ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

Progress Report

EXPERIMENTAL
FLY-ASH CONCRETE PAVEMENT
RECOR ROAD
ST. CLAIR, MICHIGAN

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Project 2211

THE DETROIT EDISON COMPANY
DETROIT, MICHIGAN

February 1956

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SYNOPSIS

As a phase of its research in the use of fly ash in Portland cement concrete, The Detroit Edison Company constructed an experimental highway pavement during the summer of 1955 near their St. Clair power plant midway between St. Clair and Marine City, Michigan.

During both the planning and construction stages of the road, the Michigan State Highway Department cooperated by conducting preliminary laboratory investigations, performing field and laboratory tests, and furnishing field engineering personnel and advice to the end that a maximum of information would be developed from the experimental project. During the construction, the Engineering Research Institute of The University of Michigan furnished assistance in performing field tests and has since conducted laboratory tests on samples collected at the construction site.

The data presented herein are a composite of information gathered by the above three agencies. It is expected that this compilation may be useful at some future date when correlation with field performance of the various test sections can be established.

Insofar as applicable, the pavement was constructed in accordance with present Michigan State Highway Department standards. The materials, with the exception of the fly ash, were tested by the Department prior to construction of the project. The fly ash was furnished the paving contractor by The Detroit Edison Company from its St. Clair plant adjacent to the construction site. Tests of the fly ash from samples taken at the job showed it to have a loss on ignition of from 13 to 14 percent and a silicon dioxide content of from 34 to 38 percent. The carbon content of this ash is thus much higher than has been reported in the literature as having been used for an experimental fly-ash project of this scope and should make field observations of the performance of the pavement of particular value. The silica content of the ash is also somewhat lower than is usually reported.

Numerous tests were conducted on the fresh concrete during the course of paving, while specimens also were secured for testing at ages up to 5 years. Included were tests for air content, slump, and yield and molding of specimens to determine the compressive strength, flexural strength, resistance to freezing and thawing, and resistance to salt scaling.

The paving of the road progressed satisfactorily although minor difficulties were encountered in batching the fly ash and in controlling the air content with hand addition of the air-entraining admixture. Both these

difficulties can be corrected should the use of fly ash in paving concrete become a more general practice.

Compressive strengths were determined from tests of two independent sets of 6- x 12-inch cylinders molded on the job and from cores drilled from the finished pavement. Generally, the job-made cylinders exhibit 28-day strengths only slightly exceeding, or actually below, the Michigan State Highway Department 3500-psi Grade A class of concrete specified for paving. Since the cores drilled from the finished pavement show, with one exception, much higher strengths, the inference is strong that the unusually hot weather during construction, and subsequent thereto, may have hindered proper strength development of the job-made small-size strength specimens. Flexural strengths of job-made beams likewise tended to be low, again probably due to lack of moist curing at very early ages. Only one section had unusually low flexural strengths, possibly due to a high air content in the test specimens. These strengths are thought to be not necessarily representative of the concrete throughout that section.

Concrete made in the laboratory, using materials brought directly from the job and using the same proportions as for one of the test sections, gave higher compressive and flexural strengths at all ages even though a slightly higher water-cement ratio was used in the laboratory mix. The laboratory concrete was moist cured at standard temperature the entire time.

Tests and observations will continue to be made until some definite indication of the ranking of the test sections is established. Laboratory tests are in progress or are planned for studying resistance to freezing and thawing, resistance to salt scaling, and strengths in flexure and compression at later ages.

Since the pavement is only six months old at this writing, it is too early to arrive at conclusions as to its wearing or weathering qualities.

OBJECTIVE

The purpose of this investigation is to study the properties of fly ash and concrete containing fly ash. This will be achieved by determining the effect of fly ash as an admixture in concrete as indicated by the compressive strength, workability, durability in freezing and thawing, resistance to sulfate attack, volume change, flexural strength, and other measures of quality.

The specific purpose of the phase of the investigation covered by this report is to determine the effect of fly ash on concrete used in highway pavement and exposed to natural weathering and normal wear.

INTRODUCTION

With the completion of The Detroit Edison Company power plant near St. Clair, Michigan, it became necessary to improve an existing gravel road in order to support large trucks from the plant as well as other plant and local traffic. Although a public road, the construction cost was borne by the Edison Company since the improvement would be of principal benefit to the Company. As a result, the Company decided that the road would be paved with fly-ash concrete as an experimental project to study the performance of such concrete in pavement.

By agreement, the Michigan State Highway Department conducted preliminary laboratory tests early in 1954 on fly-ash concrete, using fly ash from the Marysville station since at that time there was no ash available at the St. Clair station. The purpose of these tests was to determine the range of mix proportions most desirable for the different test sections. Due to delays in placing the contract, the road was not constructed during the 1954 construction season.

In the spring of 1955, plans were again made for construction of the road and the paving contract was let to the Cooke Contracting Company, Detroit. It was desired to use fly ash from the St. Clair station, which had now become available. The mix proportions to be used for the five test sections were selected somewhat arbitrarily, but predicated on the work done by the Highway Department on the Marysville ash and on laboratory work on concrete containing St. Clair fly ash performed by the Engineering Research Institute of The University of Michigan. The actual paving was done on July 7, 8, and 9, 1955. Prior to this time, drainage structures were installed and the subgrade was shaped and compacted in accordance with Highway Department standards. The subbase is composed of a thick layer of sand (9 to 13 inches) over the highly plastic natural-clay soil. Table I-A in the Appendix gives the results of soil tests for the subbase and subgrade.

Numerous tests, such as air content, slump, and yield, were performed throughout the paving operation, as was the fabrication of specimens for testing at later dates in compression, flexure, freezing and thawing, and salt-scaling resistance.

These tests and the results reported herein were obtained through the combined efforts of the Michigan State Highway Department, The Detroit Edison Company, and the Engineering Research Institute. In addition to the tests of the field mixes, laboratory mixes using the same proportions as were used on one of the test sections were made for a comparison between field and laboratory results. The results of this laboratory investigation are also reported herein.

The pavement was opened to traffic on July 30, 1955. Since that time, it has carried mixed traffic, including approximately 30 to 40 heavily loaded trucks daily.

LOCATION AND LAYOUT

The experimental pavement is on Recor Road, about four miles south of the city of St. Clair, Michigan, and four miles north of Marine City, Michigan. The pavement is in a section 1750 feet long, extending from new highway M-29 to old M-29 (River Road) just south of the power plant. The latter road was closed for the construction of the Edison power plant and the former was constructed to replace it (see Fig. 1).

The pavement is 22 feet wide, 8 inches thick, and wire-mesh reinforced throughout. Transverse contraction joints are spaced nominally every 99 feet and have dowel load-transfer devices. The longitudinal center joint was not preformed but was sawed shortly after the pavement was laid (July 11 and 12). All joints were sealed with asphalt-rubber joint filler. The pavement is divided into five test sections varying in length from 256 to 396 feet. The first section is made of the standard 5.5-sack Highway Department air-entrained paving concrete, and the other sections are made of concrete containing varying amounts of fly ash and varying cement factors.

Due to the shortness and layout of the test pavement, all sections are expected to be exposed to the same vehicular traffic.

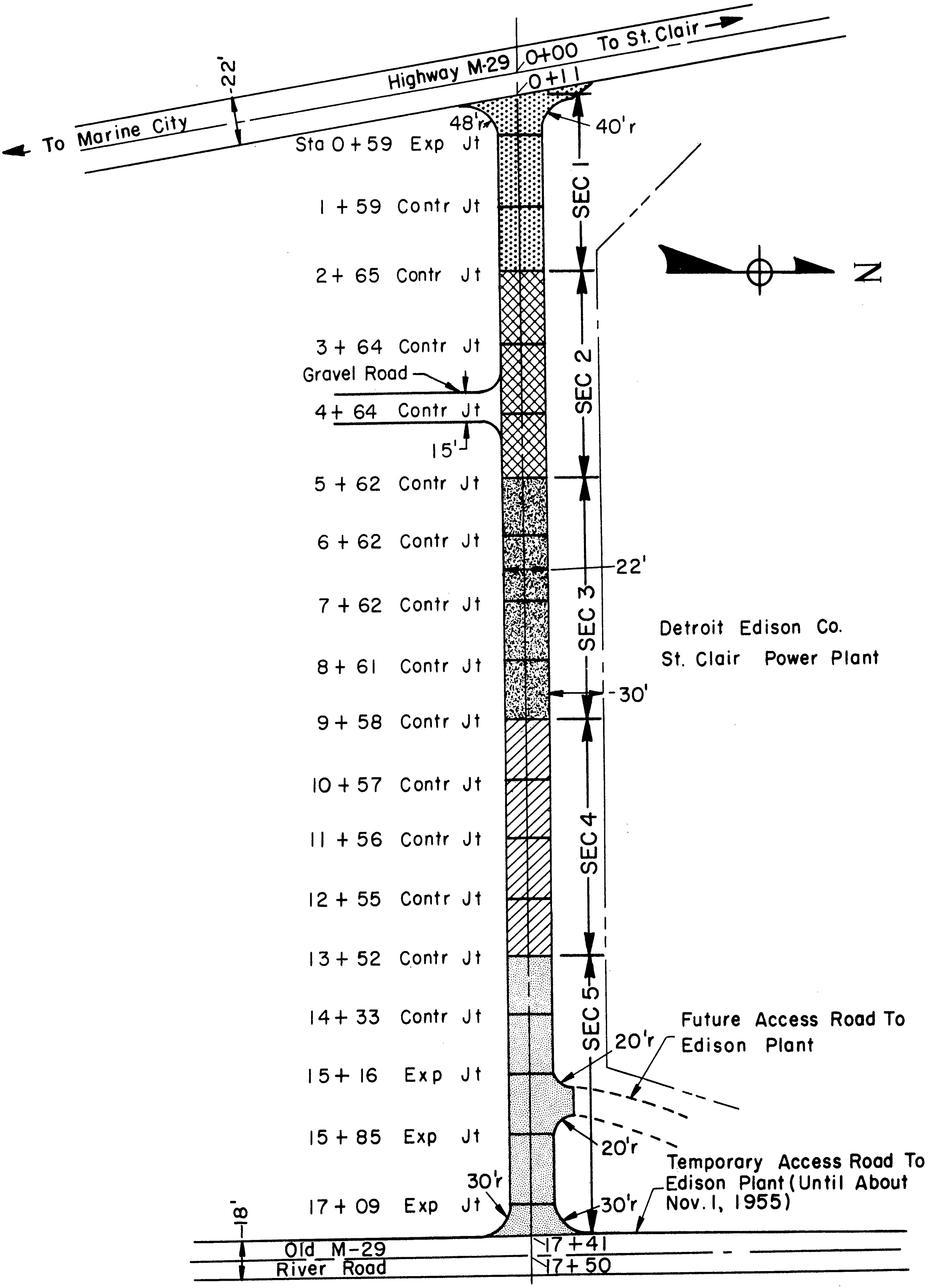

Fig. 1. Plan of experimental road.

MATERIALS

CEMENT

The cement was produced by the Peerless Portland Cement Company, Port Huron, Michigan, and was Type I (regular, non-air-entraining). After routine testing of the silo, the cement was approved for use. Samples were taken from the batching plant on the job in the afternoons of July 7 and 8. Complete chemical and physical analyses of these samples will be found in Table II-A in the Appendix.

FLY ASH

The fly ash was from the St. Clair plant of The Detroit Edison Company. It was obtained directly from the collecting silo in truckload lots and was used without prior testing. Job samples of the fly ash were obtained on July 7 and 8. Results of the chemical and physical tests are in Table III-A in the Appendix, along with the current A.S.T.M. specification requirements. It will be noted that the loss on ignition exceeds the specification limit, and the silicon dioxide is deficient for the requirement.

FINE AGGREGATE

The fine aggregate was natural sand from the Maerton Pit No. 2 located near Romeo, Michigan. The sand is believed to be typical of the concrete sand used in southeastern Michigan, except possibly for the somewhat high amount passing the No. 50 sieve. Analyses of the job samples collected on July 7 and 8 are shown in Appendix Table IV-A.

COARSE AGGREGATE

The coarse aggregate was crushed dolomitic limestone from Drummond Island, Michigan. It is considered to have excellent durability properties. It was furnished and batched as stone meeting Michigan State Highway Department requirements for 4A coarse aggregate (2-inch maximum size) and 10A coarse aggregate (1-inch maximum size). Equal weights of each size were used to make the total weight of coarse aggregate in each batch. Samples were collected on July 7 and 8, and the results of tests on them are shown in Appendix Table V-A.

AIR-ENTRAINING ADMIXTURE

The air-entraining admixture used in all batches was neutralized Vinsol resin produced by the Hercules Powder Company. The Vinsol was obtained in powdered form (NVX) and dissolved in warm water at the ratio of 50 pounds of Vinsol to 50 gallons of water. It was stored in drums along the roadway until used.

