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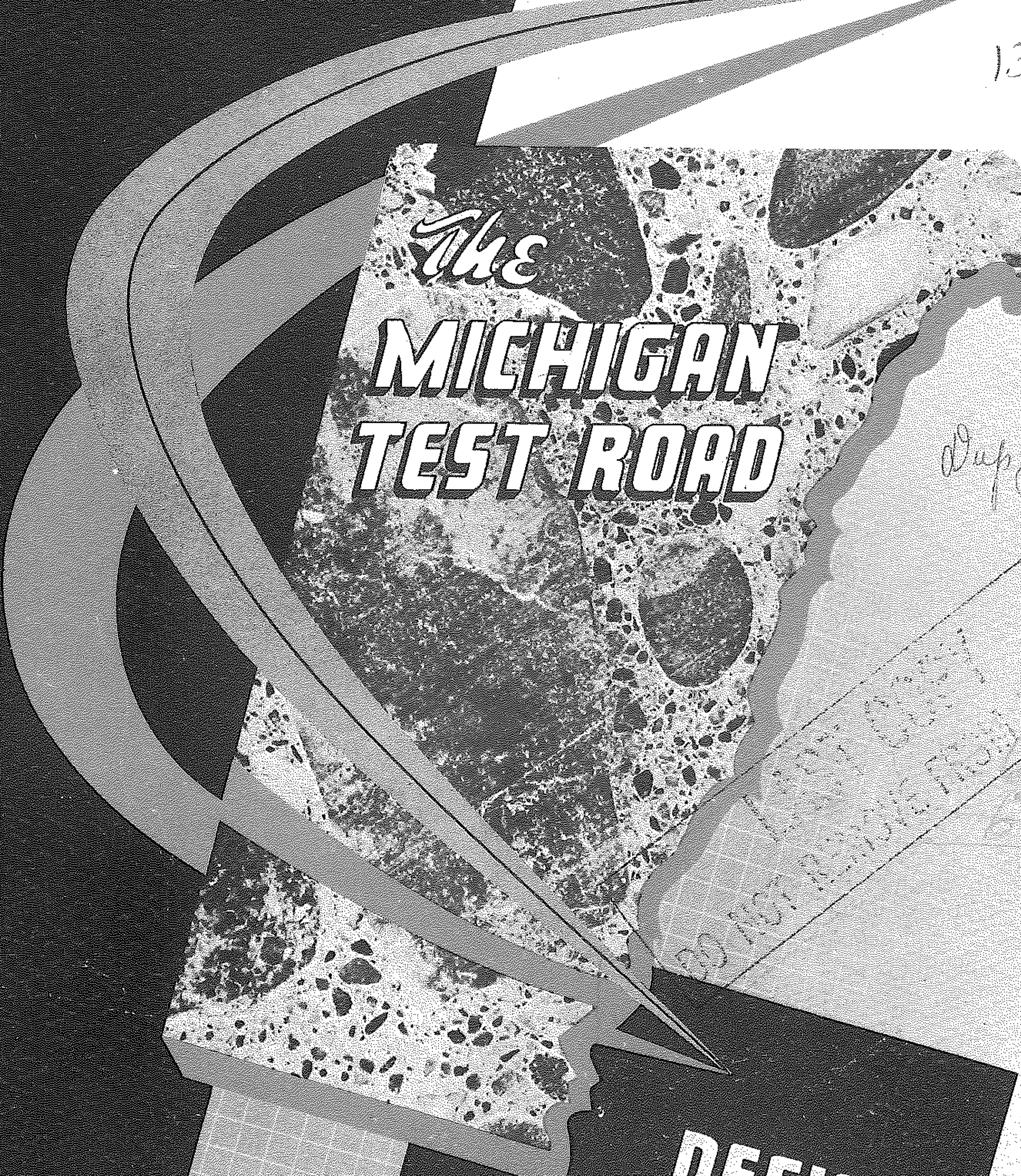


# The MICHIGAN TEST ROAD

# DESIGN PROJECT

Dup { C-C S-3 N-14



MICHIGAN
STATE HIGHWAY DEPARTMENT
CHARLES M. ZIEGLER
STATE HIGHWAY COMMISSIONER
IN COOPERATION WITH
U. S. DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS

Test

GUAR

Avge winter readings

3F & 7c'

4F 10'

avge for above.

Test Roa

GUARD-

RESEARCH LABORATORY
TESTING AND RESEARCH DIVISION

SUBJECT Fall '56

CONST. PROJ. M115 STA. 841+00±
DATE 10-23-56 TAKEN BY O.L.
PICTURE NUMBER ______ RESEARCH PROJECT ______

Avge winter readings
3F g 7c'
4F 10'

Avge for above.

Test Road - M115

GUARD-RAIL BEAMS

Avge winter readings
3F      70'
4F      10'

Avge for above.

Plot daily movement on seasonal curve.

---

final reading ~~[illegible]~~ last summer ~~and winter~~.
reading. use last 3 summer readings.


# DESIGN PROJECT

## NINE YEAR PROGRESS REPORT

1940-1949

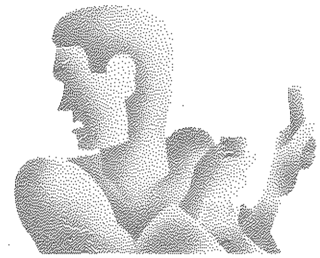
RESEARCH LABORATORY
TESTING & RESEARCH DIVISION
MICHIGAN STATE HIGHWAY DEPARTMENT

Report No. 137
Published August 1950


The Michigan Test Road
TO CADILLAC
M-115
M-61
Marion
M-66
HARTWICK
MIDDLE
COUNTY
COUNTY
BRANCH
SYLVAN
OSCEOLA
FREEMAN
DESIGN PROJECT
10.1 MILES
DURABILITY PROJECT
7.7 MILES
TO HOUGHTON LAKE
US-27
ORIENT
GARFIELD
SURREY
GRANT
US-10
M-66
OSCEOLA
CLARE
Farwell
Clare
US-10
US-27
CLARE
LANSING
DETROIT

Figure 1

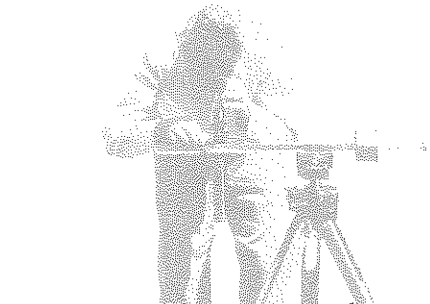
# PREFACE



In May, 1940, the administration of the Michigan State Highway Department authorized the construction of an investigational concrete pavement project under regular contract and construction procedure using the Department's 1940 plans and specifications with necessary supplementals. The specific purpose of this experimental project was twofold; *first,* to evaluate and establish certain fundamental design principles and *second,* to determine under field conditions the effect of certain factors on the durability of concrete, particularly in relation to scaling. These objectives are included in the primary objective of the Department which is continually to improve the serviceability and extend the economic life of concrete pavements in Michigan.

This experimental project, now generally known as the Michigan Test Road, was constructed in cooperation with the Bureau of Public Roads and is one of a group of six such Test Roads built throughout the United States, the others being in California, Kentucky, Minnesota, Missouri, and Oregon. The Michigan Test Road, consisting of 17.8 miles of 22-foot concrete pavement, was constructed on M-115 between US-10 and M-66 in Clare and Osceola Counties. See Figure 1. The Test Road is divided into two experimental sections. One section, designated the Design Project, is 10.1 miles in length and coincides in a general way with the Bureau of Public Roads plans and procedure for the construction of experimental roads which were submitted to various state highway organizations in 1940, (1)* but is more comprehensive in its scope. The Design Project is further identified as State Projects F 18-20, C4 and F 67-37, C6 or Federal Aid Projects 337-E (2) and 337-F (4) respectively. The other experimental section, called the Durability Project, is 7.7 miles in length and was included by the Department in the construction of the Test Road as a supplementary investigation to laboratory studies on the durability of concrete, especially in regard to scaling. This section is also identified as State Project F 18-20, C3 or Federal Aid Project 337-D (2).

*Numbers in parentheses refer to bibliography appended to this report.



The purpose and scope of the research program embodied in the Michigan Test Road has been previously reported in a bulletin entitled "The Michigan Test Road" published by the Department in July, 1942. Additional published literature concerning the scope of this experimental project will also be found in Volume 20, 1940, Proceedings of the Highway Research Board. A preliminary progress report describing the Design Project only is included in the Highway Research Board's Research Report No. 3-B, published in November, 1945. Therefore, repetition of basic information has been avoided in subsequent reports as much as is practical. In some instances repetition has been necessary for the sake of a better understanding of the work, as a connection between publications, and for convenience to those readers who have not had access to the first bulletin or are becoming acquainted with the experimental project for the first time.

During the construction of the Michigan Test Road in 1940 and subsequent to it, many observational and special studies have been made in addition to carrying out the program of seasonal and daily physical measurements which was set up in the original outline. When the experimental project was established it was anticipated that it would require a long period of time to make a complete analysis of all factors involved, including the necessary subsequent investigations, and that progress reports would be forthcoming as the work progressed.

The Test Road has been in existence now for 9 years and during this period there has been collected and analyzed a considerable amount of data. This data has been sufficient to show several significant trends in slab and joint behavior as well as other interesting disclosures which are believed to be of sufficient interest in relation to present design and construction problems to warrant the publication of a comprehensive progress report at this time.

The value of the work is clearly reflected in the Department's new standards for the design and construction of postwar concrete pavements. The most outstanding contributions emanating from the Test Road studies to date have been: *first,* the use of air-entrained concrete for scale prevention; *second,* the use of bituminous-rubber joint seal materials; *third,* the change to long slabs with heavier steel and no intermediate plane of weakness joints; and finally, the elimination of expansion joints, except at designated locations.

Two complete Bulletins have been prepared which are an account of all the various research activities carried on in the Design and Durability Projects of the Michigan Test Road, respectively, for the first 9 years subsequent to construction. These Bulletins are being published separately under the titles "Design Project" and "Durability Project".

This report on the "Design Project" contains miscellaneous project information pertaining to soil, concrete, and traffic conditions, and includes also a discussion of the general behavior of joints, slab movement and several incidental studies associated with the Project.

# TABLE OF CONTENTS

# LIST OF FIGURES

(1) EXPANSION JOINT CONSTRUCTION:
Type DB-1—¾″ x 15″ Dowel Bar Expansion Joint Assembly. Dowels at 15″ spacing.
Type TE—Thickened Edge 1¼″ x 18″ Corner Dowel Bar Expansion Joint Assembly. Dowels 9″ from slab edge.
Type CB-1—Unthickened Edge, 1¼″ x 18″ Corner Dowel Bar Expansion Joint Assembly, Dowels 9″ from slab edge.
Type TB—Translode Base Expansion Joint Assembly.
Type TA—Translode Angle Unit Expansion Joint Assembly.
Type A—No Load Transfer Feature.

(2) CONTRACTION JOINT CONSTRUCTION:
Type DB—¾″ x 15″ Dowels at 15″ spacing, premolded filler.
Type 1B—¾″ x 15″ Dowels at 15″ spacing, groove and poured seal.
Type 2A—¾″ x 15″ Dowels at 15″ spacing, premolded filler, metal parting strip at bottom.
Type 2B—¾″ x 15″ Dowels at 15″ spacing, groove and poured seal, metal parting strip at bottom.
Type 3—¾″ x 15″ Dowels at 15″ spacing, groove and poured seal, full depth metal divider plate.
Type 4—Continuous Plate Dowel Assembly.
Type 5—Keylode Contraction Joint Assembly.
Type CB—1¼″ x 18″ Dowels at corners, 9″ from slab edge, premolded filler.
Type 6—Aggregate Interlock. No Dowels.

(3) DUMMY PLANE OF WEAKNESS JOINTS:
R—Aggregate Interlock, steel mesh reinforcement continuous through joint.

(4) EXPANSION JOINT, FILLER AND SEAL:
Type 1—Premolded fiber filler with Asphalt-Latex Seal.
Type 2—Premolded fiber filler with Asphalt-Vultex Seal.
Type 3—Air chamber with top, bottom and sides sealed with Asphalt-Latex compound.
Type 4—Air chamber with premolded rubber seal at top, bottom and sides, Asphalt-Latex Seal in bottom.
Type 5—Premolded fiber filler with Thermoplastic Seal.
Type 6—Premolded fiber filler with SOA Seal.

