.7 | 147.4 | 5.8 |
| 2 | 0 | 148.5 | 4.9 | 147.6 | 6.1 | 146.0 | 5.1 |
| 2 | 1 | 146.5 | 6.1 | 145.3 | 5.4 | 144.0 | 4.8 |
| 2 | 0 | 149.9 | 5.4 | 148.9 | 6.1 | 146.3 | 5.4 |
| 3 | 3 | 150.8 | 5.7 | 149.2 | 5.9 | 147.0 | 6.7 |
| 3 | 0 | 149.0 | 4.2 | 147.5 | 5.5 | 146.6 | 5.2 |

(Continued)

TABLE D-6. (Concluded)

| Lane Number | Lane Interval | 2-in. Reading Density (lb/cu ft) | 2-in. Reading Moisture (percent) | 4-in. Reading Density (lb/cu ft) | 4-in. Reading Content (percent) | 6-in. Reading Reading (lb/cu ft) | 6-in. Reading Content (percent) |
|---|---|---|---|---|---|---|---|
| 3 | 11 | 147.6 | 4.6 | 146.9 | 5.3 | 143.9 | 6.0 |
| 3 | 5 | 148.8 | 5.6 | 147.7 | 5.2 | 145.3 | 5.3 |
| 3 | 0 | 147.4 | 5.2 | 148.1 | 5.0 | 145.8 | 5.5 |
| 3 | 11 | 145.4 | 5.0 | 142.7 | 4.9 | 139.4 | 5.6 |
| 3 | 11 | 149.6 | 5.1 | 146.5 | 5.7 | 143.2 | 5.7 |
| 3 | 7 | 150.0 | 5.6 | 148.2 | 5.8 | 146.5 | 5.8 |
| 3 | 0 | 152.6 | 4.9 | 150.7 | 5.2 | 149.3 | 5.6 |
| 3 | 4 | 150.3 | 5.1 | 150.5 | 5.9 | 149.8 | 5.6 |
| 3 | 0 | 149.0 | 5.2 | 149.6 | 4.9 | 146.7 | 6.0 |
| 3 | 11 | 147.5 | 5.2 | 145.8 | 5.4 | 149.0 | 5.3 |
| 4 | 1 | 146.7 | 5.1 | 145.7 | 6.3 | 145.1 | 6.5 |
| 4 | 0 | 151.5 | 5.7 | 149.4 | 5.8 | 147.5 | 5.8 |
| 4 | 2 | 150.7 | 6.4 | 149.1 | 7.0 | 149.3 | 5.4 |
| 4 | 0 | 150.8 | 5.3 | 149.1 | 6.0 | 148.1 | 6.6 |
| 4 | 10 | 150.0 | 5.7 | 151.4 | 6.0 | 149.1 | 5.4 |
| 4 | 0 | 152.5 | 5.4 | 151.4 | 5.5 | 149.5 | 6.1 |
| 4 | 9 | 151.1 | 5.4 | 149.1 | 5.8 | 146.3 | 5.7 |
| 4 | 0 | 151.0 | 6.1 | 151.4 | 6.0 | 148.3 | 6.3 |

TABLE D-7. NUCLEAR DENSITY GAUGE READINGS: HARDSTAND DAY 4

| Lane Number | Lane Interval | 2-in. Reading Density (lb/cu ft) | 2-in. Reading Moisture (percent) | 4-in. Reading Density (lb/cu ft) | 4-in. Reading Content (percent) | 6-in. Reading Reading (lb/cu ft) | 6-in. Reading Content (percent) |
|---|---|---|---|---|---|---|---|
| 1 | 3 | 151.9 | 5.7 | 150.3 | 6.4 | 149.5 | 5.9 |
| 1 | 0 | 151.9 | 5.5 | 150.3 | 6.4 | 148.2 | 5.3 |
| 1 | 11 | 148.6 | 5.6 | 148.7 | 6.5 | 147.7 | 5.6 |
| 1 | 8 | 150.7 | 5.8 | 149.7 | 6.3 | 149.0 | 6.0 |
| 1 | 0 | 151.6 | 6.3 | 152.4 | 5.5 | 150.5 | 6.1 |
| 1 | 11 | 150.4 | 6.2 | 148.6 | 5.9 | 146.7 | 5.7 |
| 1 | 11 | 152.0 | 5.7 | 150.9 | 6.0 | 149.1 | 5.7 |
| 1 | 11 | 150.3 | 5.9 | 147.6 | 6.5 | 146.5 | 5.2 |
| 2 | 4 | 148.7 | 6.8 | 147.7 | 6.3 | 148.3 | 5.9 |
| 2 | 0 | 152.3 | 6.0 | 151.4 | 6.5 | 148.5 | 5.8 |
| 2 | 11 | 151.6 | 5.6 | 150.5 | 6.9 | 149.8 | 5.7 |
| 2 | 6 | 151.9 | 5.6 | 147.0 | 6.0 | 148.6 | 6.4 |
| 2 | 0 | 152.1 | 5.9 | 149.0 | 6.1 | 147.1 | 6.4 |
| 2 | 2 | 150.5 | 6.1 | 150.2 | 6.2 | 149.1 | 5.7 |
| 2 | 0 | 149.8 | 5.9 | 149.1 | 5.8 | 147.7 | 5.9 |
| 3 | 7 | 151.6 | 6.1 | 151.5 | 5.4 | 150.0 | 6.1 |
| 3 | 0 | 153.0 | 5.9 | 151.4 | 5.6 | 150.5 | 6.3 |
| 3 | 11 | 151.3 | 5.6 | 151.1 | 5.4 | 148.5 | 5.2 |
| 3 | 1 | 151.9 | 6.6 | 150.4 | 5.8 | 149.8 | 6.5 |
| 3 | 0 | 151.6 | 5.3 | 150.9 | 5.8 | 150.1 | 6.3 |
| 3 | 11 | 150.9 | 5.9 | 149.6 | 5.6 | 148.0 | 5.7 |
| 4 | 10 | 148.5 | 6.4 | 147.6 | 5.9 | 148.1 | 6.8 |