PAVEMENT REINFORCEMENT

The pavement was reinforced throughout with welded wire mesh with No. 00 wires running longitudinally, spaced at 6 inches, and No. 4 wires running transversely, spaced at 12 inches. Load-transfer devices (1-inch-diameter bars, 12 inches on center) used at all expansion and contraction joints conformed to Michigan State Highway Department standards.

CURING COMPOUND

The concrete was cured by spraying the surface with Truscon Tru-Cure Compound. This forms a white, waterproof membrane on the surface of the concrete, inhibiting moisture loss by evaporation.

MIX DESIGN

General details of the mix design were decided upon at a meeting of representatives of the Edison Company, Highway Department, and Engineering Research Institute. The selection of cement and fly-ash contents was based on results of experiments conducted previously. The following quantities per cubic yard of concrete were selected for the different test sections:

Section 1 - 5.5 sacks cement, no fly ash
Section 2 - 5.0 sacks cement, 100 lb fly ash
Section 3 - 4.5 sacks cement, 100 lb fly ash
Section 4 - 4.5 sacks cement, 150 lb fly ash
Section 5 - 4.0 sacks cement, 200 lb fly ash

The mix for Section 1 is the Highway Department standard paving mix. All mixes were designed by the Mortar-Voids method of proportioning which is used by the Highway Department.

The stone content of the mixes containing fly ash was increased over that used in the standard paving mix. The volumes of loose coarse aggregate per unit volume of concrete used in the five sections were:

Section 1 - 0.78
Section 2 - 0.83
Section 3 - 0.83
Section 4 - 0.85
Section 5 - 0.85

This increase in the stone content is possible due to the addition of fly ash. The fly ash has the effect of lubricating the mix, permitting the use of additional stone with no apparent change in workability.

PAVING EQUIPMENT

The paving equipment was standard for highway work in Michigan, subject to Highway Department control. The batching plant was set up in Marine City and a fleet of batch trucks used for transporting the weighed materials to the paving site. Two additional trucks were equipped with water tanks to supply the mixer and to wet the subgrade ahead of the paving equipment.

The concrete was mixed in a Worthington Dual Drum mixer of 38-cubic-feet capacity. It was equipped with an automatic dispenser for proportioning the air-entraining admixture. However, the mixes containing fly ash required an increased amount of admixture and it was consequently added by hand to the dry materials in the skip of the mixer.

The mixer was followed by a Blaw-Knox spreader which spread the fresh concrete over the subgrade after it was dumped from the mixer. A Blaw-Knox finisher gave the concrete the initial finishing operation. The concrete was then floated with a Koehring longitudinal float. After hand finishing with float and straightedge, including a burlap drag to roughen the surface, the surface of the concrete was sprayed with curing compound by a Heltzel Flexplane curing compound spreader.

DESCRIPTION OF PAVING OPERATIONS

PAVING PROCEDURE

Trucks were batched with the dry materials in the following order at the batching plant: (a) the two sizes of stone, (b) the cement, and (c) the sand. The fly ash for Sections 2, 3, 4, and 5 of the road was added to the top of the load in the trucks at the job site.

The concrete was laid in two courses. The lower course, about 5 inches thick, was placed for about 30 feet and leveled by the spreader. The steel reinforcing mats were then placed, after which the top course was placed, spread, and finished.

Section 1 - Station 0 + 11 to 2 + 65.—Paving on Section 1 commenced at about 9 a.m. on July 7, 1955. The cement bin at the batching plant had a small amount of air-entrained cement (Type IA) remaining from a previous job. This cement was used for the first 34 batches before starting with the Type I cement specified and used on the remainder of the job. The Type IA cement was in only the first 50 feet of Section 1. The air-entraining admixture (Vinsol resin solution) was added to the mix by the automatic dispenser in Section 1. Checks of the air content and slump were made periodically.

The air temperature averaged about 86°F during the time of the pour.

Section 2 - Station 2 + 65 to 5 + 62.—A contraction joint was used to separate Sections 1 and 2. There was only a slight pause as the trucks were held up to be sure that there were enough materials for Section 1 before the quantities were changed for Section 2.

As mentioned earlier, the fly ash was batched at the job site. Steel drums were filled with the proper weight of fly ash for a batch from a bulk-cement truck. These drums were then hoisted to a platform from which the contents were dumped on top of the other concrete materials in the batch truck. This method of batching had several drawbacks:

> (1) A great deal of dust was created during the process of dumping the fly ash into the trucks, dumping the materials from the trucks, and raising the mixer skip to charge the mixer. Such dust would be highly objectionable in a built-up area and may have caused the loss of some material from the mix.

(2) Some ash spilled from the trucks and flowed through holes and cracks in the truck bodies. Each truck carried materials for two batches, the batches being separated by a wood partition. When the batch in the rear compartment of the truck was dumped into the mixer skip, some of the fly ash in the front compartment would flow over the dividing partition, tending to make too much fly ash in the first batch and not enough fly ash in the second batch.

(3) The process was very slow and at times it was not possible to batch the fly ash fast enough to keep up with the demand of the mixer, slowing down the whole paving operation.

The air-entraining admixture created another problem in the sections where fly ash was used. The automatic dispenser on the mixer could not handle the large amounts of admixture required to entrain the desired amount of air in the fly-ash mixes. Therefore, it was necessary to have a man stationed beside the mixer skip to dump the measured amount of admixture on the dry materials in the skip. The measuring was very crude. The Vinsol resin solution was measured from drums in a one- and a two-quart measure and a gallon can. There was no attempt made to measure any closer than the nearest pint, and there was some variation in the fullness of the containers.

By making numerous air checks at the start of the section it was possible to adjust the amount of Vinsol solution promptly to obtain the proper air content. Several more air checks and slump tests were made as the paving of the section progressed.

The air temperature during the time of pour ranged from 92° to 82°F with an average of about 88°F. The sky was clear all day.

Section 3 - Station 5 + 52 to 9 + 58.—Paving on Section 3 started at about 7:30 a.m. on July 8, 1955. The operation ran smoothly throughout the morning. The proper amount of Vinsol was quickly determined and the air content remained relatively constant. The temperature was about 72°F when work started and rose rapidly to about 87°F.

Section 4 - Station 9 + 58 to 13 + 52.—Paving of Section 4 followed directly after Section 3 with only the delay of placing a contraction joint to interrupt the progress. The first estimate on the amount of Vinsol resin solution proved to be correct. However, after about 1:30 p.m. the weighing of the fly ash delayed the work greatly. For the previous sections using fly ash, some of the drums had been filled with the proper amount of ash previous to the start of the work on each section. This was not done prior to starting Section 4. As a result, each batch truck had to wait while the proper amount of fly ash was weighed into the drums and they were hoisted up on the trucks and dumped. Instead of mixing a batch of concrete every 45 to 60 seconds, only one batch was mixed about every 5 minutes. The slump was allowed to run a little high so that the concrete would be sufficiently plastic to allow proper hand finishing by the time all the equipment was out of the way and the hand finishers could get to the pavement. The temperature was again high, ranging between 87° and 94°F. Consequently, there was a tendency toward drying of the surface of the concrete.

Section 5 - Station 13 + 52 to 17 + 41.—Work commenced at 7:30 a.m. on July 9, 1955, for the paving of Section 5. There was trouble throughout the section in obtaining the proper air content. Adding the same nominal amount of Vinsol resin solution, the air content varied considerably.

The batching of the fly ash progressed at a more satisfactory rate, although there were some delays. There were also some delays with the paving operation itself. In one place the concrete had to be dug away from an expansion joint when it was not aligned properly, halting the progress for several minutes.

The day was clear and hot, the temperature ranging from 80° to 97°F during the time of pouring.

SAMPLING AND TESTING PROCEDURES

The procedures used in sampling and testing the fresh concrete, concrete materials, and hardened concrete generally followed Michigan State Highway Department practices, which are based on American Society for Testing Materials methods. Samples of the concrete materials were taken daily, as mentioned previously, for testing in the laboratory.

Field tests on the fresh concrete consisted of the following:

(1) Air test: Using an Acme pressure air meter, tests were made about every hour after the proper amount of air-entraining admixture was determined for each section. The samples of concrete were taken from three successive batches whenever possible to rule out minor variations between batches.

(2) Slump test: An average of 3 slump tests were made in each section. More frequent tests were unnecessary since it was possible to tell from the appearance of the fresh concrete if any substantial change in slump had occurred.

(3) Kelly ball penetration: As a proposed method for measuring the workability of the plastic concrete as a possible replacement for the slump test, this method was used only infrequently in the first three sections and not at all in the last two sections.

(4) Weight per cubic foot determinations: These determinations were made at one point in each section. The calibrated measure was filled and weighed three times for each test in order to give an average.

(5) Temperature of the fresh concrete was observed once or twice in each section. The temperature remained quite steady, ranging between 82° and 89°F with little regard for the variations in air temperature.

(6) Air temperature was recorded by a recording thermometer for the entire period from 8 a.m., July 7, to noon on July 12 (see Fig. 2).

In addition to these tests on the fresh concrete, there was a continual visual inspection, watching particularly for finishing qualities, sufficiency of the mortar constituent, and other matters which may effect the concrete quality. A log showing the results of the field tests and observations may be found in the Appendix.

Samples of the fresh concrete were cast into cylinders, slabs, beams, and bars for testing at later ages. Two groups of 6- x 12-inch cylinders were cast for compression testing. Group A consisted of three cylinders for each age of 1, 3, 7, 28, and 90 days and 1 and 5 years. These cylinders were cast in waxed cardboard molds with metal bottoms. No effort was made after molding to prevent loss of moisture by evaporation. The 1-day cylinders were returned to the laboratory in time to be broken 24 hours after molding. The other cylinders were returned to the laboratory 2 or 3 days after molding and were placed in a moist-fog room for curing until the time for testing. Group B consisted of 4 cylinders for each age of 1, 7, 28, and 90 days and 1 year. These cylinders were cast in tin molds and the top surface was sprayed with curing compound one to two hours after casting. The 1-day cylinders from this series were similarly taken to the laboratory for testing 24 hours after molding. The cylinders for testing at later ages were taken to the laboratory after approximately 4 days. They were air cured, protected by the tin mold and curing compound, until the time for testing.

Several sizes of beams were made for various types of testing. Fourteen beams, 6 x 6 x 36 inches, were made for each section, furnishing two beams for testing in flexure at each age of 1, 3, 7, 28, and 90 days and 1 and 5 years. Two flexure breaks are obtained from each beam, giving four values for the flexural strength in each section for each age. The steel molds were stripped from the beams the morning after casting. Again no effort was made to protect the concrete from the sun and wind. The beams for testing at 1 and

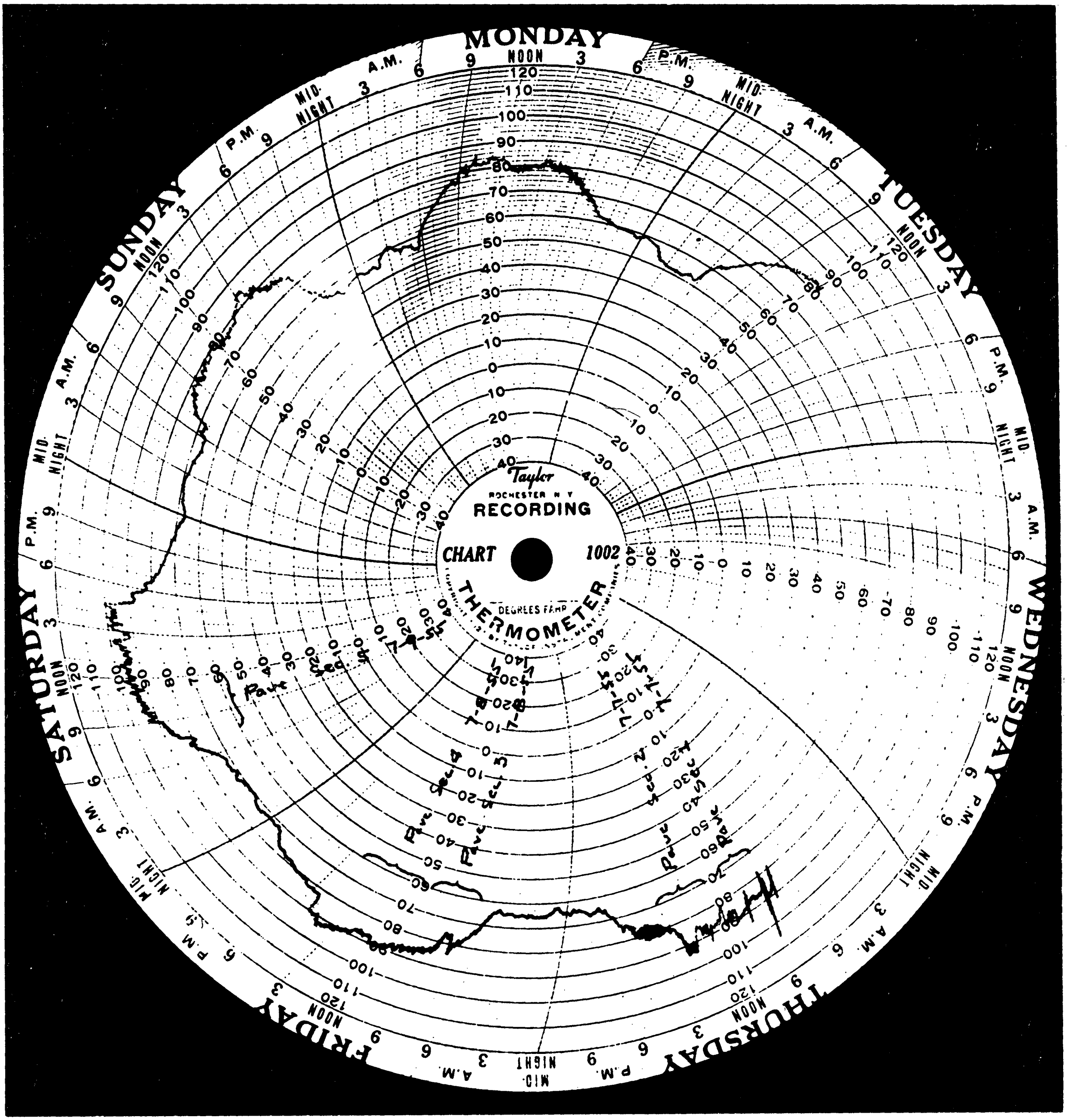

Fig. 2. Air temperatures recorded at experimental road from 8 a.m., July 7 to noon, July 12, 1955.

and 3 days of age were tested in the field. The beams for testing at ages of 7, 28, and 90 days were taken to the laboratory on July 12 and were stored in the moist-fog room until time for testing. The beams for testing at 1 year and 5 years were buried with the top face flush with the ground surface adjacent to the pavement.