**Table I**

## SUMMARY OF TEST SECTIONS

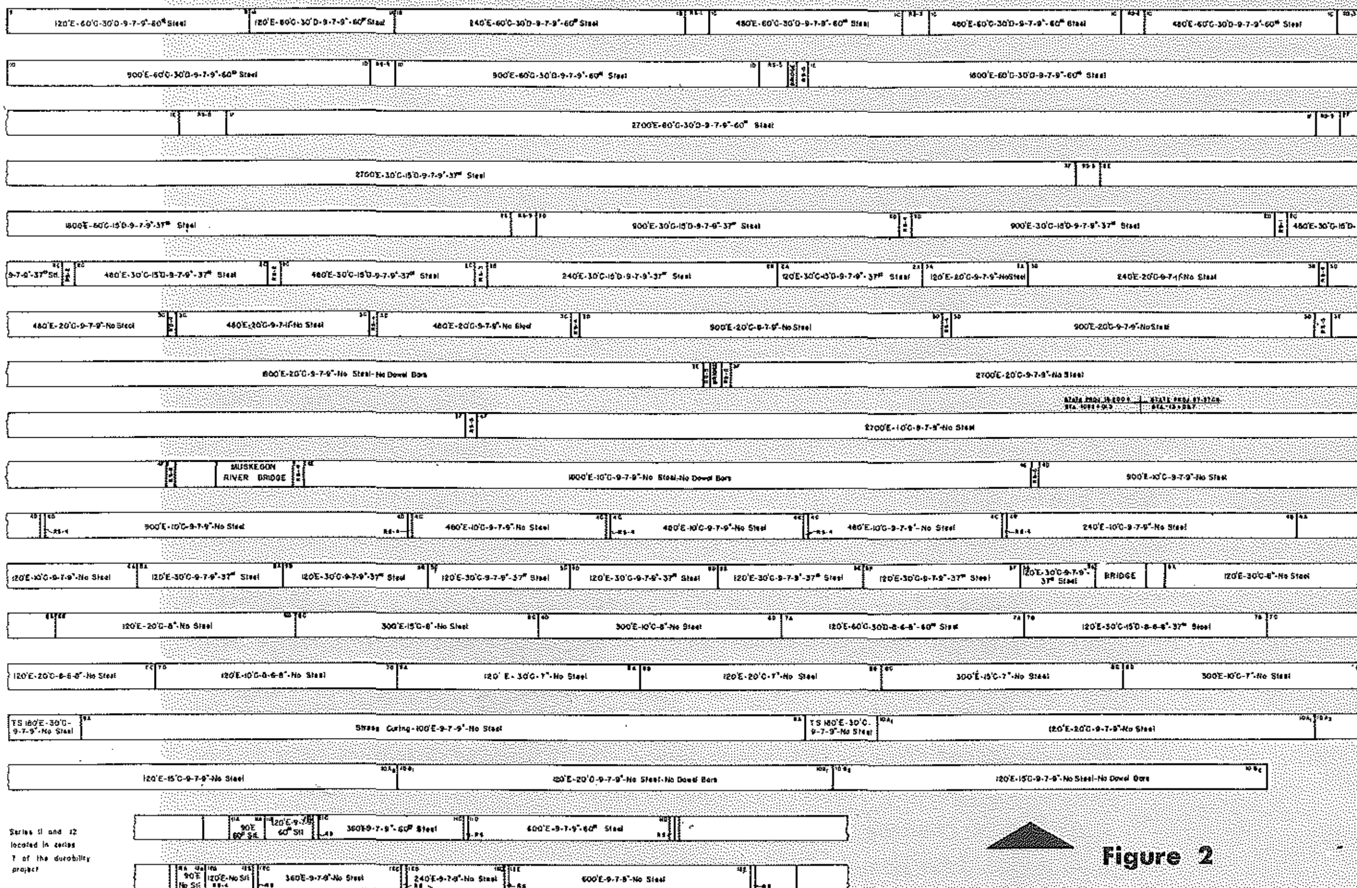
| TEST AREA DESIGNATION | | Number of Sections in Division | Length of Division in feet | Pavement Thickness, Inches | Reinforcement lbs./100 sq. ft. | JOINT SPACING IN FEET | | | LOAD TRANSFER TYPE | | | FILLER AND SEAL | Special Factors Under Study |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Series | Division | | | | | Expansion | Contraction | Dummy | Expansion (1) | Contraction (2) | Dummy (3) | Expansion Joint (4) | |
| S | — | 1 | 600 | 9-7-9 | 60 | 120 | 60 | 30 | DB-1 | DB | R | 1 | |
| 1 | A | 3 | 360 | 9-7-9 | 60 | 120 | 60 | 30 | DB-1 | DB | R | 1 | Joint Spacing |
| | B | 3 | 720 | 9-7-9 | 60 | 240 | 60 | 30 | DB-1 | DB | R | 1 | Joint Design |
| | C | 3 | 1440 | 9-7-9 | 60 | 480 | 60 | 30 | TE | DB | R | 1 | Reinforcement |
| | D | 2 | 1800 | 9-7-9 | 60 | 900 | 60 | 30 | DB-1 | DB | R | 1 | Expansion Space |
| | E | 1 | 1800 | 9-7-9 | 60 | 1800 | 60 | 30 | DB-1 | DB | R | 1 | |
| | F | 1 | 2700 | 9-7-9 | 60 | 2700 | 60 | 30 | DB-1 | DB | R | 1 | |
| 2 | F | 1 | 2700 | 9-7-9 | 37 | 2700 | 30 | 15 | DB-1 | DB | R | 1 | Joint Spacing |
| | E | 1 | 1800 | 9-7-9 | 37 | 1800 | 30 | 15 | DB-1 | DB | R | 1 | Joint Design |
| | D | 2 | 1800 | 9-7-9 | 37 | 900 | 30 | 15 | DB-1 | DB | R | 1 | Reinforcement |
| | C | 3 | 1440 | 9-7-9 | 37 | 480 | 30 | 15 | TE | DB | R | 1 | Expansion Space |
| | B | 3 | 720 | 9-7-9 | 37 | 240 | 30 | 15 | DB-1 | DB | R | 1 | |
| | A | 3 | 360 | 9-7-9 | 37 | 120 | 30 | 15 | DB-1 | DB | R | 1 | |
| 3 | A | 3 | 360 | 9-7-9 | None | 120 | 20 | None | DB-1 | DB | None | 1 | Joint Spacing |
| | B | 3 | 720 | 9-7-9 | None | 240 | 20 | None | DB-1 | DB | None | 1 | Reinforcement |
| | C | 3 | 1440 | 9-7-9 | None | 480 | 20 | None | DB-1 | DB | None | 1 | Contraction Joints With and |
| | D | 2 | 1800 | 9-7-9 | None | 900 | 20 | None | DB-1 | DB | None | 1 | Without Load Transfer Devices |
| | E | 1 | 1800 | 9-7-9 | None | 1800 | 20 | None | DB-1 | None | None | 1 | Expansion Space |
| | F | 1 | 2700 | 9-7-9 | None | 2700 | 20 | None | DB-1 | DB | None | 1 | |
| 4 | F | 1 | 2700 | 9-7-9 | None | 2700 | 10 | None | DB-1 | DB | None | 2 | Joint Spacing |
| | E | 1 | 1800 | 9-7-9 | None | 1800 | 10 | None | DB-1 | None | None | 2 | Reinforcement |
| | D | 2 | 1800 | 9-7-9 | None | 900 | 10 | None | DB-1 | DB | None | 2 | Contraction Joints With and |
| | C | 3 | 1440 | 9-7-9 | None | 480 | 10 | None | DB-1 | DB | None | 2 | Without Load Transfer Devices |
| | B | 3 | 720 | 9-7-9 | None | 240 | 10 | None | DB-1 | DB | None | 2 | Expansion Space |
| | A | 3 | 360 | 9-7-9 | None | 120 | 10 | None | DB-1 | DB | None | 2 | |
| 5 | A | 3 | 360 | 9-7-9 | 37 | 120 | 30 | None | DB-1 | 1B | None | 3 | Contraction Joint Design |
| | B | 3 | 360 | 9-7-9 | 37 | 120 | 30 | None | DB-1 | 2A | None | 3 | Reinforcement |
| | C | 3 | 360 | 9-7-9 | 37 | 120 | 30 | None | DB-1 | 2B | None | 3 | |
| | D | 3 | 360 | 9-7-9 | 37 | 120 | 30 | None | DB-1 | 3 | None | 3 | |
| | E | 3 | 360 | 9-7-9 | 37 | 120 | 30 | None | DB-1 | 3 | None | 3 | |
| | F | 3 | 360 | 9-7-9 | 37 | 120 | 30 | None | DB-1 | 4 | None | 3 | |
| | G | 3 | 360 | 9-7-9 | 37 | 120 | 30 | None | DB-1 | 4 | None | 3 | |
| 6 | A | 5 | 600 | 8″ | None | 120 | 30 | None | CB-1 | CB | None | 2 | Cross Section |
| | B | 5 | 600 | 8″ | None | 120 | 20 | None | CB-1 | CB | None | 2 | Joint Design |
| | C | 2 | 600 | 8″ | None | 300 | 15 | None | CB-1 | CB | None | 2 | Reinforcement |
| | D | 2 | 600 | 8″ | None | 300 | 10 | None | CB-1 | CB | None | 2 | |
| 7 | A | 5 | 600 | 8-6-8 | 60 | 120 | 60 | 30 | DB-1 | CB | R | 2 | Cross Section |
| | B | 5 | 600 | 8-6-8 | 37 | 120 | 30 | 15 | DB-1 | CB | R | 2 | Reinforcement |
| | C | 5 | 600 | 8-6-8 | None | 120 | 20 | None | DB-1 | CB | None | 2 | |
| | D | 5 | 600 | 8-6-8 | None | 120 | 10 | None | DB-1 | CB | None | 2 | |
| 8 | A | 3 | 360 | 7″ | None | 120 | 30 | None | CB-1 | DB | None | 2 | Cross Section |
| | B | 7 | 840 | 7″ | None | 120 | 20 | None | CB-1 | DB | None | 2 | Reinforcement |
| | C | 2 | 600 | 7″ | None | 300 | 15 | None | CB-1 | DB | None | 2 | Joint Design |
| | D | 2 | 600 | 7″ | None | 300 | 10 | None | CB-1 | DB | None | 2 | |
| 9 | TS | 1 | 180 | 9-7-9 | None | 180 | 30 | None | TB | DB | None | 4 | Stress Curing |
| | A | 1 | 1800 | 9-7-9 | None | 100 | None | None | TB | None | None | 4 | Joint Design |
| | TS | 1 | 90 | 9-7-9 | None | 180 | 30 | None | TB | DB | None | 4 | |
| | TS | 1 | 90 | 9-7-9 | None | 180 | 30 | None | DB-1 | 5 | None | 4 | |
| 10 | A-1 | 9 | 1080 | 9-7-9 | None | 120 | 20 | None | DB-1 | DB | None | 5 | Contraction Joints With and |
| | A-2 | 9 | 1080 | 9-7-9 | None | 120 | 15 | None | DB-1 | DB | None | 5 | Without Load Transfer Devices |
| | B-1 | 9 | 1080 | 9-7-9 | None | 120 | 20 | None | A | None | None | 2 | |
| | B-2 | 9 | 1080 | 9-7-9 | None | 120 | 15 | None | A | None | None | 2 | |
| 11 | A | 1 | 90 | 9-7-9 | 60 | 90 | None | None | TA | None | None | 6 | Continuous Slab Construction |
| | B | 1 | 120 | 9-7-9 | 60 | 120 | None | None | TA | None | None | 6 | With Reinforcement |
| | C | 1 | 362 | 9-7-9 | 60 | 362 | None | None | TA | None | None | 6 | |
| | D | 1 | 600 | 9-7-9 | 60 | 600 | None | None | TA | None | None | 6 | |
| 12 | A | 1 | 90 | 9-7-9 | None | 90 | None | None | TA | None | None | 6 | Continuous Slab Construction |
| | B | 1 | 120 | 9-7-9 | None | 120 | None | None | TA | None | None | 6 | Without Reinforcement |
| | C | 1 | 360 | 9-7-9 | None | 360 | None | None | TA | None | None | 6 | |
| | D | 1 | 242 | 9-7-9 | None | 242 | None | None | TA | None | None | 6 | |
| | E | 1 | 600 | 9-7-9 | None | 600 | None | None | TA | None | None | 6 | |

# THE DESIGN PROJECT

The Design Project of the Michigan Test Road is devoted to a study of several important principles and factors incidental to the design and construction of modern concrete pavements. The important design studies included in this project are joint spacing, joint design, pavement cross section, steel reinforcement, uniform thickness versus balanced cross section, stress curing, and relation of pavement cross section to subgrade supporting value. In addition, such construction features as mechanical spreading of concrete, mechanical tamping of forms, and joint sealing compounds were included for observational study.

In order to evaluate the design features previously mentioned under controlled conditions it was necessary to divide the project into 12 test areas. The test areas, designated as Series 1 to 12, are described in Table I entitled, "Summary of Test Areas of Design Project". The table includes important information pertinent to each test area. To facilitate the study of a particular design feature each series has been further subdivided into divisions and sections designated by letters and numerals, respectively. In addition to Table I, a schematic diagram of the Design Project is presented in Figure 2 which shows the relative location of the various test sections in the project, and a profile sketch is given in Figure 3.

Important factual information resulting from the various visual observations and field measurements associated with the Design Project are discussed under the headings of miscellaneous project information, concrete pavement design studies, and incidental studies.



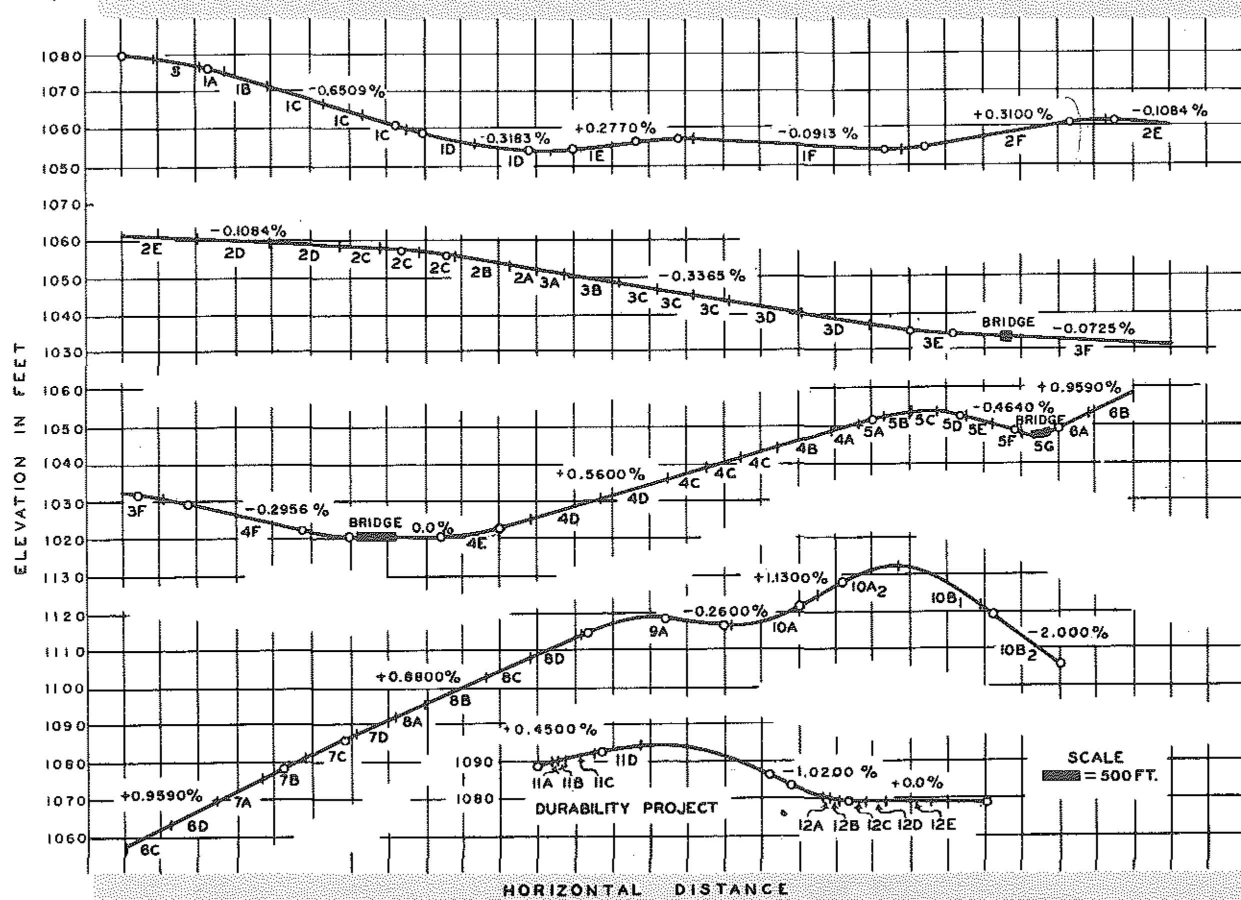
Series 11 and 12 located in series 7 of the durability project

**Figure 2**

## SCHEMATIC DIAGRAM OF THE DESIGN PROJECT

**Figure 3**

## PROFILE OF THE DESIGN PROJECT



# MISCELLANEOUS PROJECT INFORMATION

During the construction of the pavement surface and subsequent to it, certain important factual data have been procured which are directly or indirectly associated with the general behavior of the pavement slabs. Such information includes general soil conditions and subbase construction operations, concrete mix design, physical properties of the concrete, traffic conditions, and climatological data taken at the site of the project.

## GENERAL SOIL CONDITIONS

The subgrade materials are composed primarily of well-drained sandy or gravelly soils with the exception of two areas, Stations 88 + 00 to 129 + 00 and Stations 170 + 00 to 225 + 06, where it was necessary to construct a 12-inch sand subbase or cushion on the existing subgrade material. The physical properties of the soil immediately under the concrete pavement at four representative locations where a sand cushion was not required are given in Table II. The extent and relative location of soil types and earth work operations for the Design Project are illustrated in Figure 4.

SUBGRADE RESISTANCE: Laboratory and field studies were made to determine a probable value for the coefficient of friction between the granular subbase material and the pavement slab. Friction studies were made in the laboratory on soil imported from the Test Road site which was representative of subgrade conditions. A concrete slab 4 feet square and 6 inches thick was placed on a prepared subbase 12 inches thick. The force necessary to cause horizontal movement and the magnitude of the displacement caused by the thrust were measured from the beginning of test until movement of the slab took place. The procedure was repeated several times both in a forward and backward direction. Studies were made with the soil wet and dry and the bottom surface of the slab smooth and corrugated to simulate possible field conditions.

Subgrade friction values of the following order were obtained:

| | |
|---|---|
| Subgrade wet, slab smooth | Average Value 1.00 |
| Subgrade dry, slab smooth | Average Value 0.75 |
| Subgrade wet, slab corrugated | Average Value 1.33 |

In the field a 100-foot continuous slab located in Series 9-A was moved back and forth in situ by inflating air cells which were inserted in the expansion joint openings at each end of the slab. An average friction coefficient of 1.67 was obtained from this work. It is to be expected that the load transfer devices at the joints and undesirable subgrade conditions would influence the friction measurements which are slightly higher than those obtained under ideal conditions in the laboratory.

Taking all factors into consideration, the coefficient values determined from these studies would indicate the horizontal resistance of the subgrade to slab movement to be low as compared to values which are known to exist on the heavy or clay type subgrades.

DENSITY: Natural soil densities of the subbase at a point approximately 9 inches below the surface were determined immediately prior to the placing of the concrete slab. The density values obtained ranged from 103 to 113 pounds per cubic foot. The moisture content of the subbase during the measurements varied from 4.2 to 7.6 per cent of the dry weight of soil.

## CONCRETE MIX DESIGN

The concrete mixture was designed in accordance with the mortar-void principle which has been used by the Department for a great many years. Specification requirements stipulated Class A concrete having a minimum compressive strength of 2500 pounds per square inch at 28 days and flexural strengths of 550 and 650 pounds per square inch at 7 days and 28 days, respectively. Cement factor was 1.375 barrels per cubic yard. Basic concrete mix portions per sack of cement were:

| | |
|---|---|
| Cement | 94 pounds |
| Water | 52.5 pounds |
| Fine Aggregate | 228 pounds |
| Coarse Aggregate 10-A | 190.5 pounds |
| Coarse Aggregate 4-A | 190.5 pounds |

## PHYSICAL PROPERTIES OF CONCRETE

Certain physical properties of the concrete such as weight per cubic foot, consistency, compressive and flexural strength, modulus of elasticity, and coefficient of thermal expansion are given in Table III.

MODULUS OF ELASTICITY: The modulus of elasticity values presented in Table III were determined from stress-strain measurements on 6- by 12-inch compression cylinders cast at different stations along the road during pouring operations.

