MICHIGAN
STATE HIGHWAY DEPARTMENT
Charles M. Ziegler
State Highway Commissioner

PRELIMINARY PROGRESS REPORT
ON DESIGN PROJECT
MICHIGAN TEST ROAD

By

E. A. Finney

Research Project 39 F-7 (2)

Research Laboratory
Testing and Research Division
Report No. 59
October 2, 1944

MICHIGAN
STATE HIGHWAY DEPARTMENT
LANSING 13

HARRY T. WARD
CHIEF DEPUTY COMMISSIONER

HARRY C. COONS
DEPUTY COMMISSIONER,
CHIEF ENGINEER

CHARLES M. ZIEGLER
STATE HIGHWAY COMMISSIONER

September 27, 1944

Mr. W. W. McLaughlin
Testing and Research Engineer
Michigan State Highway Department
Lansing, Michigan

Dear Mr. McLaughlin:

In accordance with the request of H. C. Coons, Deputy Commissioner, Chief Engineer, and in compliance with the wishes of E. F. Kelley, Chief of Division of Tests, Public Roads Administration of March 15, 1944, a report has been prepared on the behavior of the design project of the Michigan Test Road. The report submitted herewith covers the four year life of the project including summer measurements taken in July and August of 1944.

The work is in the form of a preliminary progress report disclosing only the more important developments which have come out of the investigation. It was believed desirable to do this in view of the fact that the Department proposes to publish as soon as possible a complete progress report on the test road as a sequal to the Michigan Test Road Bulletin published by the Department in 1942. The progress report will include results from studies performed on both the design and durability projects.

This report follows very closely the outline suggested by Mr. E. F. Kelley in presenting certain important factual data concerning the design project, the observed movements of expansion and contraction joints in the joint spacing study and in discussing the general physical condition of the pavement including cracking, spalling, faulting and smoothness. General comments on certain other studies are also included in the report.

Very truly yours,

E. A. Finney
E. A. Finney
Assistant Testing and Research
Engineer in charge of Research

EAF:GT

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PRELIMINARY PROGRESS REPORT ON DESIGN PROJECT

MICHIGAN TEST ROAD

This is a preliminary progress report describing the behavior of the design project of the Michigan Test Road. The Michigan Test Road was constructed in 1940 by the Michigan State Highway Department in cooperation with the Public Roads Administration for the purpose of establishing certain principles in concrete pavement design, in particular those principles involved in joint spacing and construction methods. This experimental project 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 test project in its entirety is 17.9 miles in length and composed of two separate test sections, namely the Design project and the Durability project. The scope of the study has been outlined and the construction of the project fully described in a bulletin entitled "The Michigan Test Road" published by the Department in July 1942. The scope of the design project has also been described in the proceedings of the Twentieth Annual Meeting of the Highway Research Board (1940).

The report presents a brief discussion of the general behavior of the pavement, especially the joint movement section and includes some of the more important developments and trends that have become evident during the four years of its life.

Repetition of basic information has been avoided as much as possible. However, in some instances repetition has been necessary for the sake of better understanding of the discussion and data presented in the report. To this end a summary of major factors under study together with a detailed plan of the design project are presented in table I and figure 1 respectively.

The schedule of observations established at the beginning of the project has been followed quite closely. In brief, the program consists of the following observations:

1. Seasonal and daily measurements of: joint widths, slab movement, strain, temperature and moisture of the concrete and subbase.
2. Periodic measurements of vertical displacement of the slabs.
3. Periodic condition surveys of pavement.
4. Continuous record of temperature and precipitation.
5. Continuous traffic record.

The report is divided into three parts in which are discussed: first, miscellaneous data; second, joint and slab movement; and third, present condition of the pavement.

MISCELLANEOUS DATA

In addition to the various problems included for study in the project, consideration has been given to the procurement of certain important miscellaneous data directly or indirectly associated with the general behavior of the pavement slabs. Such information includes general soil conditions, concrete design data, physical properties of concrete, traffic data, and climatological data.