A number of bars 3 x 4 x 16 inches were cast for each section. This concrete was screened prior to molding to eliminate all coarse aggregate retained on a 1-inch sieve. Several of these bars from each section were cast with stainless-steel gage inserts embedded in the ends. These bars are being used to measure the drying shrinkage of the concrete. Another set of bars of the same size were made in the same manner, but without the gage inserts. These bars are being used to study the durability of the concrete in freezing and thawing in water. As with the larger beams, these bars were unprotected from the weather until taken to the laboratory about 3 days after casting and were moist-cured from that time until the freezing and thawing was started.

Two small slabs, 16 x 24 inches, with integral curbs about 1 inch high, were made for each section. These are to be used to study the resistance to scaling due to application of sodium chloride for ice removal. These slabs were sprayed with curing compound shortly after molding. About 5 days after molding they were buried with the top surface flush with the ground adjacent to the pavement. On November 10 the slabs were brought to the laboratory since there would not be personnel available at the road site to conduct the test. The top surface of one slab from each section is flooded with a sodium chloride solution and alternately frozen and thawed in the laboratory cold room. The top of the other slab from each section will be subjected to natural freezing and thawing with sodium chloride outdoors.

In all cases, the concrete for the test specimens was obtained toward the end of each test section. In Section 1 the concrete was obtained by the shovelful just after it was deposited by the mixer on the subgrade. This involved carrying the concrete across a ditch to get to the point where the specimens were fabricated. Because of the large amount of concrete required for the numerous samples, about 3/4 cubic yard, the concrete for the specimens in the remaining sections was deposited from the mixer immediately adjacent to the molds. In this way all the concrete for one group of cylinders came from one batch, all the concrete for the other group of cylinders and the slabs came from another batch, and all the concrete for the beams and bars came from still another batch. This permits the possibility of large differences due to variations between batches, instead of permitting an average by taking the concrete from several batches as was done in the first section.

DISCUSSION OF TEST RESULTS

In Table I is recorded the data in regard to mix proportions, tests on fresh concrete, and compressive and flexural strengths.

AIR CONTENT AND ADMIXTURE REQUIREMENT

There was no trouble in obtaining as much air as desired in any of the sections, but in some cases there was considerable trouble in controlling the uniformity of air content. Near the beginning of each section, there was some experimenting to find the proper amount of air-entraining admixture to be added; but the correct amount was usually determined after one adjustment. Section 2 required three adjustments, but the correct amount of admixture proved to be that used after the first adjustment. In Section 5 the air content never stabilized, so it is unknown which amount of admixture was correct. This may have been caused by variations between the amount of admixture which it was desirable to add and the amount actually added due to the procedure used in measuring the admixture. Some batches may have had considerably more mixing than normal, due to delays, which would tend to cause more air to be entrained.

The quantity of air-entraining admixture used in the sections containing fly ash was many times the amount used in Section 1. The amount of Vinsol resin solution used in Section 1 was about 1/3 quart per batch, whereas the sections containing fly ash required from 2 to 5-1/2 quarts per batch. Table II shows the amount of Vinsol resin used per cubic yard of concrete to produce the desired air content and also the amount used in the fly-ash sections in relation to that used in the control section.

The use of fly ash in air-entrained concrete does present some serious, although not insurmountable, problems in regard to the air-entraining admixture requirement. The hand batching of the air-entraining admixture would not be satisfactory for extensive operations since there is a great chance for inaccuracy in the measurement and the batching. Some type of automatic dispenser would be required.

It may be somewhat more difficult to determine the proper amount of admixture to use when starting a job using fly ash than at present using plain cement concrete. Thus, it may be necessary to take more checks of the air content than is the present practice.

TABLE II

VINSOL RESIN REQUIRED IN EACH TEST SECTION

Section	Vinsol Resin	
	lb/cu yd	Amount Used in Relation to Section 1
1	0.078	1.0
2	0.442	5.7
3	0.447	5.7
4	0.539	6.9
5	0.892	11.4

COMPRESSIVE STRENGTH

The compressive strength of the concrete was determined in three ways: from the two sets of cylinders described previously and from cores drilled from the pavement. The compressive-strength results from the three groups of compression specimens have been plotted against age in Figs. 3, 4, and 5. Each group gave different values for the compressive strength for the same section and age, but the variation is quite consistent in direction if not in magnitude.

The cylinders which did not receive protection on top from weather during the first two or three days (Group A in Table I) have the lowest compressive strength in nearly all cases. The cylinders which had the top surface sprayed with curing compound (Group B) generally had the next highest strength. The drilled cores (Group C) usually had the highest strength. There are some exceptions to these generalities, however. In Section 4 the two sets of cylinders gave strengths which are approximately equal at all ages. The core strengths have a tendency to fluctuate somewhat and occasionally had strengths below the corresponding cylinders from Group B.

None of the sections containing fly ash develop as much compressive strength as the control section at any age up to 90 days, with one exception. At 90 days of age the Group B cylinder strengths show Sections 2 and 5 to be slightly stronger than Section 1. The Group A cylinders and the cores do not confirm this, however.

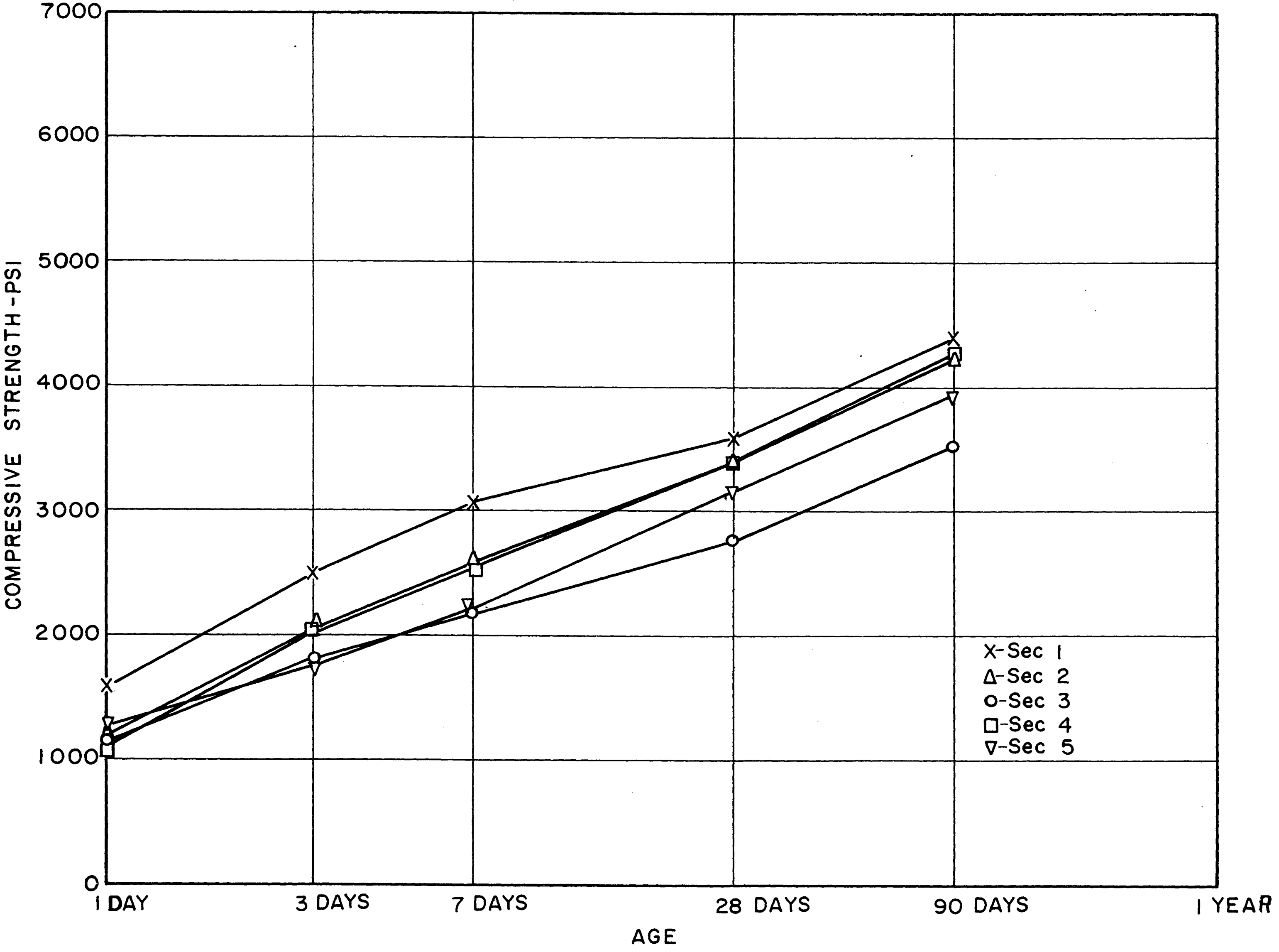

Fig. 3. Compressive strength of Group A cylinders.

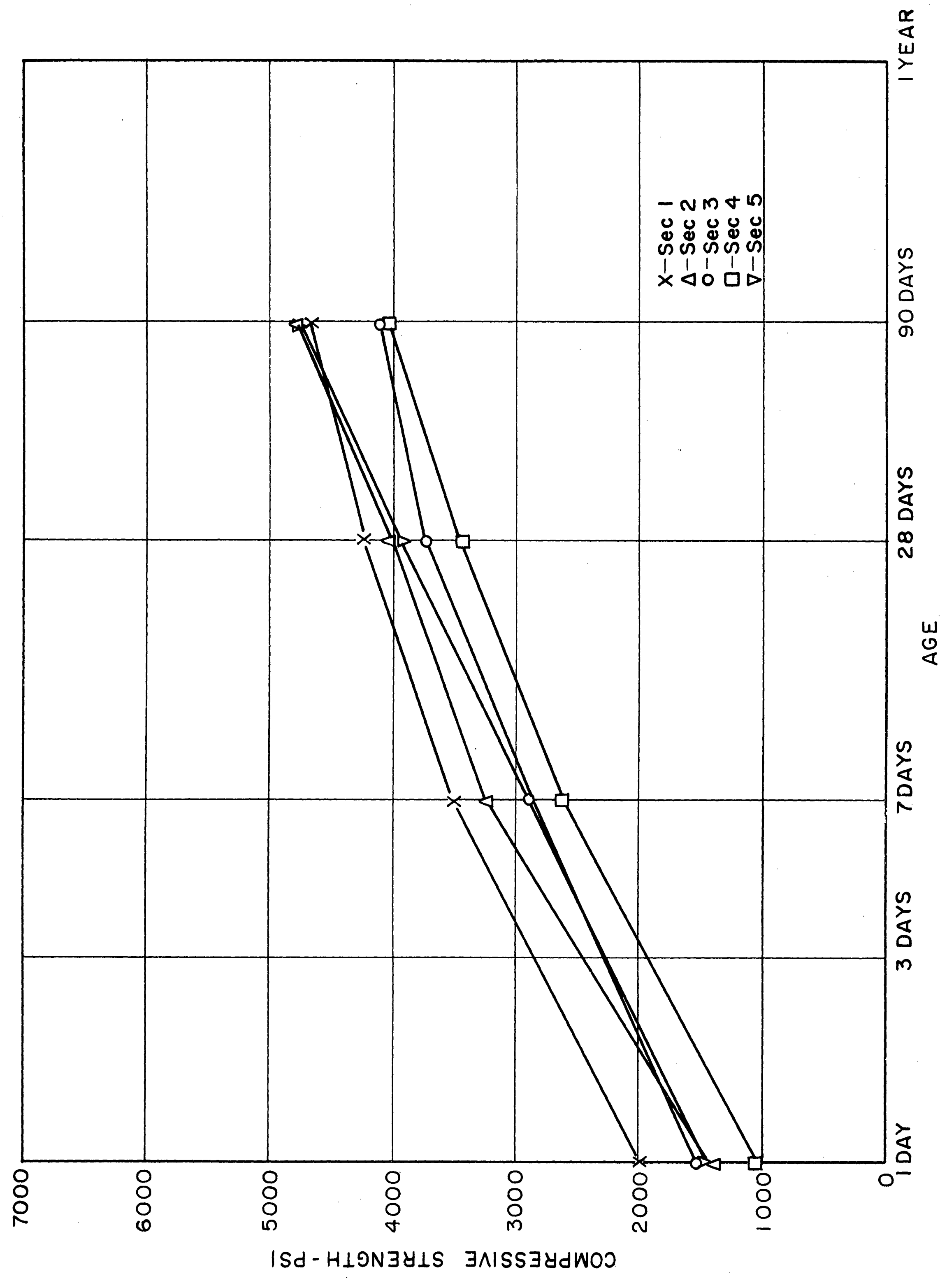

Fig. 4. Compressive strength of Group B cylinders.