COEFFICIENT OF THERMAL EXPANSION: In determining the coefficient of thermal expansion, measurements were made on 3- by 6- by 15-inch concrete specimens in both the saturated and oven dry conditions. This was done to differentiate

**Table II**

**PHYSICAL PROPERTIES OF SOIL AT MOISTURE CELL STATIONS**

| | Station 772 + 10 | Station 851 + 80 | Station 1055 + 75 | Station 61 + 05 |
|---|---|---|---|---|
| Gravel, percent retained, No. 18 sieve | 15 | 5 | 6 | 26 |
| Sand, percent retained, No. 270 sieve | 84 | 91 | 90 | 74 |
| Silt, percent retained, 0.005 mm. | 1 | 3 | 3 | 2 |
| Clay, percent retained, 0.001 mm. | 0 | 1 | 1 | 0 |
| Liquid limit | 19 | 19 | 20 | 18 |
| Plasticity index | Non-plastic | Non-plastic | Non-plastic | Non-plastic |
| Specific gravity | 2.62 | 2.62 | 2.65 | 2.63 |
| Shrinkage limit, % | No shrinkage | No shrinkage | No shrinkage | No shrinkage |
| Loss on ignition, % | 0.67 | 0.80 | 1.39 | 0.61 |
| Organic content, % | 0.62 | 0.64 | 1.36 | 0.45 |
| Capillary rise, inches | 7 | 12.0 | 10 | 10.5 |
| Field moisture equivalent, % | 19 | 18 | 20 | 17 |
| Moisture, bottom inch of rise, % | 24.9 | 23.9 | 23.0 | 20.2 |
| Moisture, top inch of rise, % | 6.7 | 4.7 | 5.4 | 5.0 |
| Coefficient of permeability, feet per day | 26 | 52 | 38 | 40 |
| Weight on samples, lbs. per square inch | 0.6 | 0.6 | 0.6 | 0.6 |
| Voids, % | 30.8 | 32.0 | 32.0 | 30.8 |

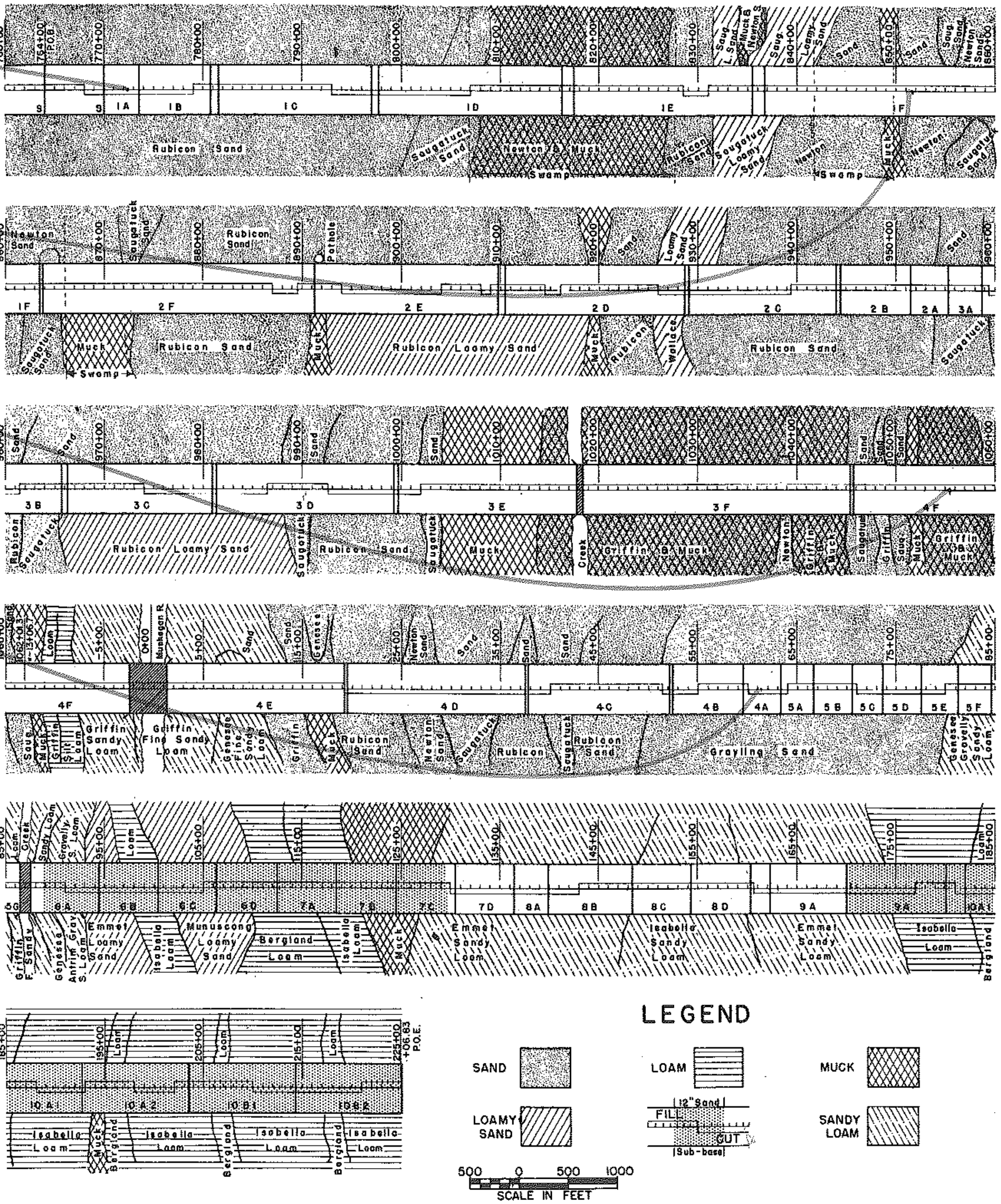


**Figure 4**

## SOIL TYPES AND EARTHWORK OPERATIONS

volume changes due to temperature and moisture. Change in length measurements were made by means of a gage constructed especially to fit the specimens, one end of which had a fixed contact point, the other consisting of a Federal dial reading directly to .0001 inch. Brass targets ½ inch in diameter were installed in the ends of the specimens to serve as gage contact points. Thermocouples were embedded in the center of the specimens to determine temperature.

Coefficients derived from these tests with specimens in a saturated condition for the temperature range between 32° and 130° F. averaged 0.0000053. In a saturated condition the specimens contained approximately 4.1 per cent of absorbed moisture. The concrete in an oven-dry state gave a lower value of 0.0000049 for the coefficient of expansion.

On the basis of these data it was determined that for a temperature of 72° F. the average change in length of the specimens from a dry to a saturated state was 0.000246 inch per inch of length. This value is equivalent to a change in temperature of about 46° F. Assuming the same relative linear contraction of the specimen in all directions, the change in volume from saturated to dry state was 0.075 per cent which agrees closely with the results of Davis [2] for concrete with gravel aggregate. According to Davis, subsequent saturation produces an increase in volume of only about one-tenth of the original contraction for this type of concrete.

# TRAFFIC CHARACTERISTICS

Automatic recording equipment was installed on the Test Road to obtain a continuous daily record of traffic flow. In addition to the daily traffic counts, classification surveys are made quarterly—April, July, October, and December—covering a six-hour period per day for five days. The six-hour periods are rotated around the clock in order that data representative of a 24-hour day for the different seasons may be obtained at the end of the year. During these surveys the axle loads, axle spacings, and frequency of the various types of commercial vehicles are recorded. Wheel loads are obtained by means of portable loadometers from which axle loads may be determined. See Figure 5. From this work it is possible to estimate quite closely, for any period of time, the frequency of wheel loads which warrant consideration of their effect on the future behavior of the pavement slabs. In this category it is customary to consider wheel loads in excess of 4000 pounds.

**Table III**

**PHYSICAL PROPERTIES OF CONCRETE**

| | Compressive Strength psi | | Flexural Strength psi | | Modulus of elasticity, $10^6$ pounds per square inch | |
|---|---|---|---|---|---|---|
| | 12-in. cylinders | 6-in. dia. cores | 6 by 8 by 24-in. beams | | | |
| | 28 days | 21 months | 7 days | 28 days | at 500 psi | at 1000 psi |
| Low | 2880 | 3780 | 439 | 518 | 6.35 | 6.05 |
| High | 5360 | 7185 | 718 | 849 | 7.22 | 6.59 |
| Average | 5203 | 5643 | 376 | 697 | 6.89 | 6.30 |

Coefficient of Thermal Expansion .......... 0.0000053
Consistency — Slump Cone Method — 1 to 3.5 in. — Average .... 2.03 inches
Weight per Cubic Foot .......... 153 pounds

The monthly traffic record presented graphically in Figure 6 illustrates quite clearly the total traffic characteristics of the Test Road for the years 1941 to May 1949, inclusive. It is interesting to see how the influence of wartime conditions caused an appreciable drop in passenger car traffic with a corresponding increase in commercial vehicles.

Values representing the percentages of different types of vehicles traveling the Test Road based on an average annual day for the years 1941 to 1949 inclusive are given in Table IV. Annual average wheel load distribution values by direction of travel are presented in Table V.

In order to evaluate certain structural failures in relation to traffic conditions, a load factor will be established for the Test Road based on the data obtained in these surveys.

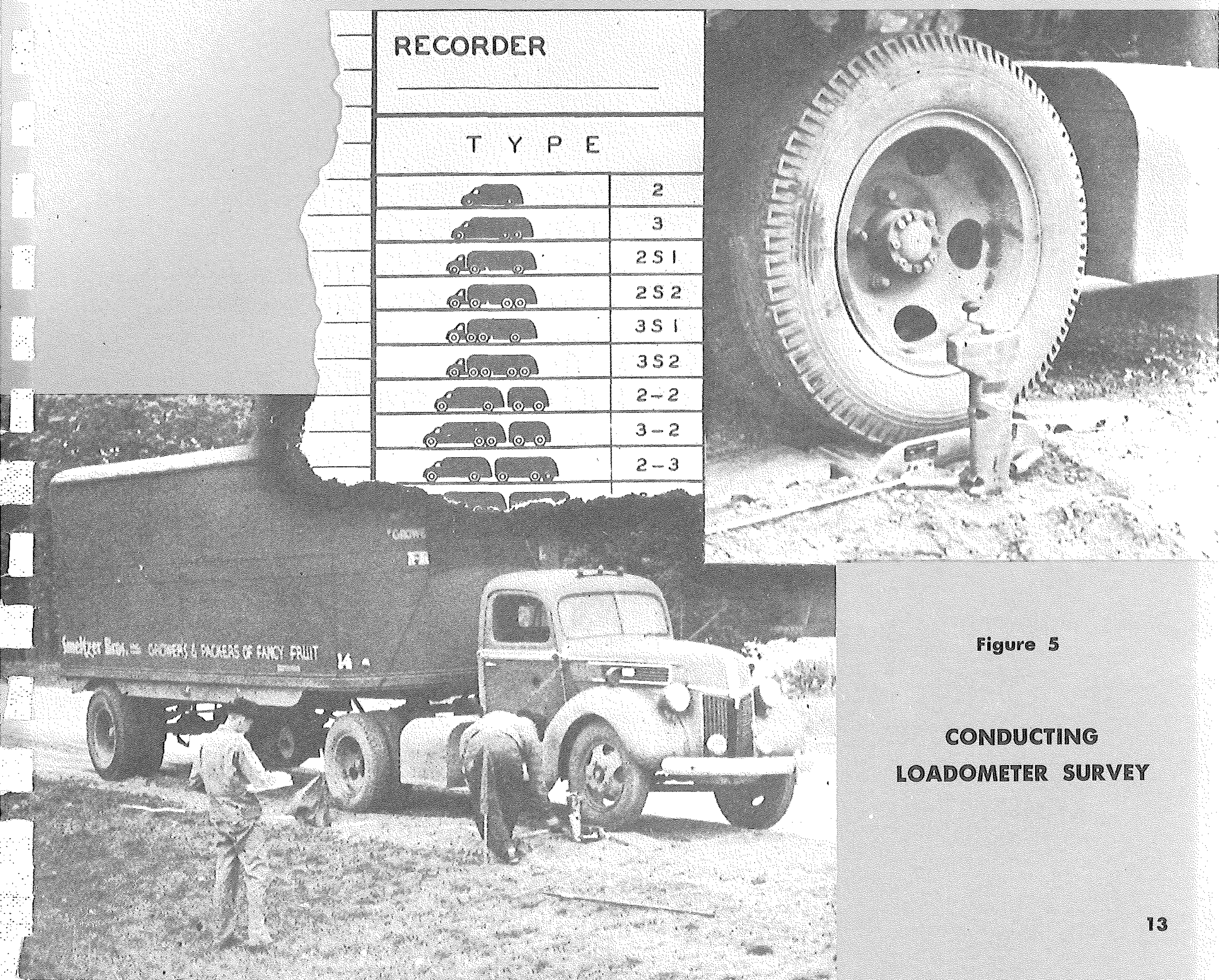



**Figure 5**

**CONDUCTING LOADOMETER SURVEY**

# MONTHLY TRAFFIC RECORD

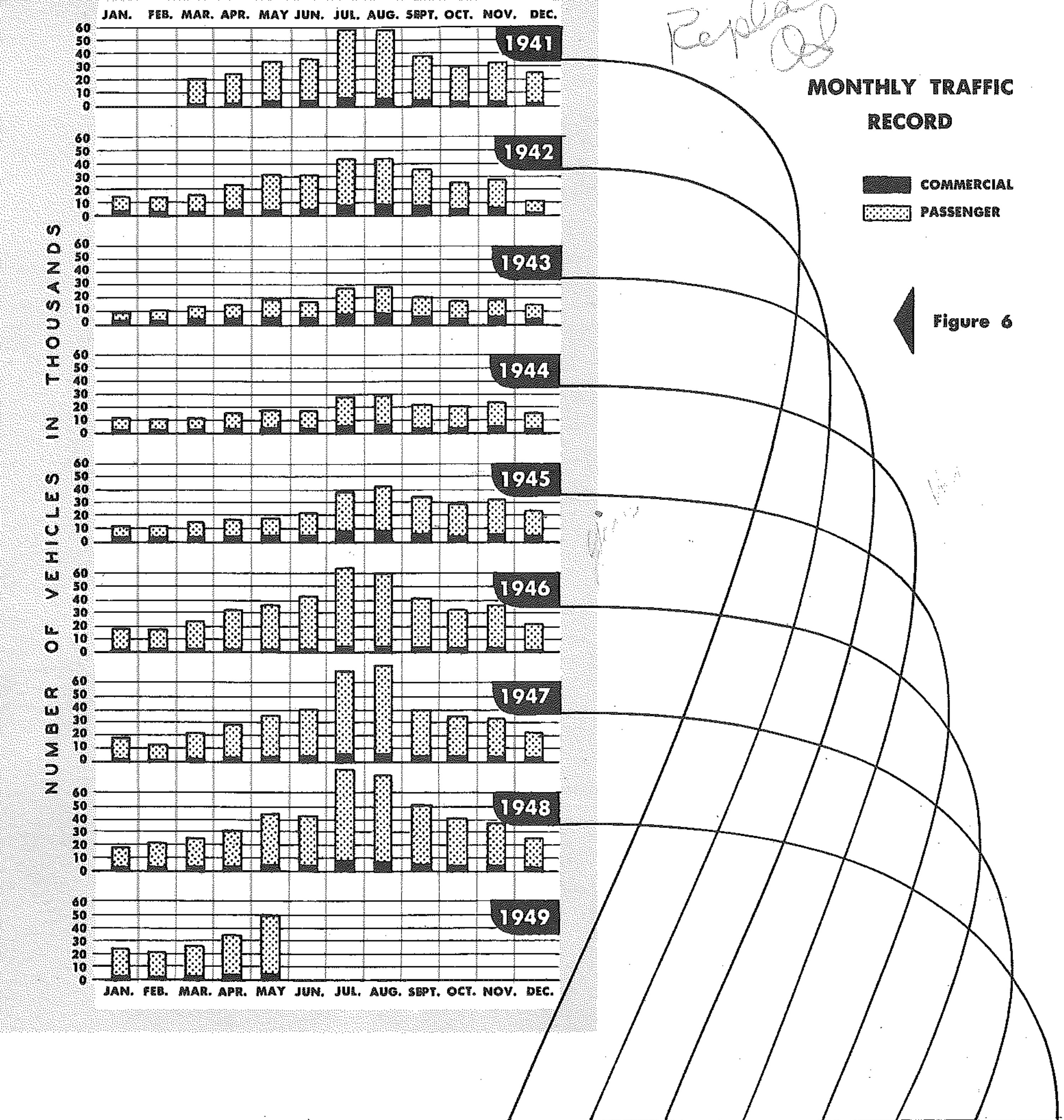


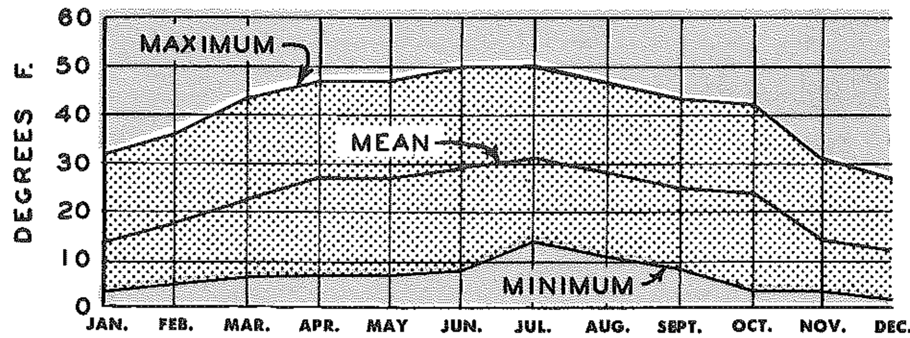

Figure 6

Table IV

## CLASSIFICATION OF ANNUAL AVERAGE DAILY TRAFFIC

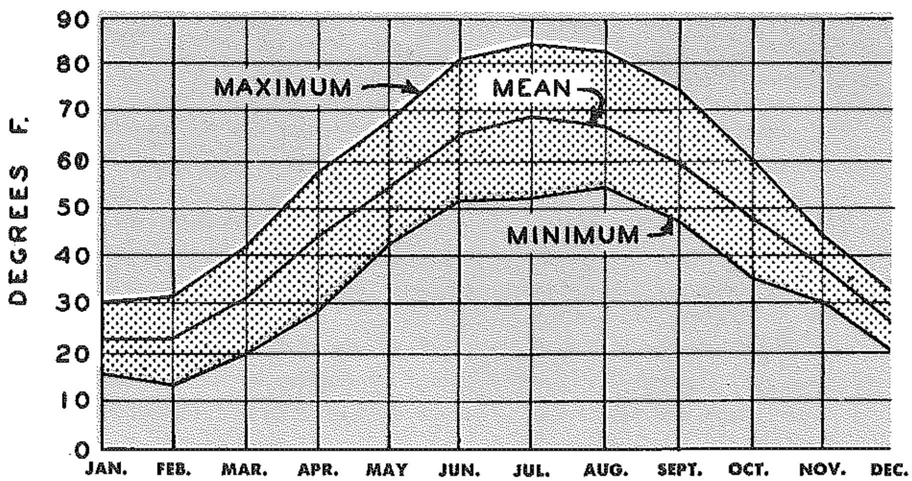
| Classification | 1941 | | 1942 | | 1943 | | 1944 | | 1945 | | 1946 | | 1947 | | 1948 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Percent | Number | Percent | Number | Percent | Number | Percent | Number | Percent | Number | Percent | Number | Percent | Number | Percent |
| Total traffic | 1590 | 100.0 | 829 | 100.0 | 578 | 100.0 | 733 | 100.0 | 803 | 100.0 | 1204 | 100.0 | 1176 | 100.0 | 1361 | 100.0 |
| Passenger cars | 1437 | 90.4 | 668 | 80.6 | 394 | 68.2 | 583 | 79.5 | 666 | 82.9 | 1117 | 92.8 | 1066 | 90.7 | 1238 | 91.0 |
| Total commercial | 153 | 9.6 | 161 | 19.4 | 184 | 31.8 | 150 | 20.5 | 137 | 17.1 | 87 | 7.2 | 110 | 9.3 | 123 | 9.0 |
| Light | 43 | 2.7 | 44 | 5.3 | 14 | 2.4 | 32 | 4.4 | 16 | 2.0 | 4 | 0.3 | 5 | 0.4 | 29 | 2.1 |
| Medium | 26 | 1.6 | 37 | 4.4 | 56 | 9.7 | 51 | 7.0 | 27 | 3.4 | 30 | 2.5 | 28 | 2.4 | 25 | 1.8 |
| Heavy | 43 | 2.7 | 12 | 1.5 | 13 | 2.2 | 5 | 0.7 | 5 | 0.6 | 7 | 0.6 | 18 | 1.5 | 5 | 0.4 |
| Trailer combinations | 41 | 2.6 | 68 | 8.2 | 101 | 17.5 | 62 | 8.4 | 89 | 11.1 | 46 | 3.8 | 59 | 5.0 | 64 | 4.7 |