(Continued)

(Sheet 1 of 3)

TABLE D-7. (Continued)

| Lane Number | Lane Interval | 2-in. Reading Density (lb/cu ft) | 2-in. Reading Moisture (percent) | 4-in. Reading Density (lb/cu ft) | 4-in. Reading Content (percent) | 6-in. Reading Reading (lb/cu ft) | 6-in. Reading Content (percent) |
|---|---|---|---|---|---|---|---|
| 4 | 0 | 152.6 | 6.0 | 150.2 | 6.6 | 150.7 | 5.7 |
| 4 | 9 | 149.3 | 6.4 | 150.4 | 6.2 | 149.6 | 6.1 |
| 4 | 0 | 152.0 | 5.8 | 151.0 | 6.2 | 148.3 | 5.8 |
| 4 | 11 | 151.3 | 5.4 | 150.8 | 6.4 | 149.5 | 6.4 |
| 4 | 10 | 148.4 | 6.5 | 148.8 | 6.2 | 147.3 | 5.4 |
| 4 | 0 | 152.7 | 6.0 | 150.3 | 5.5 | 147.2 | 6.3 |
| 4 | 11 | 150.8 | 5.7 | 149.6 | 5.2 | 149.5 | 5.8 |
| 5 | 5 | 151.7 | 6.7 | 149.7 | 6.4 | 148.4 | 4.9 |
| 5 | 0 | 152.8 | 6.6 | 150.8 | 5.7 | 149.6 | 6.2 |
| 5 | 11 | 149.2 | 5.4 | 148.5 | 5.7 | 148.5 | 6.3 |
| 5 | 7 | 149.6 | 6.2 | 147.0 | 6.1 | 145.8 | 6.0 |
| 5 | 0 | 152.1 | 6.2 | 150.6 | 4.9 | 149.6 | 5.8 |
| 5 | 11 | 150.4 | 5.6 | 149.2 | 5.5 | 147.2 | 5.1 |
| 6 | 5 | 146.8 | 6.2 | 147.2 | 5.4 | 144.7 | 6.4 |
| 6 | 0 | 149.8 | 5.8 | 148.4 | 5.7 | 148.3 | 5.5 |
| 6 | 0 | 149.7 | 5.5 | 148.9 | 6.3 | 148.6 | 5.8 |
| 6 | 0 | 150.8 | 5.5 | 148.6 | 6.6 | 147.3 | 6.0 |
| 7 | 8 | 149.3 | 6.2 | 148.1 | 6.5 | 146.4 | 6.7 |
| 7 | 0 | 151.5 | 6.0 | 150.3 | 5.6 | 148.9 | 6.8 |
| 7 | 11 | 148.0 | 5.8 | 146.1 | 5.7 | 144.8 | 5.8 |
| 7 | 6 | 151.6 | 6.4 | 148.5 | 6.1 | 149.6 | 5.4 |
| 7 | 0 | 153.0 | 5.6 | 150.9 | 6.2 | 149.4 | 6.3 |
| 7 | 11 | 150.5 | 6.6 | 147.6 | 6.2 | 145.5 | 5.7 |

(Continued)

(Sheet 2 of 3)

TABLE D-7. (Concluded)

| Lane Number | Lane Interval | 2-in. Reading Density (lb/cu ft) | 2-in. Reading Moisture (percent) | 4-in. Reading Density (lb/cu ft) | 4-in. Reading Content (percent) | 6-in. Reading Reading (lb/cu ft) | 6-in. Reading Content (percent) |
|---|---|---|---|---|---|---|---|
| 8 | 5 | 150.7 | 6.2 | 149.8 | 5.3 | 149.6 | 6.3 |
| 8 | 0 | 152.9 | 5.1 | 149.0 | 5.0 | 146.7 | 6.1 |
| 8 | 11 | 146.9 | 5.7 | 145.2 | 5.7 | 144.5 | 4.6 |
| 8 | 9 | 149.0 | 5.6 | 147.1 | 6.0 | 146.3 | 6.3 |
| 8 | 0 | 151.1 | 5.8 | 147.5 | 5.3 | 144.1 | 6.1 |
| 8 | 11 | 147.8 | 5.3 | 143.9 | 5.3 | 142.8 | 5.8 |
| 9 | 3 | 147.7 | 5.8 | 145.3 | 5.8 | 145.0 | 5.9 |
| 9 | 0 | 145.7 | 6.3 | 145.7 | 5.9 | 144.0 | 5.8 |
| 9 | 11 | 146.5 | 5.8 | 144.5 | 6.0 | 143.1 | 5.6 |
| 9 | 10 | 147.3 | 6.3 | 145.6 | 6.2 | 143.0 | 6.0 |
| 9 | 0 | 148.8 | 6.6 | 145.8 | 6.8 | 145.1 | 5.7 |
| 9 | 11 | 148.0 | 6.1 | 144.7 | 6.2 | 143.4 | 6.3 |
| 10 | 1 | 146.9 | 5.6 | 146.0 | 5.8 | 145.0 | 6.2 |
| 10 | 0 | 148.1 | 5.9 | 144.8 | 5.4 | 142.0 | 5.5 |
| 10 | 2 | 151.3 | 5.2 | 146.6 | 6.4 | 147.2 | 6.2 |
| 10 | 0 | 149.9 | 6.1 | 145.5 | 7.0 | 143.2 | 6.3 |
| 10 | 0 | 147.4 | 5.7 | 145.8 | 5.9 | 143.8 | 6.2 |

(Sheet 3 of 3)