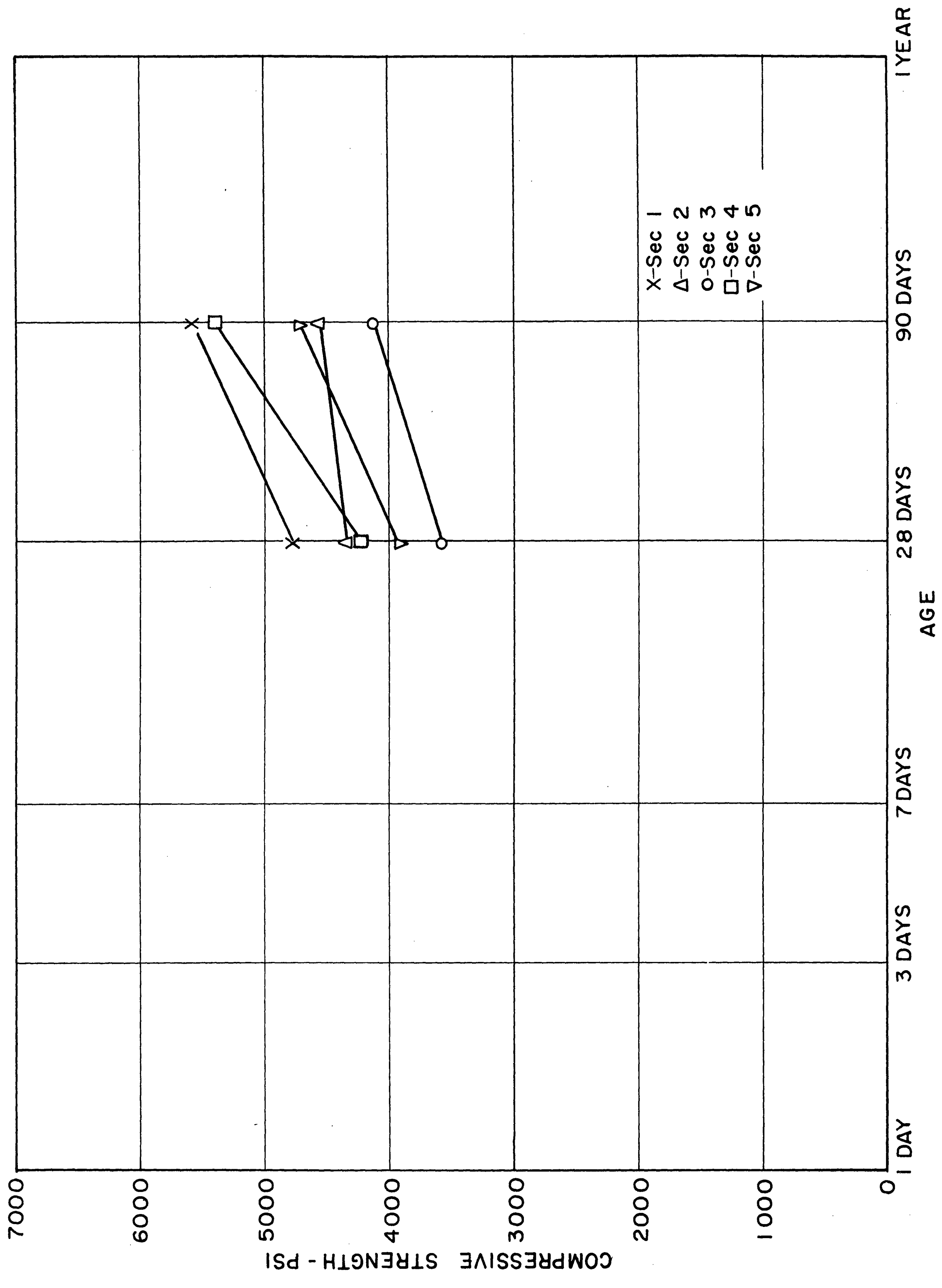

Fig. 5. Compressive strength of drilled cores (Group C).

The Michigan State Highway Department specifications require that the concrete for pavements have a compressive strength at 28 days of age of 3500 psi. Based on the core strength, the concrete in all sections exceeded this requirement. Based on the strength of cylinders in Group B, the concrete in Section 4 was slightly low in compressive strength. Based on the Group A cylinder strengths, Section 1 is the only section with concrete of sufficient strength to meet specification requirements. By 90 days the concrete in all sections had surpassed the 3500-psi requirement, but concrete from Section 3 in the Group A cylinders was just slightly over the requirement.

FLEXURAL STRENGTH

The flexural strengths of all the test beams are shown in Table I. Two beams, 6 x 6 x 36 inches, were made for each section for each age of 1, 3, 7, 28, and 90 days and 1 and 5 years. Two breaks are obtained from each beam, giving four values for the flexural strength for each section and each age. The average results are shown graphically in Fig. 6.

There is no real ranking of the different sections before 7 days of age. The values for Section 5 have been consistently the lowest, even though from the compressive strengths that section would be ranked third or fourth. At 28 and 90 days of age, Sections 2, 3, and 4 had higher flexural strengths than the control, even though the control had the highest compressive strength.

All the flexural strengths appear to be somewhat low as compared to the State Highway Department specifications. These specifications call for strengths of 550 psi at 7 days and 650 psi at 28 days. Only the beams from Section 1 exceed the requirement at 7 days and only the beams from Section 4 exceed the requirement at 28 days. Section 5 beams are particularly low, failing to attain the 7-day requirement at 28 days of age and the 28-day requirement at 90 days of age. Part of the reason for the poor results in the flexural strength in Section 5 may be excessively high air content in the test specimens. Checks of the air content on batches made before and after the beams were made gave readings of 6.3 percent and 9 to 10 percent (latter value estimated - off the scale) with a constant amount of air-entraining admixture being added. Another factor which probably contributed to the relatively low strength of all beams was the lack of moist-curing for the first 3 to 5 days. During that time the beams were exposed to the drying of the sun and wind. The pavement itself was protected by the curing compound, which prevented loss of moisture during the important first few days and, therefore, has probably greater flexural strength than is indicated by the test beams.

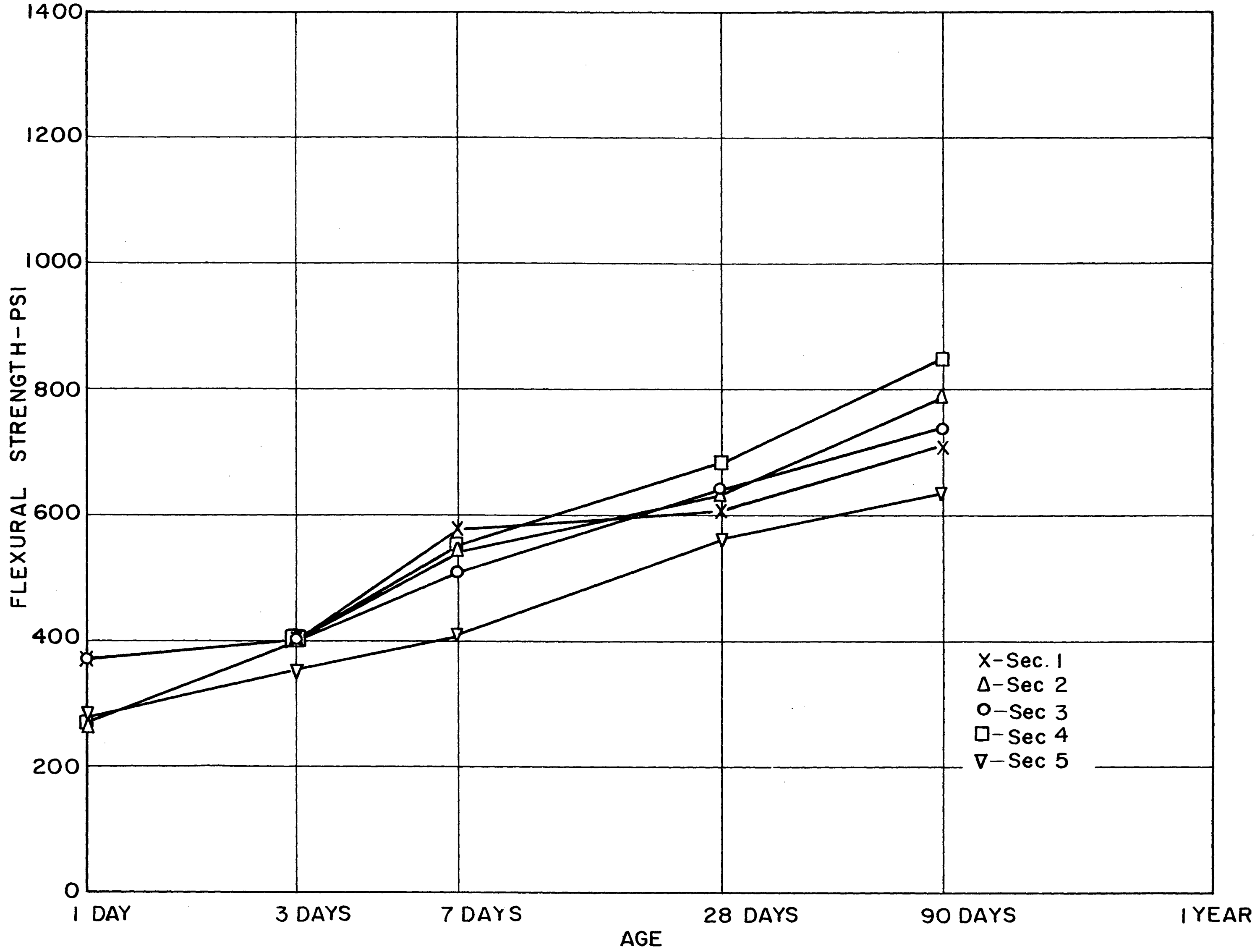

Fig. 6. Flexural strength of beams.

WATER REQUIREMENT

Examination of Table I shows that there was very little difference in the amount of net water used per cubic yard of concrete in the various sections of the project. The greatest variation in water from the amount used in the control section was about 5 percent additional water in Section 4. In this section, the progress of the work was slowed by the batching of the fly ash and the water was intentionally increased so that the concrete would be sufficiently plastic for finishing. In many cases, this variation is less than the adjustment in the amount of water to correct the slump.

Comparison of the slump with the amount of water used reveals a direct relationship in nearly all sections. Only in Section 5 did the slump fail to fall in line when the sections were ranked by the amount of water used. This is excellent correlation considering the great differences between the concrete of the various sections and especially the higher coarse-aggregate contents used in the fly-ash mixes.

There is a much greater difference when considering the various mixes from the viewpoint of the relative water-cement ratios. Because of the considerable difference in cement content, the water-cement ratio varies from about 5 gallons per sack to 7.2 gallons per sack. However, there is not the normal drop in strength usually experienced with such an increase in the water-cement ratio.

COMPARISON OF FIELD AND LABORATORY CONCRETE

Samples of the stone, sand, cement, and fly ash used on the experimental project were obtained directly from the batch-plant bins on the job for use in concrete to be made, cured, and tested in the laboratory. These were used in the same proportions as in Section 4 of the road project. Two cylinders for compression testing at 1, 7, 28, and 90 days, and one beam of 6 x 6 x 36 inches for flexural testing at 7, 28, and 90 days, were made from each of 3 batches, providing 6 cylinders and 3 beams for each age.