Figure 7




MEAN DAILY TEMPERATURE VARIATION

## TEMPERATURE RECORD




MEAN DAILY TEMPERATURE

Table V

## ANNUAL AVERAGE WHEEL LOAD DISTRIBUTION

| | 1945 | | | | 1946 | | | | 1947 | | | | 1948 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S. E. Bound (South Lane) | | N. W. Bound (North Lane) | | S. E. Bound (South Lane) | | N. W. Bound (North Lane) | | S. E. Bound (South Lane) | | N. W. Bound (North Lane) | | S. E. Bound (South Lane) | | N. W. Bound (North Lane) | |
| Wheel Load | Number | Percent | Number | Percent | Number | Percent | Number | Percent | Number | Percent | Number | Percent | Number | Percent | Number | Percent |
| Under 4000 | 302 | 62.27 | 293 | 59.07 | 391 | 67.76 | 287 | 63.21 | 387 | 54.28 | 501 | 65.24 | 318 | 52.22 | 428 | 68.70 |
| 4000 - 4499 | 19 | 3.92 | 13 | 2.62 | 19 | 3.29 | 12 | 2.64 | 23 | 3.23 | 32 | 4.17 | 33 | 5.42 | 24 | 3.85 |
| 4500 - 4999 | 19 | 3.92 | 6 | 1.21 | 8 | 1.39 | 11 | 2.42 | 19 | 2.66 | 17 | 2.21 | 18 | 2.96 | 22 | 3.53 |
| 5000 - 5499 | 20 | 4.12 | 11 | 2.22 | 18 | 3.12 | 7 | 1.54 | 22 | 3.09 | 24 | 3.13 | 29 | 4.76 | 22 | 3.53 |
| 5500 - 5999 | 13 | 2.68 | 11 | 2.22 | 18 | 3.12 | 19 | 4.19 | 20 | 2.81 | 23 | 2.99 | 17 | 2.79 | 14 | 2.25 |
| 6000 - 6499 | 21 | 4.33 | 15 | 3.03 | 23 | 3.99 | 19 | 4.19 | 22 | 3.09 | 18 | 2.34 | 19 | 3.12 | 17 | 2.73 |
| 6500 - 6999 | 19 | 3.92 | 20 | 4.03 | 18 | 3.12 | 18 | 3.97 | 24 | 3.37 | 19 | 2.47 | 19 | 3.12 | 20 | 3.21 |
| 7000 - 7499 | 17 | 3.50 | 22 | 4.44 | 18 | 3.12 | 12 | 2.64 | 26 | 3.65 | 23 | 2.99 | 20 | 3.28 | 27 | 4.34 |
| 7500 - 7999 | 19 | 3.92 | 39 | 7.86 | 20 | 3.47 | 19 | 4.19 | 40 | 5.61 | 27 | 3.52 | 29 | 4.76 | 17 | 2.73 |
| 8000 - 8499 | 11 | 2.27 | 39 | 7.86 | 11 | 1.90 | 22 | 4.85 | 38 | 5.32 | 26 | 3.39 | 26 | 4.27 | 15 | 2.41 |
| 8500 - 8999 | 9 | 1.85 | 17 | 3.43 | 12 | 2.08 | 14 | 3.08 | 38 | 5.32 | 24 | 3.13 | 31 | 5.09 | 5 | 0.80 |
| 9000 - 9499 | 10 | 2.06 | 8 | 1.61 | 10 | 1.73 | 9 | 1.98 | 34 | 4.77 | 21 | 2.73 | 19 | 3.12 | 9 | 1.44 |
| 9500 - 9999 | 6 | 1.24 | 2 | 0.40 | 9 | 1.56 | 5 | 1.10 | 14 | 1.96 | 8 | 1.04 | 15 | 2.46 | 2 | 0.32 |
| 10000 - 10499 | | | | | 2 | .35 | 0 | | 4 | 0.56 | 2 | 0.26 | 8 | 1.31 | 1 | 0.16 |
| 10500 - 10999 | | | | | | | | | 1 | 0.14 | 3 | 0.39 | 5 | 0.83 | | |
| 11000 - 11499 | | | | | | | | | 1 | 0.14 | | | 1 | 0.16 | | |
| 11500 - 11999 | | | | | | | | | | | | | 2 | 0.33 | | |
| Total axles | 485 | 100.00 | 496 | 100.00 | 577 | 100.00 | 454 | 100.00 | 713 | 100.00 | 768 | 100.00 | 609 | 100.00 | 623 | 100.00 |
| Total vehicles | 170 | | 178 | | 210 | | 165 | | 238 | | 270 | | 200 | | 214 | |
| Ratio axles to vehicles | 2.85 | | 2.79 | | 2.65 | | 2.75 | | 3.00 | | 2.84 | | 3.04 | | 2.91 | |

*Sampling consists of taking one 6 hour sample per day for 5 consecutive days at four periods in each year—January, April, July, October. The time of taking the 6 hour samples is changed for each period to give a 24 hour sample per year.

# CLIMATOLOGICAL DATA

Complete records of temperature and precipitation at the Test Road covering the first 9 years of the project are presented in Figures 7 and 8.

The graph in Figure 7 shows that the average temperature in winter is approximately 25° F. while in summer it is 70° F., making an average temperature difference of about 45° F. It may be observed also that daily temperature fluctuations in winter are about 16 degrees F. less than those occurring during the summer.

Figure 8 gives the precipitation by months as well as the total value for each year.

# CONCRETE PAVEMENT DESIGN STUDIES

The three main design studies under consideration are the spacing and design of transverse joints, pavement cross section, and steel reinforcement.

The evaluation of the several features included in these three major design studies is based upon the behavior of the respective concrete slabs under service conditions, taking into account performance, physical irregularities, and vertical alignment.

In order to evaluate the elements of design considered in the project, periodic examinations together with measurement of displacements and physical conditions have been made during its life. The schedule of observations established at the be-

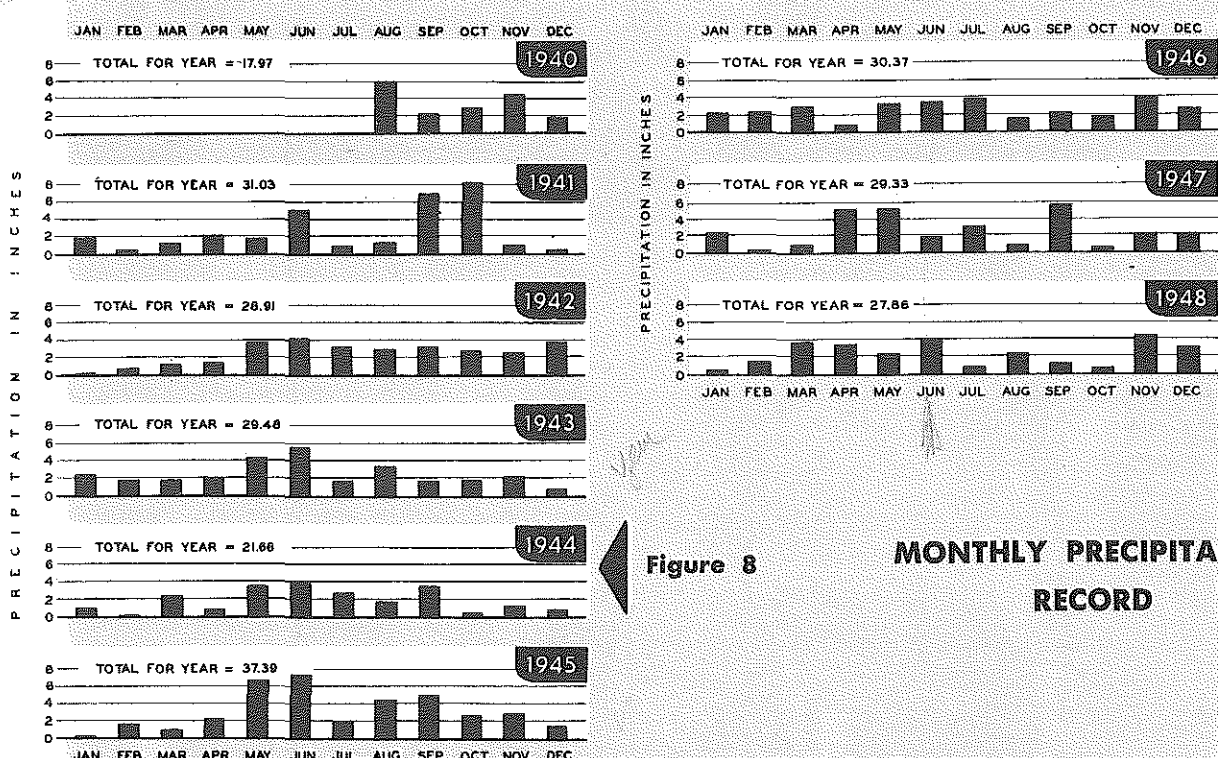



Figure 8

**MONTHLY PRECIPITATION RECORD**

ginning of the project has been followed closely. In brief, the program consists of the following observations:

1. Seasonal and daily measurements of joint widths, slab movements, strain, temperature, and moisture of the concrete and subbase.
2. Periodic measurements of vertical displacement of the slabs.
3. Biannual condition survey of pavement.
4. Continuous record of air temperature and precipitation.
5. Continuous daily traffic record with quarterly traffic classification surveys each year.

Factual information obtained from the various observations and measurements is presented under the headings of joint spacing and pavement movement, joint design, pavement cross section, reinforcement, and continuous slab versus hinged slab construction.

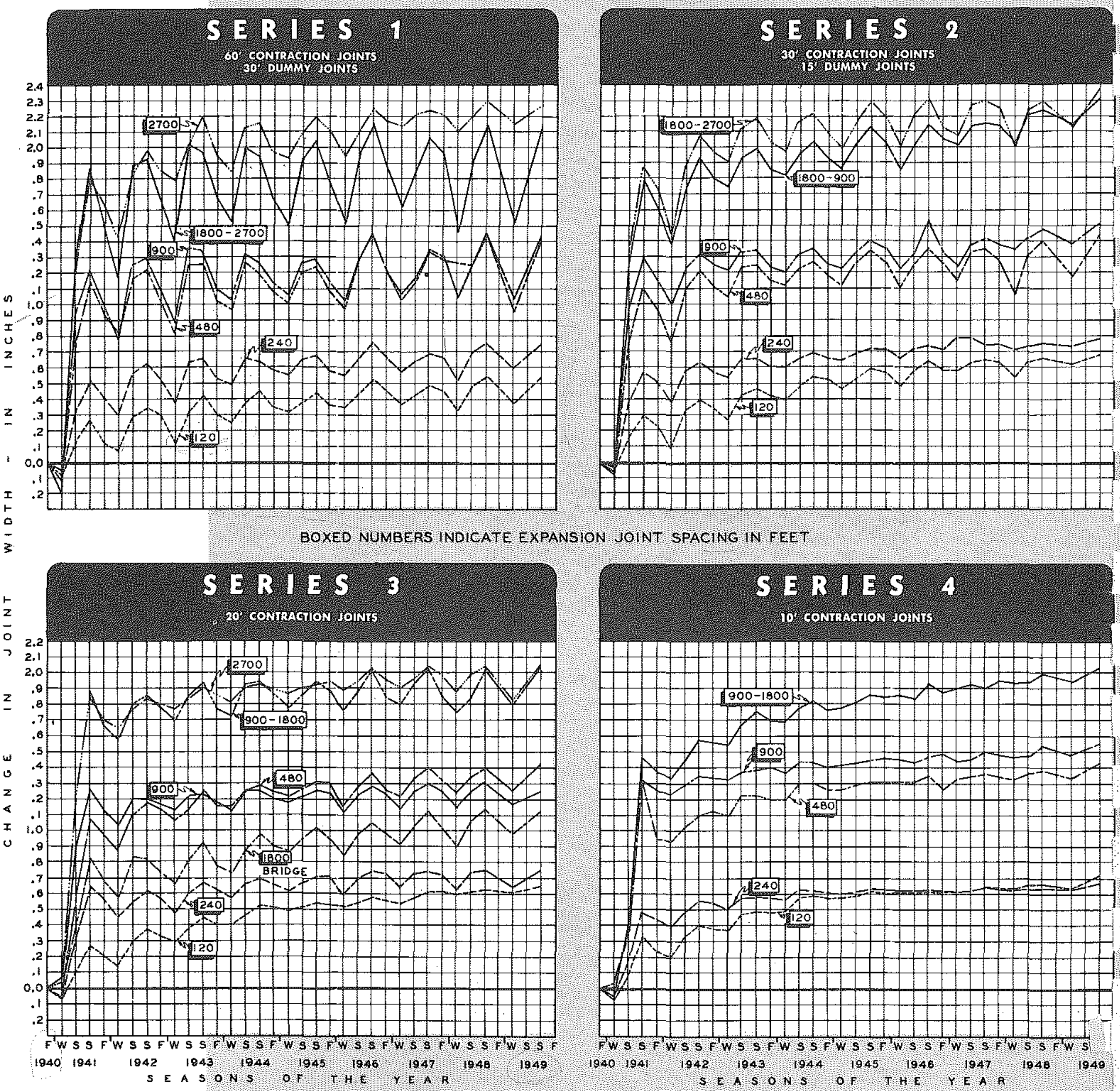
# JOINT SPACING AND PAVEMENT MOVEMENT

Although joint spacing is considered throughout the entire Design Project, it has received special emphasis in Series 1, 2, 3, and 4. In these four series expansion joints have been spaced to give sections of 120, 240, 480, 900, 1800, and 2700 foot lengths, and contraction joints have been spaced at 10, 20, 30, and 60 foot intervals. Dummy, or so-called warping, joints are included in the sections containing 60 and 30 foot contraction joint spacing. Contraction joints are plane of weakness joints with or without slip dowels or other types of load transfer devices, whereas dummy joints are constructed in the same manner except that they do not contain load transfer devices and the pavement reinforcement is continuous through the joint.

Initial measurements of joint width and slab position were made immediately upon completion of each series in the summer and fall of 1940, and the readings have been used as a reference in determining subsequent displacements. Seasonal and daily readings were taken as nearly as possible at the same time of day during all periods of observation. Since the time required to make all measurements for the entire project covers a period of three to four weeks, fluctuations in climatic conditions from day to day will naturally influence the seasonal measurements between series to a certain extent. Joint width readings are undoubtedly affected to some extent by the curling of the slabs also. The effect of these day to day changes in slab conditions during the observation period has not been considered in the presentation and interpretation of the data in this report.

The joint width movements of the different test sections have been reduced to average curves which represent the average seasonal movement for all joints under observation in any given section. This has been necessary because of the vast amount of data accumulated over the past 9 years.