TABLE D-8. NUCLEAR DENSITY GAUGE READINGS: HARDSTAND DAY 5

| Lane Number | Lane Interval | 2-in. Reading Density (lb/cu ft) | 2-in. Reading Moisture (percent) | 4-in. Reading Density (lb/cu ft) | 4-in. Reading Content (percent) | 6-in. Reading Reading (lb/cu ft) | 6-in. Reading Content (percent) |
|---|---|---|---|---|---|---|---|
| 1 | 5 | 151.0 | 6.3 | 150.4 | 7.2 | 149.5 | 6.5 |
| 1 | 0 | 150.1 | 6.3 | 151.6 | 6.6 | 149.5 | 6.3 |
| 1 | 11 | 151.7 | 6.3 | 150.0 | 6.2 | 148.8 | 6.6 |
| 1 | 9 | 151.5 | 6.2 | 150.8 | 6.6 | 150.5 | 6.0 |
| 1 | 0 | 150.3 | 6.4 | 149.0 | 6.4 | 149.0 | 6.3 |
| 1 | 11 | 152.1 | 5.8 | 150.0 | 5.3 | 150.1 | 5.9 |
| 2 | 2 | 150.8 | 6.4 | 150.1 | 6.4 | 150.5 | 7.0 |
| 2 | 0 | 152.7 | 6.1 | 151.5 | 6.5 | 150.6 | 6.4 |
| 2 | 4 | 150.0 | 7.0 | 150.5 | 6.1 | 151.3 | 5.7 |
| 2 | 0 | 153.1 | 5.9 | 150.4 | 6.2 | 151.5 | 5.6 |
| 2 | 11 | 151.6 | 5.6 | 151.3 | 5.6 | 151.1 | 6.2 |
| 3 | 1 | 152.3 | 5.7 | 150.7 | 6.1 | 150.0 | 6.2 |
| 3 | 0 | 152.3 | 6.0 | 150.6 | 6.0 | 150.8 | 6.7 |
| 3 | 11 | 153.1 | 5.4 | 151.8 | 5.9 | 151.3 | 5.2 |
| 4 | 1 | 154.3 | 6.2 | 152.4 | 5.6 | 152.6 | 6.4 |
| 4 | 0 | 153.8 | 5.8 | 151.8 | 6.3 | 152.0 | 5.5 |
| 4 | 11 | 151.6 | 5.9 | 150.6 | 5.5 | 149.0 | 5.2 |
| 5 | 7 | 152.4 | 5.2 | 151.4 | 6.0 | 149.4 | 5.7 |
| 5 | 0 | 155.0 | 5.4 | 151.9 | 5.2 | 150.1 | 5.7 |
| 5 | 11 | 152.3 | 5.5 | 150.1 | 5.8 | 146.6 | 6.2 |
| 5 | 0 | 151.5 | 5.1 | 148.6 | 6.1 | 147.9 | 6.3 |
| 6 | 0 | 152.2 | 6.3 | 150.6 | 6.3 | 149.2 | 6.1 |
| 6 | 6 | 151.3 | 6.0 | 149.8 | 5.2 | 148.6 | 5.2 |
| 6 | 0 | 151.8 | 5.5 | 149.8 | 6.2 | 148.5 | 6.2 |

(Continued)

TABLE D-8. (Concluded)

| Lane Number | Lane Interval | 2-in. Reading Density (lb/cu ft) | 2-in. Reading Moisture (percent) | 4-in. Reading Density (lb/cu ft) | 4-in. Reading Content (percent) | 6-in. Reading Reading (lb/cu ft) | 6-in. Reading Content (percent) |
|---|---|---|---|---|---|---|---|
| 6 | 11 | 152.3 | 5.5 | 150.1 | 5.6 | 150.0 | 4.8 |
| 7 | 0 | 151.1 | 5.7 | 148.8 | 6.0 | 147.8 | 5.6 |
| 7 | 8 | 152.3 | 5.1 | 150.7 | 5.9 | 150.7 | 5.6 |
| 7 | 0 | 153.9 | 4.8 | 151.6 | 5.1 | 150.8 | 5.7 |
| 7 | 11 | 149.5 | 5.6 | 148.1 | 5.6 | 146.5 | 5.0 |
| 8 | 0 | 149.0 | 5.3 | 149.0 | 5.7 | 145.8 | 6.2 |
| 8 | 3 | 152.3 | 5.8 | 149.6 | 6.5 | 150.7 | 5.7 |
| 8 | 0 | 151.6 | 5.9 | 149.7 | 6.3 | 148.6 | 6.1 |
| 8 | 11 | 151.6 | 6.2 | 151.6 | 5.6 | 152.0 | 5.3 |
| 9 | 0 | 153.0 | 5.9 | 151.3 | 5.6 | 149.7 | 6.8 |
| 9 | 2 | 151.0 | 6.4 | 151.5 | 6.1 | 149.4 | 6.3 |
| 9 | 0 | 151.5 | 5.9 | 151.9 | 6.7 | 151.3 | 5.7 |
| 9 | 11 | 153.1 | 6.1 | 152.4 | 5.9 | 151.5 | 7.1 |
| 10 | 0 | 150.8 | 6.3 | 149.7 | 7.5 | 148.6 | 6.2 |
| 10 | 8 | 149.1 | 6.6 | 150.0 | 5.7 | 148.6 | 6.2 |
| 10 | 0 | 154.0 | 5.7 | 150.8 | 6.6 | 150.8 | 6.3 |
| 10 | 0 | 151.8 | 5.1 | 150.7 | 6.0 | 150.5 | 6.2 |