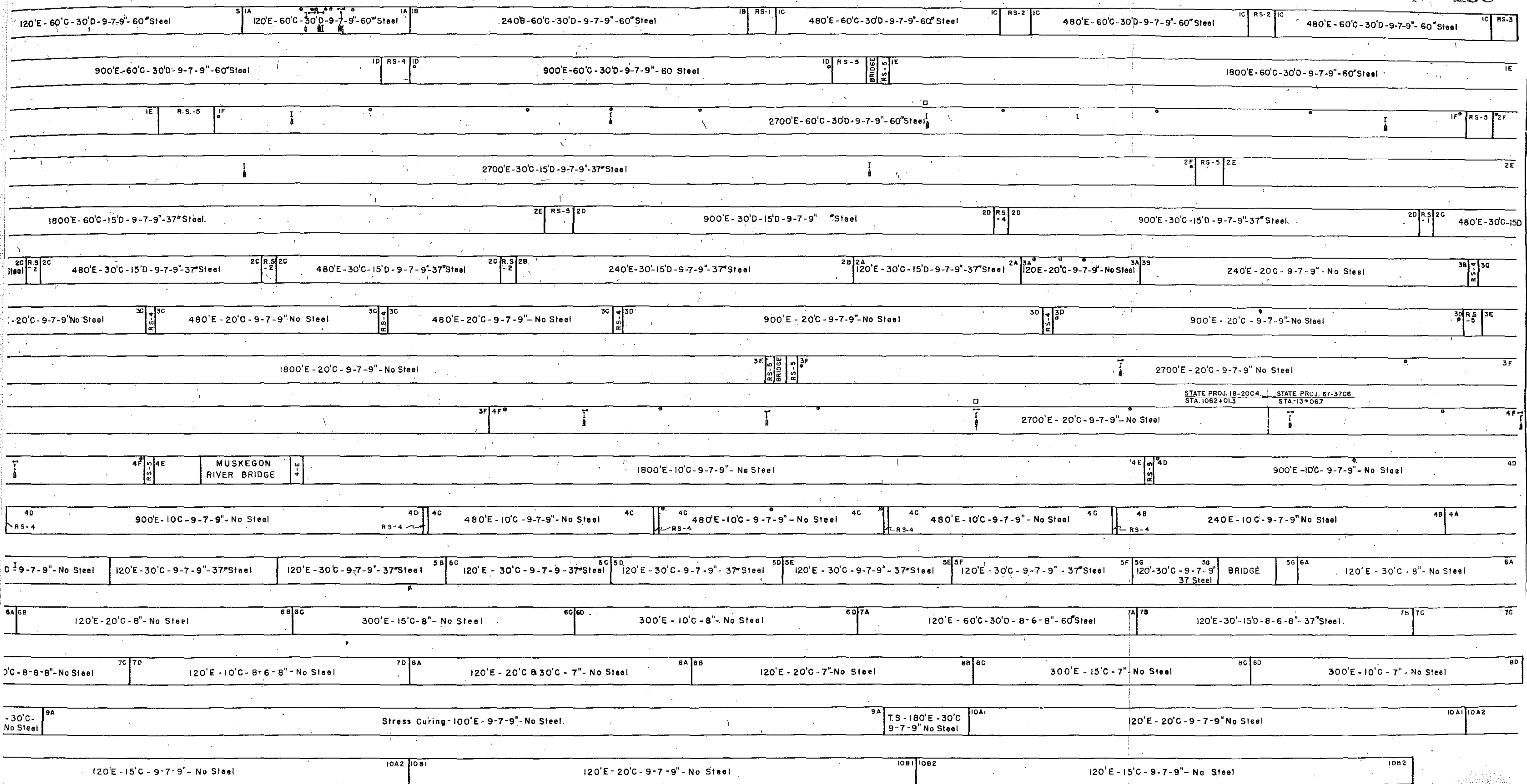
TABLE I
SUMMARY OF TEST SECTIONS
DESIGN PROJECT - MICHIGAN TEST ROAD

Area ~~TEST SECTION~~ DESIGNATION Series	Div.	Number Sections in Division	Length in Feet of Division	Pavement Thickness Inches	Reinforcement lbs/100 sq.ft.	JOINT SPACING Expansion	JOINT SPACING Contraction	JOINT SPACING Dummy	TYPE LOAD TRANSFER Expansion	TYPE LOAD TRANSFER Contraction	TYPE LOAD TRANSFER Dummy *	# Joint Filler and Seal	Special Factors Under Study
		1	600	9-7-9	60	120	60	30	Dowels	Dowels	Mesh	Type 1	Standard Construction
1	A	3	~~120~~ 360	9-7-9	60	120	60	30	Dowels	Dowels	Mesh	Type 1	Joint Spacing
	B	3	~~240~~ 720	9-7-9	60	240	60	30	Dowels	Dowels	Mesh	Type 1	Joint Design
	C	3	~~480~~ 1440	9-7-9	60	480	60	30	TE	Dowels	Mesh	Type 1	Reinforcement
	D	2	~~900~~ 1800	9-7-9	60	900	60	30	Dowels	Dowels	Mesh	Type 1	
	E	1	1800	9-7-9	60	1800	60	30	Dowels	Dowels	Mesh	Type 1	TE - Thickened Edge with 1 1/4" Corner Bars
	F	1	2700	9-7-9	60	2700	60	30	Dowels	Dowels	Mesh	Type 1	
2	F	1	2700	9-7-9	37	2700	30	15	Dowels	Dowels	Mesh	Type 1	Joint Spacing
	E	1	1800	9-7-9	37	1800	30	15	Dowels	Dowels	Mesh	Type 1	Joint Design
	D	2	~~900~~ 1800	9-7-9	37	900	30	15	Dowels	Dowels	Mesh	Type 1	Reinforcement
	C	3	~~480~~ 1440	9-7-9	37	480	30	15	TE	Dowels	Mesh	Type 1	
	B	3	~~240~~ 720	9-7-9	37	240	30	15	Dowels	Dowels	Mesh	Type 1	
	A	3	~~120~~ 360	9-7-9	37	120	30	15	Dowels	Dowels	Mesh	Type 1	
3	A	3	~~120~~ 360	9-7-9	None	120	20	None	Dowels	Dowels	None	Type 1	Joint Spacing
	B	3	~~240~~ 720	9-7-9	None	240	20	None	Dowels	Dowels	None	Type 1	Reinforcement
	C	3	~~480~~ 1440	9-7-9	None	480	20	None	Dowels	Dowels	None	Type 1	
	D	2	~~900~~ 1800	9-7-9	None	900	20	None	Dowels	Dowels	None	Type 1	
	E	1	1800	9-7-9	None	1800	20	None	Dowels	~~Dowels~~ NONE	None	Type 1	
	F	1	2700	9-7-9	None	2700	20	None	Dowels	Dowels	None	Type 1	
4	F	1	2700	9-7-9	None	2700	10	None	Dowels	Dowels	None	Type 2	Joint Spacing