The mixing in the laboratory was done in a Blystone mixer having rotating paddles on a horizontal shaft. The mixer was "buttered" with a mixture of sand, cement, and water before the materials were introduced. The measured amounts of sand, cement, and fly ash were introduced into the mixer along with most of the water and the Vinsol resin. The mixer was started and the stone was dumped into it during the first 15 seconds of mixing. This procedure was followed since there was not sufficient room in the mixer for all the materials without the shrinkage due to the intermixing. The mixing continued for two minutes, during which time small additional quantities of water were added to bring the estimated slump to about 2 inches. The concrete was then given a 2-minute rest period with the mixer stopped to give the aggregates a chance to absorb moisture. This rest period was followed by a 3-minute final mixing. The concrete was then dumped into a moistened pan and slump and air tests were performed, followed by a weight-per-cubic-foot determination. The concrete was then cast into 3 beams and 8 cylinders. After 1 day in the molds, the concrete specimens were placed in the moist-fog room for curing until tested.

The sand used in the mixes was damp and the sand in the third batch was considerably more damp than that used in the first 2 batches. As a result of the use of an incorrect value for the moisture content, the actual weight of sand was slightly less than the amount called for by the design.

The mix proportions and test results are tabulated in Table III.

AIR CONTENT

In the first batch, the same relative quantity of Vinsol resin was used as in the field operation; but the resulting air content was appreciably lower. This decrease in air content probably was due to the different types of mixing action received by the concrete from the paving mixer on the one hand and the laboratory mixer on the other hand. The Vinsol resin was increased slightly in the second and third batches. The amount of water used in these mixes was also increased, which has a tendency to increase the amount of air entrained by the concrete. The effect of these two adjustments was to increase the air content so that it more nearly equaled the amount obtained in the field mixing of the concrete.

COMPRESSIVE STRENGTH

The laboratory-mixed concrete had compressive strengths approximately 200 to 600 psi greater than the field-mixed concrete, the larger increase being at the ages of 28 and 90 days. This increase is in spite of an increase in the water averaging approximately 3/4 of a gallon per sack of cement in the laboratory mixes. The strength gain is orderly as it was with the concrete made in the field.

In the three batches made in the laboratory, the first batch consistently had the highest strengths and the third batch consistently had the lowest strengths. This can be attributed largely to the changes in the water-cement ratio between the three batches. The first batch had the additional advantage of a low air content, which usually has a tendency to produce higher strengths in concrete with sufficient fine material to lubricate the mix.

TABLE III. ST. CLAIR TEST ROAD MATERIALS IN LABORATORY CONCRETE

Batch No.	Date Made	Fly Ash, lb/cu yd	Actual Cement Content, sk/cu yd	Material Proportions lb/cu yd			Actual w/c gal/sk	Wt. Fresh Concrete, lb/cu ft	Pressure Air Content, percent	Slump, in.	Vinsol Resin, lb/cu yd	Compressive Strength, psi				Flexural Strength, psi		
				Sand	Stone	Net Water						1 day	7 days	28 days	90 days	7 days	28 days	90 days
297	9-15-55	150	4.69	927	2250	249	6.63	155.4	3.6	1-1/2	0.539	1505	3040	4595	5460	600	883	907
												1525	3180	4150	5300	550	787	947
										Average		1515	3110	4370	5380	575	835	927
298	9-19-55	150	4.50	927	2250	267	7.12	149.8	4.7	2-1/4	0.578	1245	2650	3675	4645	540	733	870
												1295	2670	3960	4715	513	753	907
										Average		1270	2660	3815	4680	527	743	889
299	9-20-55	150	4.50	885	2250	292	7.79	149.2	5.5	2-1/4	0.578	1095	2685	3550	4665	533	780	967
												1160	2650	3550	4505	493	813	767
										Average		1125	2665	3550	4585	513	797	867
Grand Average		150	4.56	913	2250	269	7.18	151.5	4.6	2.0		1304	2812	3913	4882	538	792	894

FLEXURAL STRENGTH

The flexural strength, like the compressive strength, generally was higher for the laboratory concrete than for the concrete made in the field. An exception was in the 7-day strengths, when the strengths of the laboratory beams were slightly below the strengths of the beams made in the field. This was reversed at 28 and 90 days, when the laboratory beams had the higher strengths. In all cases, the differences was quite small—about 100 psi at 28 days and 50 psi at 90 days.

The higher strengths were again achieved in spite of an increased amount of water used in the laboratory. Improved curing is presumed responsible for the strength improvement. The beams and cylinders were covered to prevent loss of moisture by evaporation while they were in the molds and were placed in the moist-fog room for curing within 24 hours after molding.

CONTINUING TESTS

A number of tests will be continued over a period of months or years.

COMPRESSION AND FLEXURE TESTS

Sufficient beams and cylinders were made on the field job to provide for testing at 1 year and 5 years of age. Of the two groups of cylinders, Group A, cast in cardboard molds, was placed in the moist-fog room for curing until tested. There are three cylinders for each section for both 1-year and 5-year compression tests. The Group B cylinders, cast in metal molds, were sprayed with a membrane curing compound on the top surface to prevent loss of moisture, but received no other curing. There are four of these cylinders for each section remaining and they will all be tested at 1 year of age. Cores will be drilled from the pavement at 1 and 5 years of age for compression testing, and at other ages if this should seem desirable.

Two concrete beams, 6 x 6 x 36 inches, for each section for each age of 1 year and 5 years are available for testing at the proper time. These beams are buried with the top face flush with the ground surface near the road. At the proper time these beams will be brought into the laboratory for testing in flexure.

FREEZING AND THAWING STUDY

Bars made of the concrete from each section are being tested for resistance to rapid freezing in water and thawing in water. Two of the bars, 3 x 4 x 16 inches, from each section were placed in the automatic freeze-thaw unit at the age of 4 months, when space became available. This was early in November, 1955, about the time the pavement would be first subjected to freezing and thawing. One additional bar from each section was placed in freezing and thawing at the age of 5 months, when additional space became available.

The temperature of each bar drops from 40° to 0°F in 3 hours and then is raised to 40°F again in 1 hour, with the automatic equipment. Thus, six cycles are obtained each 24 hours.

The beams are tested at intervals by determining the sonic modulus of elasticity. This is compared with the value obtained just before the initial cycle of freezing and thawing. When the sonic modulus has dropped to 70 percent of the initial value, the beam is considered to have failed.

Table IV gives the number of cycles required for failure of the concrete in freezing and thawing. Bars 1 and 2 were placed in the freezer at the age of 4 months and Bar 3 was placed there at the age of 5 months. It should be noted that the additional month of curing did not add appreciable resistance to freezing and thawing.

TABLE IV

CYCLES OF FREEZING AND THAWING IN WATER TO CAUSE FAILURE

Section	Cycles for Failure				Approximate Air Content, Percent
	Bar 1	Bar 2	Bar 3	Average	
1	*684+	445	*504+	544+	4.5
2	122	82	107	104	4.5
3	142	246	160	183	5.7
4	118	335	184	212	5.5
5	349	347	98	265	3.4

*Still in freezer at time of writing

The status of this severe artificial-weathering test, wherein the concrete is repeatedly frozen and thawed while continually immersed, is now such that scarcely more than an indication should be drawn from the results obtained. The literature is now well documented with contradictions when attempt has been made to correlate field performance with laboratory exposure using this method. The facts seem to be that small variations in the composition of the concrete of presently unknown character greatly influence the behavior of specimens in this test. Recognition is given, however, to the overwhelming importance of air entrainment, which field studies have amply demonstrated.

In this particular series of tests, it seems proper to assume that there were no differences in freeze-thaw behavior due to differences in handling the specimens since, with the exception of the above-mentioned two curing periods, all specimens were physically close together and handled as a single lot.

From the indications of these tests, the superiority of the control section without fly ash is outstanding. It may well be, however, that all the specimens show sufficient resistance to freezing and thawing to predict that the pavement sections may give a good account of themselves in field performance. The trend of the data, which shows somewhat improved resistance with increasing fly-ash contents and diminishing cement contents, is unexpected and deserves confirmation by observation of field performance.

SURFACE-SCALING STUDY

To study the effect of the use of sodium chloride for ice removal on the surface of the concrete, small slabs were cast at the experimental road site. Two slabs, approximately 16 x 24 inches with integral curbs were cast for each section. The top surface was sprayed with curing compound shortly after the slabs were cast. Approximately 1 week later the slabs were buried with the top face flush with the ground surface adjacent to the pavement. After 4 months the slabs were transferred to the laboratory for testing. Most of the curing compound was removed from the surface by wirebrushing.

One slab from each section is being tested under "natural" conditions. It is placed outdoors and the top surface flooded with a 4-percent solution of sodium chloride. The surface will be flushed occasionally and the solution renewed.

The other slabs from each section are being subjected to a more rapid test. These slabs are flooded with a solution of sodium chloride, moved into the laboratory cold room for the solution to freeze overnight at a temperature of 0°F, and then removed for the solution to thaw at laboratory room temperature. This furnishes one complete cycle each working day.

The progress of the resulting scaling will be determined by visual examination and by photographs which will be taken at suitable intervals.

VISUAL INSPECTION

The pavement has been and will continue to be under a visual inspection whenever it is possible for personnel to get to the site.

Vehicles were driven on the pavement soon after it was laid. On July 9, 1955, a light panel truck drove on Sections 1 and 2 when that concrete was about 48 hours old. Visual inspection revealed no damage to the concrete. One or two cars drove from the beginning of the project to approximately Station 16 + 00, turned around and drove back to highway M-29, before the concrete in Section 5 was 24 hours old. Again visual inspection revealed no damage to the concrete.

During an inspection when the pavement was 3 months old, the first crack was discovered. It is located at the eastern end of the project in Section 5 where the pavement flares for the turning radius from River Road. The pavement is 6 feet wide where cracked, 12 feet from the point of the flare. Trucks hauling fly ash from the Edison Plant cut the corner short so that the wheels dropped off the pavement of River Road, traveled several feet on the shoulder, and then hit this corner of pavement and bounced up on it. The concrete in the Section 5 pavement could not be said to be inferior on the basis of this one crack since it was caused by an unusual impact loading.

GENERAL OBSERVATIONS ON TEST ROAD

Certain observations made during construction of the test road and during assembly of the data seem worthy of note here.

(1) Although partially anticipated when planning the project, actual experience on the job amply demonstrated that the individual test sections were too short to develop fully all the information desired. The contractor provided the paving equipment, as requested, for a full-scale operation capable of paving perhaps 1500 feet daily. This meant that his operations were slowed down in paving a 300- to 400-foot test section in a half day and further meant that the paving equipment itself was spread out over practically an entire test section. By the time progress had settled down on a given section, the necessary air and yield checks made and test specimens fabricated, the section was essentially completed. This did not give much opportunity to predict how operations would continue under extended use for a given mix. Practically no opportunity arose to experiment with finishing procedures. Appearance of the pavement after construction indicated that for the sections

having greater fly-ash contents, the burlap drag was applied too early to provide a properly roughened surface. The contractor's personnel were naturally acquainted with procedures where straight Portland cement mixes are used which do stiffen earlier, particularly in the hot dry weather prevalent at the time of construction. There was, therefore, an understandable tendency to finish the surface too early. This was particularly apparent for Section 5, having the lowest cement content and highest fly-ash content.

Briefly, if fly-ash concrete were to be used extensively in pavement work, some re-indoctrination would be required of both the contractor's and the engineer's personnel.

(2) Only one section, Section 5, exhibited job characteristics such as to cause obvious questioning of the wisdom of its use. Severe fluctuations in air content occurred on this section, the reasons for which were not understood, and there was insufficient opportunity to trace the source of the difficulty. It is natural to suspect that the low and, more frequently, high air contents measured were characteristic of the low-cement—high-ash mix; but it is recognized that some other job variable may have been the cause of the trouble. There is reason, therefore, to predict a spotty service behavior of this section in view of the variations in air. These variations may well be reflected in differences in resistance to salt scaling.

(3) The pronounced differences in compressive strengths from the three different series of test specimens give cause for concern and emphasize once again the necessity for strict attention to a standard procedure if comparable results are to be obtained. Relative values did not seem too greatly affected by the different treatments of the test specimens, but absolute values varied considerably, which for acceptance tests could be of considerable consequence.

APPENDIX

LOG—RECOR ROAD EXPERIMENTAL PROJECT

Time	Station	Test	Remarks
July 7 A.M.	0 + 11	-	Start Section 1.
		-	First 34 batches to about station 0 + 50 made with AE cement.
10:20	0 + 65	Air	4.0%—Regular cement with 9 fl oz Vinsol.
10:25		Conc. temp.	86°F.
10:30	0 + 75 (Bottom)	Air	4.4%.
10:30	"	-	Cylinders made (Group B).
10:35		-	Increase Vinsol to 11 fl oz per batch.
10:45	0 + 75 (Top)	Air	6.1%.
10:45	"	Conc. temp.	85°F.
10:55		Slump Kelly Ball	2-3/4 inches. 2-3/4 inches.
11:05	1 + 75	Air	4.8%.
11:05	"	-	Making cylinders (Group A).
11:15		Air	4.3%.
11:20		Wt/cu ft	150.8 lb/cu ft.
12:00	2 + 50	Air	4.6%.
		-	Adding 29 gal water per batch at mixer.

