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Synopsis

A cement with expansive properties of a magnitude designed to offset the shrinkage characteristics found in normal concrete was used in two full-scale paving projects on freeways in California in 1963. It is believed that this cement, referred to as "compensated shrinkage cement", received its first full-scale field application in concrete pavements on these projects. This report covers only one of these projects. It is located in Los Angeles County on the Antelope Freeway.

The experimental pavement section consisted of six one-quarter mile units. Four of the units contained compensated shrinkage cement and two contained regular Type II Portland cement. Additional variables in the construction of the test section were: (1) two different cement factors (2) air-entrained and non-air-entrained concrete. No contraction joints or weakened plane joints were constructed in any of the six units of the experimental section. A 7-day polyethylene cure was used for the entire experimental section.

Evaluation of the behavior and the properties of the concrete in the experimental sections was aided by the use of Carlson electrical strain gages embedded in the concrete, surface gage readings using a dial gage extensometer, external reference points, crack surveys, and testing of field fabricated test specimens.

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DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

CALIFORNIA FINDINGS ON AN EXPERIMENTAL PAVEMENT USING COMPENSATED SHRINKAGE CEMENT

A STUDY MADE BY THE

CA

64-05

MATERIALS & RESEARCH DEPARTMENT

State of California
Department of Public Works
Division of Highways
Highway Transportation Agency

MATERIALS AND RESEARCH DEPARTMENT

September 15, 1964

Laboratory Project
Work Order 53087 R
Hdqtrs. W.O.300259

Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Mr. Womack:

Submitted for your consideration is a report

on:

California Findings on an

Experimental Pavement Using Compensated

Shrinkage Cement

Project conducted by . . . . Concrete Section
Under direction of . . . . D. L. Spellman
Work supervised by . . . . J. H. Woodstrom
Report prepared by . . . . J. H. Woodstrom
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Research Files

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CALIFORNIA FINDINGS ON AN EXPERIMENTAL PAVEMENT USING COMPENSATED SHRINKAGE CEMENT

Synopsis

A cement with expansive properties of a magnitude designed to offset the shrinkage characteristics found in normal concrete was used in two full-scale paving projects on freeways in California in 1963. It is believed that this cement, referred to as "compensated shrinkage cement", received its first full-scale field application in concrete pavements on these projects. This report covers only one of these projects. It is located in Los Angeles County on the Antelope Freeway.

The experimental pavement section consisted of six one-quarter mile units. Four of the units contained compensated shrinkage cement and two contained regular Type II portland cement. Additional variables in the construction of the test section were: (1) two different cement factors, (2) air-entrained and non-air-entrained concrete. No contraction joints or weakened plane joints were constructed in any of the six units of the experimental section. A 7-day polyethylene cure was used for the entire experimental section.

Evaluation of the behavior and the properties of the concrete in the experimental sections was aided by the use of Carlson electrical strain gages embedded in the concrete, surface gage readings using a dial gage extensometer, external reference points, crack surveys, and testing of field fabricated test specimens.

Findings

1. The findings reported herein indicate that the "compensated shrinkage cement" concrete used in the field had expansive characteristics similar to such concrete previously tested in the laboratory and met the specified requirements considered desirable for this type of material.

2. The behavior of this new type of pavement after curing was not as expected and was not significantly different from that of regular concrete which was mixed, placed, and cured in the same manner.

3. Expansion of the compensated shrinkage cement concrete pavement did occur, although not entirely in the manner that had been anticipated.

4. In the sections containing compensated shrinkage cement, very little compressive stress was developed in the slabs during the 7-day curing period.

5. The expansion that occurred in the section containing compensated shrinkage cement can be compared to a growing plastic mass with the movement being greatest in the direction of least restraint.

6. There is no significant difference in the cracking pattern in the portions of the experimental section containing compensated shrinkage cement as compared to those portions containing regular cement.

7. The crack interval in the two units containing regular cement was smallest for the air-entrained concrete. The same pattern existed in the units made with compensated shrinkage cement; the closer crack intervals occurred in the air-entrained units.

Recommendation

It is recommended that further studies be made to develop more information regarding the behavior of expanding cements, including cements with a greater percentage of expansive component which could possibly be used in self-stressing of pavements. More specific information is needed regarding the effects of partial restraint in more than one direction. In addition, other properties of the cement such as freeze-thaw resistance and sulfate resistance should be studied as these could be important factors in the durability of concrete made with expanding cements.

Introduction

For many years the possibility of producing a shrinkage-free concrete has appealed to those concerned with producing crack-free concrete. Shrinkage takes place as moisture leaves concrete by evaporation. The principal factors contributing to the rate and magnitude of the drying shrinkage are items associated with the water demand and evaporation of water from the fresh concrete mixtures, and the properties of the cement and aggregate going into the mix.

Drying shrinkage of any magnitude is normally undesirable. Where drying shrinkage is unusually high, structures may develop unsightly cracks which may hasten deterioration of the concrete and the reinforcing steel. Roadway construction suffers in a similar manner, but in addition, allows the entry of water into the subgrade. Differential drying shrinkage also causes curling of pavement slabs. Much can be done in designing a concrete mixture and controlling construction operations to keep the amount of shrinkage to a minimum. While a tremendous amount of research has been applied to the drying shrinkage problem, it has not been completely solved and is still of major concern to those closely associated with concrete construction.

Recent developments in the field of expansive cements have generated some optimism with respect to a possible solution to the drying shrinkage problem. Research work at the University of California and elsewhere, led to the manufacture of a cement with expansive properties that could be controlled within desirable limits, at least under laboratory conditions. While the idea of an expanding cement is not exactly new, (work being done as early as 70 years ago), the improved ability to control expansion to a predictable degree made the use of the material enticing at this time.

The potential application of the new expanding cements is considered by some researchers to be quite extensive. For example, it is hoped that the expansive force developed with cements containing a high expansive component will be sufficient to stress steel tendons and eventually compete in some areas with present-day prestress operations. It might also be used in concrete pipes and tanks. The cement for this type of application has been referred to as "self-stressing cement", and contains considerably more expansive component than the cement used in the experimental pavement described in this report.

The idea of this project was that such a cement might be used to offset drying shrinkage of concrete and make joint-free pavements possible. The amount of expansive component would have to be less than that required for self-stressing; just enough to cause an expansion equal to, or slightly greater than the contraction resulting from drying shrinkage. Such pavements, in addition to being nearly crack-free, would be smoother riding because there would be no "curled" slabs. Since there would be fewer cracks, there would be less maintenance.

Preliminary work reported by Alexander Klein, Tsevi Karby, and Milos Polivka[1], indicated that a cement having about 15% expansive component would be suitable. It is referred to as "compensated shrinkage cement" in this report.

Compensated shrinkage cement would have special application for the construction of slabs such as concrete pavements. The theory on which this experimental project was based is that in a monolithic slab structure, the tendency toward expansion would be restrained by subgrade friction of the mass and special pavement anchors near the ends of the slab, and would be manifested in the development of an internal compressive stress in the concrete. The compressive stresses would increase during the curing period and later when concrete dried, accompanied by the tendency for shrinkage, the internal compressive stresses would diminish and the slab would reach a more or less neutral position with respect to stress-strain conditions.

A small amount of shrinkage compensated cement was made available to the Materials and Research Department for preliminary tests in the laboratory. Our work, plus work done by the University of California, the Concrete Research Development Corporation of Van Nuys, California, and others, led to the establishment of two experimental pavement sections in California highways. The first, reported herein, is located on the Antelope Valley Freeway, Road VII-L.A-23-I,B,C,D. The second section is in a freeway through Lodi, Road X-S.J-4-C,Lod, which will be covered by a separate report.

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1 "Properties of an Expansive Cement for Chemical Prestressing" Klein, Karby and Polivka, Journal of the American Concrete Institute, July, 1961

Test Conditions

The Contract Change Order establishing the experimental section for the Antelope Valley Freeway project was prepared jointly by Headquarters Construction Department and the Materials and Research Department. Principle features involves in the Contract Change Order were as follows:

I. General

A. The experimental section was to consist of six one-quarter mile units, each with different mix designs. (Refer to the "As Constructed" plan of the test section, Figure 1.)

B. Pavement containing compensated shrinkage cement was not to be placed within 200 feet of any structure that interrupted the continuity of paving.

C. Transverse weakened plane joints were not to be constructed within any of the units of the experimental pavement.

D. No interruption exceeding 18 hours was to occur between construction of any of the test units containing compensated shrinkage cement.

E. The end of any unit containing compensated shrinkage cement which terminates against pavement containing regular cement, was to be constructed with a system of lugs formed in the subgrade, plus a pavement end anchor. The end of any day's run occurring between these units also would require the anchorage system.

II. Cement

The cement used in the sections containing compensated shrinkage cement was to be manufactured by the Permanente Cement Company and was required to have the same characteristics as the cement furnished to the Materials and Research Department for preliminary testing.

III. Curing

A. The entire experimental section, including the two "job cement" units, was to be cured using white polyethylene sheeting, 4 mils thick.

B. Immediately in advance of placing the plastic sheeting, the pavement was to be sprayed with a fog spray of water as excess moisture is a necessity for complete expansion to take place.

C. The sheeting was to remain in place for a period of 7 days after placement of the concrete.

IV. Testing

Provisions were made for Materials and Research Department personnel to supervise the field work, make the specified concrete specimens in the field, and install numerous gages for measuring the volume changes of the concrete.

Construction Operations

Preliminary discussions were held with the Resident Engineer, H. F. Meinke, and a final location for the experimental section was selected near the westerly end of the Antelope Valley Freeway project.

The Contractor obtained aggregate from a source developed in the Santa Clara River, known as the Pierce Material Site. The plant, including the mixer, was located 1/2-mile from the freeway alignment and about 3-1/2 miles from the experimental section.

The concrete was mixed in a Rex central mixer having an 8-cubic yard capacity, and hauled to the site, without agitation, in end dump trucks. Concrete was placed on the cement-treated base by a Guntert Zimmerman slipform paver. The operation was generally well organized and production was good. A total of about 110,000 cubic yards of paving concrete was placed on this contract.

Unit A of the experimental section containing non-air-entrained portland cement concrete made with regular Type II cement was paved on May 20, 1963. At the end of the day's run, a night header was constructed at Station 110+10. The excavation for the end anchor and pavement lugs was made in preparation for the following day's placement of concrete containing the compensated shrinkage cement. On the morning of May 21, work began on Unit B. It was believed that there would not be enough compensated shrinkage cement to pave an entire mile, and Units B, C, D and E were reduced in length so as to provide four approximately equal units of about 1000 feet each. (See Figure 1.) The Contractor elected to complete the paving of the four compensated shrinkage cement units in one day, eliminating the need for constructing more than two of the anchorage systems and avoiding the possible difficulties in switching cement types in his plant in the middle of a day's run. The end anchorage system for Unit E, the last unit containing compensated shrinkage cement, was constructed on the afternoon of May 21, as the day's run neared completion.

Unit F, using regular cement, was then constructed on the following morning, May 22, 1963.

The compensated shrinkage cement was delivered to the job and handled in the same manner as the commonly used Type II cement. No difficulties were encountered in unloading the cement from the delivery trucks into the cement storage silos, or in augering the cement from the storage silos to weigh hoppers.

The proportioning, mixing, transporting, and placing of the concrete made with the compensated shrinkage cement in no way varied from the methods and equipment used with conventional concrete. The operator of the slipform paver and the finishers were of the opinion that the concrete produced with the special cement was easier to place. No other differences were observed or reported.

Placing of the non-air-entrained concrete called for in the experimental pavement was at first viewed with some apprehension because of the type of paving operation the Contractor had elected to use. It is considered highly desirable, if not a necessity, to use some air entrainment in slipform paving, from the standpoint of placing and finishing the concrete. Also, previous experience with hauling fresh concrete without agitation indicated that the use of air entrainment helped reduce the problems of segregation and consolidation or "lock-up" in the trucks.

None of the anticipated problems presented themselves to any serious degree however, and paving of the non-air-entrained portions were handled in much the same manner as the air-entrained portions. It should be pointed out that the haul distance to the experimental section was relatively short, and that if hauling distances had been much greater, some serious segregation or consolidation might have occurred. Some difference was noted in discharging the non-air-entrained concrete from the dump trucks. There was more of a tendency for it to slide out in block form and break up into smaller chunks as it went through the tail gate, rather than flow out as a fluid mass. It also proved to be more of a strain on the paving machine and a minor breakdown occurred causing a 30-minute delay. The slump was increased slightly to facilitate handling and placing of the concrete.

The finishing of the non-air-entrained concrete was handled as easily as the air-entrained concrete. All concerned with the operation were surprised at the workability of the non-air-entrained concrete, and the finishers were unaware that the change in air had taken place. The high cement factors used, 6 and 6-1/2 sacks per cubic yard, contributed to good workability.

The polyethylene sheet for curing the slab was usually applied soon after the final burlap drag. A converted curing compound spray rig was used to thoroughly wet the concrete just prior to spreading the plastic sheeting. In some cases, the application of the plastic sheeting followed placement of the concrete by as much as 3 hours. When such a delay occurred, water was applied by spray trucks to keep the concrete surface wet until the curing crew could "catch up".

The plastic sheeting came in rolls 28 feet wide by 200 feet long, and was folded along its 200-foot length so as to provide a roll 7 feet wide. The rolls were spooled on special brackets attached to the converted curing compound spray rig. At times, the wind made the sheet spreading operation difficult, and sand bags were used to hold it down. The sheeting was brought down over the edges of the pavement and banked with earth.