	E	1	1800	9-7-9	None	1800	10	None	Dowels	~~Dowels~~ NONE	None	Type 2	Reinforcement
	D	2	~~900~~ 1800	9-7-9	None	900	10	None	Dowels	Dowels	None	Type 2	
	C	3	~~480~~ 1440	9-7-9	None	480	10	None	Dowels	Dowels	None	Type 2	
	B	3	~~240~~ 720	9-7-9	None	240	10	None	Dowels	Dowels	None	Type 2	
	A	3	~~120~~ 360	9-7-9	None	120	10	None	Dowels	Dowels	None	Type 2	
5	A	3	360	9-7-9	37	120	30	None	Dowels	Type 1B	None	Type 3	Design of Contraction Joints
	B	3	360	9-7-9	37	120	30	None	Dowels	Type 2A	None	Type 3	Reinforcement
	C	3	360	9-7-9	37	120	30	None	Dowels	Type 2B	None	Type 3	Type 1B - Dowel Bars with groove and poured filler
	D	3	360	9-7-9	37	120	30	None	Dowels	Type 3	None	Type 3	Type 2A - Dowel Bars with premolded filler and metal parting strip
	E	3	360	9-7-9	37	120	30	None	Dowels	Type 3	None	Type 3	Type 2B - Dowel Bars with groove and poured filler, parting strip
	F	3	360	9-7-9	37	120	30	None	Dowels	Type 4	None	Type 3	Type 3 - Dowel Bars, groove and poured filler, metal dividing Plat
	G	3	360	9-7-9	37	120	30	None	Dowels	Type 4	None	Type 3	Type 4 - Continuous Plate Dowel, grooved and poured filler
6	A	5	600	8"	None	120	30	None	Corner Bars	Corner Bars	None	Type 2	Cross Section
	B	5	600	8"	None	120	20	None	Corner Bars	Corner Bars	None	Type 2	Expansion and Contraction Joint Spacing
	C	2	600	8"	None	300	15	None	Corner Bars	Corner Bars	None	Type 2	Joint Design
	D	2	600	8"	None	300	10	None	Corner Bars	Corner Bars	None	Type 2	Reinforcement
7	A	5	600	8-6-8	60	120	60	30	Dowels	Dowels	Mesh	Type 2	Cross Section
	B	5	600	8-6-8	37	120	30	15	Dowels	Dowels	Mesh	Type 2	Contraction and Dummy Joint Spacir
	C	5	600	8-6-8	None	120	20	None	Dowels	Dowels	None	Type 2	Reinforcement
	D	5	600	8-6-8	None	120	10	None	Dowels	Dowels	None	Type 2	
8	A	3	360	7"	None	120	30	None	Corner Bars	Corner Bars	None	Type 2	Cross Section
	B	7	840	7"	None	120	20	None	Corner Bars	Corner Bars	None	Type 2	Expansion and Contraction Joint Spacing
	C	2	600	7"	None	300	15	None	Corner Bars	Corner Bars	None	Type 2	Reinforcement