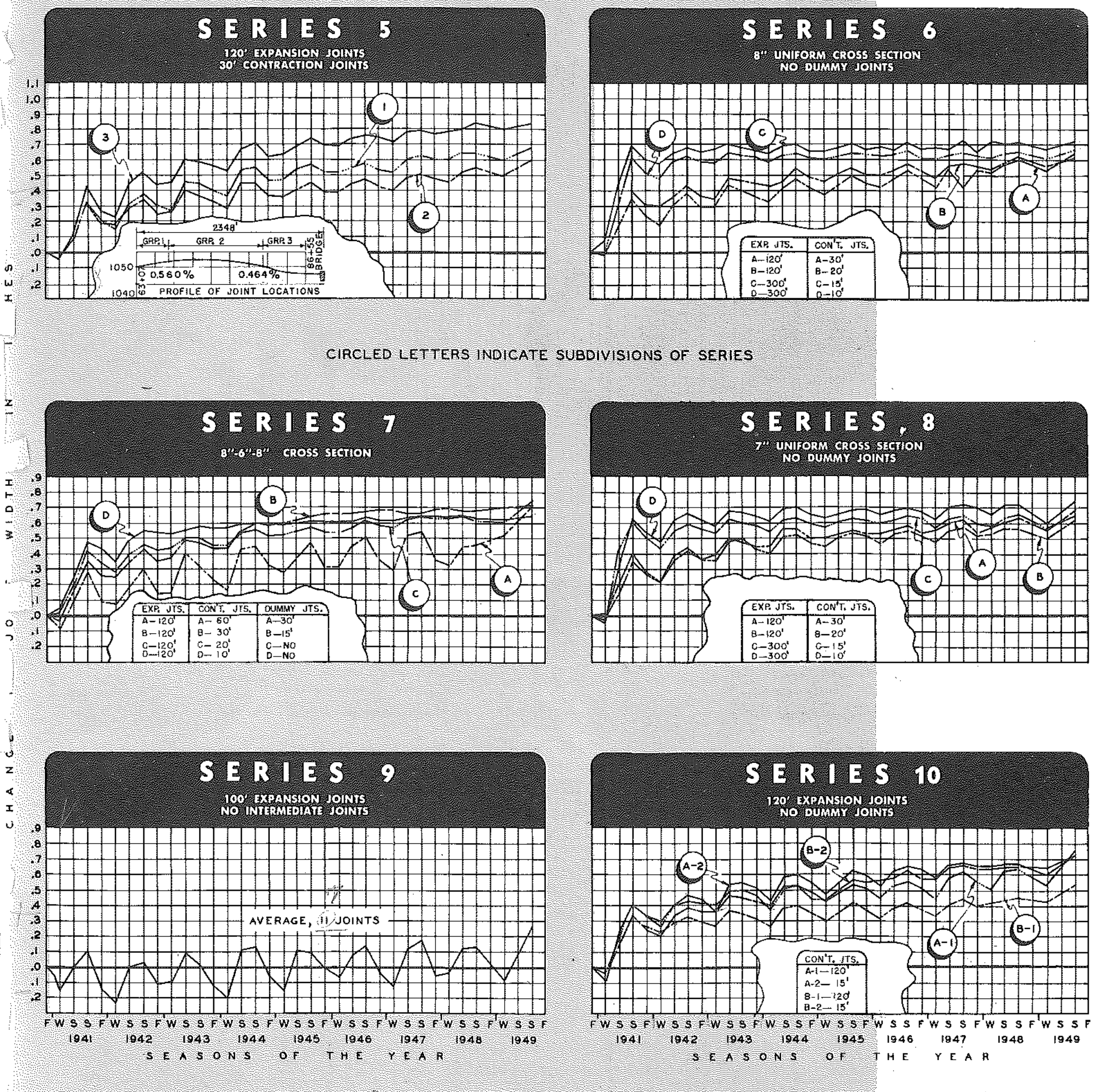
The results from these joint studies will be discussed under seasonal changes in joint widths, daily changes in joint widths, and pavement movement.




PAVEMENT CROSS SECTION 9"-7"-9"

**Figure 9**

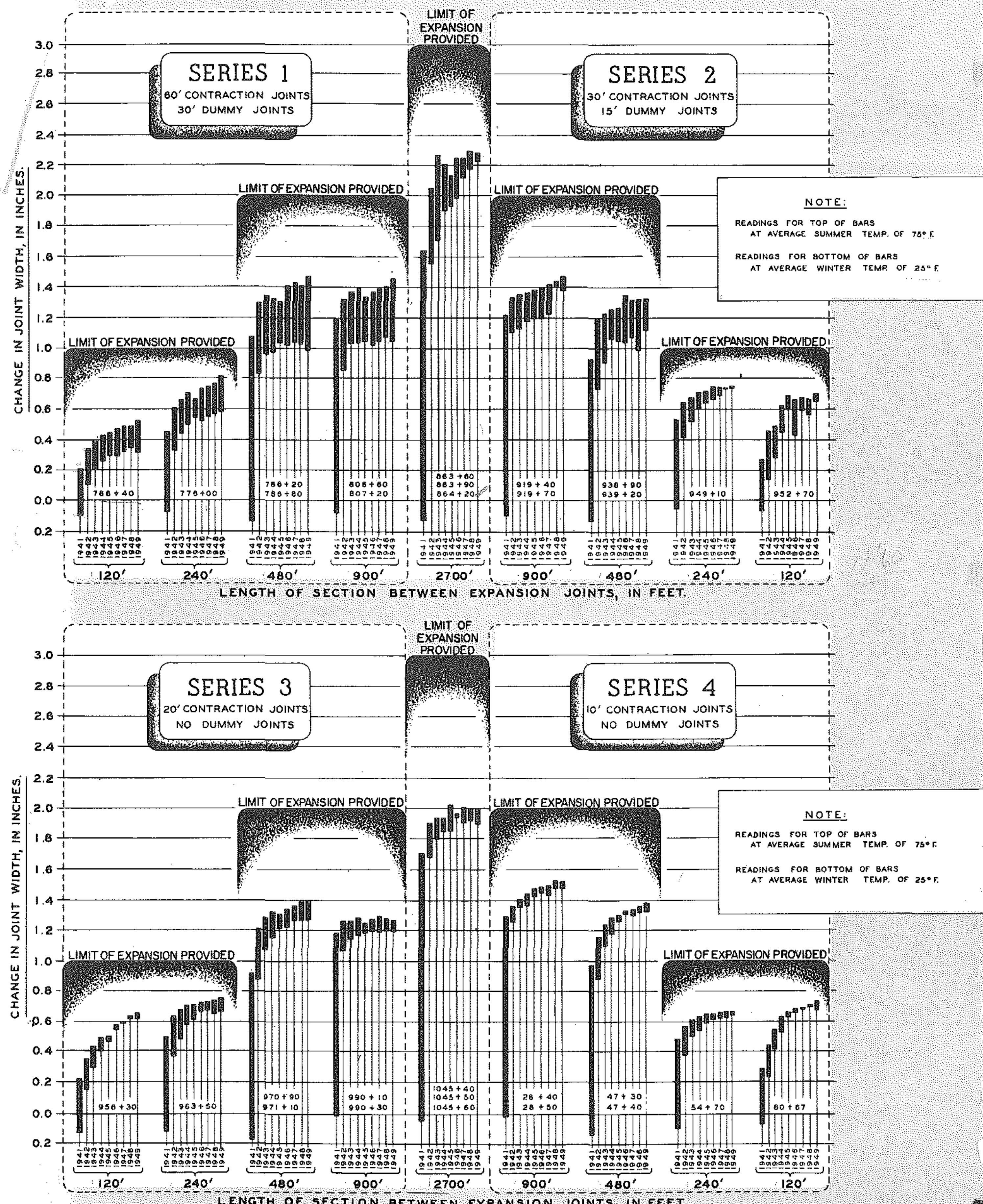
# SEASONAL




UNLESS OTHERWISE INDICATED

2, 3, 8, 9, 10, 11, 14

# CHANGES IN EXPANSION JOINT WIDTH




**ANNUAL AND PROGRESSIVE CHANGES IN EXPANSION JOINT WIDTH**

**Figure 10**

# SEASONAL CHANGES IN JOINT WIDTHS

In presenting the data on seasonal changes in joint widths, each type of joint under study will be discussed separately. The joints given major consideration in this investigation include individual expansion joints, and relief sections composed of two or more one-inch expansion joints, contraction joints, and dummy or plane of weakness joints.

EXPANSION JOINTS: Seasonal changes in expansion joint width for the several sections, together with their progressive or permanent change, are presented graphically in Figure 9 for the years 1941 to 1949 inclusive. These graphs also show the relationship between change in joint width and length of section between expansion joints. Unless otherwise stated, only those expansion joints separating sections of equal length were considered in plotting the graph. Where relief sections are involved, consisting of two or more expansion joints separated by small slabs of concrete, the individual expansion joint movements were combined algebraically to form a single value representative of one joint or equivalent width.

Figures 11 & 12

The values shown in Figure 9 represent actual measurements taken at the time without any adjustment for volume changes due to temperature, moisture, or age. The period of taking measurements was dependent to a large extent upon weather conditions. In general, the spring readings were taken during the latter part of April and the first part of May, summer measurements include those taken in July and August, fall readings were usually taken in October and November, and winter readings any time from January to March. Winter readings were taken when temperatures were seasonable and the pavement surface was sufficiently free of snow and ice to permit measurements.

Figure 10 presents the joint width movement of certain expansion joints in relation to length of section after the joint width readings had been adjusted to an average summer temperature of 75° F. and an average winter temperature of 25° F., using coefficients derived from daily movements.

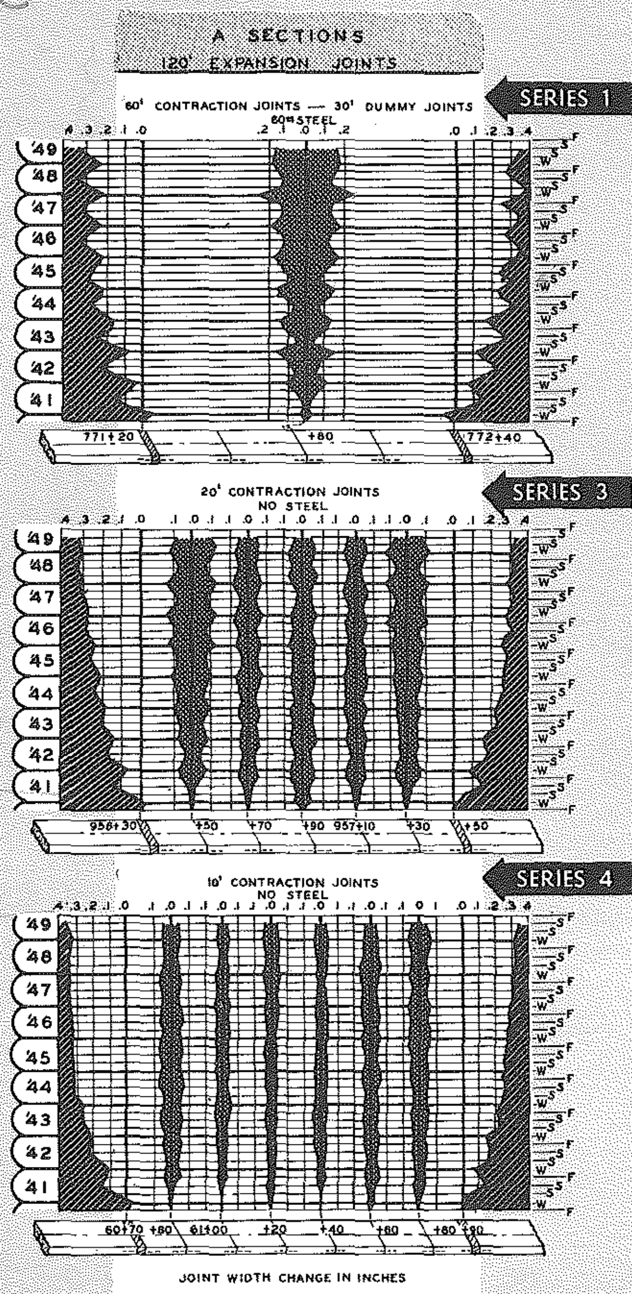
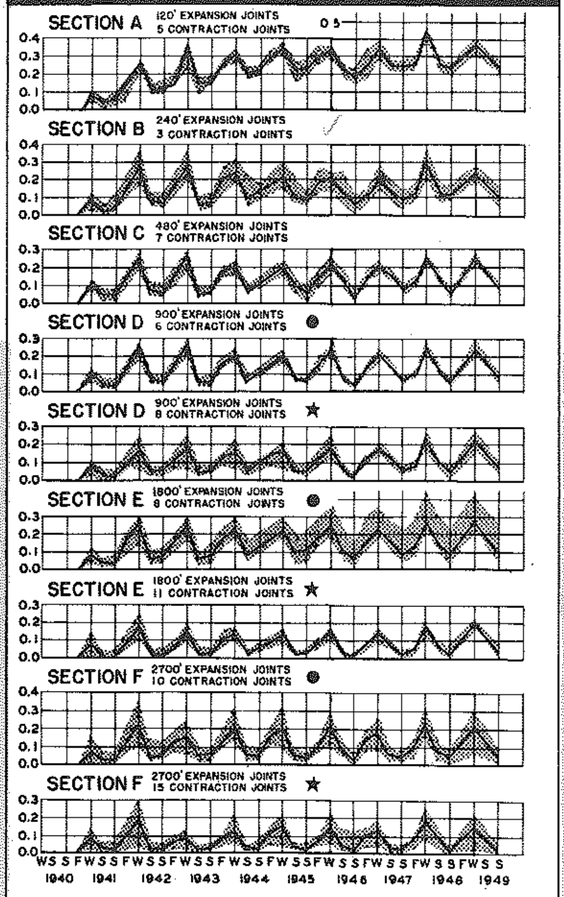



Figure 13

**CONTRACTION JOINT MOVEMENT**

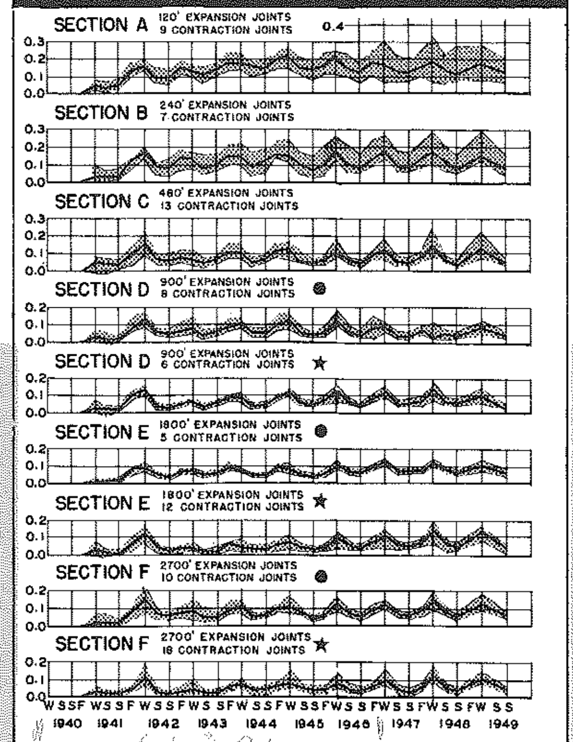
# SERIES 1

60' CONTRACTION JOINTS — 30' DUMMY JOINTS




# SERIES 2

30' CONTRACTION JOINTS — 15' DUMMY JOINTS



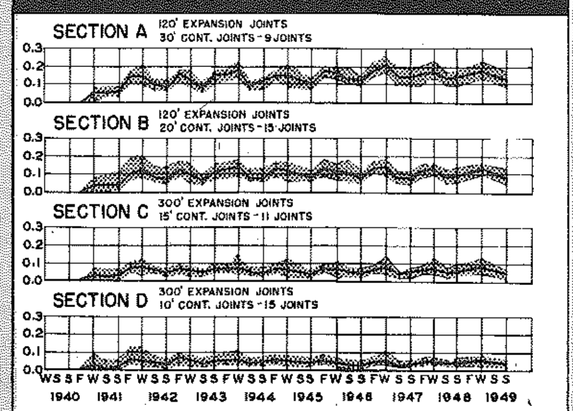

**LEGEND:**

★ **MIDDLE OF SECTION**

● **NEAR EXPANSION JOINT**

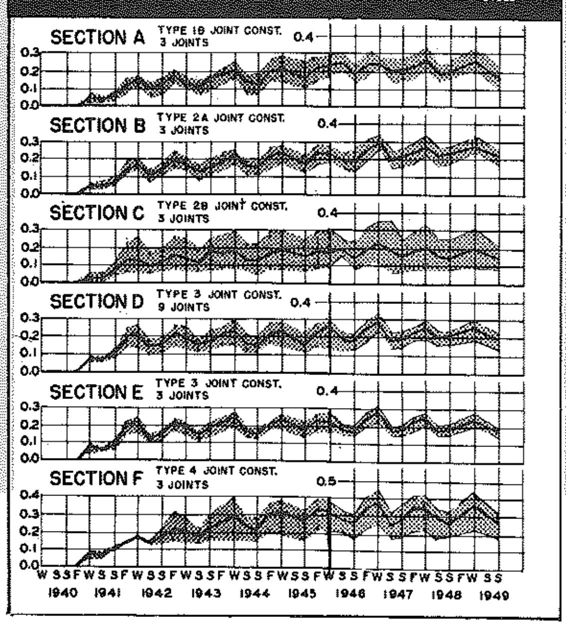
# SERIES 6

8" UNIFORM — NO STEEL



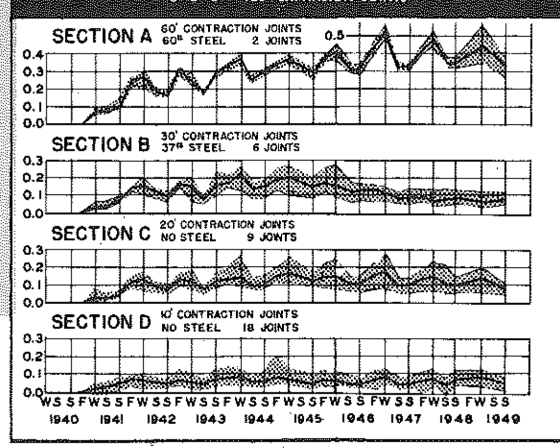

# SERIES 5

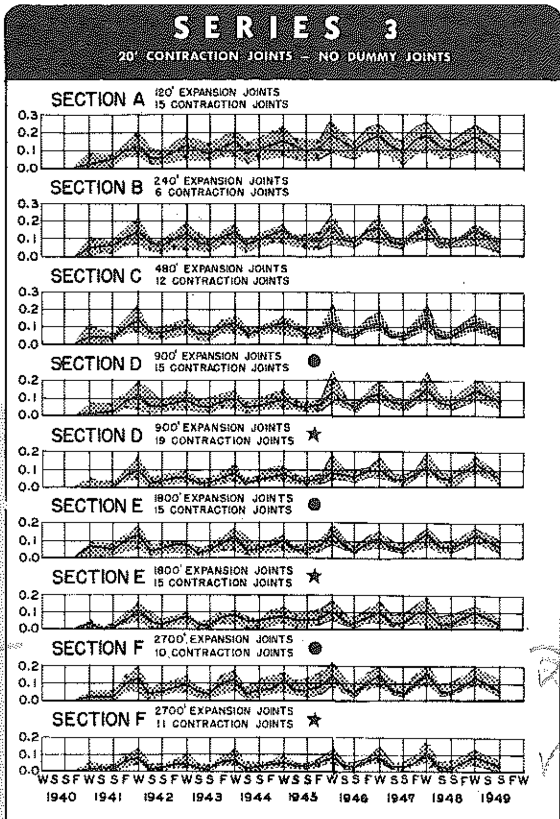
120' EXPANSION JOINTS — 30' CONTRACTION JOINTS — 37# STEEL