TABLE D-9. NUCLEAR DENSITY GAUGE READINGS: HARDSTAND DAY 6

| Lane Number | Lane Interval | 2-in. Reading Density (lb/cu ft) | 2-in. Reading Moisture (percent) | 4-in. Reading Density (lb/cu ft) | 4-in. Reading Content (percent) | 6-in. Reading Reading (lb/cu ft) | 6-in. Reading Content (percent) |
|---|---|---|---|---|---|---|---|
| 1 | 4 | 152.6 | 6.7 | 150.7 | 6.3 | 150.5 | 6.5 |
| 1 | 0 | 151.0 | 6.1 | 151.6 | 5.9 | 151.3 | 5.7 |
| 1 | 0 | 150.6 | 5.6 | 149.7 | 6.5 | 149.1 | 6.7 |
| 1 | 6 | 150.1 | 6.8 | 148.1 | 6.5 | 149.3 | 7.0 |
| 1 | 0 | 151.8 | 6.3 | 150.8 | 6.0 | 150.1 | 6.5 |
| 1 | 1 | 153.4 | 5.5 | 150.0 | 6.1 | 149.6 | 6.5 |
| 1 | 0 | 152.3 | 6.2 | 149.9 | 5.9 | 150.6 | 6.1 |
| 1 | 11 | 148.3 | 6.4 | 146.0 | 7.0 | 145.3 | 6.5 |
| 1 | 11 | 148.5 | 5.6 | 148.8 | 6.1 | 148.1 | 6.1 |
| 2 | 7 | 150.0 | 5.9 | 149.0 | 6.7 | 147.8 | 6.1 |
| 2 | 0 | 152.0 | 6.1 | 150.8 | 6.4 | 149.6 | 6.2 |
| 2 | 11 | 148.4 | 6.2 | 148.3 | 5.8 | 149.3 | 6.2 |
| 2 | 3 | 151.1 | 6.5 | 150.2 | 6.3 | 149.3 | 6.9 |
| 2 | 0 | 151.2 | 6.3 | 148.7 | 6.5 | 147.6 | 6.0 |
| 2 | 11 | 151.1 | 7.1 | 150.8 | 5.7 | 150.5 | 5.8 |
| 3 | 5 | 151.8 | 5.9 | 151.2 | 5.6 | 149.3 | 6.2 |
| 3 | 0 | 152.3 | 6.2 | 150.1 | 6.8 | 149.0 | 5.2 |
| 3 | 11 | 148.8 | 6.0 | 147.9 | 5.8 | 147.8 | 5.9 |
| 3 | 10 | 150.7 | 6.1 | 149.5 | 6.3 | 147.6 | 6.0 |
| 3 | 0 | 152.5 | 6.4 | 152.0 | 6.3 | 150.1 | 6.8 |
| 3 | 11 | 150.9 | 6.3 | 149.9 | 5.8 | 148.8 | 6.1 |

(Continued)

(Sheet 1 of 3)

TABLE D-9. (Continued)

| Lane Number | Lane Interval | 2-in. Reading Density (lb/cu ft) | 2-in. Reading Moisture (percent) | 4-in. Reading Density (lb/cu ft) | 4-in. Reading Content (percent) | 6-in. Reading Reading (lb/cu ft) | 6-in. Reading Content (percent) |
|---|---|---|---|---|---|---|---|
| 4 | 0 | 148.5 | 5.6 | 148.1 | 5.0 | 146.8 | 6.3 |
| 4 | 4 | 149.6 | 5.8 | 146.7 | 5.5 | 143.5 | 5.9 |
| 4 | 0 | 148.8 | 6.5 | 149.3 | 5.7 | 148.2 | 5.6 |
| 4 | 11 | 150.3 | 6.3 | 146.4 | 6.3 | 144.0 | 6.3 |
| 4 | 8 | 150.6 | 5.9 | 148.9 | 5.5 | 148.1 | 6.3 |
| 4 | 0 | 151.6 | 6.3 | 148.5 | 5.8 | 147.8 | 5.9 |
| 4 | 11 | 150.3 | 6.2 | 149.8 | 6.0 | 147.1 | 6.2 |
| 5 | 0 | 150.5 | 6.7 | 148.4 | 6.5 | 148.5 | 6.1 |
| 5 | 6 | 153.2 | 5.7 | 149.3 | 6.0 | 149.6 | 6.5 |
| 5 | 0 | 150.1 | 6.6 | 146.9 | 6.5 | 144.5 | 6.6 |
| 5 | 0 | 150.1 | 5.8 | 149.6 | 6.6 | 148.3 | 6.7 |
| 5 | 3 | 149.4 | 6.7 | 149.8 | 6.3 | 149.2 | 6.6 |
| 5 | 0 | 150.4 | 5.7 | 148.3 | 6.2 | 145.0 | 6.2 |
| 5 | 0 | 149.1 | 6.6 | 149.7 | 6.3 | 147.5 | 6.5 |
| 5 | 5 | 149.8 | 6.7 | 147.5 | 6.9 | 147.1 | 6.5 |
| 5 | 0 | 149.5 | 5.9 | 147.6 | 6.3 | 144.2 | 5.8 |
| 5 | 0 | 149.4 | 6.2 | 148.2 | 6.1 | 145.1 | 6.0 |
| 6 | 0 | 150.5 | 6.4 | 150.6 | 6.7 | 149.6 | 6.3 |
| 6 | 0 | 151.3 | 6.6 | 149.8 | 6.1 | 148.8 | 6.1 |
| 6 | 0 | 149.2 | 6.2 | 147.8 | 6.1 | 146.6 | 6.4 |
| 6 | 3 | 150.2 | 5.9 | 149.8 | 6.3 | 149.6 | 6.3 |
| 6 | 0 | 149.2 | 6.5 | 148.3 | 6.7 | 147.2 | 6.4 |
| 6 | 11 | 149.1 | 6.1 | 147.7 | 6.7 | 148.6 | 6.4 |

(Continued)

(Sheet 2 of 3)

TABLE D-9. (Concluded)

| Lane Number | Lane Interval | 2-in. Reading Density (lb/cu ft) | 2-in. Reading Moisture (percent) | 4-in. Reading Density (lb/cu ft) | 4-in. Reading Content (percent) | 6-in. Reading Reading (lb/cu ft) | 6-in. Reading Content (percent) |
|---|---|---|---|---|---|---|---|
| 7 | 0 | 150.5 | 6.7 | 147.7 | 6.5 | 146.5 | 6.3 |
| 7 | 4 | 150.6 | 5.9 | 148.3 | 6.5 | 147.4 | 6.2 |
| 7 | 0 | 150.9 | 6.4 | 149.0 | 6.7 | 147.5 | 6.2 |
| 7 | 0 | 148.7 | 5.8 | 146.8 | 5.8 | 143.7 | 6.1 |
| 8 | 0 | 152.5 | 7.1 | 151.9 | 5.6 | 149.0 | 6.1 |
| 8 | 2 | 153.1 | 6.4 | 152.0 | 6.3 | 151.1 | 6.6 |
| 8 | 0 | 155.1 | 6.9 | 155.6 | 6.6 | 153.2 | 6.6 |
| 8 | 0 | 155.0 | 6.5 | 152.8 | 7.4 | 150.8 | 6.7 |
| 9 | 0 | 154.3 | 6.6 | 153.2 | 7.4 | 152.6 | 7.6 |
| 9 | 2 | 153.6 | 6.6 | 152.3 | 6.9 | 152.1 | 7.3 |
| 9 | 0 | 153.6 | 6.6 | 151.0 | 6.6 | 151.2 | 6.7 |
| 9 | 0 | 153.0 | 6.3 | 153.1 | 6.6 | 153.6 | 6.4 |