LOG (Continued)

Time	Station	Test	Remarks
July 7 P.M.	2 + 65	-	Start Section 2.
	2 + 75	Air	2.2% with 1 qt Vinsol.
1:25		Air	3.0% with 2 qt Vinsol.
1:25		Conc. temp.	89°F.
1:45	3 + 45	Air	6.2% with 3 qt Vinsol.
1:55		Slump	3 inches.
2:00		-	Adding 30 gal water per batch at the mixer.
2:00		Kelly ball	1-1/2 inches.
2:07		Air	9%± with 3 qt Vinsol.
2:15		Air	4.7% with 2 qt Vinsol.
2:15		-	Cylinders made (Group B).
2:40	3 + 80	Wt/cu ft	150.0 lb/cu ft.
2:40	"	-	Still adding 30 gal water
	4 + 00	Air	4.5%.
	"	-	Cylinders made (Group A).
3:15		Air	4.7%.
3:30		Slump	3 inches.
3:30		-	Beams made.
4:00	5 + 00	Air	4.2%.

LOG (Continued)

Time	Station	Test	Remarks
July 8			
A.M.	5 + 62	-	Start Section 3.
	"	-	Adding 30 gal water per batch at the mixer.
7:35	5 + 80	Air	3.0% with 2 qt Vinsol.
7:35	"	Slump	7 inches.
8:00	6 + 00	Air	3.3%.
8:05		-	Increase Vinsol to 2-1/2 qt per batch.
8:12		Slump	3 inches.
8:17		Air	6.7% with 2-1/2 qt Vinsol.
8:17		Kelly ball	2 inches.
8:17		-	Plenty of mortar.
	6 + 85	Slump	2 inches.
8:30		Kelly ball	7/8 inch.
8:50	7 + 00	Slump	2-1/2 inches.
8:50	"	Air	5.4%.
9:00	7 + 25	Wt/cu ft	147.1 lb/cu ft.
9:00	"	-	Cylinders made (Group B).
9:05		-	28 gal per batch added at the mixer seems to be about the right water for this mix.
	8 + 00	-	Cylinders made (Group A).
	"	Conc. temp.	82°F.
10:30	8 + 75	-	Beams made.
10:45	9 + 25	Air	6.2%.

LOG (Continued)

Time	Station	Test	Remarks
July 8 A.M.			
11:15	9 + 58	-	Start Section 4.
11:15	"	-	Add 3 qt Vinsol.
11:15	"	Slump	2-1/2 inches.
11:30		Air	4.5%.
P.M.			
1:05	10 + 75	Air	4.8%.
1:05	"	Slump	3 inches.
-	-	-	Production slow after about 1:30 p.m. Fly-ash weighing delaying the job, consequently running the slump about 4 inches to allow proper finishing.
2:00	-	-	Cylinders made (Group B).
		Conc. temp.	85°F.
2:30	11 + 60	-	Adding 33 gal water per batch at the mixer.
2:30	"	Air	4.8%.
2:30	"	Wt/cu ft	150.1 lb/cu ft.
			Cut water to 30 gal per batch added at mixer.
3:30	12 + 15	-	Cylinders made (Group A).
4:20	12 + 75	Air	6.4%.
4:45	13 + 20	-	Beams made.

LOG (Continued)

Time	Station	Test	Remarks
July 9 A.M.			
	13 + 52	-	Start Section 5.
7:45	13 + 80	Air	1.8% with 3-1/2 qt Vinsol.
8:00	14 + 20	Air	3.8% with 1 gal Vinsol.
8:20	14 + 50	Air	2.8%.
8:20	"	-	Adding 34 gal water per batch at the mixer.
8:20	"	Slump	3-1/2 inches.
8:30		-	Increase Vinsol to 4-1/2 qt per batch.
8:40		-	Decrease water to 32 gal per batch at the mixer.
8:40		Slump	2-1/4 inches.
8:40		Conc. temp.	88°F.
8:45		Air	4.7%.
8:50	15 + 00 (Bottom)	Air	4.0%.
8:50	"	Wt/cu ft	150.0 lb/cu ft.
9:15	14 + 75 (Top)	-	Cylinders made (Group A and Group B).
9:15	"	Air	2.8%
	15 + 00 (Top)	-	Small beams made.
9:30		Air	3.7%.
9:50	15 + 70	Air	6.3% with 5-1/2 qt Vinsol.
10:00	16 + 00	Slump	2-1/2 inches.
10:00	"	Conc. temp.	88°F.

LOG (Concluded)

Time	Station	Test	Remarks
July 9 A.M.			
10:10	16 + 25	-	Beams made.
	-	-	Light panel truck observed driving on Sections 1 and 2, from highway M-29 to station 5 + 00 where it left the pavement. Visual inspection did not reveal any damage to the pavement.
		Slump	3/4 inch.
		-	Change water at the mixer to 30 gal per batch.
10:45		Air	9 to 10%.
10:45		-	Cut water at the mixer to 29 gal per batch.
11:00	16 + 75	Slump	3-1/2 inches.
11:05		Air	9 to 10%.
11:05		-	Cut Vinsol to 5 qt per batch.

TABLE I-A

SUBBASE AND SUBGRADE SOIL SAMPLES
TAKEN JUNE 30, 1955

Subbase

	Station				
	2 + 25R	5 + 25R	8 + 50R	11 + 25R	14 + 25L
Depth of subbase, inches	13	13	9	13	-
Passing, percent					
1 inch	100	100	100	100	-
No. 40 sieve	97	95	96	93	-
No. 100 sieve	23.4	12.4	25.4	19.3	-
Loss by washing, percent	14.5	6.2	17.3	11.6	-
Density in place (Rainhart)					
lb/cu ft	115	116	112	115	-
at moisture, percent	11.7	11.6	13.3	12.0	-
Field cone density, lb/cu ft	118	-	-	-	-
at moisture, percent	10.8	-	-	-	-

Subgrade

	2 + 25R	5 + 25R	8 + 50R	11 + 25R	14 + 25L
Composition, percent					
Coarse sand	4	3	1	2	1
Fine sand	20	17	12	22	14
Silt	37	38	37	37	36
Clay	39	42	50	39	49
Liquid limit	51	56	62	59	57
Plasticity index	28	32	36	33	33

TABLE II-A

PHYSICAL PROPERTIES OF CEMENT

	Date Sampled	
	July 7, 1955	July 8, 1955
Specific surface, air-permeability test, sq cm per gram	3455	3221
Autoclave expansion, percent	0.09	0.12
Normal consistency, percent	24.4	24.4
Time of set, Gillmore		
Initial	3:05	3:00
Final	5:05	5:00
Compressive strength, psi		
7 days	3933	3354
28 days	5246	4779
Air in mortar, percent	8.6	8.6

TABLE II-A (Concluded)

CHEMICAL ANALYSIS OF CEMENT

	Date Sampled	
	July 7, 1955	July 8, 1955
Ultimate Analysis, Percent by Weight		
Silicon dioxide, SiO_2	20.1	20.1
Aluminum oxide, Al_2O_3	6.3	6.0
Ferric oxide, Fe_2O_3	2.8	2.8
Calcium oxide, CaO	63.7	63.7
Magnesium oxide, MgO	2.4	2.4
Sulfur trioxide, SO_3	2.7	2.4
Loss on ignition	1.5	1.4
Sodium oxide, Na_2O	0.27	0.29
Potassium oxide, K_2O	0.75	0.76
Proximate Analysis, Percent by Weight		
Loss on ignition	2.0	1.0
Tricalcium silicate, $3CaO.SiO_2$	52.0	55.0
Dicalcium silicate, $2CaO.SiO_2$	18.0	16.0
Tricalcium aluminate, $3CaO.Al_2O_3$	12.0	11.0
Tetracalcium aluminoferrite, $4CaO.Al_2O_3.Fe_2O_3$	9.0	9.0
Calcium sulfate, $CaSO_4$	5.0	4.0
Magnesia, MgO	2.0	2.0
Total alkali expressed as Na_2O	0.76	0.79

TABLE III-A

PROPERTIES OF FLY ASH

	Date Sampled		ASTM Requirement
	July 7, 1955	July 8, 1955	
Physical Properties			
Specific surface, air-permeability test, sq cm per gram	3204	3010	2800 min
Compressive strength, percent of control			
7 days	173	160	100 min
28 days	147	167	100 min
90 days	161	171	
Autoclave expansion, percent	0.04	0.04	0.50 max
Drying shrinkage of mortar	0.10	0.11	0.10 max
Specific gravity	2.48	2.36	
Chemical Properties			
Percent by Weight, Moisture-Free Basis			
Silicon dioxide, SiO_2	34.0	37.8	40 min
Aluminum oxide, Al_2O_3	21.2	21.7	
Ferric oxide, Fe_2O_3	25.2	25.9	
Magnesium oxide, MgO	0.8	1.0	3.0 max
Sulfur trioxide, SO_3	0.8	0.5	3.0 max
Loss on ignition	14.0	13.0	12.0 max
Moisture	0.4	0.3	3.0 max

TABLE IV-A

TESTS ON FINE AGGREGATE

	Date Sampled	
	July 7, 1955	July 8, 1955
Passing, percent by weight		
3/8-inch sieve	100	100
No. 4 sieve	97	96
No. 8 sieve	83	84
No. 16 sieve	66	66
No. 30 sieve	47	46
No. 50 sieve	20	17
No. 100 sieve	3.3	2.9
Loss by washing, percent	1.0	1.2
Specific gravity	2.64	2.64
Absorption, percent	1.11	1.27
Fineness modulus	2.85	2.89
Organic matter, plate number	I	I
1:3 mortar-strength ratio		
7 days	1.05	1.21

TABLE V-A

TESTS ON COARSE AGGREGATE

	Size Designation			
	10A		4A	
	Date Sampled		Date Sampled	
	7/7/55	7/8/55	7/7/55	7/8/55
Passing, percent by weight				
2-inch sieve			100	100
1-1/2-inch sieve	100	100	90	96
1-inch sieve	99	99	32	38
1/2-inch sieve	60	43	6	8
3/8-inch sieve			4.1	4.9
No. 4 sieve	6.9	3.8		
Loss by washing, percent	1.5	1.0	1.2	1.3
1. Soft and nondurable particles, percent	0.6	0.3	0.1	0.0
2. Chert, percent	0.0	0.0	0.0	0.0
3. Hard absorbent sandstone, percent	0.0	0.9	0.0	2.7
4. Sum of 1, 2, and 3, percent	0.6	1.2	0.1	2.7
5. Thin or elongated pieces, percent	1.8	2.3	0.0	0.0
Specific gravity	2.78	2.78	2.78	2.79
Absorption, percent	0.74	0.64	0.54	0.51

Plate I. Fresh concrete being deposited for the top course of the pavement from the mixer bucket. Note the steel reinforcing which was used throughout the project. Section 1.

Plate II. The spreader distributes the fresh concrete over the full width of the pavement, leveling it to the approximate finished grade. Section 5.