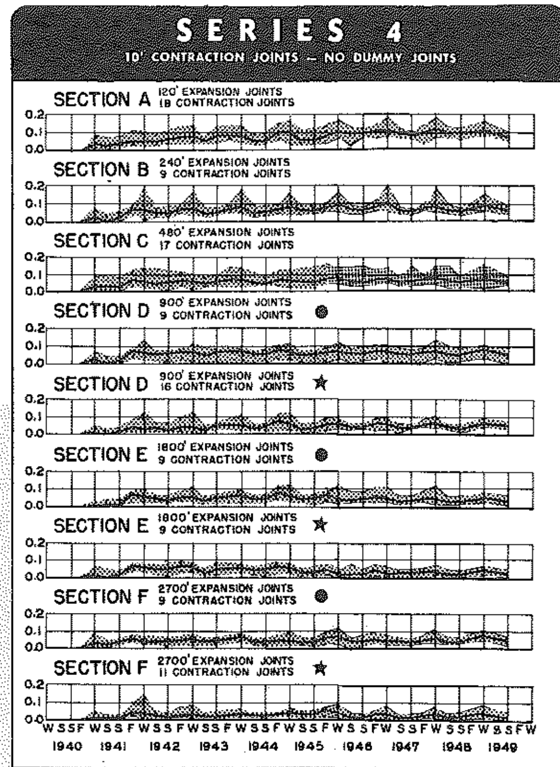



# SERIES 7

8"-6"-8" 120' EXPANSION JOINTS



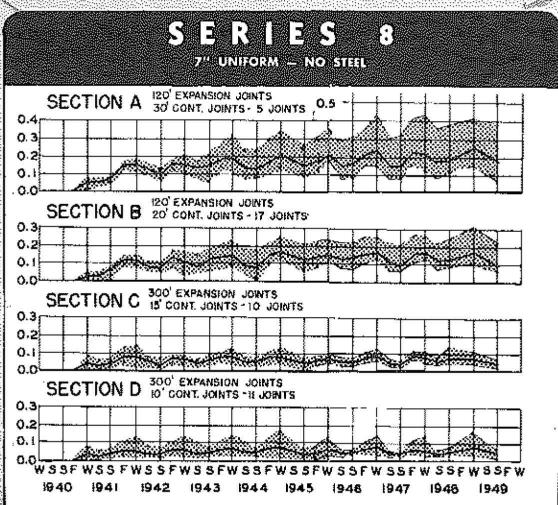


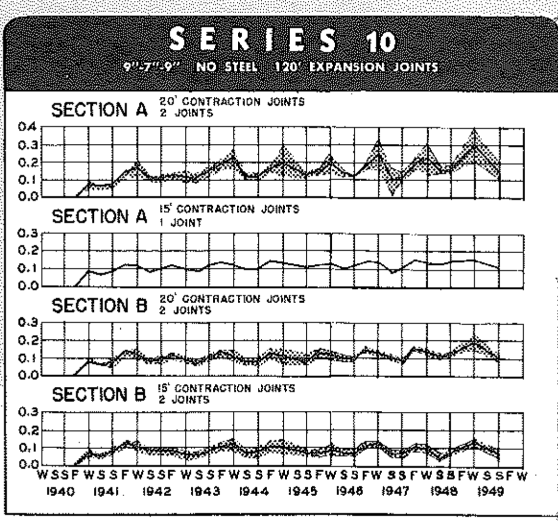

**LEGEND:**

★ MIDDLE OF SECTION

● NEAR EXPANSION JOINT




## SEASONAL CHANGES IN CONTRACTION JOINT WIDTH



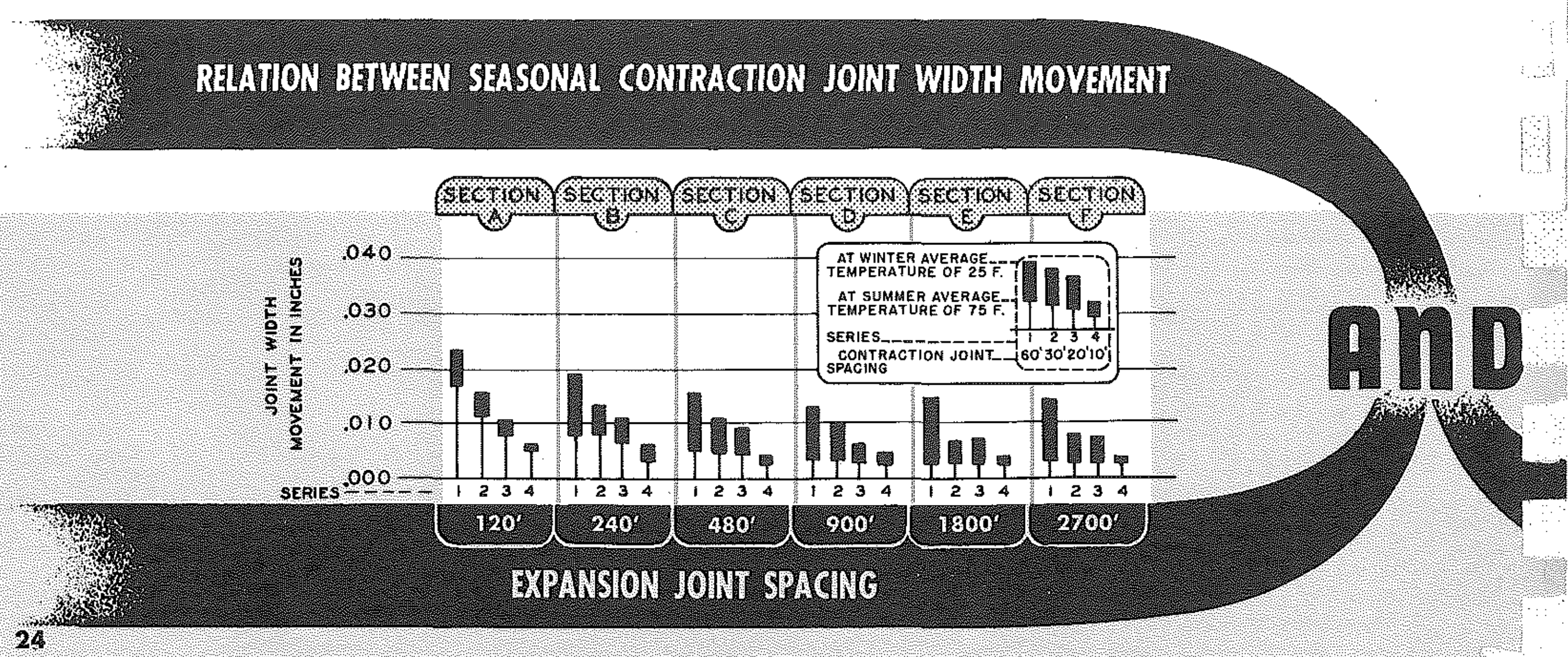

**SOLID CURVES INDICATE AVERAGE VALUES SHADED BANDS INDICATE MAXIMUM AND MINIMUM VALUES**

**Figure 11**

Several significant facts are revealed by the graphs in Figures 9 and 10. *First,* in most cases the sections contracted sufficiently during the first winter season to cause a slight widening of the expansion joints in excess of the one-inch width originally provided. *Second,* without exception all of the sections experienced their greatest movement during the first year after construction. *Third,* the annual amplitude of joint width movement diminishes with time. *Fourth,* all expansion joints show a progressive, permanent change in joint width resulting in a gradual closing of the joints, to the extent that after 9 years the sections have absorbed approximately 60 to 80 per cent of the expansion space provided. There is no doubt that the progress of these residual displacements will diminish rapidly in the future, since the joint filler will eventually reach a stage of compaction sufficient to resist practically all further movement of the slabs adjacent to the joint. *Fifth,* as one would expect, the longer sections produced the greatest changes in joint width the first year, although the amplitude of annual joint width movement after the first year is comparable to that of the shorter sections. *Sixth,* the amplitude of yearly movement was the least for the sections composed of 10-foot contraction joints and greatest for the sections with 60-foot contraction joints. This phenomenon would indicate that a considerable amount of section movement is absorbed by the greater number of contraction joints existing in a section containing 10-foot contraction joints.

CONTRACTION JOINTS: The actual changes in contraction joint widths for different seasons of the year and for variable expansion and contraction joint spacings are shown graphically in Figure 11. The graphs show the maximum and minimum joint width movements as well as the average value.

The bar graphs in Figure 12 show the relation between seasonal contraction joint width movement and contraction joint spacing based on a five year average and



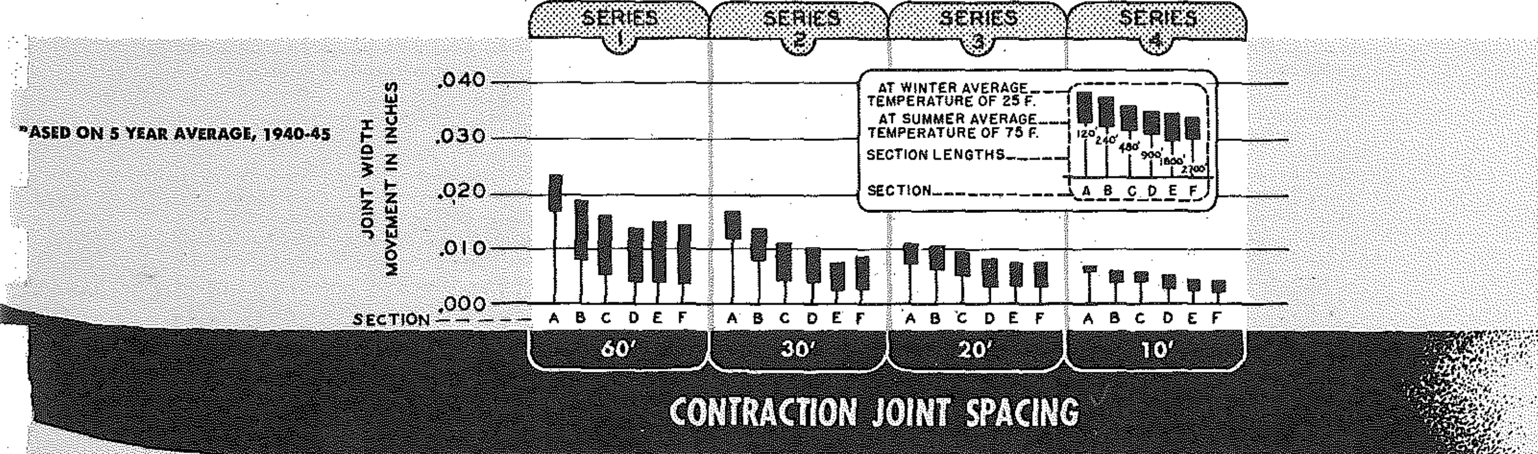
adjusted for an average summer and winter temperature condition of 75° F. and 25° F. respectively.

The relative change in contraction joint width for three particular joint spacings—60, 20, and 10 feet—are graphically presented in Figure 13. In addition to showing the effect of joint spacing upon joint width changes, these graphs show the residual opening of the joints with time and that the joints closest to the expansion joints open more than the joints near the center portion of the section. This same phenomenon may be observed on all of the test sections.

The following significant facts are disclosed by the graphs in Figures 11, 12, and 13: *first*, that under similar conditions of expansion joint spacing the movement of the 60-foot contraction joints is at least four times as great as those spaced at 10 feet; *second*, the changes in width of contraction joints vary with the section length, the shorter the section length the greater the contraction joint movement; *third*, in the long sections the movement of the contraction joints near the expansion joints is slightly greater than that of the joints near the center of the section; *fourth*, the contraction joints show an annual amplitude of joint width change which apparently decreases with time, the amplitude being greater in the longer slabs and diminishing with decrease in slab length; and *fifth*, with few exceptions, all contraction joints experienced a gradual progressive increase in width during the first 5 years, and very little increase in residual opening thereafter. The seasonal variation in joint width is still very pronounced, however, under certain design conditions.

DUMMY JOINTS: In Series 1 and 2, 60-pound and 37-pound per 100 square feet mesh reinforcement respectively was laid continuously through the dummy joints. Measurements have been taken at several joint locations throughout Series 1 and 2 to study the effect of the reinforcement upon joint behavior. The seasonal changes in joint width are shown by graphs in Figure 14. Maximum, minimum and average movement is shown.

**Figure 12**



The graphs show that in practically all cases the maximum opening of joints does not exceed 0.05 inches. As in the case of contraction joints, the movement of the dummy joints near the center of the long sections is less than that of joints near the ends. The graphs also indicate that the dummy joints react in the same manner as contraction joints but to a much smaller degree, in that they fluctuate slightly with seasonal changes and seem to acquire a small, gradually increasing residual opening with time. No relation is apparent between joint width change and weight of steel reinforcement. In the eighth and ninth years, however, several dummy joints in Sections B and E of lightly reinforced Series 2 have opened excessively during the winter, indicating a break in the steel at those points.

## DAILY CHANGES IN JOINT WIDTHS

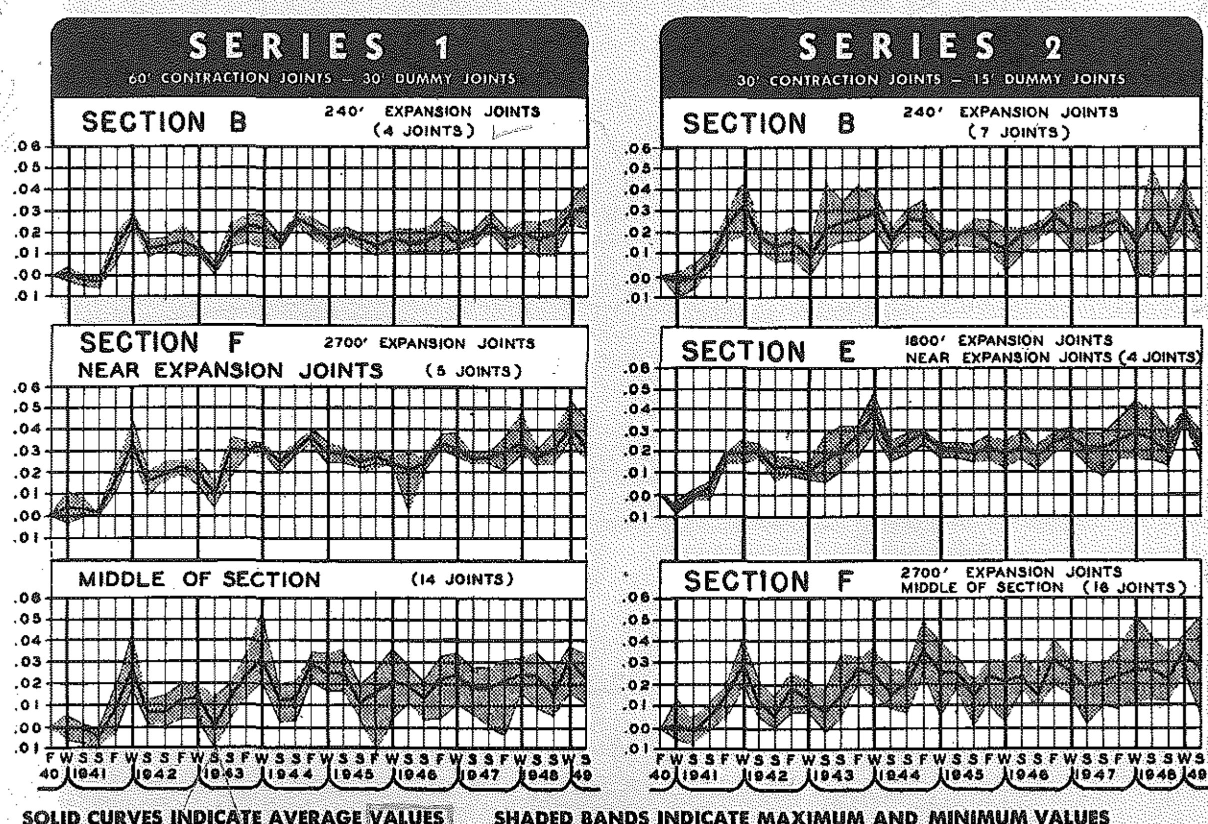
In conjunction with the seasonal joint width measurements certain joints were selected for daily observations. Readings on the same joints were taken early in the morning while the pavement was cool and then in the mid-afternoon when the pavement would be normally at its maximum temperature. The relationships for the daily joint width movements for all series are expressed in comparable terms, such as change in joint width in inches per degree Fahrenheit versus length of section and spacing of joints.