(Sheet 3 of 3)

TABLE D-10. DENSITY VERSUS SPLITTING TENSILE STRENGTH: HARDSTAND CYLINDERS

| Sample Number | Age (days) | Density (lb/cu ft) | Splitting Tensile (lb/sq in.) |
|---|---|---|---|
| 1 | 9 | 150.2 | 574.4 |
| 4 | 8 | 140.4 | 237.9 |
| 7 | 8 | 141.6 | 240.8 |
| 10 | 7 | 145.9 | 393.1 |
| 13 | 7 | 144.4 | 319.1 |
| 16 | 7 | 150.0 | 543.9 |
| 19 | 7 | 148.0 | 366.9 |
| 22 | 7 | 146.8 | 404.7 |
| 25 | 7 | 149.8 | 503.3 |
| 28 | 7 | 149.0 | 516.3 |
| 31 | 7 | 150.1 | 417.7 |
| Average | | 146.92 | 410.72 |
| No. of Tests | | 11 | 11 |
| Std. Dev. | | 3.49 | 115.63 |
| 2 | 28 | 147.6 | 516.3 |
| 3 | 28 | 148.2 | 442.4 |
| 5 | 28 | 139.5 | 258.2 |
| 6 | 28 | 140.1 | 176.9 |
| 8 | 28 | 141.0 | 307.5 |
| 9 | 28 | 138.8 | 249.5 |
| 11 | 28 | 147.3 | 465.6 |
| 12 | 28 | 146.4 | 467.0 |
| 14 | 28 | 146.4 | 506.2 |
| 15 | 28 | 146.6 | 407.6 |
| 17 | 28 | 147.5 | 417.7 |
| 18 | 28 | 147.8 | 475.7 |
| 20 | 28 | 146.6 | 533.7 |
| 21 | 28 | 148.1 | 512.0 |
| 23 | 28 | 145.6 | 538.1 |
| 24 | 28 | 145.8 | 391.6 |
| 26 | 28 | 149.9 | 522.1 |
| 27 | 28 | 150.5 | 688.9 |
| 29 | 28 | 150.2 | 690.4 |
| 30 | 28 | 148.8 | 684.6 |
| 32 | 28 | 150.8 | 609.2 |
| 33 | 28 | 150.1 | 616.4 |
| Average | | 146.52 | 476.25 |
| No. of Tests | | 22 | 22 |
| Std. Dev. | | 3.57 | 141.17 |

TABLE D-11. DENSITY VERSUS SPLITTING TENSILE STRENGTH: HARDSTAND CORES

| Sample Number | Age (days) | Density (lb/cu ft) | Splitting Tensile Strength (lb/sq in.) |
|---|---|---|---|
| 1/7/1 | 9 | 148.2 | 255 |
| 1/7/2 | 9 | 151.6 | 323 |
| 2/7/1 | 8 | 142.5 | 218 |
| 2/7/2 | 8 | 146.2 | 351 |
| 3/7/1 | 7 | 150.6 | 373 |
| 3/7/2 | 7 | 148.0 | 278 |
| 4/7/1 | 7 | 151.1 | 455 |
| 4/7/2 | 7 | 146.3 | 300 |
| 5/7/1 | 7 | 150.5 | 403 |
| 5/7/2 | 7 | 147.0 | 321 |
| 6/7/1 | 7 | 150.3 | 387 |
| 6/7/2 | 7 | 150.6 | 428 |
| 1/28/1 | 28 | 150.2 | 470 |
| 1/28/2 | 28 | 147.0 | 390 |
| 2/28/1 | 28 | 151.0 | 416 |
| 2/28/2 | 28 | 151.1 | 548 |
| 2/28/3+ | 35 | 148.7 | 412 |
| 3/28/1 | 28 | 147.8 | 451 |
| 3/28/2 | 28 | 151.3 | 566 |
| 3/28/3+ | 35 | 148.6 | 453 |
| 3/28/4+ | 35 | 150.5 | 538 |
| 4/28/1 | 28 | 147.8 | 532 |
| 4/28/2 | 28 | 148.8 | 493 |
| 5/28/1 | 28 | 151.6 | 486 |
| 5/28/2 | 28 | 147.1 | 451 |
| 6/28/1 | 28 | 151.1 | 540 |
| 6/28/2 | 28 | 147.6 | 477 |

TABLE D-12. FLEXURAL STRENGTH VERSUS DENSITY:
LABORATORY SPECIMENS (HARDSTAND)

| 28-day Flexural Strength (lb/sq in.) | Density (lb/cu ft) |
|---|---|
| 785 | 146.3 |
| 274 | 132.4 |
| 591 | 140.3 |
| 466 | 137.2 |
| 476 | 137.5 |
| 861 | 147.1 |