Testing Program

A program of testing and inspection was carried out by Materials and Research Department personnel with assistance from the Resident Engineer's forces. The program included installation of the Carlson and surface strain gages, with a schedule of readings; cement and concrete sampling and testing; plant inspection and accumulation of mix design data; and collection of miscellaneous weather data. This was followed by numerous cracking surveys. Profiles of the pavement were made with the truck-mounted Profilograph.

The Carlson strain gage is an electrical resistance wire type. Actual unit strain and temperature of the concrete was determined with this device.

The locations of the Carlson strain gages and surface gages are shown in Figure 1. All the Carlson gages that were oriented in a horizontal plane were located 4 inches below the surface of the concrete (about mid-depth). When the Carlson gages were placed in a vertical position, it was necessary to excavate a shallow basin in the subgrade to accomodate their 10+-inch length, as the design thickness of the pavement was 8 Inches. The resulting depression was filled with concrete. Installation of the Carlson gages was carried out by constructing a narrow trench in the subgrade in advance of the paving operation to bring the wire cable outside the pavement edge. The gage was placed on the cement treated base and covered with a canvas sample bag which was nailed to the subgrade. The wire cable was placed in the trench and extended to reading stations set up in the median. The gages were not disturbed by the paving process. After the paving machine had passed, the gages were dug out of the fresh concrete. Plywood floats were used to support the weight of the men placing the gages to minimize disturbance of the formed surface. The gages were then set to the desired position and the concrete carefully replaced and compacted. (See photographs.) An initial reading of the gage was then taken.

The surface gage units consisted of brass plugs, 3/4-inch diameter by 2 inches long. Each plug had a 1/16-inch hole drilled in the top for receiving the point of a dial gage extensometer. Measurements were made to 0.0001-inch over a 30-inch gage length, and referred to a "standard bar" made of Invar steel. Templates of steel strapping were constructed to hold the gage plugs 30 inches apart during placement in the fresh concrete, and as many as 10 plugs (9 gage lengths) were attached to one template. These gage point assemblies were installed when the concrete was about 2 hours old. Initial readings could not be taken until the age of about 6 hours when it was determined that the plugs were secure enough to support the weight and manipulation of the extensometer without movement.

A comprehensive schedule of readings of the Carlson strain gages and the surface gage units was followed for the initial period of expansion. Refer to Figures 2 through 9 for the charts showing the movement of the concrete with respect to time as measured by the Carlson gages.

The reading of the surface gage plugs using the dial gage extensometer was facilitated by cutting small holes in the plastic sheeting above each gage plug. The holes were covered with masking tape between readings to prevent loss of moisture. Because of the large number of gage and extensometer readings obtained, they are not all shown in this report. The results however, will be discussed and the "reduced" data was used to plot the curves in Figures 2 to 11, inclusive.

To ascertain whether or not there was movement of the slab at the end anchors of the units containing compensated shrinkage cement, external reference points were located adjacent to the pavement. A survey reference line was established and points were placed in the fresh concrete from which any movement could be detected. Also, a line parallel with the center line of the pavement was measured using a 100-foot steel tape extending from a point at the end anchor to a point 200 feet from the end in an effort to detect any large movements that might occur.

To further evaluate the performance of the entire experimental section, a series of crack surveys was made at different times and profiles were obtained with the truck-mounted profilograph. The results of the crack surveys are shown in Table I.

Discussion

The Carlson strain gages were located throughout the project so as to obtain measurements in each of the units as well as relative readings in the three orthagonal directions of the concrete mass. (See Figure 1.) They were also located so as to assist in evaluating the expansion or movement that might take place at the end anchors.

The plotted Carlson gage data, Figures 2 through 9, show the unit strain corrected for the temperature of the concrete at the time the reading was taken. The "Indicated Unit Strain" curve was adjusted for thermal movements of the concrete using a more or less arbitrary coefficient of thermal expansion of 5.5×10^{-6} inches/inch/degree F. Thus, the "Adjusted Unit Strain" curves show the net strain that can be attributed to the volume change caused essentially by the action of the expanding concrete. Figure 2 also shows the temperature of the concrete and the indicated unit strain at the time the reading was taken. It is realized that the thermal coefficient of concrete varies with respect to age, moisture content, ambient temperature, and probably other variables, but the factor of 5.5×10^{-6} selected appears to be reasonable and provides a series of "Adjusted Unit Strain" curves that show probable expansive movement nearly independent of the movement caused by thermal changes.

The Carlson gages in the shrinkage compensated cement units oriented transversely to the center line and vertically showed the greatest movement, and are indicative of the rate and amount of expansion that occurred in these two directions. These data agree closely with that found previously in the laboratory; namely, that expansion begins at an early age, about 3 or 4 hours after mixing, continues at a fairly rapid rate during the first 24 hours, then gradually levels off but continues to expand for a period of about 6 to 7 days in a manner similar to strength gain curves for concrete.

A series of Carlson gages were located in a transverse direction at a point 3 feet in from the edge of the pavement in each of the test units. These gages were numbered C-108T, C-113T, C-114T, C-115T, C-119T, and C-121T, and are located in Units A, B, C, D, E, and F, respectively. Examination of the adjusted expansion curves for each of these gages illustrate the relative degree of expansion that took place in the six units. It is seen that the transverse gages located in Units A and F which contained regular Type II cement show virtually no movement. Gages at the same location in Units B, C, D, E, show appreciable movement with some variation in the degree of maximum expansion measured, the range being from 330 to 450 x 10^{-6} inches per inch. The amount of transverse expansion measured in the units with a cement factor of 6-1/2 sacks per cubic yard was greater than that in the units containing 6 sacks of cement per cubic yard. There was no apparent difference in the expansion in the air-entrained units as compared to non-air-entrained units.

In Units B and E, groups of three Carlson gages were located 9 feet from the edge of the pavement and were oriented so as to measure movement in the three orthagonal directions. In Unit B, the gage numbers were C-110L, C-111V and C-112T. In Unit E, the gage numbers were C-116T, C-117V and C-118L. Gage C-112T, oriented transversely to the center line of the pavement in Unit B, reached its maximum expansion (adjusted for temperature) at 7 days of 150 x 10^{-6} inches per inch. Gage C-116T in Unit E, in a location similar to C-112T, was lost due to internal malfunction of the gage. Gages C-111V and C-117V, oriented vertically, reached maximum expansions at 7 days of 880 and 1110 x 10^{-6} inches per inch of strain, respectively. Again, the 6-1/2-sack concrete showed greater expansion than did the 6-sack concrete. Gages C-110L and C-118L oriented longitudinally, indicated practically no expansive strain, accompanied by a reversal in direction (contraction) at an early age. This latter feature will be discussed later in this report.

The expansion characteristics of the "expanding concrete" in a pavement slab, can best be evaluated by the data gained from the Carlson gages, together with the measurements of surface gage plugs made with the dial gage extensometer. Figure 10 shows measurements of a typical pavement cross-section with the adjusted expansion data (that contributed by shrinkage compensated cement) plotted on a vertical scale. This chart more or less reflects the degree of measured transverse expansion observed in all of the expanding cement units at mid-depth of the slab. Probable expansion curves are shown for both measurement methods. The curve based on the Carlson gage measurements indicate movement of greater magnitude than that indicated by the surface gages. It is believed that the reason for the difference is that the initial readings for the Carlson gages were taken within 1/2-hour after the concrete was placed, whereas the initial readings for the surface gages were taken approximately 6 hours after the concrete was placed and some expansion had already taken place. Thus, the Carlson data are probably more indicative of the actual expansion that occurred.

In the transverse direction, the unit expansion was greatest at the outer edges of the slab, and least at the center of the slab. Since the tendency for expansion to take place is assumed to be uniform throughout the width of the slab, the factor affecting the degree of expansion in the transverse direction is the frictional resistance offered by the subgrade. The frictional force that must be overcome for any expansion to take place in a transverse direction is maximum at the center of the slab and minimum at the edges.

Since the frictional force was along the bottom of the slab at the interface of the slab and subgrade, it is possible that movement at this point might have been nil, and the movement at the top surface of the slab might have been greater than that measured at mid-depth.

The total vertical movement of Gages C-111V and C-117V, located 9 feet from the edge of the pavement was 880 and 1110 x 10^{-6} inches per inch respectively. (The increase in strain noted in C-117V over that of C-111V is attributed in part to a higher cement factor.) This high degree of expansion was more than thought possible with the cement manufactured for this project, but the observed condition might be explained by considering the concrete mass both elastic <u>and</u> plastic. The maximum transverse movement measured at the same location is very nominal (150 x 10^{-6} inches per inch), and the longitudinal movement, negligible. This indicates that while the tendency for expansion was in the concrete, it was completely restrained in the longitudinal direction, partially restrained in the transverse direction, and virtually unrestrained in the vertical direction. The triaxial expansion was greatest in the direction of least restraint. This finding appears to be in conflict with the theory on which the project was based; that is, complete restraint in one direction is all that is needed to develop compressive stresses within the concrete as it expands. It now appears that lack of restraint in at least two directions permitted movements which prevented any large build-up of compressive stress in any direction.

Had more vertical measurements been taken transversely at different distances from the edges, it is believed that they would show a maximum vertical expansion near the center of the 24-foot slab and a minimum vertical expansion near the edges of the slab.

The prime purpose of the remainder of the gages on the project was to evaluate the actions in the vicinity of the end anchors and the effectiveness of the anchorage design. Figure 11 shows a plot of all the measurements relating to movement at the end anchor, along with a "Probable Expansion Curve" which shows the general degree of expansion that took place in the expanding concrete for a distance of 200 feet from the end anchor. The two sets of data taken from the two end anchorages in the expanding cement sections are in close agreement. It is seen that the maximum degree of expansion occurred at the extreme end of the slab and dropped sharply to a slight negative movement at a point approximately 20 feet in. This would indicate that very little movement, if any, took place at the end anchor. The external reference points opposite the end of this slab and chain measurements along the center line also show that virtually no movement at the end anchors occurred. The slight negative movement noted 20± feet from the end of the slab is believed to be associated with the large vertical bearing area of the end anchor. The stress developed in bearing against the 2-foot by 24-foot face, when concentrated in an 8-inch thickness of concrete, generated a compressive stress causing a reduction in length at that point.

The final, and probably most meaningful evaluation of the behavior of the entire experimental pavement made to date, consists of a series of surveys in which the cracking pattern of the concrete was mapped, and the average distance between cracks tabulated. This crack interval is also called "slab length." Refer to Table I. It is interesting to note that at the end of the 7-day curing period, not a single crack was evident in the entire experimental section, including the regular cement units, and free moisture was present on the surface of the concrete. As the cracking pattern developed, it became evident that there was no appreciable difference in the crack interval in the units containing compensated shrinkage cement as compared to those with regular cement. This would support the conclusion that little if any, beneficial results were achieved by the use of the compensated shrinkage cement having the amount of expanding component used in this work.

The findings and conclusions reported herein are based on observations and data collected and interpreted by the Materials and Research Department, California Division of Highways. Readers closely associated with basic research in the field of cement technology may or may not agree with our explanations for the observed results. However, it is hoped that this report presents pertinent data in a manner that can be constructively viewed by others for future research in the field of "expanding cement concrete."

TABLE I

ANTELOPE FREEWAY
EXPERIMENTAL PAVEMENT
(All Plastic Cured)

AVERAGE CRACK INTERVAL IN FEET, BY UNIT

CEMENT	CEMENT FACTOR	AIR	UNIT	AGE IN DAYS: 7	14	21	28	58	98	141	238
Type II	6	NON-AIR ENTRAINED	A	NO CRACKS AT AGE 7 DAYS WHEN PLASTIC CURE WAS REMOVED	122.0	122.0	122.0	63.9	41.9	41.9	41.9
COMPENSATED SHRINKAGE CEMENT	6	NON-AIR ENTRAINED	B		175.4	175.4	175.4	68.8	39.5	39.5	39.5
COMPENSATED SHRINKAGE CEMENT	6½	NON-AIR ENTRAINED	C		216.0	180.3	180.3	78.1	32.5	27.6	27.6
COMPENSATED SHRINKAGE CEMENT	6	AIR ENTRAINED	D		160.7	137.9	137.9	48.5	34.2	26.3	26.3
COMPENSATED SHRINKAGE CEMENT	6½	AIR ENTRAINED	E		168.6	168.6	168.6	45.7	29.7	23.6	23.6
Type II	6	AIR ENTRAINED	F		92.6	92.6	92.6	48.8	26.1	24.4	24.4

AVERAGE CRACK INTERVAL IN FEET, BY MIX CATEGORY

CATEGORY	AGE IN DAYS: 7	14	21	28	58	98	141	238
TYPE II CEMENT A & F	NO CRACKS AT AGE 7 DAYS WHEN CURE WAS REMOVED	107.3	107.3	107.3	56.4	34.0	33.2	33.2
COMP. SHR. CEM. B, C, D, & E		180.2	165.6	165.6	60.3	34.0	29.3	29.3
NON-AIR ENTRAINED A, B & C		171.1	159.2	159.2	70.3	38.0	36.3	36.3
AIR-ENTRAINED D, E & F		140.6	133.0	133.0	47.7	30.0	24.8	24.8
COMBINED ALL		155.9	146.1	146.1	59.0	34.0	30.6	30.6