Figure 15

**DAILY MOVEMENT OF EXPANSION JOINTS**

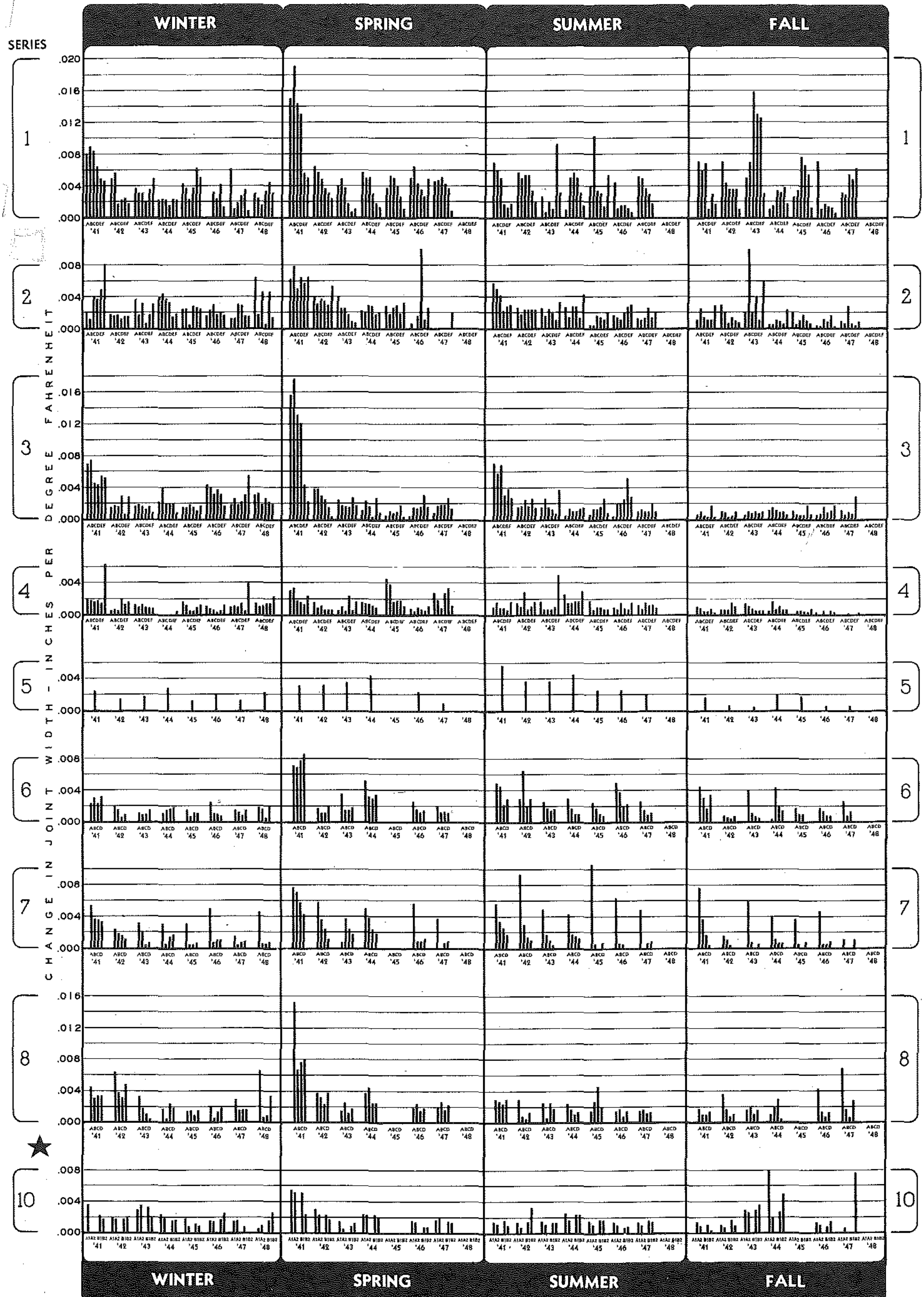
**BASED ON AVERAGE OF INDIVIDUAL JOINTS**

Figure 14




SOLID CURVES INDICATE AVERAGE VALUES SHADED BANDS INDICATE MAXIMUM AND MINIMUM VALUES

**SEASONAL CHANGES IN DUMMY JOINT WIDTH**




★ SERIES 9 GIVEN IN FIGURE 46, PAGE 56

EXPANSION JOINTS: The average daily changes in expansion joint widths by years and seasons are represented by bar graphs in Figure 15. Included in the graphs are measurements from selected joints in all ten sections of the Design Project. In general, the data disclose several significant facts. *First,* daily joint width movement is influenced to a certain extent by the degree of pavement restraint which normally increass with age due to depletion of expansion space and residual volume changes in the concrete. *Second,* intermediate contraction joint spacing has a decided effect upon daily joint width movement as may be observed by comparing graphs of Series 1 with those of Series 4 in Figure 18. *Third,* in general, the movement is greatest during the spring and least in the fall seasons, while summer and winter seasonal readings are about comparable. It is believed that this greater movement in the spring than in the fall may be due to the relatively greater freedom of the slab resulting from winter opening of the joints combined with a wider temperature range induced by the radiant heat of the sun, which is maximum at the summer solstice (June 21). *Fourth,* no definite relationship is discernible between daily joint width movement and certain construction features such as weight of reinforcement, cross section, thickness, or joint design.

In Figure 16 there is presented the average daily expansion joint width movement for joints in Series 1, 2, 3, and 4 based on a 5-year period irrespective of seasons. The bar graphs in general bear out the statements made above. It is believed that the exceptionally high daily movements for all series in section lengths greater than 240 feet are due to the fact that greater expansion space was provided in those cases. Two one-inch joints were used for the 480 and 900 foot sections, and three one-inch joints for all sections 1800 feet and 2700 feet in length.

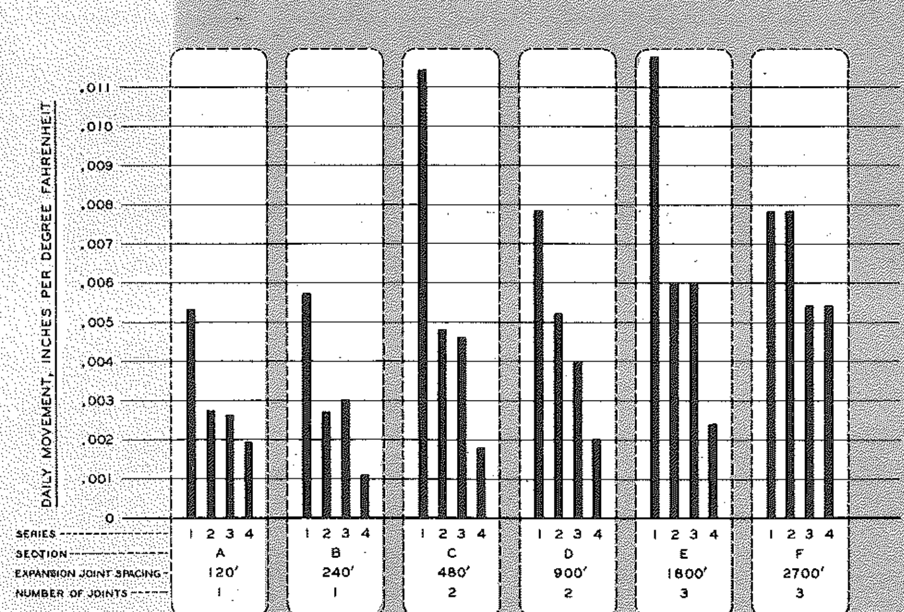



Figure 16

**AVERAGE DAILY EXPANSION JOINT WIDTH MOVEMENT**

**BASED ON FIVE-YEAR AVERAGE, 1940-1945**

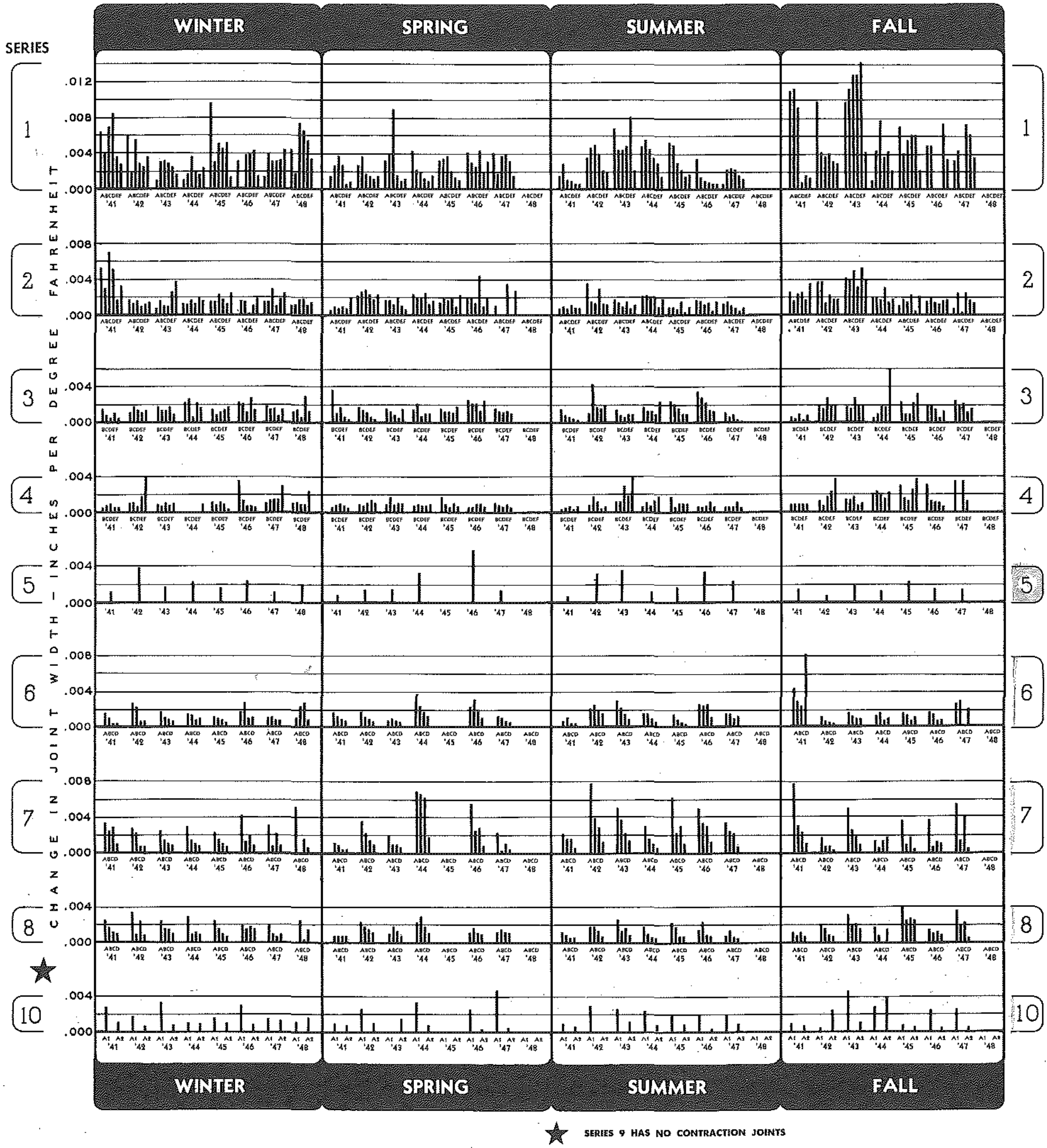



**Figure 17**

# DAILY MOVEMENT OF CONTRACTION JOINTS

CONTRACTION JOINTS: In a similar manner the average daily contraction joint width movements have been presented in Figures 17 and 18. The data presented in these two figures show in general that the contraction joints behave in the same manner as the expansion joints. Because of the greater number of joints involved in the case of contraction joints, the relationships between joint width movement and joint spacing are more pronounced.

DUMMY JOINTS: Daily observations have been made on certain dummy joints in Series 1 and 2. Data from these observations are presented graphically in Figure 19. The graphs serve to show that the joints function in the manner of other joints but to a lesser degree, and that the magnitude of the daily movement is in general under 0.001 of an inch per degree F.

# PAVEMENT MOVEMENT

In certain sections of Series 1, 2, 3, and 4 reference monuments were established to measure the relative movement of different parts of the sections with respect to fixed points in the subgrade. Monuments were placed at the center, quarter points and ends of Sections 1A, 1F, and 4F and at the ends and midpoints of Sections 3A, 4A, 1C, 4C, 1D, 3D, 2F, and 3F. The curves in Figures 20 to 23 inclusive show the relative behavior of the different parts of each section, in respect both to seasonal movement and to the distance of the monument from the center of the section.

The data indicate that for long sections of pavement the greatest movement is at the ends and rapidly diminishes until a point is reached at which practically no longitudinal movement takes place. This is clearly shown by graphs presented in Figure 24. For the two 2700-foot sections—Series 1 and Series 4—the point of zero longi-

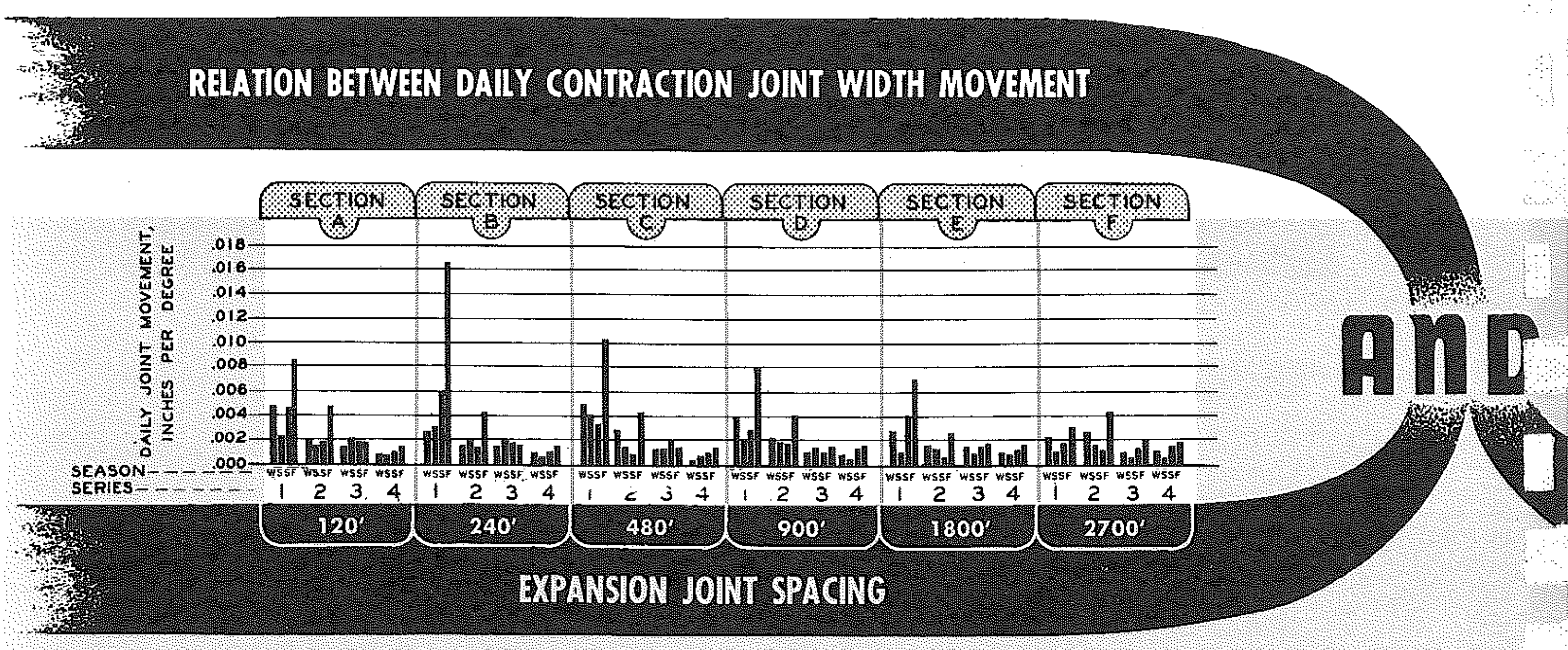
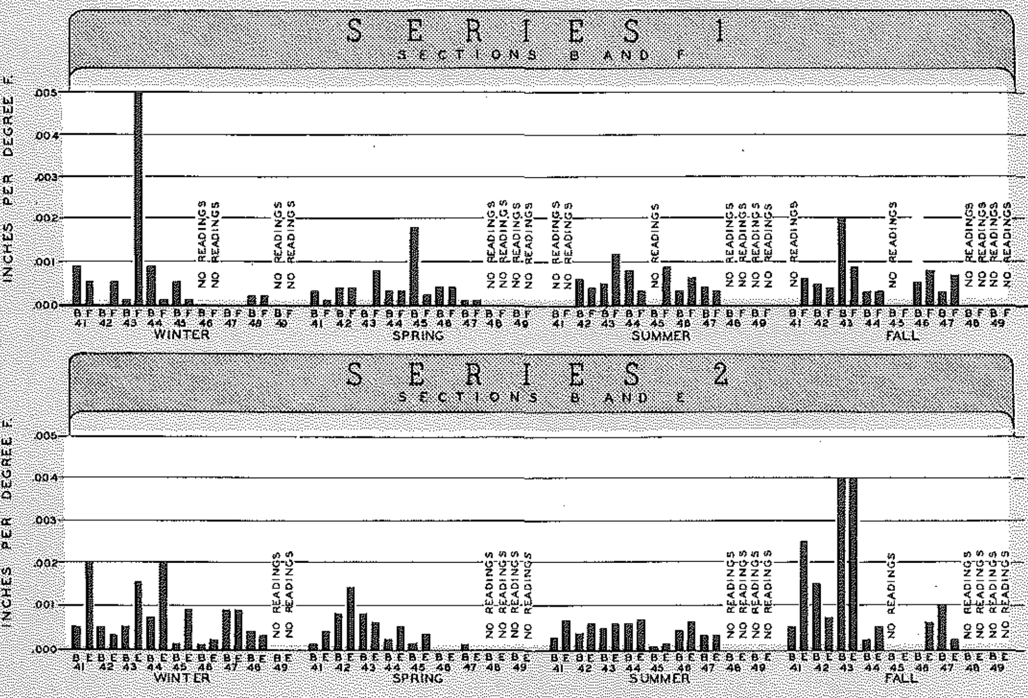