TABLE D-13. RCC MOISTURE CONTENT: HARDSTAND LABORATORY MEASUREMENT (BY DRYING)

| Day | Time (decimal hours) | Moisture Content (percent) | Statistics | |
|---|---|---|---|---|
| 1 | 7.67 | 5.9 | Average | 6.02 |
| 1 | 11.00 | 6.5 | No. of Tests | 4 |
| 1 | 13.67 | 5.8 | Std. Dev. | 0.32 |
| 1 | 15.00 | 5.9 | | |
| 2 | 7.00 | 6.5 | Average | 6.01 |
| 2 | 8.00 | 7.1 | No. of Tests | 7 |
| 2 | 8.83 | 6.1 | Std. Dev. | 0.73 |
| 2 | 11.25 | 4.8 | | |
| 2 | 11.83 | 6.2 | | |
| 2 | 14.00 | 5.5 | | |
| 2 | 15.75 | 5.9 | | |
| 3 | 9.33 | 5.5 | Average | 5.81 |
| 3 | 9.58 | 5.5 | No. of Tests | 7 |
| 3 | 10.00 | 5.9 | Std. Dev. | 0.25 |
| 3 | 11.17 | 5.9 | | |
| 3 | 2.00 | 5.7 | | |
| 3 | 2.33 | 6.1 | | |
| 3 | 4.92 | 6.1 | | |
| 4 | 5.50 | 5.6 | Average | 5.98 |
| 4 | 5.83 | 5.8 | No. of Tests | 12 |
| 4 | 6.42 | 6.0 | Std. Dev. | 0.16 |
| 4 | 6.75 | 6.0 | | |
| 4 | 8.58 | 6.0 | | |
| 4 | 10.25 | 6.2 | | |
| 4 | 10.92 | 6.2 | | |
| 4 | 13.00 | 6.0 | | |
| 4 | 13.75 | 6.0 | | |
| 4 | 16.08 | 6.0 | | |
| 4 | 16.92 | 6.0 | | |
| 4 | 16.33 | 6.0 | | |
| 5 | 5.67 | 6.1 | Average | 6.28 |
| 5 | 6.08 | 6.4 | No. of Tests | 11 |
| 5 | 6.58 | 6.3 | Std. Dev. | 0.24 |
| 5 | 8.58 | 6.7 | | |
| 5 | 9.17 | 6.3 | | |
| 5 | 10.08 | 6.7 | | |
| 5 | 10.42 | 6.0 | | |

(Continued)

TABLE D-13. (Concluded)

| Day | Time (decimal hours) | Moisture Content (percent) | Statistics | |
|---|---|---|---|---|
| 5 | 11.25 | 6.0 | | |
| 5 | 12.08 | 6.1 | | |
| 5 | 13.50 | 6.2 | | |
| 5 | 14.00 | 6.3 | | |
| 6 | 5.67 | 5.9 | Average | 6.18 |
| 6 | 5.83 | 6.5 | No. of Tests | 14 |
| 6 | 6.00 | 6.3 | Std. Dev. | 0.41 |
| 6 | 7.25 | 6.3 | | |
| 6 | 9.30 | 5.0 | | |
| 6 | 9.83 | 6.2 | | |
| 6 | 10.83 | 6.5 | | |
| 6 | 12.50 | 6.3 | | |
| 6 | 13.67 | 6.7 | | |
| 6 | 14.00 | 6.5 | | |
| 6 | 15.17 | 6.2 | | |
| 6 | 16.42 | 5.9 | | |
| 6 | 16.92 | 6.2 | | |
| 6 | 17.17 | 6.0 | | |

TABLE D-14. MODIFIED PROCTOR TEST RESULTS: HARDSTAND

| Day | Maximum Wet Density (lb/cu ft) | Optimum Moisture Content (percent) |
|---|---|---|
| 2 | 149.1 | 4.8 |
| | 148.3 | 5.5 |
| 3 | 150.8 | 5.9 |
| | 149.4 | 6.1 |
| 4 | 152.2 | 6.2 |
| | 150.0 | 6.0 |
| 5 | 149.4 | 6.0 |
| | 149.7 | 6.3 |
| 6 | 150.6 | 6.5 |
| | 151.1 | 6.7 |

TABLE D-15. START AND STOP TIMES FOR EACH LANE: HARDSTAND

| Day Number | Lane Number | Start Time* | End Time | Time to Pave Lane | Time Between Lanes | Average Length (feet) | Speed (ft/min) | Joint Age (min) |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 8.25 | 10.17 | 115.20 | 19.80 | 314.96 | 2.73 | 122.40 |
| | 2 | 10.50 | 12.00 | 90.00 | 19.80 | 314.96 | 3.50 | 105.90 |
| | 3 | 12.33 | 13.70 | 82.20 | 40.20 | 314.96 | 3.83 | 110.10 |
| | 4 | 14.37 | 15.33 | 57.60 | 47.40 | 314.96 | 5.47 | 115.20 |
| | 5 | 16.12 | 17.42 | 78.00 | | 314.96 | 4.04 | |
| 2 | 1 | 7.66 | 10.90 | 194.40 | 13.80 | 344.48 | 1.77 | 148.20 |
| | 2 | 11.13 | 12.37 | 74.40 | 37.80 | 344.48 | 4.63 | 135.30 |
| | 3 | 13.00 | 15.01 | 120.60 | 19.20 | 344.48 | 2.86 | 138.00 |
| | 4 | 15.33 | 17.28 | 117.00 | 20.40 | 344.48 | 2.94 | 131.70 |
| | 5 | 17.62 | 19.38 | 105.60 | | 344.48 | 3.26 | |
| 3 | 1 | 9.50 | 11.66 | 129.60 | 20.40 | 344.48 | 2.66 | 121.20 |
| | 2 | 12.00 | 13.20 | 72.00 | | 344.48 | 4.78 | |
| | 3 | 13.50 | 15.18 | 100.80 | 29.40 | 344.48 | 3.42 | 146.10 |
| | 4 | 15.67 | 17.88 | 132.60 | | 344.48 | 2.60 | |
| 4 | 1 | 6.42 | 7.58 | 69.60 | 11.40 | 206.69 | 2.97 | 68.10 |
| | 2 | 7.77 | 8.50 | 43.80 | 18.00 | 206.69 | 4.72 | 65.40 |
| | 3 | 8.80 | 9.65 | 51.00 | 21.00 | 206.69 | 4.05 | 81.90 |
| | 4 | 10.00 | 11.18 | 70.80 | 10.20 | 206.69 | 2.92 | 71.10 |
| | 5 | 11.35 | 12.20 | 51.00 | 19.80 | 206.69 | 4.05 | 69.30 |

(Continued)

* Times recorded in decimal hours clock time.