TABLE 2

REPORT OF TESTS ON PORTLAND CEMENT

BRAND OF CEMENT		Colton, Type II Low-alkali,		Permanente, Shrinkage Compensated Cement,	
LOCATION OF MILL		Mojave, California		Cushenbury, California	
DATE SAMPLED					
SAMPLE FROM CONTRACT					
LABORATORY NO.					
		Average of 4 Tests		Average of 8 Tests	
SPECIFICATIONS					
SiO_2 %	21.0 Min.	23.1		20.7	
Al_2O_3 %	6.0 Max.	4.75		5.70	
Fe_2O_3 %	6.0 Max.	2.85		2.40	
CaO %		64.30		63.84	
MgO %	5.0 Max.	1.3		2.10	
SO_3 %	2.5 Max.	2.17		3.51	
Ig. Loss %	3.0 Max.	0.82		1.17	
Insol. Res. %	0.75 Max.	0.52		0.44	
NA_2O %		0.17		0.17	
K_2O %		0.44		0.39	
Equiv. NA_2O %	0.60 Max.	0.47		0.43	
C_4AF %		8.75		7.00*	
C_3A %	8 Max.	8.00		11.00*	
$CaSO_4$ %		4.00		6.00*	
C_3S %		43.75		51.00*	
C_2S %		33.25		21.00*	
COMPRESSIVE STRENGTH PSI					
3 Days	1000 Min.	2307		2144	
7 Days	1800 Min.	3400		3100	
SURFACE AREA BLAINE CM^2/G	2800 Min.	3085		3414	
AUTOCLAVE EXPANSION %	0.50 Max.	0.01		6.9	
(1)					
(2)					
(3)					
INITIAL SET GILMORE HRS:MIN.	0:60 Min.	2:50		2:01	
FINAL SET HRS: MIN.	10 Hr. Max.	5:00		4:03	
AIR CONTENT %	12.0 Max.	8.4		8.80	
EXPANSION	0.010 Max.	0.0026		0.277*	
CONTRACTION	0.048 Max.	0.0196		0.062	

* Calculated compounds for compensated shrinkage have questionable meaning.

** All shrinkage compensated cement mortars were removed from molds and measured initially at 5 hours.

TABLE 3

Mix Design Data

Mix 1 - Unit A

Mix Proportions: 60% rock and 40% sand. 6-sack, non-air-entrained, Mojave, Type II Cement

Batch Proportions	7.5 cu. yd.	Free Moisture
1-1/2" x 3/4" rock	9,352 lbs.	0
3/4" x No. 4 rock	5,130 lbs.	1.0%
Concrete sand	10,485 lbs.	7.0%
Cement	4,230 lbs. (6 sks./cu.yd.)	
Water	1,519± lbs.	

Calculated Combined Aggregate Grading

Sieve Size	Percent Passing: Combined As Used	Percent Passing: Specifications
2"	100	100
1-1/2"	97	90 - 100
1"	76	50 - 86
3/4"	64	45 - 75
3/8"	47	38 - 55
No. 4	39	30 - 45
No. 8	30	23 - 35
No. 16	24	17 - 27
No. 30	14	10 - 17
No. 50	6	4 - 9
No. 100	2	1 - 3
No. 200	1	0 - 2

Mix 2 - Unit B

6-sack, non-air-entrained, Permanente, Cushenbury Compensated Shrinkage Cement

The mix proportions, batch weights and calculated combined gradings were the same as Mix 1-B, Unit A, with the exception of the water which was increased to 1597 ± lbs.

Continued Page 2

Mix 3 - Unit C

6-1/2-sack, non-air-entrained, shrinkage compensated cement
Mix Proportions: 60% rock and 40% sand

Batch Proportions	7.5 cu. yds.	Free Moisture
1-1/2" x 3/4" rock	9,023* lbs.	0
3/4" x No. 4 rock	4,943 lbs.	1.0%
Concrete sand	10,125 lbs.	7.0%
Cement	4,583 lbs. (6-1/2 sks,/cu.yd.)	
Water	1,823 ± lbs.	

No combined gradings were calculated for this mix.

Mix 4 - Unit D

6-sack, air-entrained, shrinkage compensated cement
Mix Proportions: 62% rock and 38% Sand

Batch Proportions	7.5 cu. yds.	Free Moisture
1-1/2" x 3/4" rock	9,878 lbs.	0
3/4" x No. 4 rock	5,520 lbs.	1.0%
Concrete sand	9,465 lbs.	7.0%
Cement	4,230 lbs.	
Water	1,327 ± lbs.	
Air-entraining Agent	52 fl. oz. (1.16 fl.oz./sk.)	

Calculated Combined Aggregate Grading

Sieve Size	Percent Passing	
	Combined As Used	Specifications
2"	100	100
1-1/2"	98	90 - 100
1"	77	50 - 86
3/4"	62	45 - 75
3/8"	48	38 - 55
No. 4	37	30 - 45
No. 8	30	23 - 35
No. 16	22	17 - 27
No. 30	12	10 - 17
No. 50	5	4 - 9
No. 100	2	1 - 3
No. 200	1	0 - 2

Continued Page 3

Mix 5 - Unit E 6-1/2-sack, air-entrained, shrinkage compensated cement Mix Proportions: 62% rock and 38% sand		
Batch Proportions	7.5 cu. yds.	Free Moisture
1-1/2" x 3/4" rock	9,585 lbs.	0
3/4" x No. 4 rock	5,363 lbs.	1.0%
Concrete sand	9,195 lbs.	7.0%
Cement	4,583 lbs.	
Water	1,538 lbs.	
Air-entraining Agent	46 fl. oz. (0.95 fl. oz./sk.)	
No combined gradings were calculated for this mix		

Mix 6 - Unit F 6-sack, air-entrained, Mojave, Type II cement Mix Proportions: 62% rock and 38% sand		
Batch Proportions	7.5 cu. yds.	Free Moisture
1-1/2" x 3/4" rock	9,878 lbs.	0
3/4" x No. 4 rock	5,520 lbs.	1.0%
Concrete sand	9,465 lbs.	7.0%
Cement	4,230 lbs.	
Water	1,327 lbs.	
Air-entraining Agent	46 fl. oz. (1.02 fl.oz./sk.)	

Calculated Combined Aggregate Grading

	Percent Passing	
Sieve Size	Combined As Used	Specifications
2"	100	100
1-1/2"	97	90 - 100
1"	79	50 - 86
3/4"	64	45 - 75
3/8"	47	38 - 55
No. 4	38	30 - 45
No. 8	30	23 - 35
No. 16	22	17 - 27
No. 30	13	10 - 17
No. 50	6	4 - 9
No. 100	2	1 - 3
No. 200	1	0 - 2

TABLE 4

Average Results of Tests Made on Fresh Concrete

Mix and Section	Kelly Ball Slump, Inches	Air %	Unit Wt. Lbs./CF	Net W/C Lbs./Sk.	Cement Factor	Dosage AEA, Fl. Oz./Sk.
A 6-sk. Non AE	1.5	1.5	150.6	52.0	5.94	0
B 6-sk. Non AE	2.5	1.5	151.0	52.0	5.96	0
C 6-1/2 Sack Non-AE	2.5	1.5	150.8	52.0	6.51	0
D 6-sk. AE	1.5	4.5	147.9	44.5	5.91	1.16
E 6-1/2 Sk., AE	2.0	4.3	147.7	44.9	6.42	0.95
F 6-sk. AE	2.0	3.6	149.1	44.5	5.96	1.02

TABLE 5

Summary of Test Results on Hardened Concrete

Unit	Mix	Flexural Strength psi * 14-day	Compressive Strength, psi 6" x 12" Cylinders ** 3 day	7 day	14 day	28 day	5" Cores*** 120 day
A	6-sk. Non AE Type II	570		2870	3810	4350	5500
B	6-sk. Non AE CSC	520	2090	3050	3730	4030	4930
C	6-1/2 sk. Non AE CSC	495	2370	3360	3910	4290	5240
D	6-sk. AE CSC	485	2250	2870	3600	4100	4720
E	6-1/2 sk. AE CSC	555	2300	2990	3360	3810	5030
F	6-sk. AE Type II	600		3090	4110	4180	5740

* Average of 2 - 6x6x20-in. beams, third point loading
** Average of 3 - 6x12-in. cylinders
***Average of 5 cores

Secant Modulus of Elasticity
(psi x 106, Average of 3 Cylinders)

	3-day		7-day		14-day		28-day	
	0.3 Ult.	0.6 Ult.	0.3 Ult.	0.6 Ult.	0.3 Ult.	0.6 Ult.	0.3 Ult.	0.6 Ult.
A	----	----	2.56	2.23	2.82	2.47	3.22	2.92
B	2.22	1.90	2.78	2.41	3.05	2.58	3.07	2.76
C	2.20	1.98	2.77	2.35	2.99	2.51	2.95	2.63
D	2.23	2.05	2.67	2.38	2.97	2.68	3.25	2.96
E	2.10	2.00	2.53	2.26	2.75	2.48	2.98	2.72
F	----	----	2.69	2.46	3.02	2.79	3.46	3.44

TABLE 6

Climatological Conditions During Curing Period

Date 1963	Time	Wind Velocity MPH	Relative Humidity Percent	Evaporation Rate, Ml/Hr.*	Air Temperature °F
5-20	1500	8 - 10	35	14	82
	1600	8 - 10	37	13	82
	1700	8 - 10	40	11	78
	1800	6 - 8	48	8	76
	1900	6 - 8	55	8	70
	2000			3	
5-21	0600	0 - 2	84	0	58
	0800	0 - 2	71	1	66
	1000	0 - 2	59	4	74
	1200	2 - 4	46	5	82
	1300	2 - 4	40	13	85
	1500	5 - 8	36	15	87
	1600	5 - 8	33	13	90
	1700	5	44	10	82
	2000			3	
5-22	0800	0	75	2	59
	1000	0 - 2	60	4	68
	1200	6 - 8	45	12	80
	1400	8 - 10	36	15	90
	1600	8 - 10	41	15	83
	1800	6 - 8	57	9	76
	2000			3	
5-23	0800	0	84	2	58
	1100	2	75	7	62
	1600	2 - 4	46	10	72
	1815	2	51	6	69
	2000			3	
5-24	0700	0 - 2	77	1	57
	0900	0 - 2	60	4	66
	1200	4	46	8	76
	1400	4	46	9	78
	1730	0 - 4	56	8	60
	2000			3	
5-25	0800	0 - 2	43	3	70
	1000	0 - 2	43	7	74
	1300	8 - 10	44	10	78
	1600	6 - 8	46	Out of Water	76
	1800	10	48		72
	2000				

*California type recording atmometer.

TABLE 7

Climatological Conditions After
Initial 7-day Curing Period

Pvmt. Age, Days	Date, 1963	Evaporation Rate, Ml/Hr.		Air Temperature, °F		Weather Conditions
		Avg.	Max.	Min.	Max.	
7	5-28	2.2	5.0	Avg. Temp.	63	Cool - overcast
8	5-29	---	---	57	80	- - - - - - - - -
9	5-30	---	---	57	86	- - - - - - - - -
13	6-3	0.9	4.0	52	82	Warm - clear
14	6-4	3.6	14.0	42	89	" "
15	6-5	1.8	4.0	47	70	" "
16	6-6	3.0	10.0	50	70	" "
17	6-7	12.0	14.0	51	84	" "
18	6-8	16.0	22.0	--	--	- - - - - - - - -
20	6-10	0	0	45	60	Cool - cloudy
21	6-11	0	0	50	78	Rain
22	6-12	0	0	52	73	"
23	6-13	0.1	0.5	53	77	Cloudy - rain
24	6-14	---	---	58	103	Hot - clear
27	6-17	---	---	54	100	
28	6-18			55	94	
29	6-19			52	92	
30	6-20			51	88	
31	6-21			53	79	
34	6-24			42	92	
35	6-25			48	99	
36	6-26			49	101	
37	6-27			48	88	
38	6-28			46	102	
41	7-1			48	97	
42	7-2			50	100	
43	7-3			52	98	
45	7-5			51	95	
48	7-8			50	96	
49	7-9			53	100	
50	7-10			52	100	
51	7-11			51	98	
52	7-12			50	106	
55	7-15			60	100	
56	7-16			56	97	
57	7-17			54	97	
58	7-18			58	104	
59	7-19			57	104	
62	7-22			56	100	
63	7-23			53	105	
64	7-24			57	106	
65	7-25			54	106	
66	7-26			54	98	
69	7-29			48	99	

Continued

Climatological Conditions
After Initial 7-day Curing
Period

Pvmt. Age, Days	Date, 1963	Evaporation Rate, Ml./Hr.		Air Temperature °F		Weather Conditions
		Avg.	Max.	Min.	Max.	
70	7-30			52	98	
71	7-31			54	98	
72	8-1			56	97	
73	8-2			55	99	
76	8-5			51	101	
77	8-6			52	99	
78	8-7			54	92	
79	8-8			65	93	
80	8-9			58	103	
83	8-12			51	104	
84	8-13			56	107	
85	8-14			62	109	
86	8-15			63	100	
87	8-16			64	101	
90	8-19			56	99	
91	8-20			60	100	
92	8-21			52	94	
93	8-22			58	85	
94	8-23			58	96	
97	8-26			48	97	
98	8-27			49	98	
99	8-28			50	100	
100	8-29			52	89	
101	8-30			56	---	
111	9-9			56	105	
112	9-10			58	113	
113	9-11			53	108	
114	9-12			55	106	
115	9-13			58	100	
118	9-16			52	100	
119	9-17			52	76	
120	9-18			62	76	