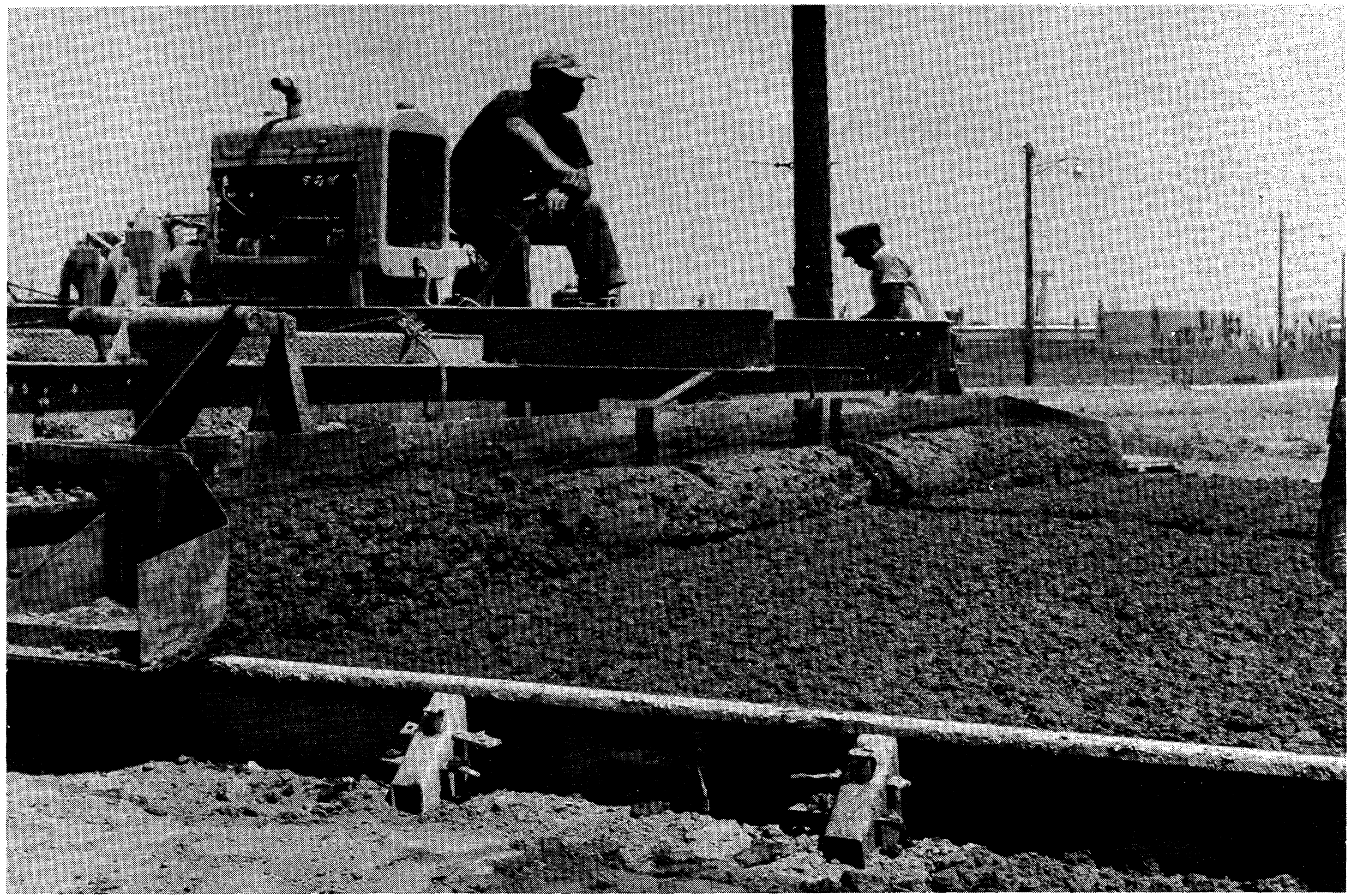

Plate III. A uniform roll of concrete in front of the finisher insures a good finish. Section 5.

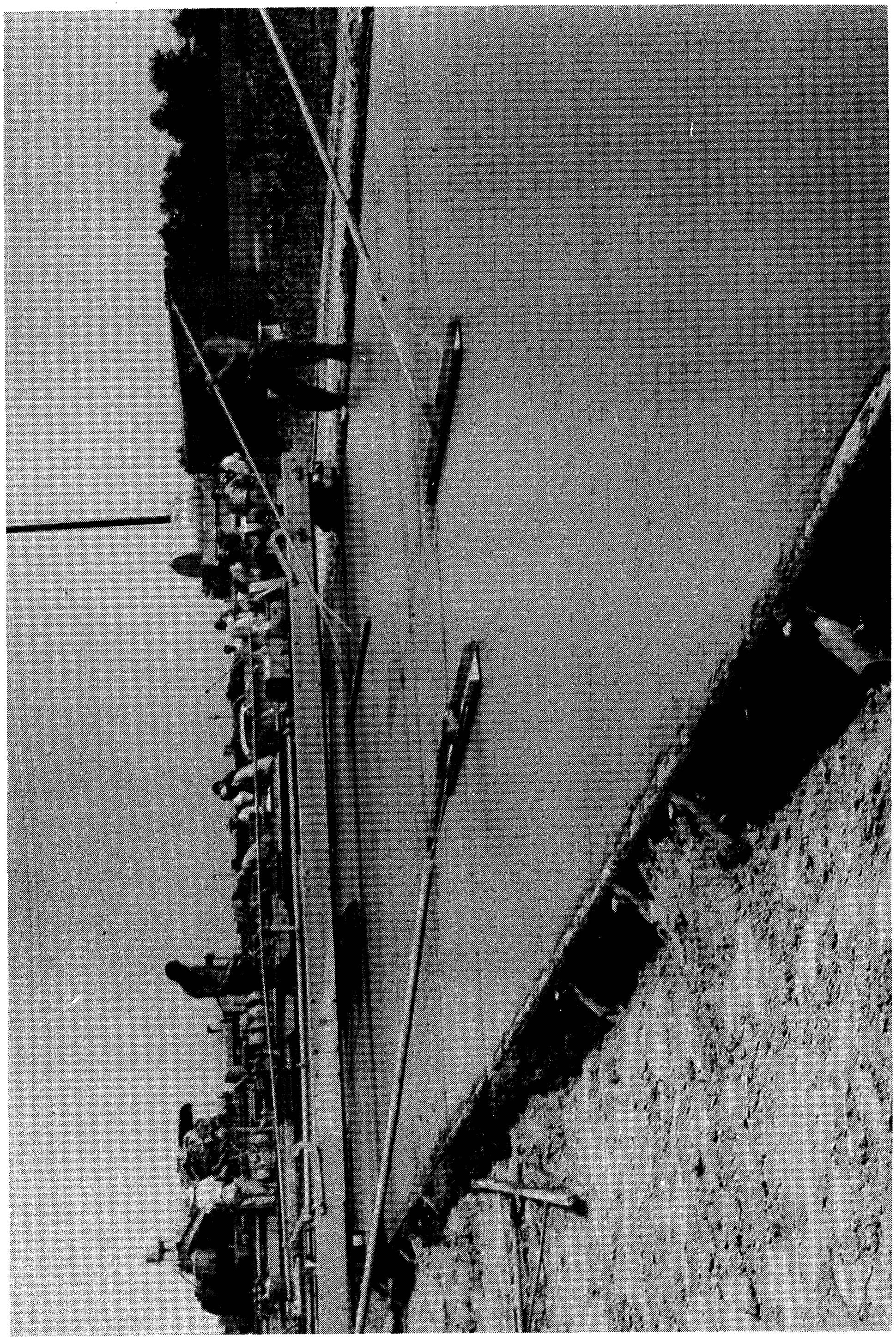

Plate IV. The longitudinal float gives a surface free from small irregularities. Hand finishers touch up any small defects. There is plenty of the mortar constituent despite increased stone content in this concrete. Section 2.

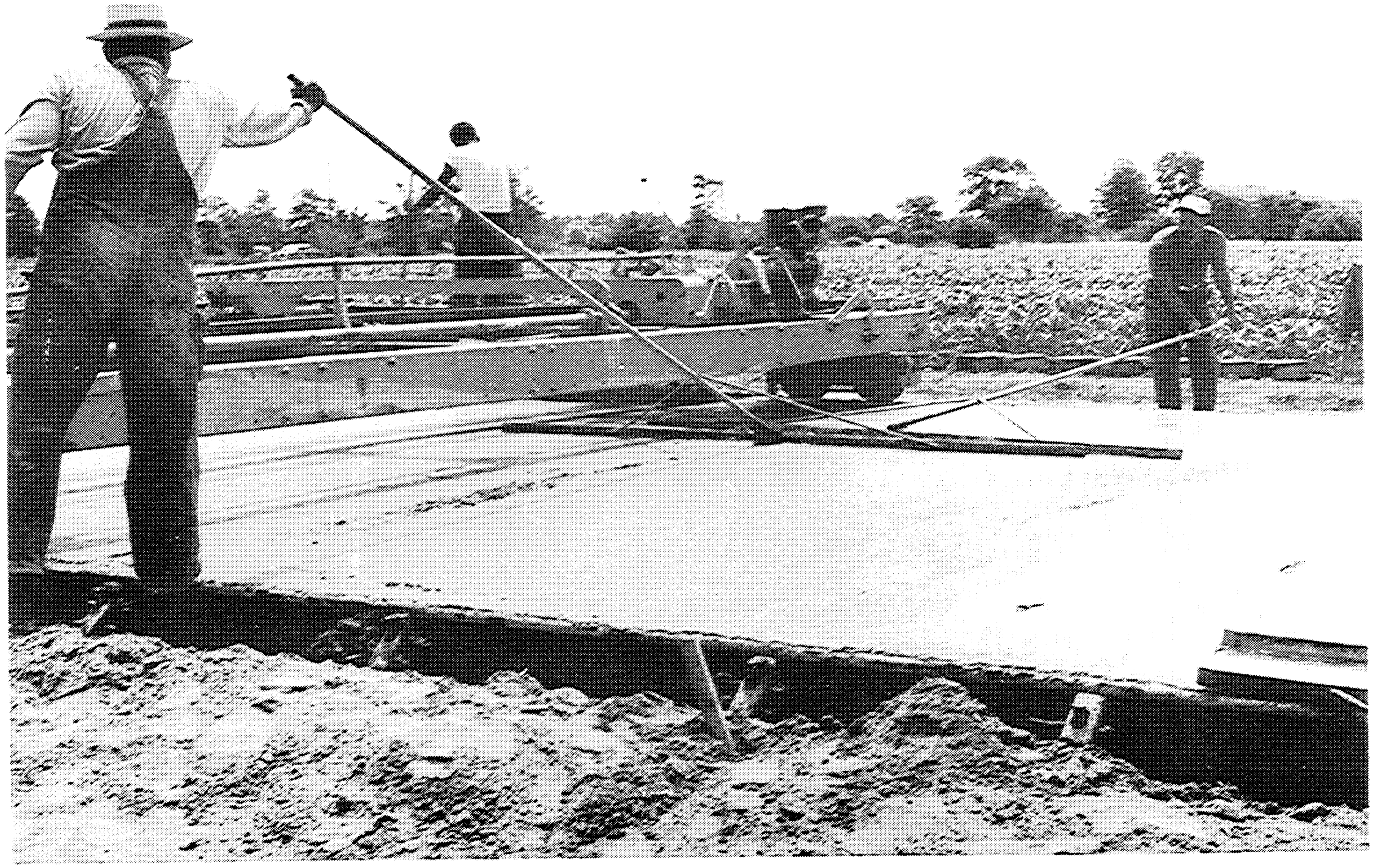

Plate V. Another view of the longitudinal float and hand finishing, in Section 1. Beams for flexural test in the background.

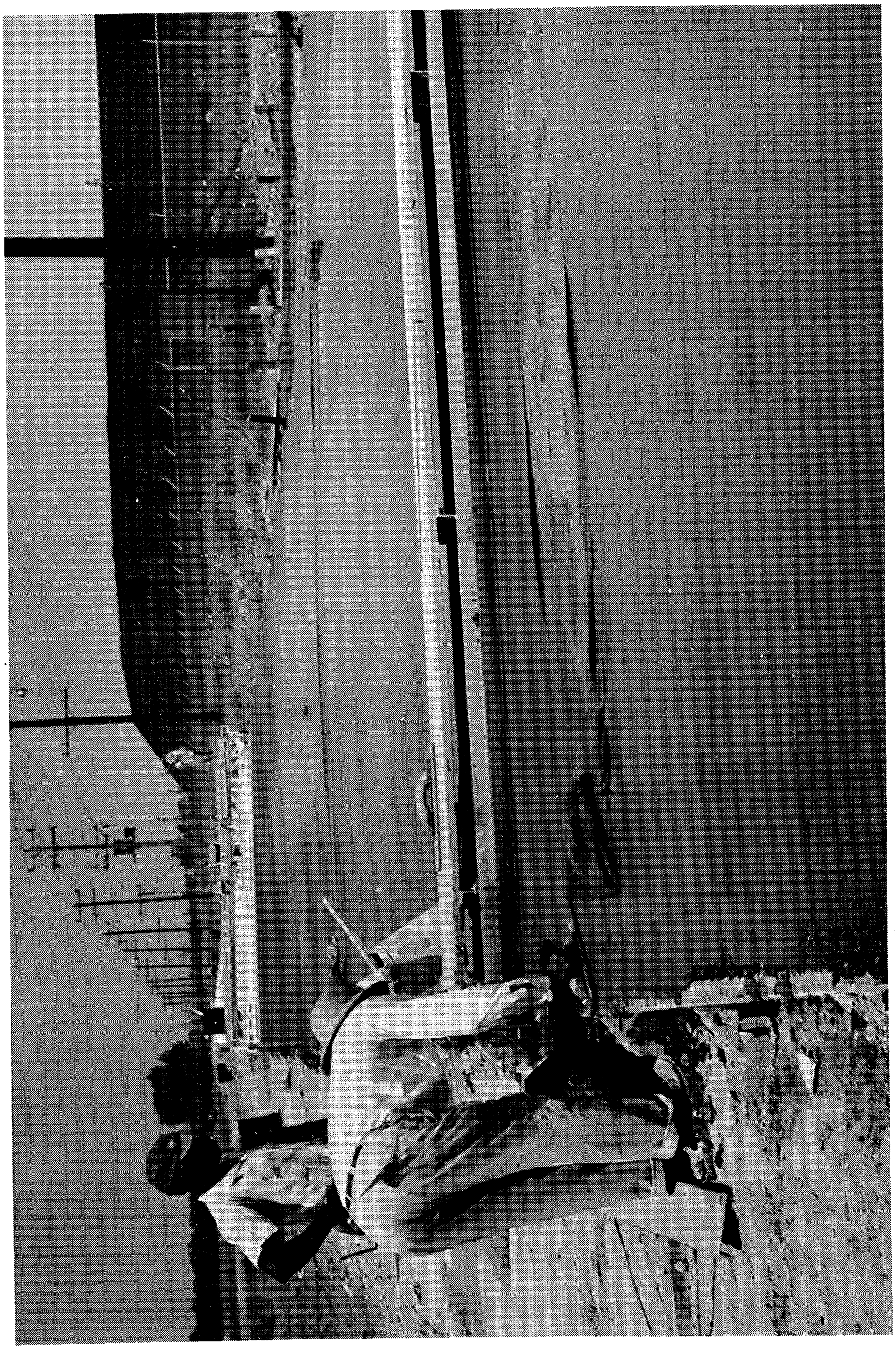

Plate VI. Hand finishers do a little touching up while the curing-compound spreader slowly approaches with its impermeable white cover for the concrete. Section 5.