TABLE D-15. (Concluded)

| Day Number | Lane Number | Start Time* | End Time | Time to Pave Lane | Time Between Lanes | Average Length (feet) | Speed (ft/min) | Joint Age (min) |
|---|---|---|---|---|---|---|---|---|
| | 6 | 12.53 | 13.33 | 48.00 | | 206.69 | 4.31 | |
| | 7 | 13.62 | 14.55 | 55.80 | 13.80 | 206.69 | 3.70 | 71.70 |
| | 8 | 14.78 | 15.78 | 60.00 | 12.00 | 206.69 | 3.44 | 72.00 |
| | 9 | 15.98 | 16.98 | 60.00 | 13.20 | 206.69 | 3.44 | 82.20 |
| | 10 | 17.20 | 18.50 | 78.00 | | 206.69 | 2.65 | |
| 5 | 1 | 6.50 | 7.12 | 37.20 | 12.60 | 137.79 | 3.70 | 54.30 |
| | 2 | 7.33 | 8.10 | 46.20 | 15.00 | 137.79 | 2.98 | 61.50 |
| | 3 | 8.35 | 9.13 | 46.80 | 4.20 | 137.79 | 2.94 | 59.10 |
| | 4 | 9.20 | 10.25 | 63.00 | 13.20 | 137.79 | 2.19 | 63.00 |
| | 5 | 10.47 | 11.08 | 36.60 | 16.20 | 137.79 | 3.76 | 50.10 |
| | 6 | 11.35 | 11.87 | 31.20 | | 137.79 | 4.42 | |
| | 7 | 12.03 | 12.73 | 42.00 | 13.20 | 137.79 | 3.28 | 54.60 |
| | 8 | 12.95 | 13.63 | 40.80 | 10.20 | 137.79 | 3.38 | 47.70 |
| | 9 | 13.80 | 14.37 | 34.20 | 9.60 | 137.79 | 4.03 | 69.30 |
| | 10 | 14.53 | 15.95 | 85.20 | | 137.79 | 1.62 | |
| 6 | 1 | 8.42 | 8.90 | 28.80 | 13.80 | 228.02 | 7.92 | 64.20 |
| | 2 | 9.13 | 10.33 | 72.00 | 18.00 | 228.02 | 3.17 | 80.70 |
| | 3 | 10.63 | 11.52 | 53.40 | 22.80 | 228.02 | 4.27 | 87.60 |
| | 4 | 11.90 | 13.17 | 76.20 | 19.80 | 228.02 | 2.99 | 95.47 |
| | 5 | 13.50 | 15.23 | 103.80 | 10.20 | 314.96 | 3.03 | 35.63 |
| | 6 | 15.40 | 15.77 | 22.20 | 3.60 | 86.94 | 3.92 | 41.40 |
| | 7 | 15.83 | 16.72 | 53.40 | 12.00 | 86.94 | 1.63 | 54.60 |
| | 8 | 16.92 | 17.45 | 31.80 | 4.80 | 86.94 | 2.73 | 38.70 |
| | 9 | 17.53 | 18.13 | 36.00 | | 86.94 | 2.42 | |

TABLE D-16. SMOOTHNESS RESULTS: TEST SECTION AND HARDSTAND

| Lane Number | Transverse (in.) | Longitudinal (in.) | Joint (in.) |
|---|---|---|---|
| | Test Section | | |
| 1 | 0.18 | 0.14 | 0.22 |
| | 0.24 | 0.02 | 0.13 |
| | 0.08 | 0.16 | 0.39 |
| 2 | 0.10 | 0.08 | 0.17 |
| | 0.22 | 0.16 | 0.26 |
| | 0.20 | 0.00 | 0.14 |
| 3 | 0.20 | 0.24 | 0.33 |
| | 0.02 | 0.14 | 0.28 |
| | 0.16 | 0.33 | 0.33 |
| 4 | 0.24 | 0.12 | |
| | 0.24 | 0.16 | |
| | 0.00 | 0.16 | |
| Average | 0.15 | 0.14 | 0.25 |
| No. of Tests | 12 | 12 | 9 |
| Std. Dev. | 0.08 | 0.08 | 0.09 |
| | Hardstand Day 1 | | |
| 1 | 0.12 | 0.02 | 0.08 |
| | 0.04 | 0.18 | 0.15 |
| | 0.10 | 0.18 | 0.28 |
| 2 | 0.02 | 0.41 | |
| | 0.22 | 0.22 | |
| | 0.28 | 0.18 | |
| 3 | 0.35 | 0.16 | 0.11 |
| | 0.26 | 0.16 | 0.14 |
| | 0.20 | 0.16 | 0.07 |
| 4 | 0.39 | 0.55 | 0.28 |
| | 0.04 | 0.10 | 0.16 |
| | 0.30 | 0.16 | 0.55 |
| 5 | 0.45 | 0.24 | |
| | 0.31 | 0.20 | |
| | 0.16 | 0.20 | |
| Average | 0.22 | 0.21 | 0.20 |
| No. of Tests | 15 | 15 | 9 |
| Std. Dev. | 0.13 | 0.12 | 0.14 |

(Continued)