FIGURE 2

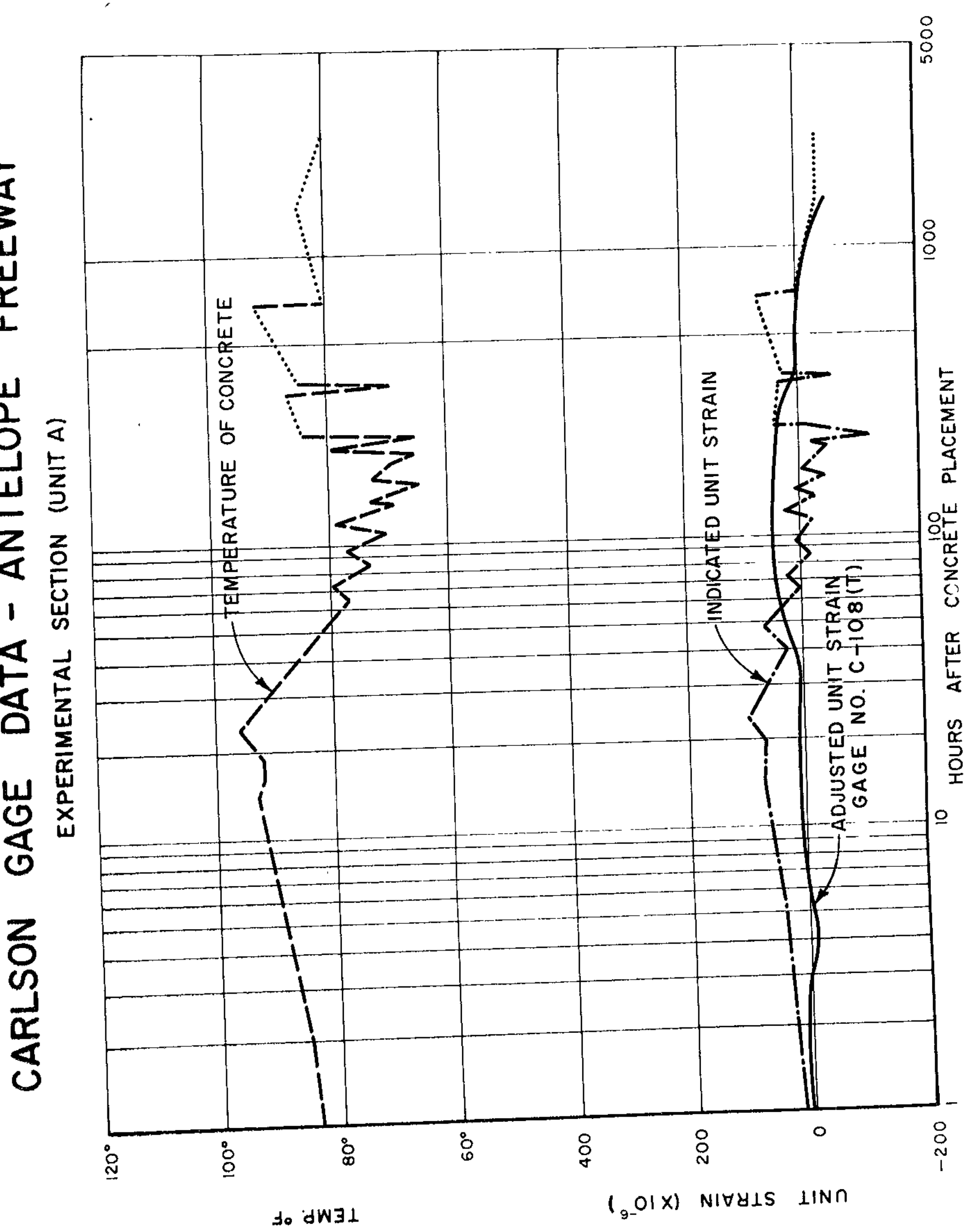

CARLSON GAGE DATA - ANTELOPE FREEWAY
EXPERIMENTAL SECTION (UNIT A)
TEMPERATURE OF CONCRETE
INDICATED UNIT STRAIN
ADJUSTED UNIT STRAIN
GAGE NO. C-108(T)
HOURS AFTER CONCRETE PLACEMENT
1
10
100
1000
5000
TEMP °F
120°
100°
80°
60°
UNIT STRAIN (X10^{-6})
400
200
0
-200

FIGURE 3

CARLSON GAGE DATA - ANTELOPE FREEWAY

EXPERIMENTAL SECTION (UNIT B)

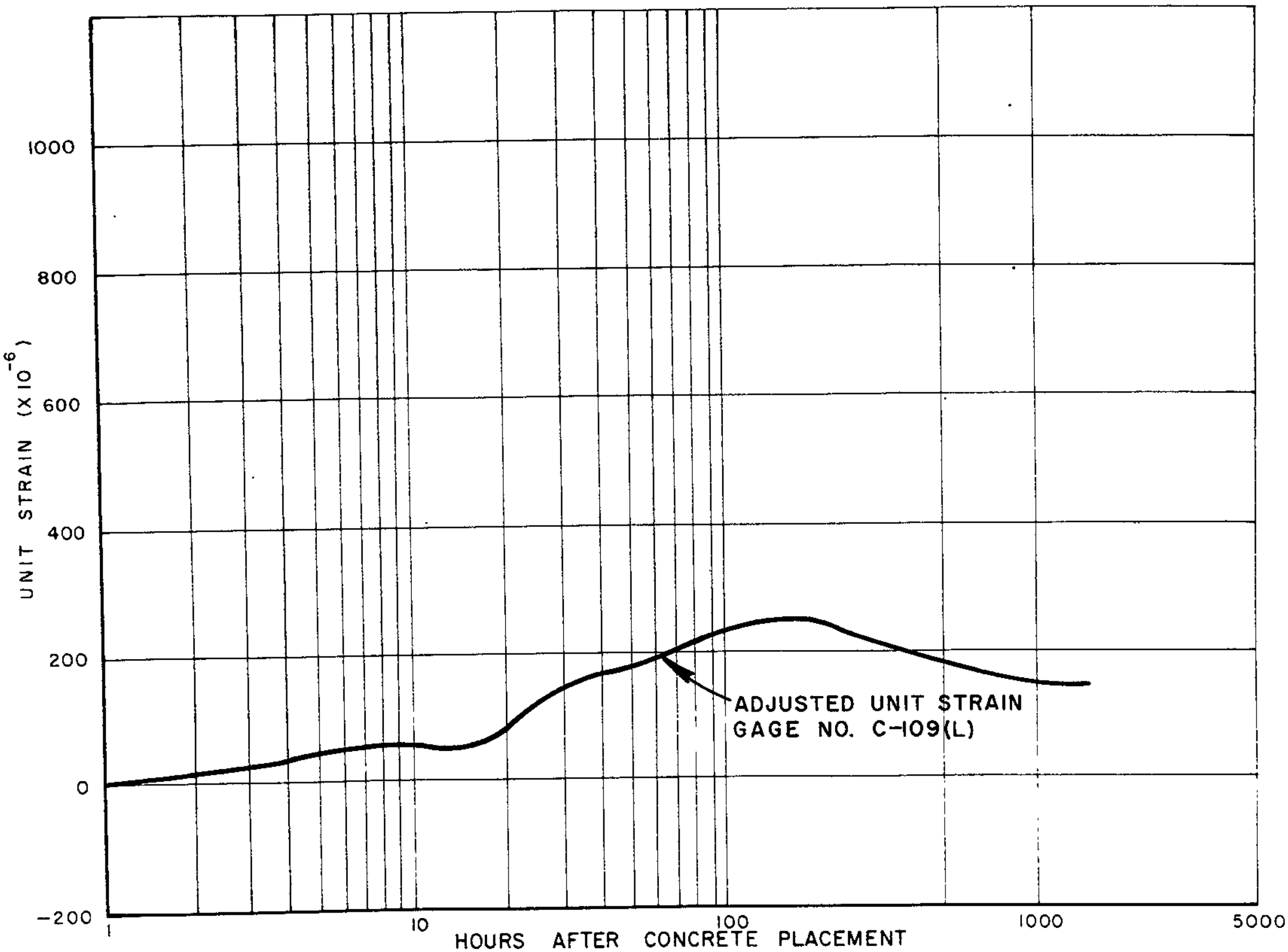


FIGURE 4

CARLSON GAGE DATA - ANTELOPE FREEWAY

EXPERIMENTAL SECTION (UNIT B)

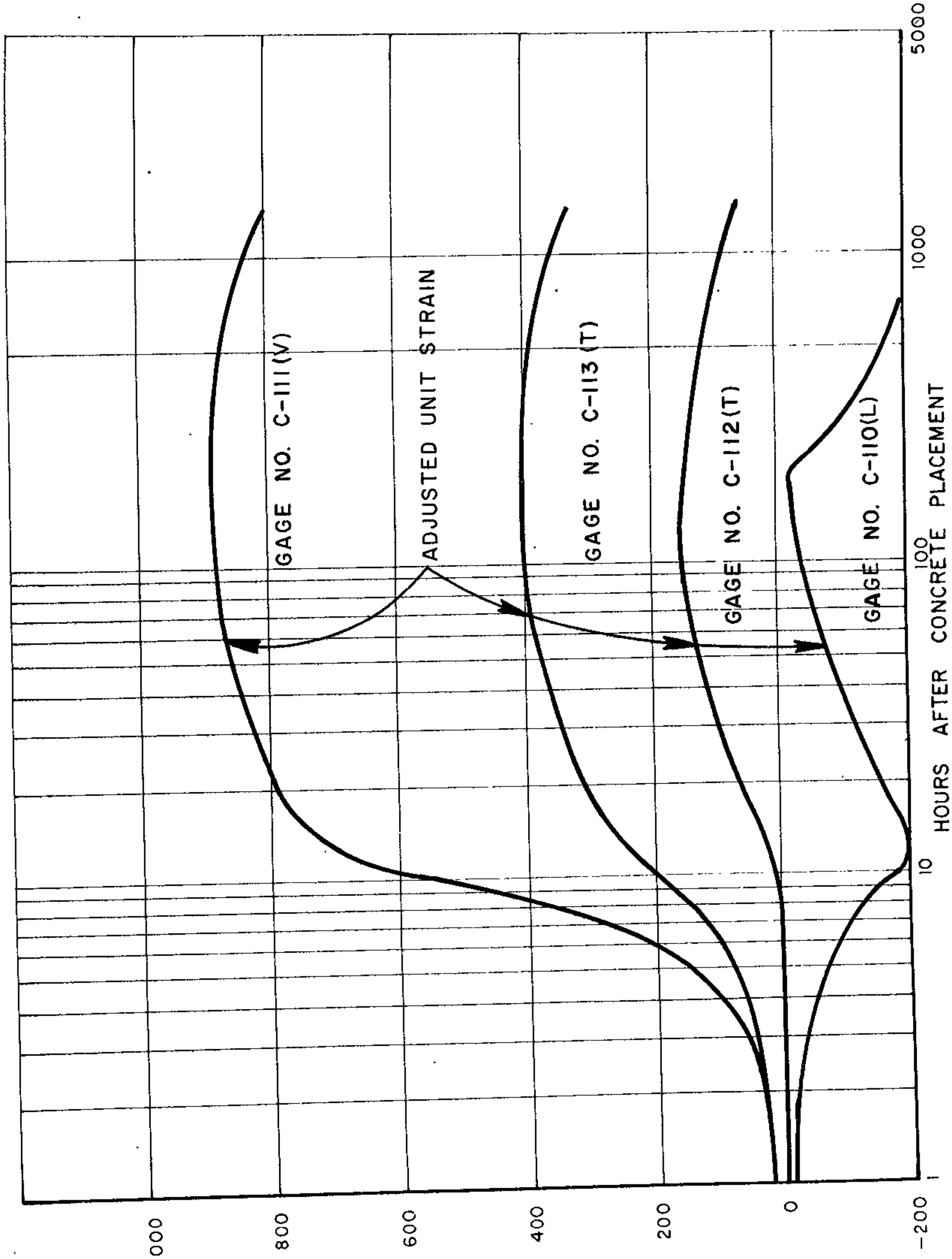
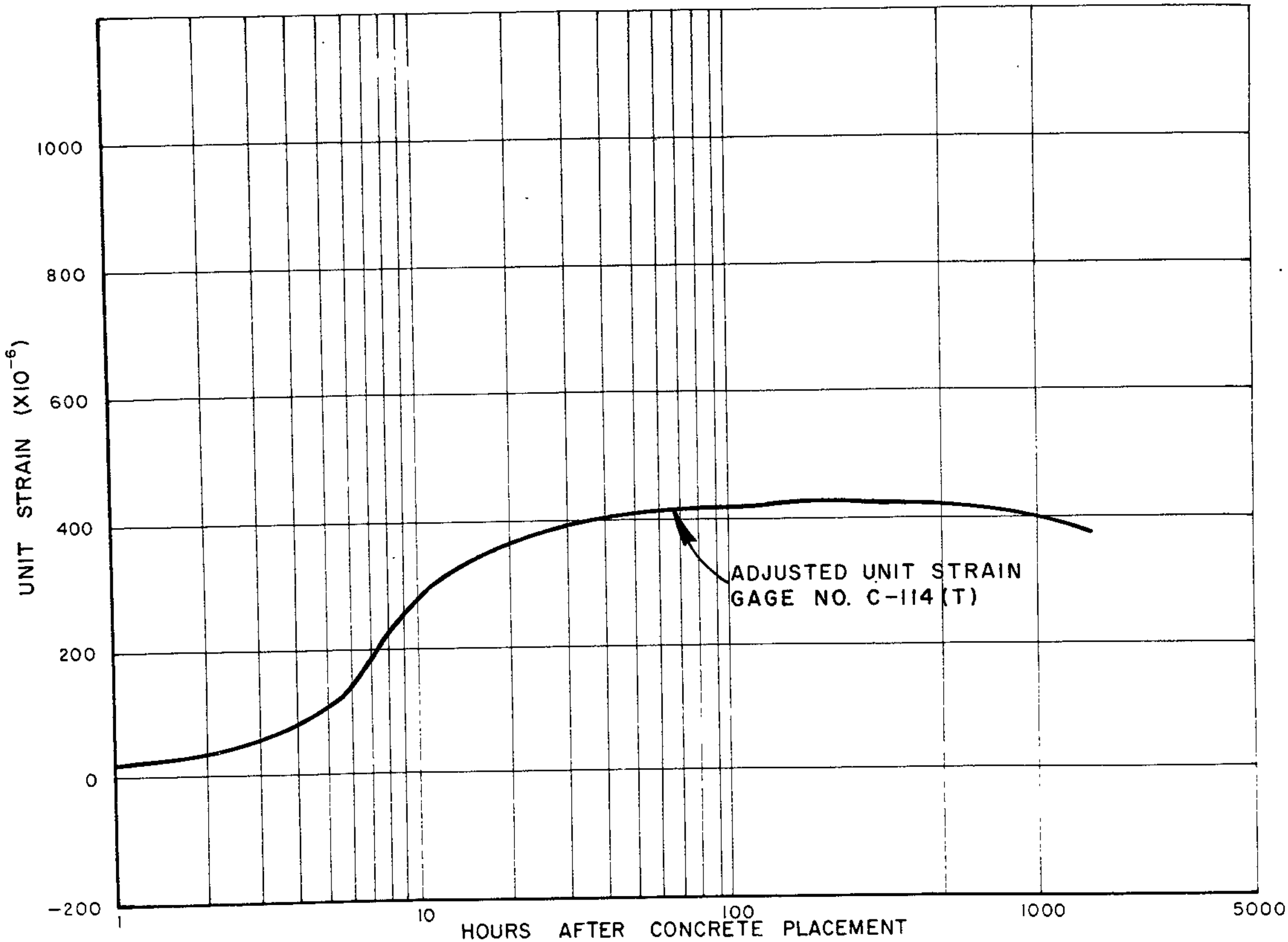