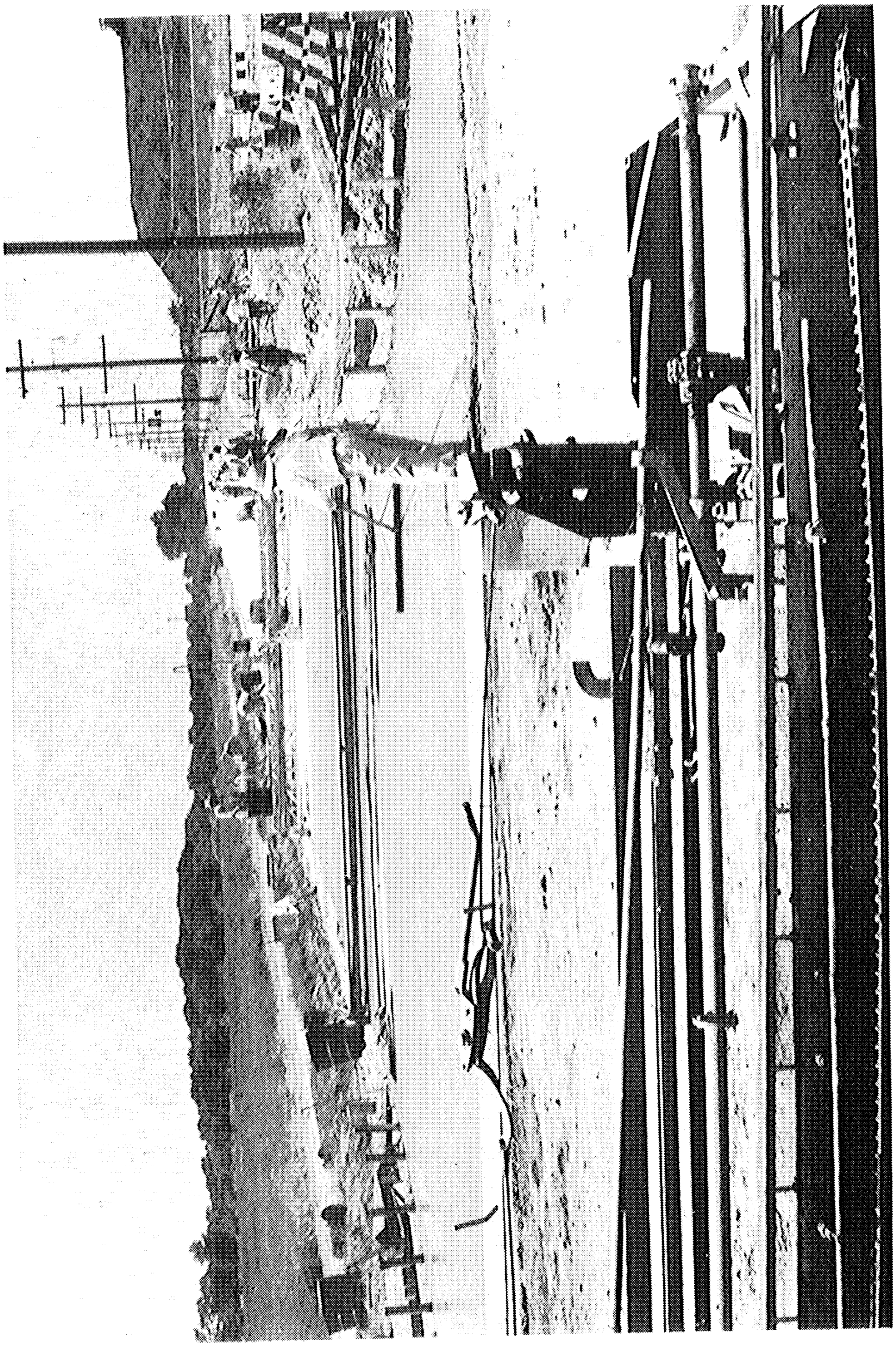

Plate VII. Finishing the project in Section 5.

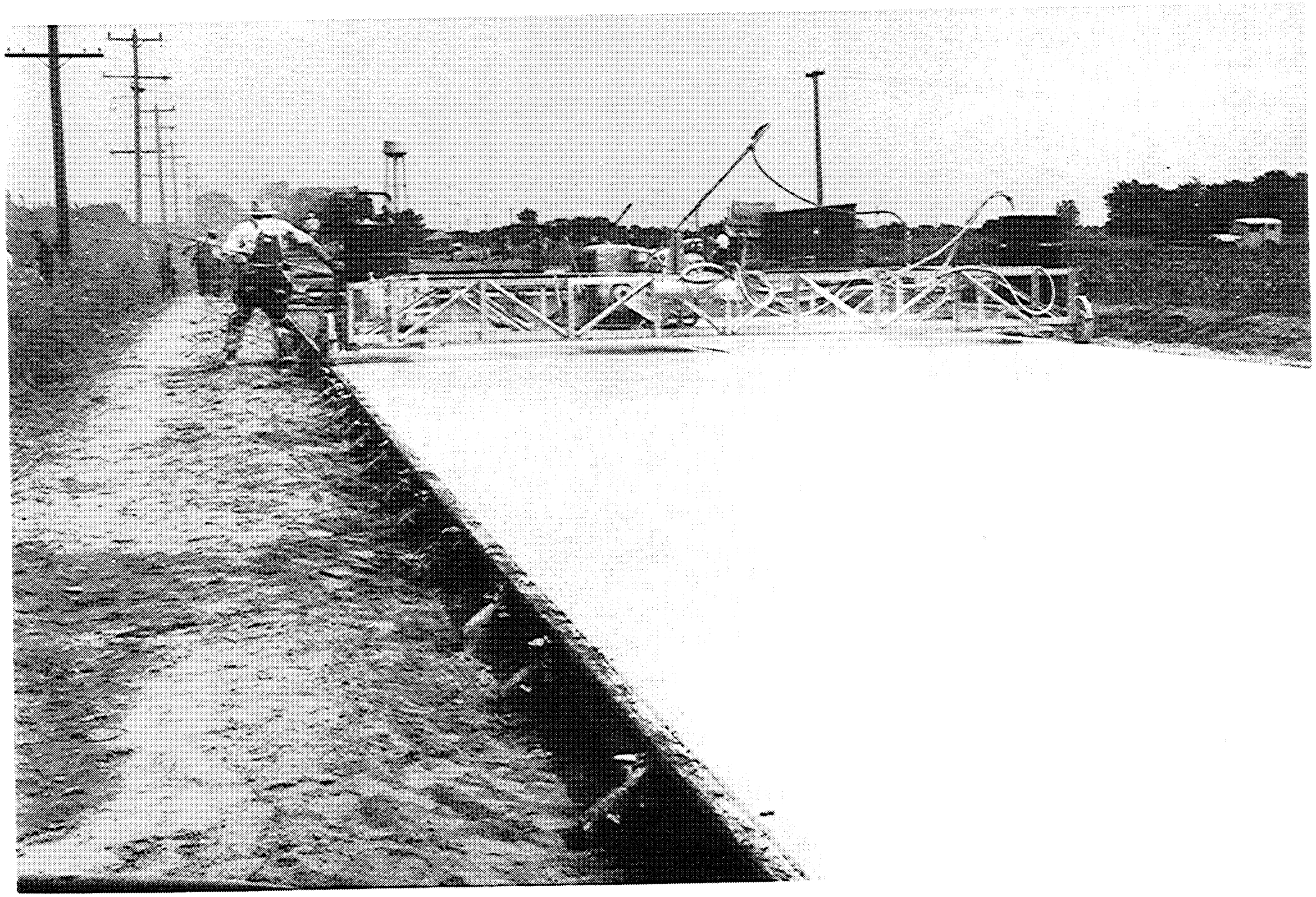

Plate VIII. Curing-compound spreader bringing up the rear of the paving train. Section 2.

Plate IX. Preparing to test for the air content of the concrete, using an Acme pressure air meter. Section 5.

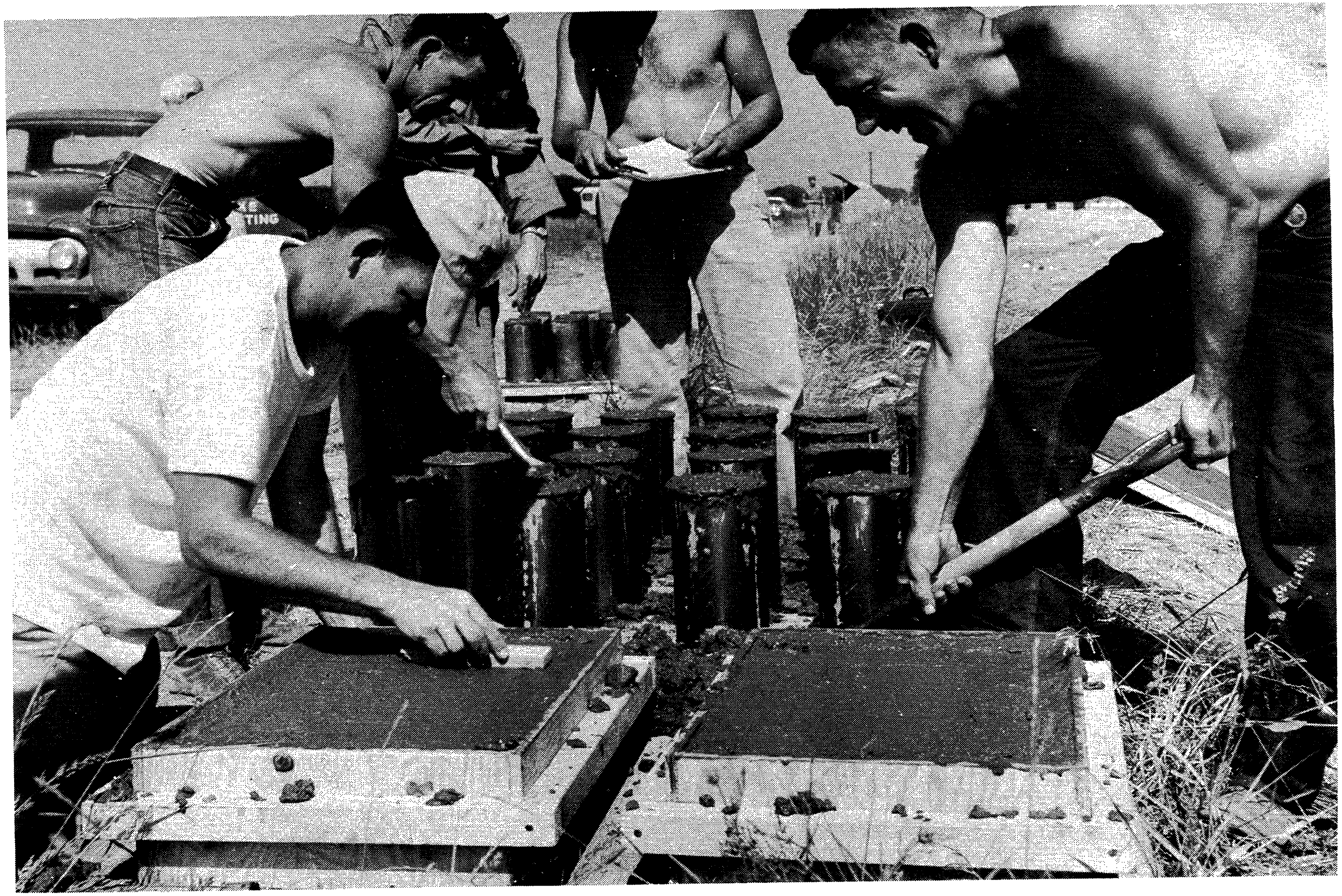

Plate X. Fabrication of test specimens. Two of the slabs to be used for measuring resistance to surface scaling in the foreground, the cylinders designated as Group B just behind them, and the Group A cylinders in the background. The pavement is to the right in the picture. Section 5.