**Figure 19**

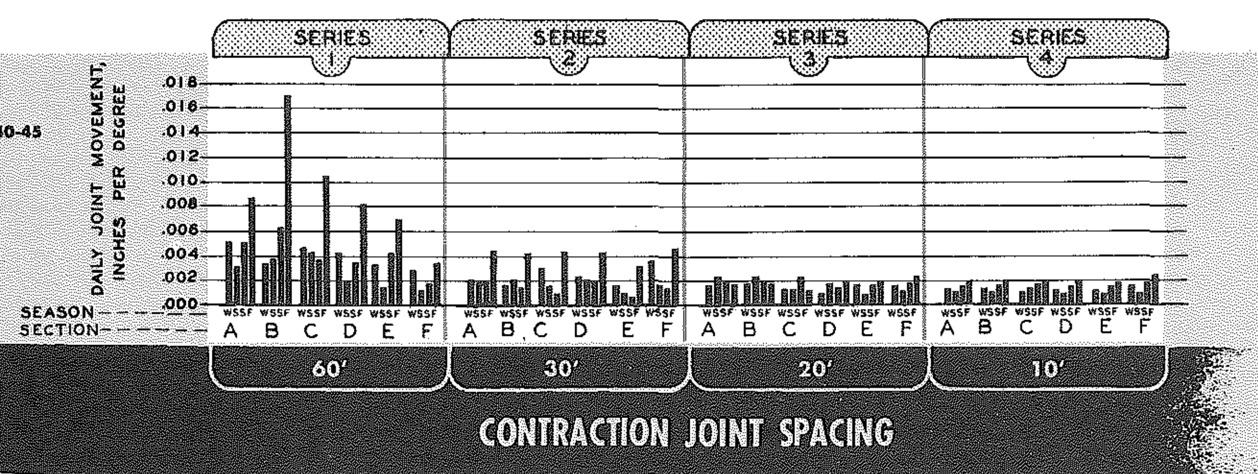
## DAILY MOVEMENT OF DUMMY JOINTS

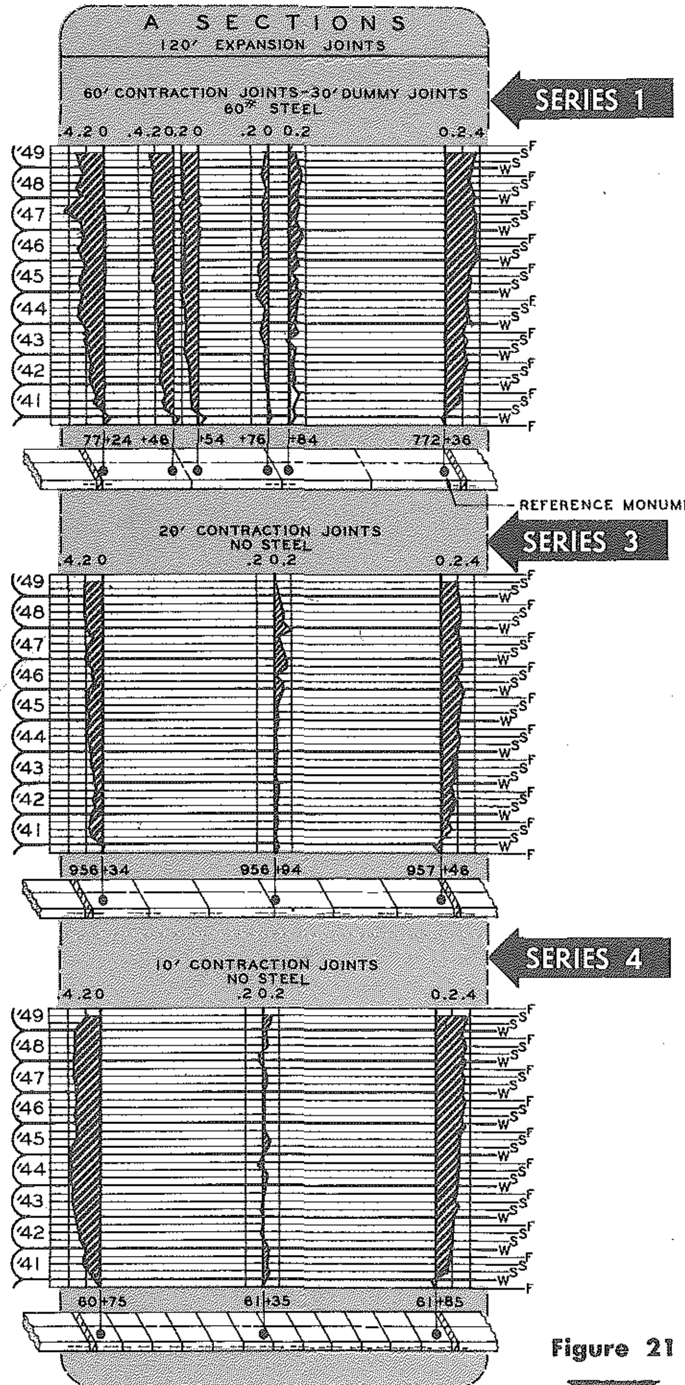



tudinal movement was, in 1941, approximately 700 to 800 feet from the ends of the sections but in 1949 the same point had retreated slightly to 1000 and 1100 feet from the ends. It is also noted in Figure 24 that the two sections have acquired a considerable increase in residual displacement during the 9-year interim. The substantially greater movement of the north end of Section 4F is due to the presence of five 1-inch expansion joints at the relief end instead of the usual three expansion joints because of the abutting Muskegon River bridge. Thus, there exists in the central part of the 2700-foot sections in Series 1, 2, 3, and 4, portions of pavement more than 500 feet long which at elevated temperatures are under restraint similar

**Figure 18**

**BASED ON 5 YEAR AVERAGE, 1940-45**





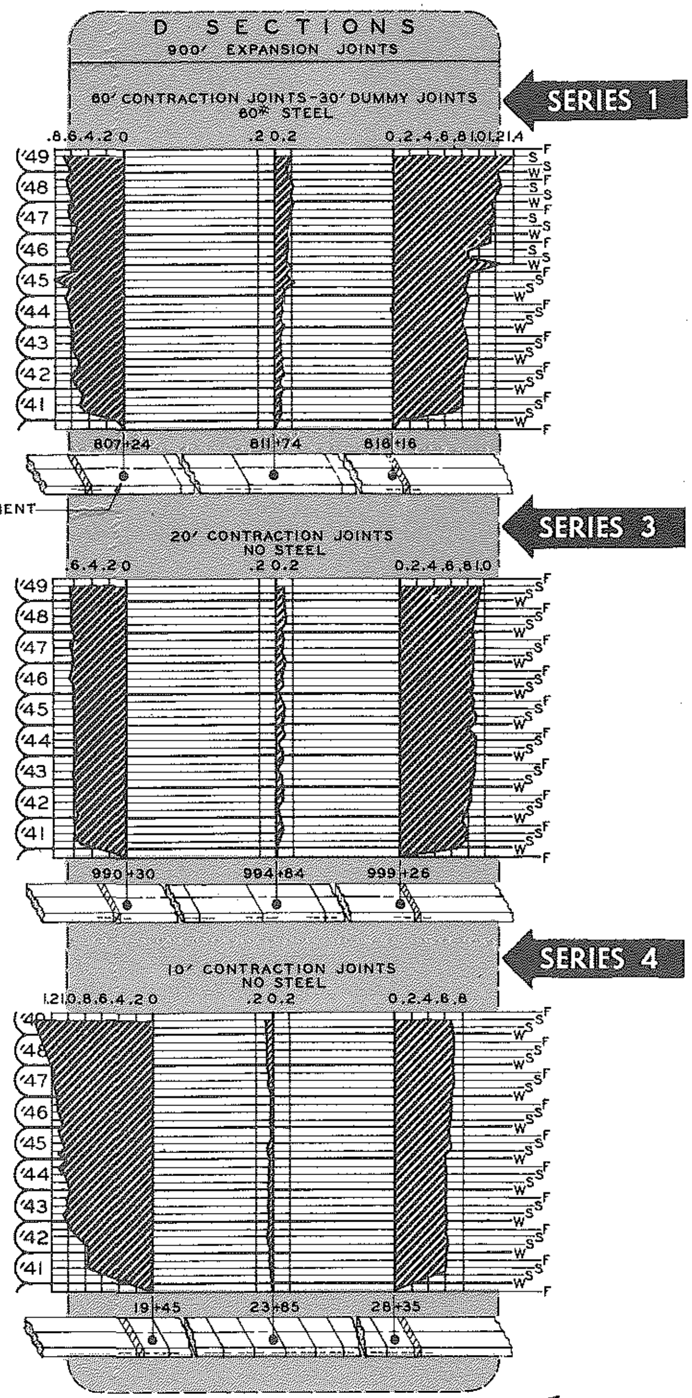




Figure 21

MOVEMENT OF SECTIONS IN INCHES

Figure 20

Figure 22

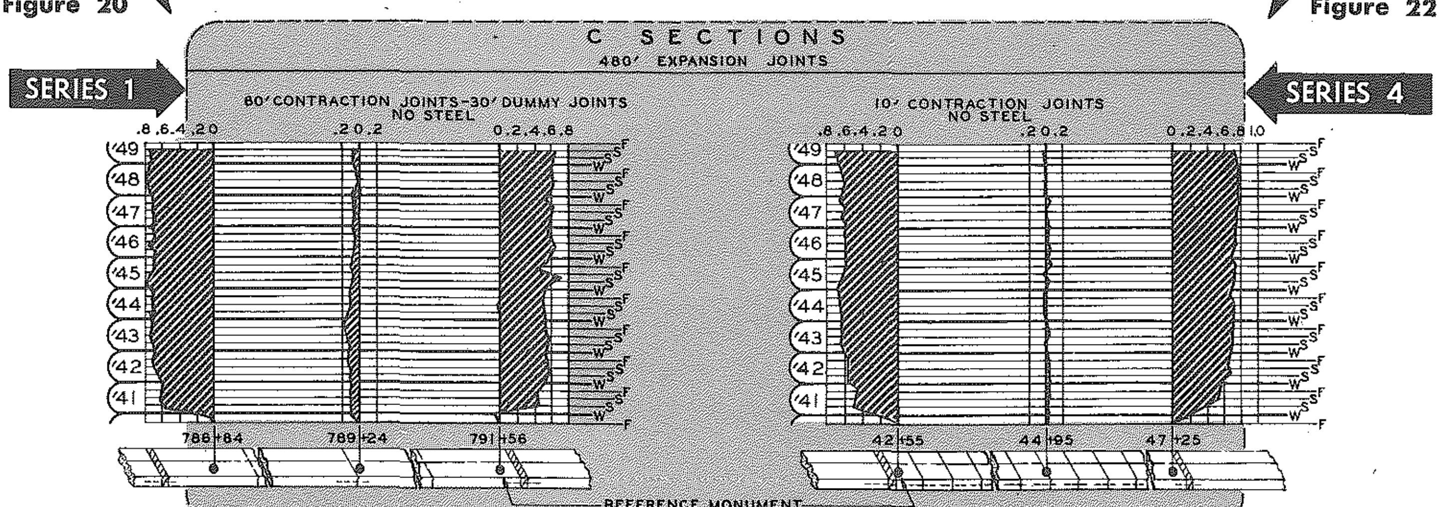
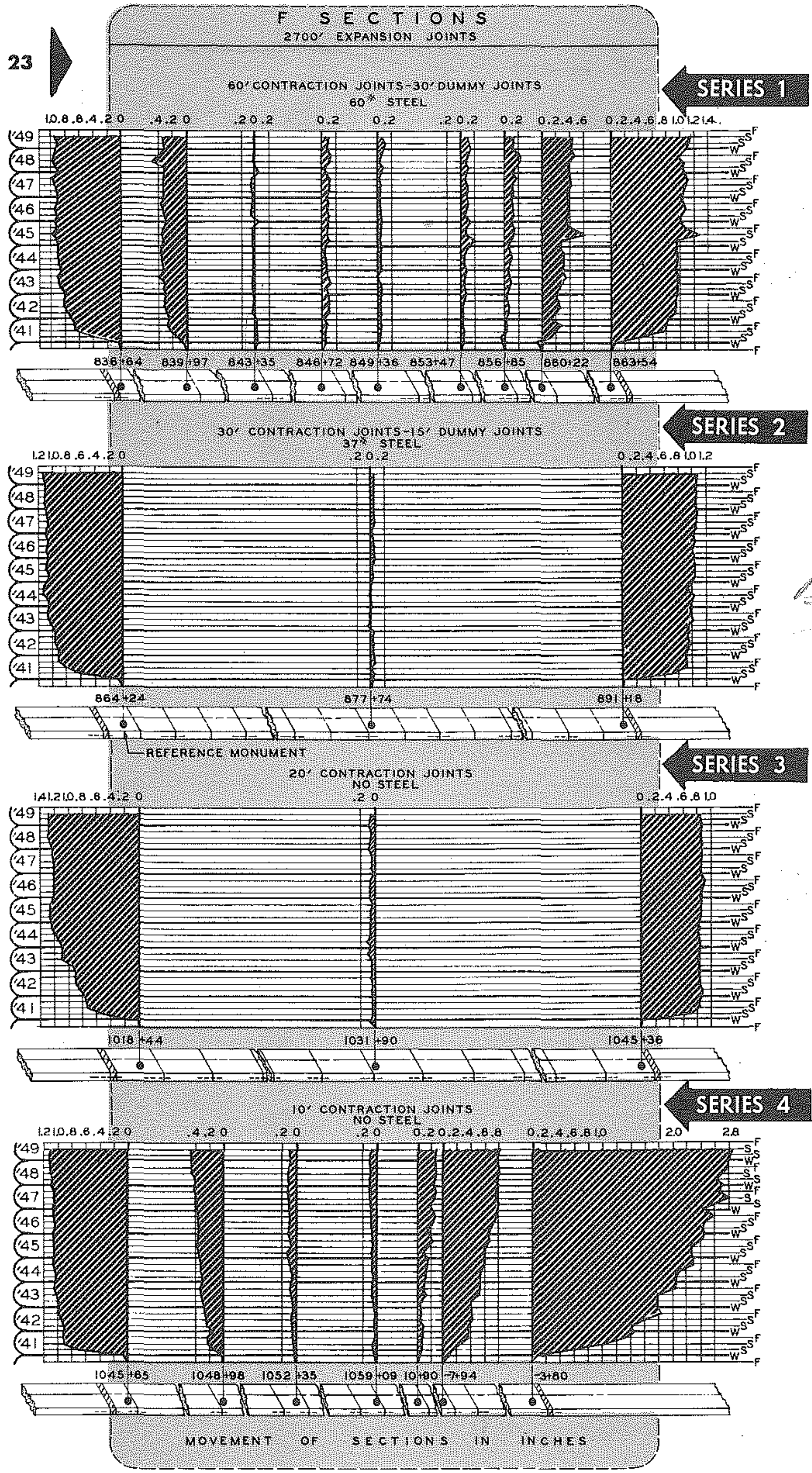


Figure 23




## SEASONAL CHANGES IN SECTION LENGTH