FIGURE 5

CARLSON GAGE DATA - ANTELOPE FREEWAY

EXPERIMENTAL SECTION (UNIT C)



CARLSON GAGE DATA - ANTELOPE FREEWAY

EXPERIMENTAL SECTION (UNIT D)

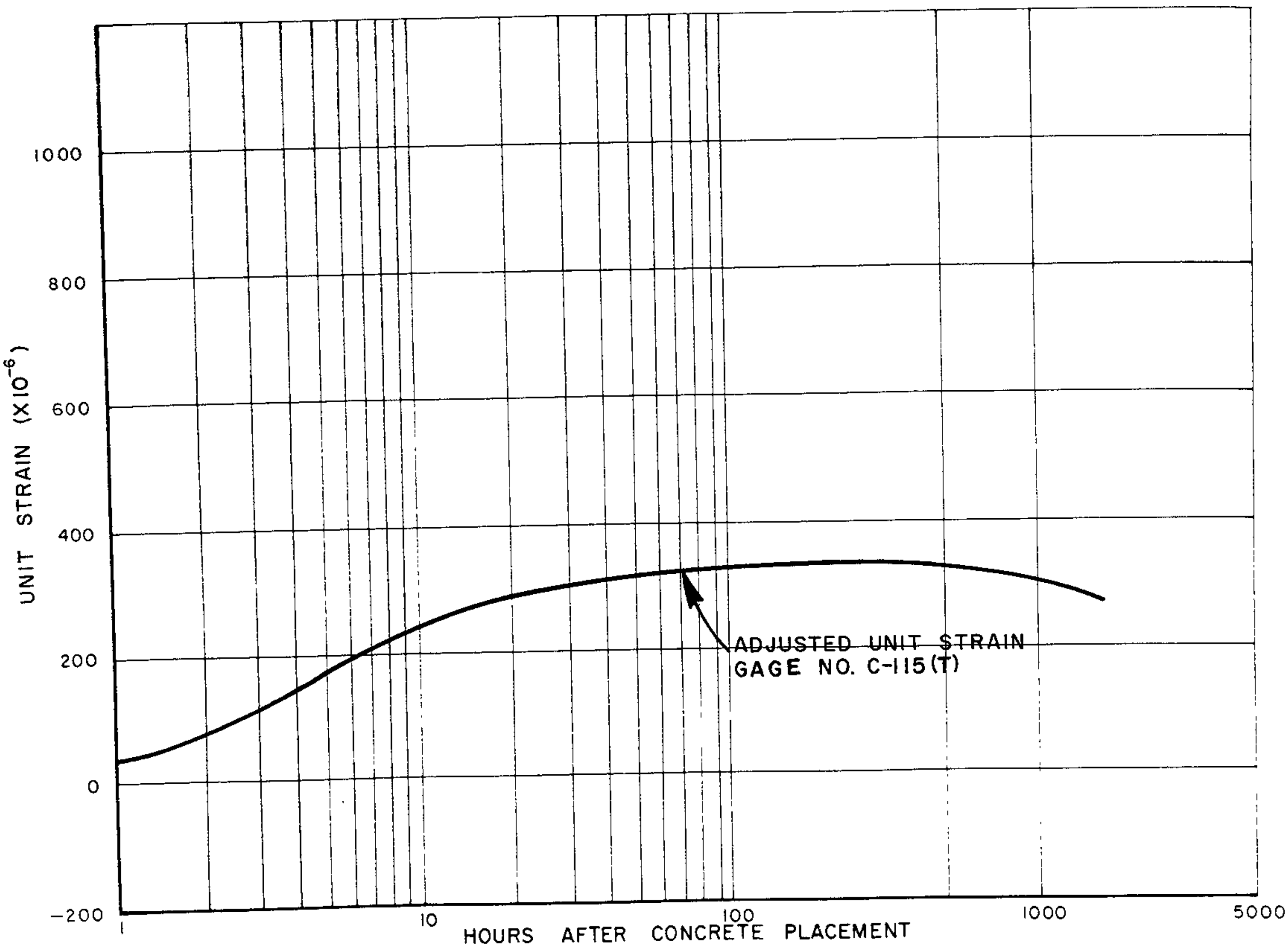


FIGURE 7

CARLSON GAGE DATA - ANTELOPE FREEWAY

EXPERIMENTAL SECTION (UNIT E)

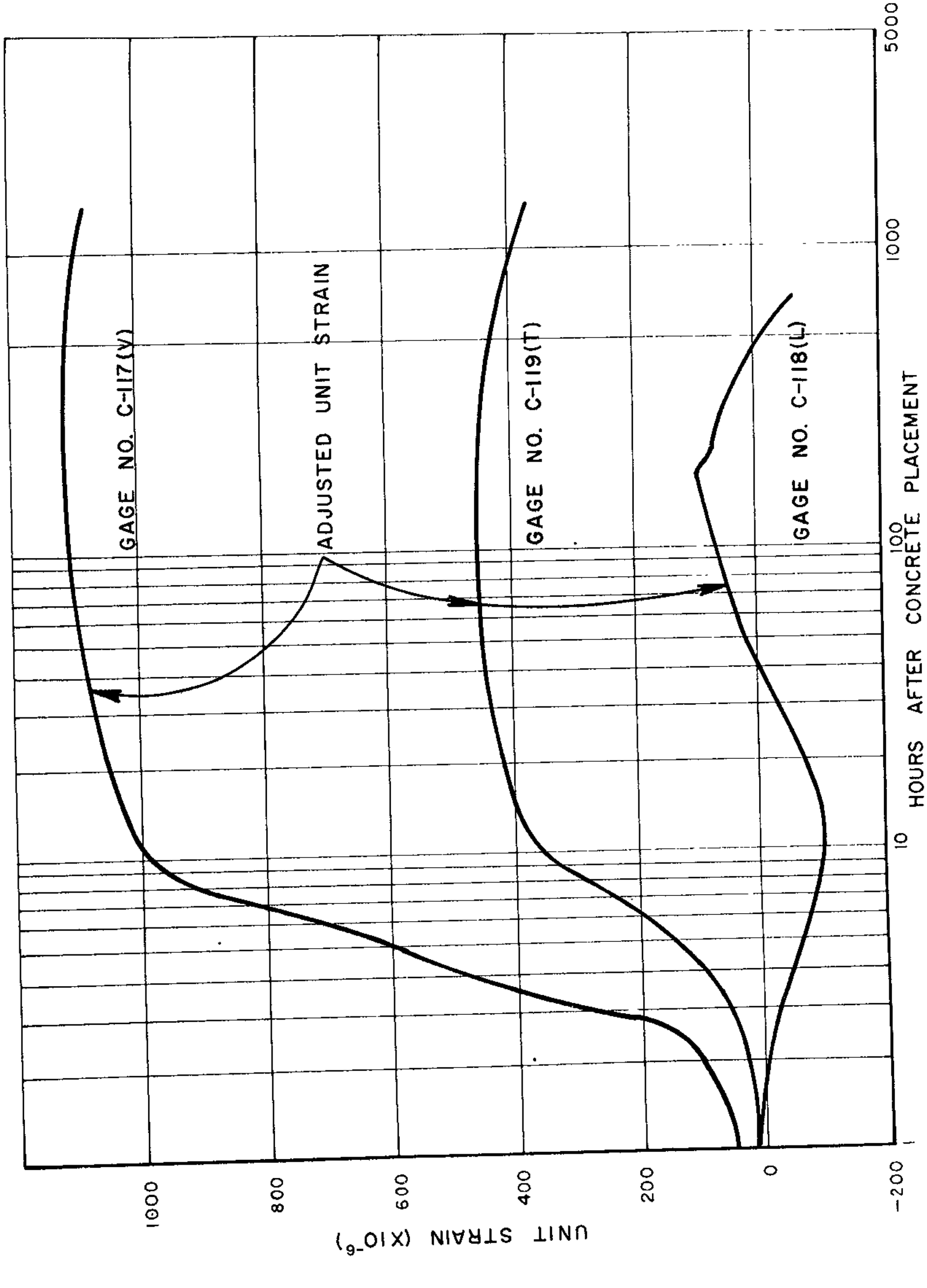


FIGURE 8

CARLSON GAGE DATA - ANTELOPE FREEWAY

EXPERIMENTAL SECTION (UNIT E)

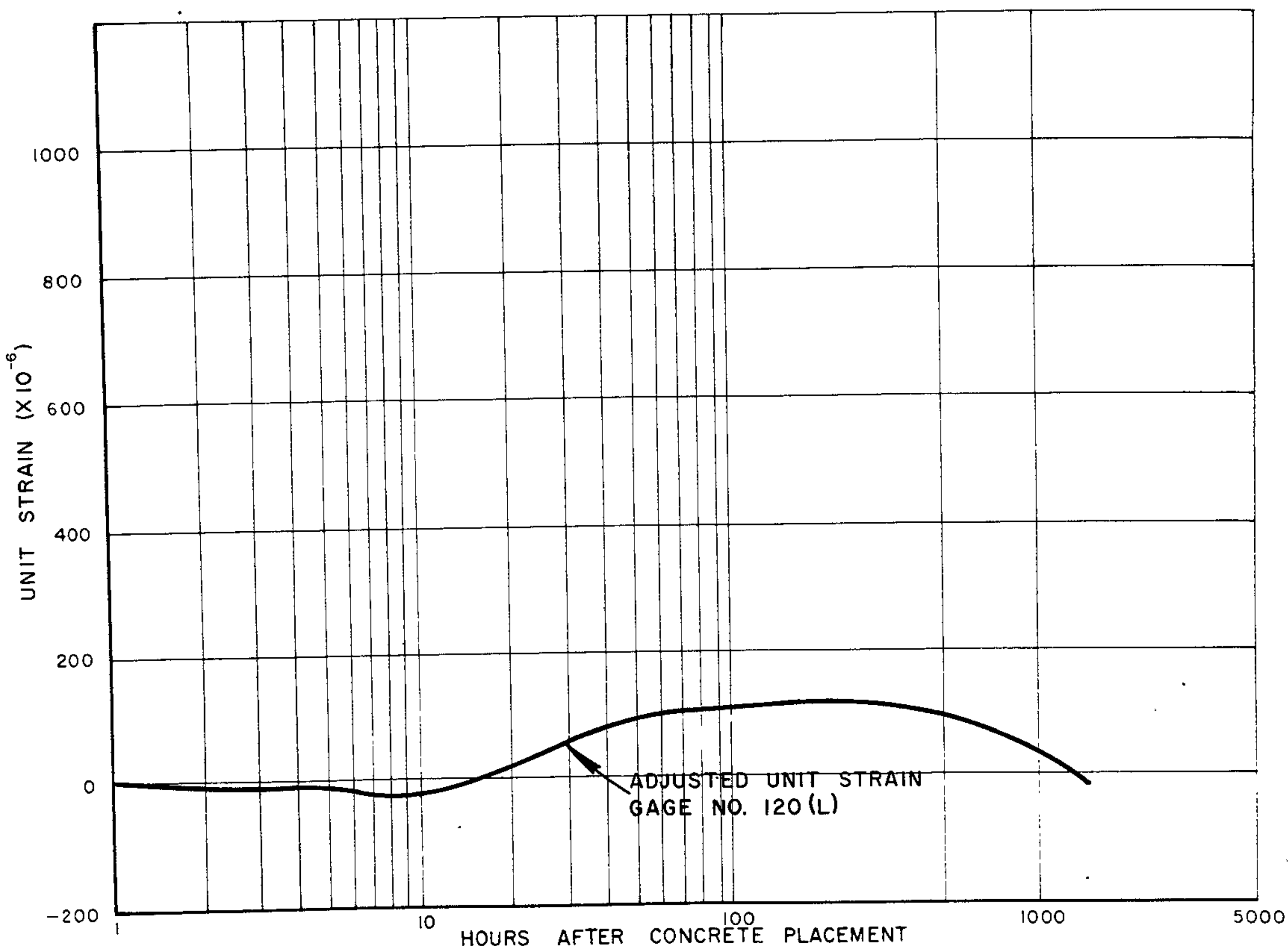


FIGURE 9

CARLSON GAGE DATA - ANTELOPE FREEWAY

EXPERIMENTAL SECTION (UNIT F)