TABLE D-16. (Continued)

| Lane Number | Transverse (in.) | Longitudinal (in.) | Joint (in.) |
|---|---|---|---|
| | Hardstand Day 2 | | |
| 1 | 0.31 | 0.16 | 0.24 |
| | 0.22 | 0.08 | 0.20 |
| | 0.04 | 0.12 | 0.30 |
| 2 | 0.55 | 0.33 | 0.71 |
| | 0.24 | 0.00 | 0.45 |
| | 0.10 | 0.20 | 0.24 |
| 3 | 0.39 | 0.08 | 0.81 |
| | 0.26 | 0.28 | 0.49 |
| | 0.53 | 0.43 | 1.26 |
| 4 | 0.12 | 0.04 | 0.41 |
| | 0.30 | 0.06 | 0.61 |
| | 0.06 | 0.24 | 0.24 |
| 5 | 0.08 | 0.06 | |
| | 0.08 | 0.10 | |
| | 0.12 | 0.22 | |
| Average | 0.23 | 0.16 | 0.50 |
| No. of Tests | 15 | 15 | 12 |
| Std. Dev. | 0.16 | 0.12 | 0.30 |
| | Hardstand Day 3 | | |
| 1 | 0.28 | 0.30 | 0.77 |
| | 0.08 | 0.20 | 0.41 |
| | 0.24 | 0.43 | 0.31 |
| 2 | 0.14 | 0.30 | |
| | 0.22 | 0.24 | |
| | 0.35 | 0.16 | |
| 3 | 0.14 | 0.08 | |
| | 0.28 | 0.16 | |
| | 0.10 | 0.08 | 0.12 |
| 4 | 0.06 | 0.14 | |
| | 0.14 | 0.04 | |
| | 0.22 | 0.06 | |
| Average | 0.19 | 0.18 | 0.40 |
| No. of Tests | 12 | 12 | 4 |
| Std. Dev. | 0.09 | 0.11 | 0.24 |

(Continued)

TABLE D-16. (Continued)

| Lane Number | Transverse (in.) | Longitudinal (in.) | Joint (in.) |
|---|---|---|---|
| | Hardstand Day 4 | | |
| 1 | 0.30 | 0.12 | 0.40 |
| | 0.26 | 0.12 | 0.10 |
| | 0.31 | 0.12 | 0.10 |
| 2 | 0.18 | 0.04 | 0.12 |
| | 0.26 | 0.12 | 0.14 |
| 3 | 0.45 | 0.20 | 0.43 |
| 4 | | 0.04 | |
| | | 0.02 | |
| 5 | 0.28 | 0.12 | 0.12 |
| | 0.24 | 0.12 | 0.08 |
| | 0.39 | 0.02 | 0.20 |
| 6 | 0.24 | 0.12 | |
| | 0.20 | 0.12 | |
| 7 | 0.28 | 0.18 | 0.18 |
| | 0.33 | 0.18 | 0.20 |
| | 0.39 | 0.14 | 0.26 |
| 8 | 0.33 | 0.02 | 0.30 |
| | 0.16 | 0.12 | |
| 9 | 0.04 | 0.16 | 0.16 |
| | 0.22 | 0.12 | 0.12 |
| | 0.35 | 0.04 | 0.39 |
| 10 | 0.20 | 0.20 | |
| | 0.20 | 0.30 | |
| Average | 0.27 | 0.12 | 0.20 |
| No. of Tests | 21 | 23 | 16 |
| Std. Dev. | 0.09 | 0.07 | 0.11 |
| | Hardstand Day 5 | | |
| 1 | 0.35 | 0.26 | |
| 2 | 0.31 | 0.20 | 0.37 |
| | 0.39 | 0.28 | 0.16 |
| 3 | 0.30 | 0.04 | |
| 4 | 0.43 | 0.04 | |
| | 0.28 | 0.04 | |
| 5 | 0.28 | 0.16 | 0.31 |
| 6 | 0.37 | 0.04 | |
| | 0.18 | 0.04 | |

(Continued)

TABLE D-16. (Concluded)

| Lane Number | Transverse (in.) | Longitudinal (in.) | Joint (in.) |
|---|---|---|---|
| | Hardstand Day 5 (Continued) | | |
| 7 | 0.22 | 0.24 | |
| 8 | 0.24 | 0.04 | 0.14 |
| | 0.24 | 0.22 | 0.33 |
| 9 | 0.30 | 0.16 | 0.28 |
| 10 | 0.49 | 0.14 | |
| | 0.28 | 0.47 | |
| Average | 0.31 | 0.16 | 0.27 |
| No. of Tests | 15 | 15 | 6 |
| Std. Dev. | 0.08 | 0.12 | 0.09 |
| | Hardstand Day 6 | | |
| 1 | 0.67 | 0.14 | 0.30 |
| | 0.43 | 0.14 | 0.31 |
| | 0.14 | 0.12 | 0.30 |
| 2 | 0.26 | 0.14 | 0.10 |
| | 0.22 | 0.04 | 0.13 |
| 3 | 0.91 | 0.41 | 0.31 |
| | 0.55 | 0.30 | 0.18 |
| 4 | 0.37 | 0.31 | 0.16 |
| | 0.24 | 0.18 | 0.14 |
| 5 | 0.14 | 0.10 | |
| | 0.10 | 0.10 | |
| | 0.39 | 0.04 | |
| 6 | 0.33 | 0.26 | 0.10 |
| 7 | 0.49 | 0.04 | 0.14 |
| 8 | 0.55 | 0.37 | 0.37 |
| 9 | 0.14 | 0.12 | 0.30 |
| Average | 0.37 | 0.17 | 0.22 |
| No. of Tests | 16 | 16 | 13 |
| Std. Dev. | 0.22 | 0.12 | 0.09 |
| | Day 1 - Day 6 Hardstand Totals | | |
| Average | 0.25 | 0.16 | 0.28 |
| No. of Tests | 106 | 108 | 69 |
| Std. Dev. | 0.15 | 0.11 | 0.20 |

(Sheet 4 of 4)

TABLE D-17. INCREMENTAL DENSITY OF CORES WITH DEPTH: HARDSTAND

| Sample Number | Age of Sample (days) | Densities (lb/cu ft) | | |
|---|---|---|---|---|
| | | Top | Middle | Bottom |
| 1/28/1 | 28 | 149.9 | 147.7 | 143.2 |
| 2/28/1 | 28 | 153.8 | 151.9 | 149.1 |
| 3/28/1 | 28 | 149.1 | 147.8 | 143.6 |
| 4/28/1 | 28 | 151.0 | 147.7 | 144.8 |
| 5/28/1 | 28 | 150.8 | 147.0 | 143.4 |
| 6/28/1 | 28 | 151.3 | 151.6 | 148.6 |