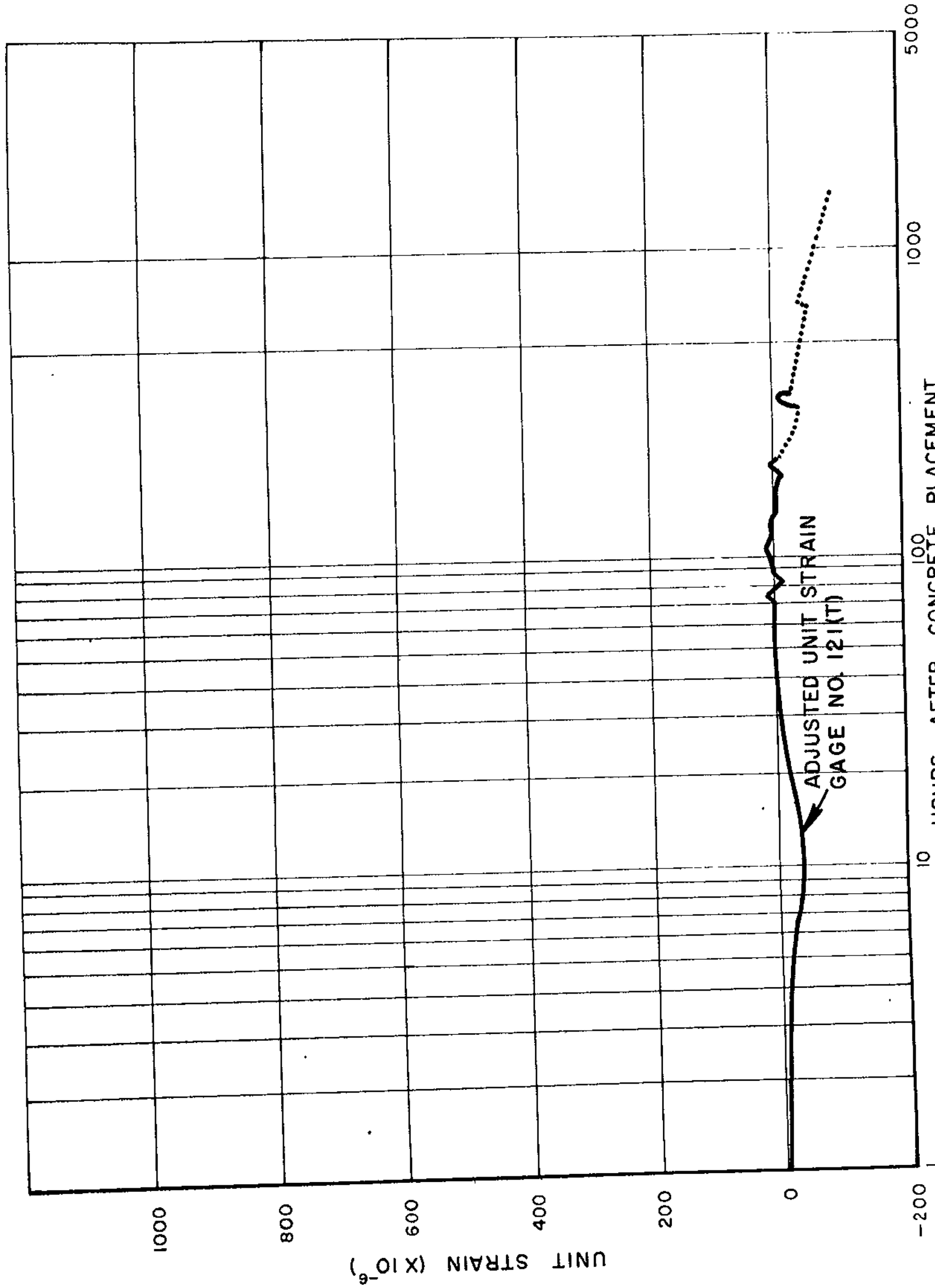


FIGURE 10

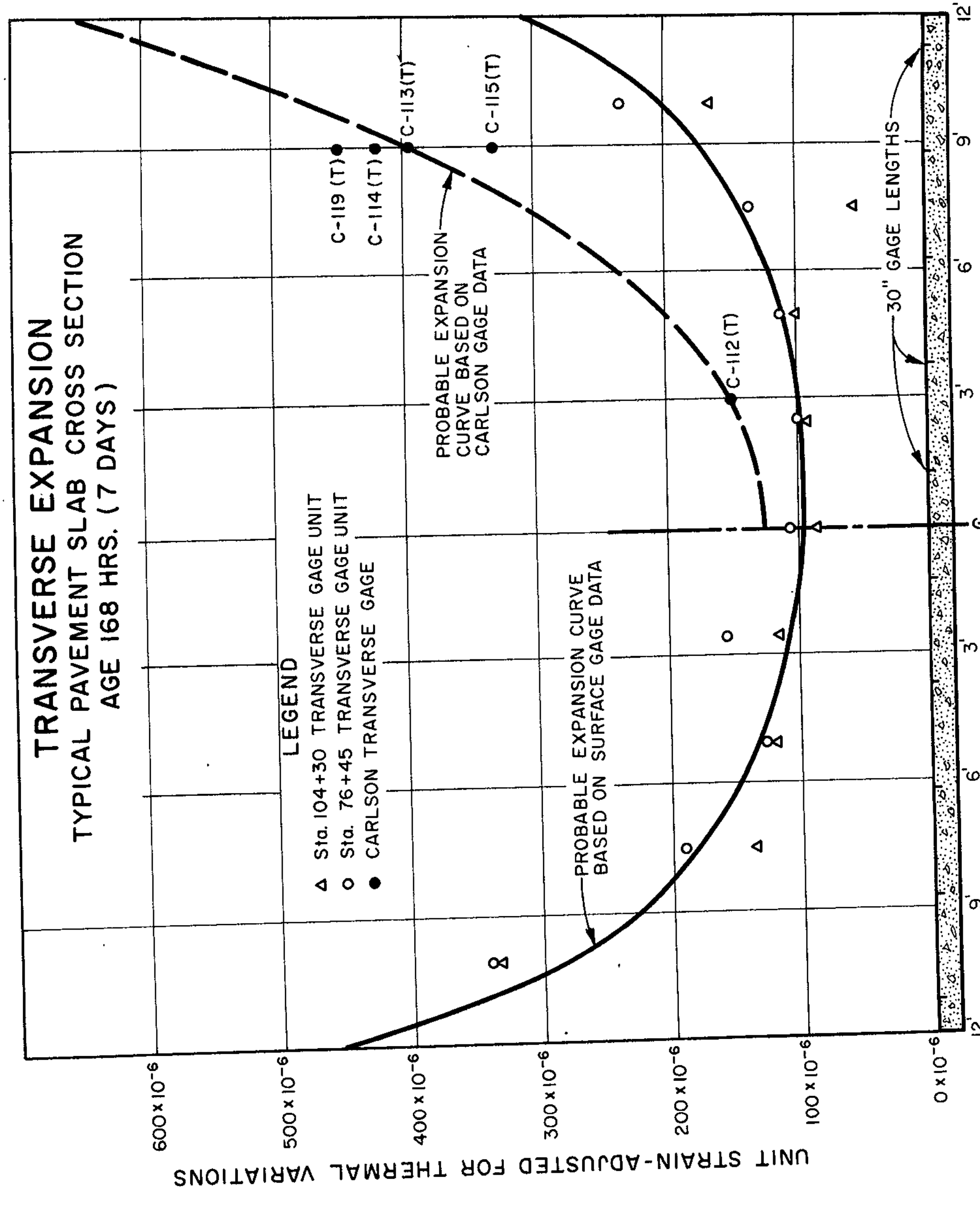

TRANSVERSE EXPANSION
TYPICAL PAVEMENT SLAB CROSS SECTION
AGE 168 HRS. (7 DAYS)
LEGEND
Sta. 104+30 TRANSVERSE GAGE UNIT
Sta. 76+45 TRANSVERSE GAGE UNIT
CARLSON TRANSVERSE GAGE
PROBABLE EXPANSION CURVE BASED ON SURFACE GAGE DATA
PROBABLE EXPANSION CURVE BASED ON CARLSON GAGE DATA
C-119 (T)
C-114 (T)
C-113 (T)
C-115 (T)
C-112 (T)
30" GAGE LENGTHS
12'
9'
6'
3'
℄
3'
6'
9'
12'
600 x 10⁻⁶
500 x 10⁻⁶
400 x 10⁻⁶
300 x 10⁻⁶
200 x 10⁻⁶
100 x 10⁻⁶
0 x 10⁻⁶
UNIT STRAIN-ADJUSTED FOR THERMAL VARIATIONS

FIGURE 11

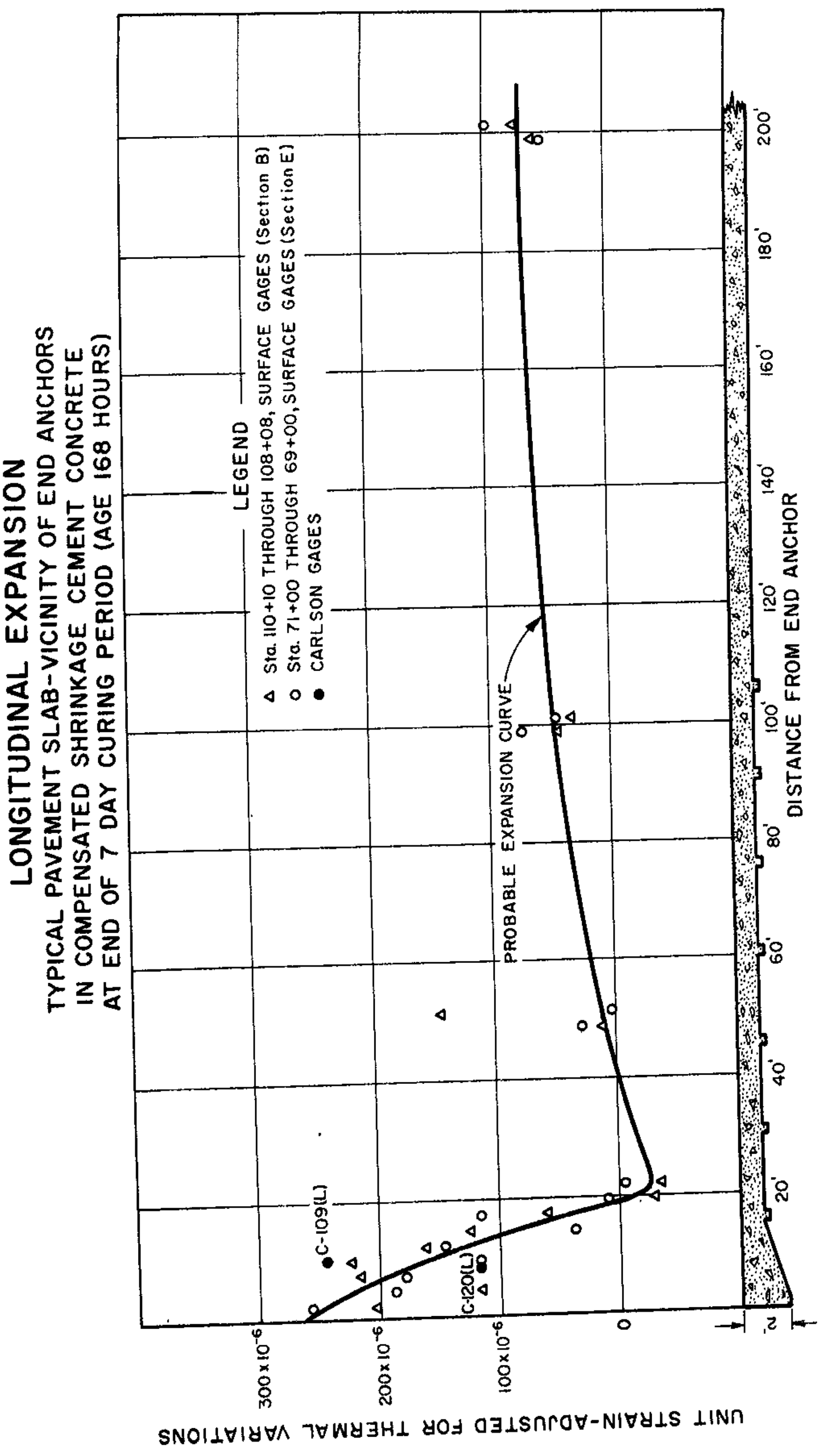
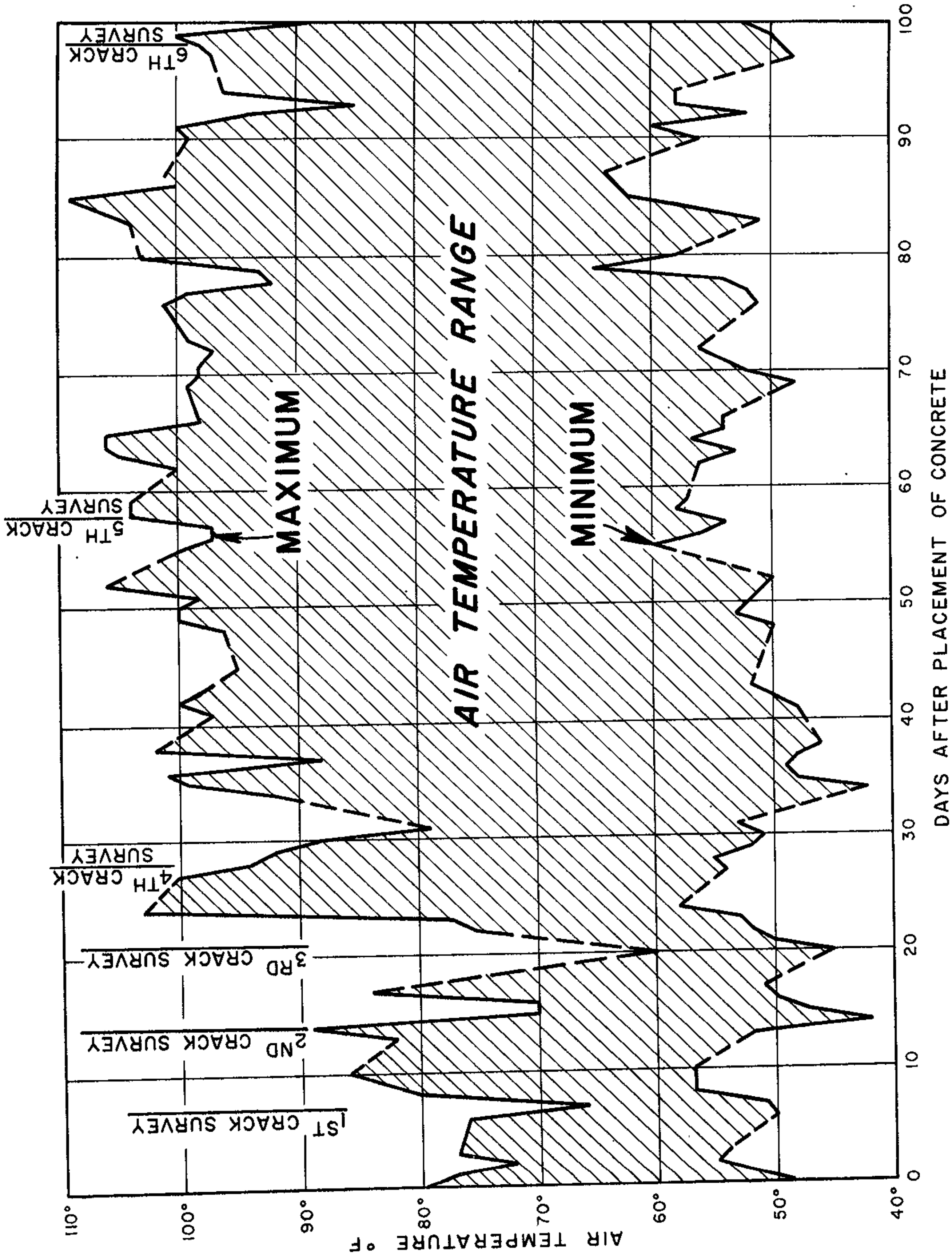

LONGITUDINAL EXPANSION
TYPICAL PAVEMENT SLAB-VICINITY OF END ANCHORS
IN COMPENSATED SHRINKAGE CEMENT CONCRETE
AT END OF 7 DAY CURING PERIOD (AGE 168 HOURS)
LEGEND
Sta. 110+10 THROUGH 108+08, SURFACE GAGES (Section B)
Sta. 71+00 THROUGH 69+00, SURFACE GAGES (Section E)
CARLSON GAGES
PROBABLE EXPANSION CURVE
C-109(L)
C-120(L)
300 x 10^-6
200 x 10^-6
100 x 10^-6
0
2'
20'
40'
60'
80'
100'
120'
140'
160'
180'
200'
DISTANCE FROM END ANCHOR
UNIT STRAIN-ADJUSTED FOR THERMAL VARIATIONS

FIGURE 12



AIR TEMPERATURE RANGE
MAXIMUM
MINIMUM
1ST CRACK SURVEY
2ND CRACK SURVEY
3RD CRACK SURVEY
4TH CRACK SURVEY
5TH CRACK SURVEY
6TH CRACK SURVEY
AIR TEMPERATURE °F
110°
100°
90°
80°
70°
60°
50°
40°
DAYS AFTER PLACEMENT OF CONCRETE
0
10
20
30
40
50
60
70
80
90
100

Photo 1. Aerial view showing westerly terminous of project and location of experimental pavement.

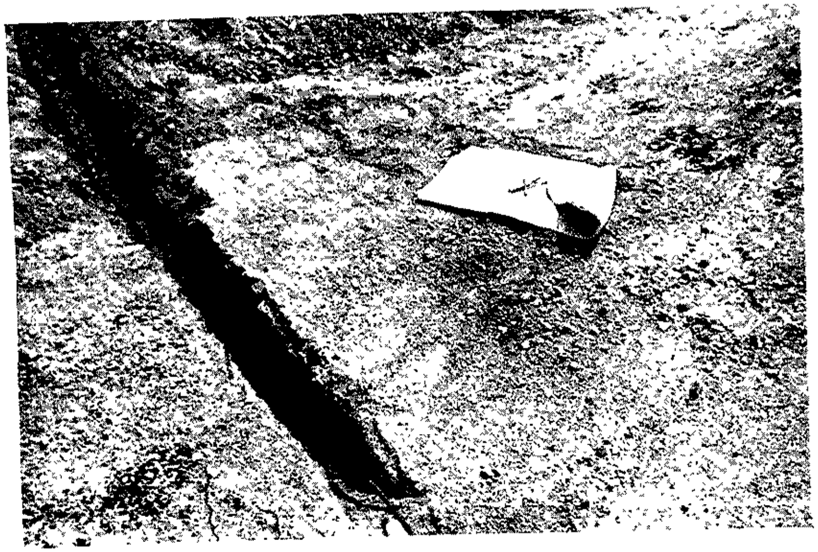


Photo 2. Typical trench in subgrade for protecting carlson strain gage lead wires.

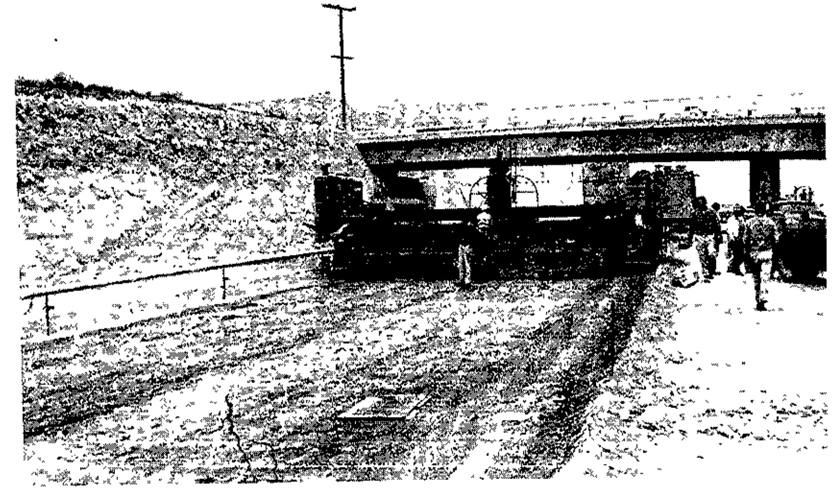


Photo 3. Protected Carlson gage installation prior to concrete placement.

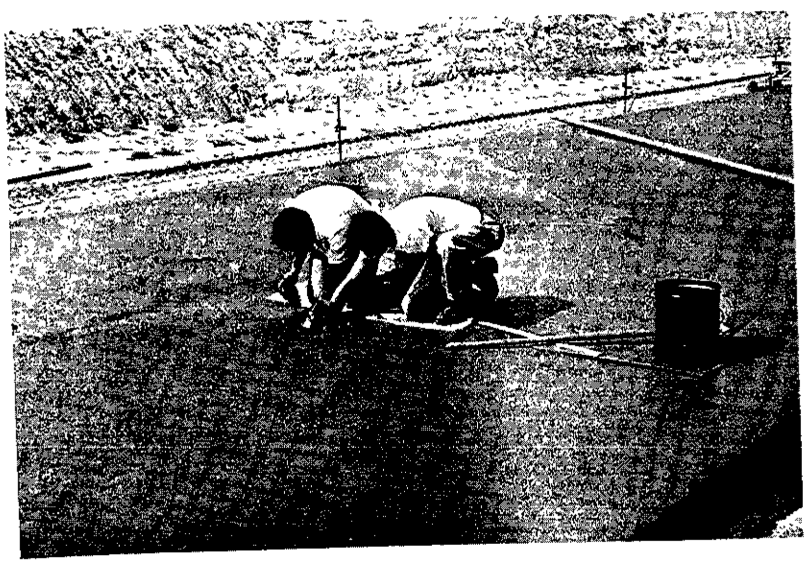


Photo 4. Digging strain gages out of fresh concrete.

Photo 5. Final positioning of three-dimensional Carlson gage installation.

Photo 6. Positioning of vertical Carlson strain gage.

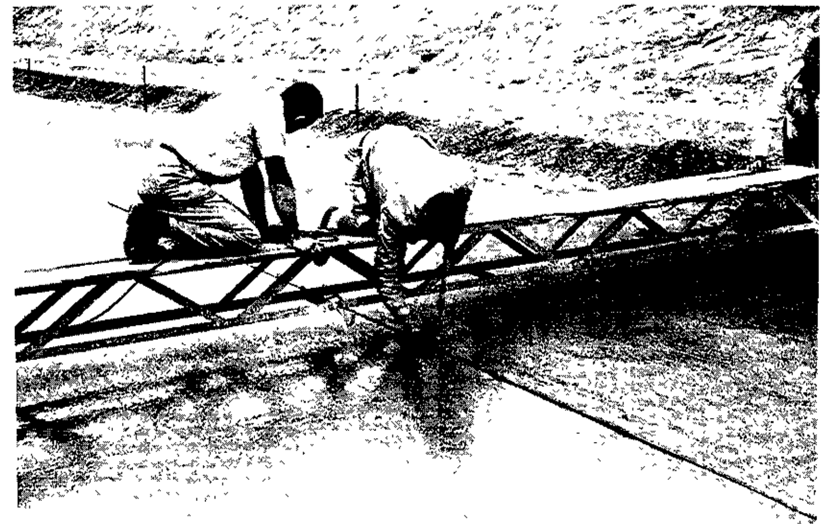


Photo 7. Placement of longitudinal surface gage plugs at beginning of Section B.

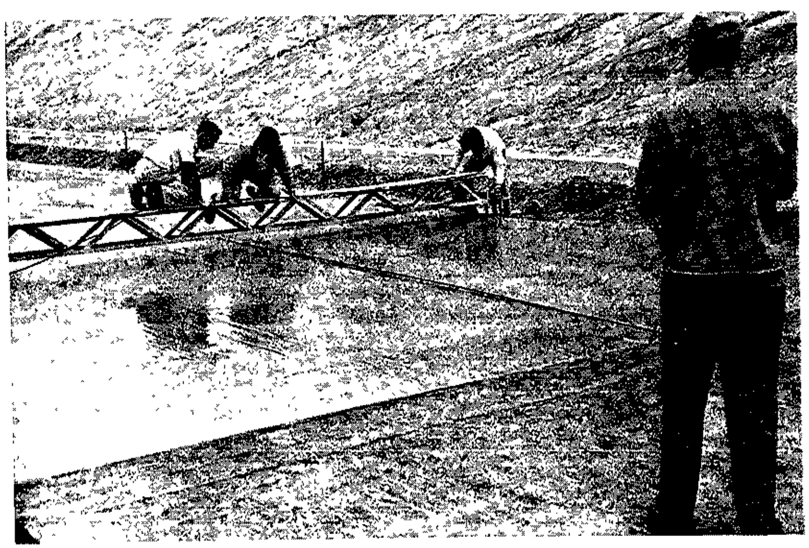


Photo 8. Finishing operation around surface gage plugs.

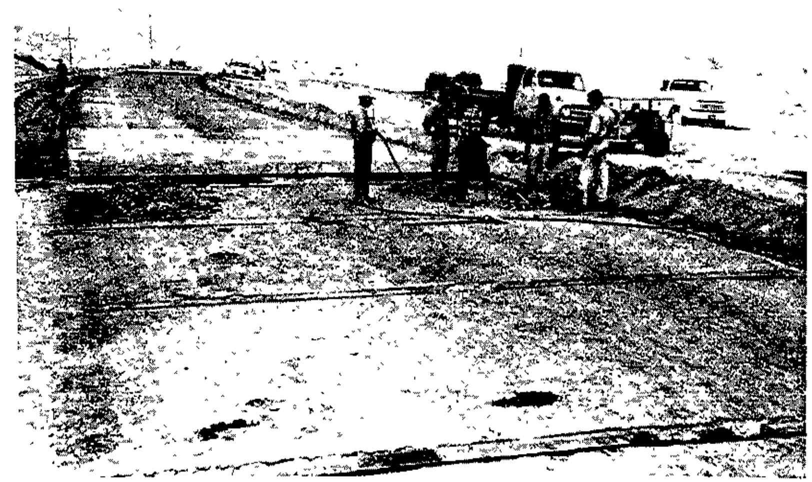


Photo 9. Excavation for end anchor at beginning of shrinkage compensated cement, Section B, Station 110.

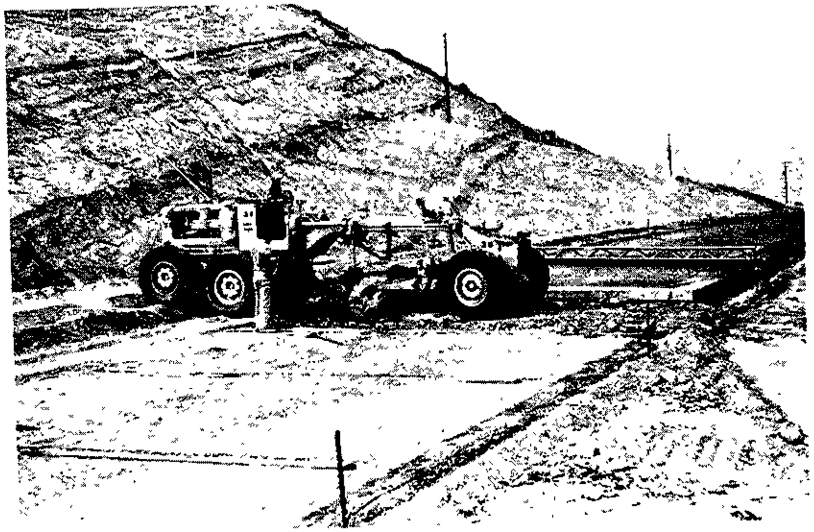


Photo 10. Excavation for end anchors, Station 110. Note pavement lug trenches in foreground with 6" x 8" timbers in place.

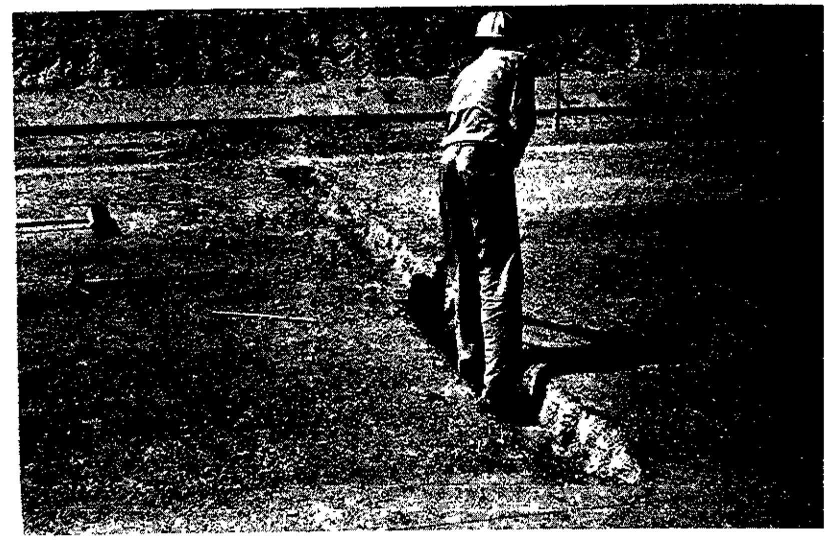


Photo 11. Final cleanup of trench for pavement lug in subgrade.

Photo 12. Excavation for end anchor at end of shrinkage compensated cement, Sec. E.

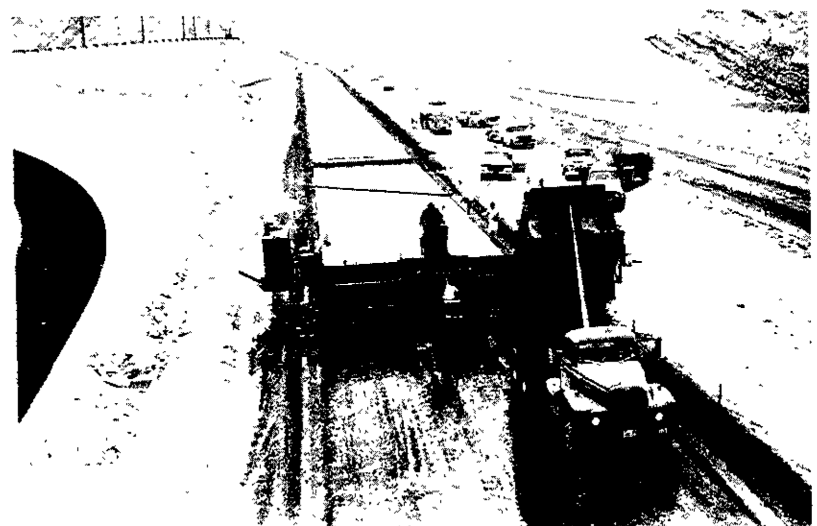


Photo 13. Looking east during paving operations in Section C.

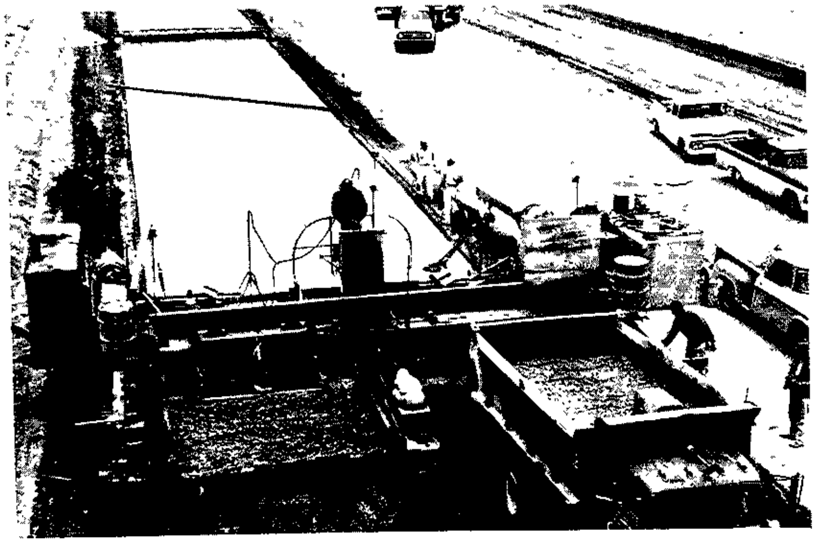


Photo 14. Paving operation.

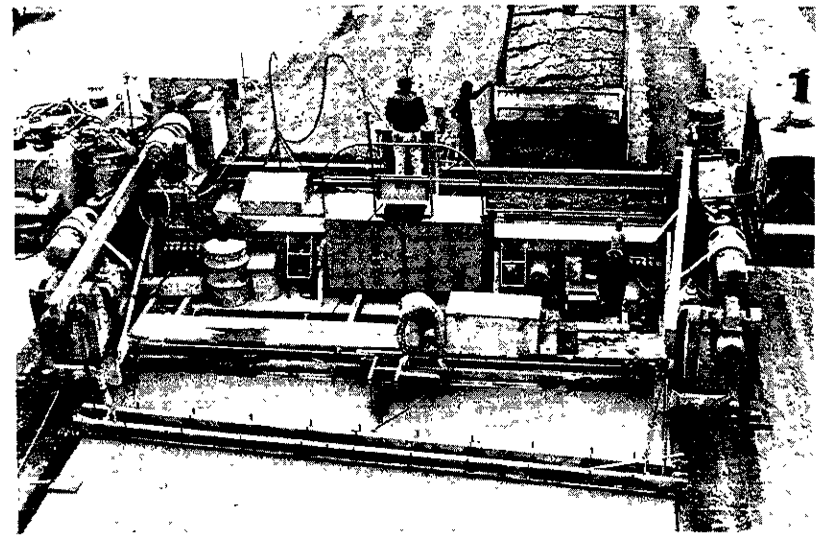


Photo 15. Rear view of paving operation.

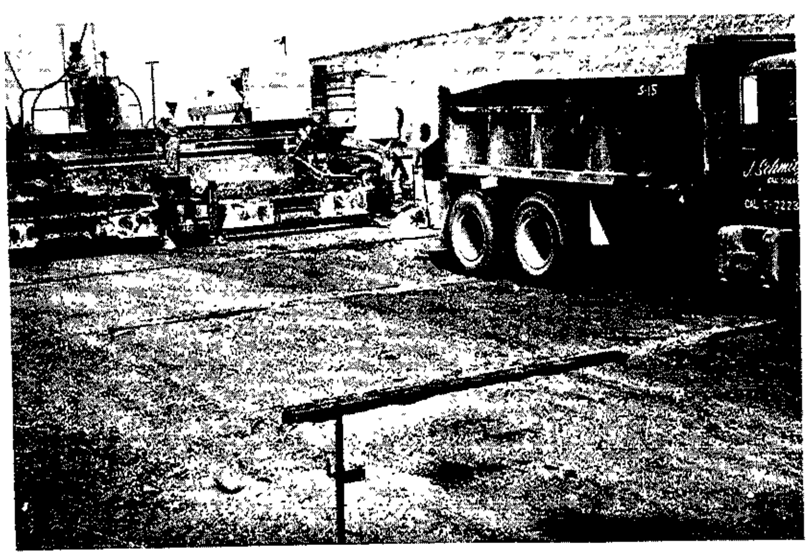


Photo 16. Paving lug trenches near end of Section E. Note timbers placed in trenches to support trucks.

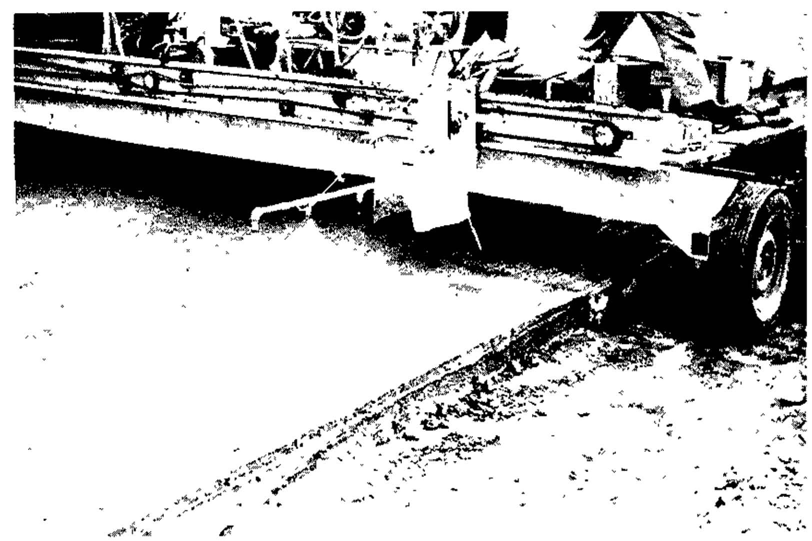


Photo 17. Applying water spray prior to white polyethylene sheeting for curing.

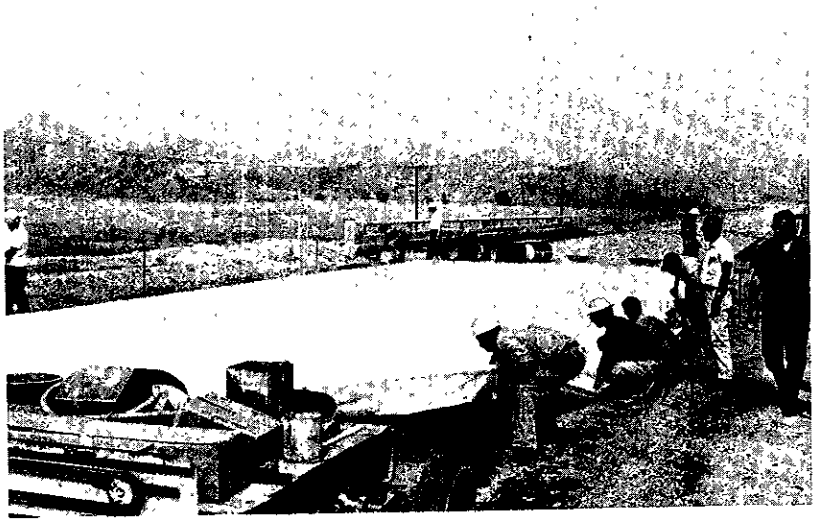


Photo 18. Spreading of polyethylene sheeting on pavement for curing.