	D	2	600	7"	None	300	10	None	Corner Bars	Corner Bars	None	Type 2	Joint Design
9	TS	1	180	9-7-9	None	180	30	None	Translode	Dowels	None	Type 4	Stress Curing
	A	1	1800	9-7-9	None	100	None	None	Translode	~~Dowels~~ None	None	Type 4	
	TS	1	90	9-7-9	None	~~[illegible]~~	30	None	Translode	Dowels	None	Type 4	Construction Joint Type 5 - Keylo
	TS	1	90	9-7-9	None	180	30	None	Dowels	~~Dowels~~ Type 5	None	Type 4	Contraction Joint
10	A-1	9	1080	9-7-9	None	120	20	None	Dowels	Dowels	None	Type 5	Joint Design With and Without Loa Transfer
	A-2	9	1080	9-7-9	None	120	15	None	Dowels	Dowels	None	Type 5	Contraction Joint Spacing
	B-1	9	1080	9-7-9	None	120	20	None	None	None	None	Type 2	
	B-2	9	1080	9-7-9	None	120	15	None	None	None	None	Type 2	
11	A	1	90	9-7-9	60	90	None	None	Trans.Angle	None	None	Type 6	Continuous Slab Construction with reinforcement
	B	1	120	9-7-9	60	120	None	None	*Trans.Angle	None	None	Type 6	* Translode Angle
	C	1	362	9-7-9	60	362	None	None	Trans.Angle	None	None	Type 6	
	D	1	600	9-7-9	60	600	None	None	Trans.Angle	None	None	Type 6	
12	A	1	90	9-7-9	None	90	None	None	Trans.Angle	None	None	Type 6	Continuous Slab Construction without reinforcement
	B	1	120	9-7-9	None	120	None	None	Trans.Angle	None	None	Type 6	* Translode Angle
	C	1	~~390~~ 360	9-7-9	None	~~390~~ 360	None	None	Trans.Angle	None	None	Type 6	
	D	1	242	9-7-9	None	242	None	None	Trans.Angle	None	None	Type 6	
	E	1	600	9-7-9	None	600	None	None	Trans.Angle	None	None	Type 6	

EXPANSION JOINT SEAL STUDY

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.

* Mesh continuous through joint.



Futher Design Studies - Series 11 A - D and 12 A - E, are described in Series 7 of the Durability Section.

— L E G E N D —

- Surface Strain Gage Plugs.
- Strain Gage Cell.
- Moisture Cell Assembly.
- Thermocouple Assembly.
- Slab Movement Box.
- Control Slab

MICHIGAN
STATE HIGHWAY DEPARTMENT.
G. DONALD KENNEDY.
STATE HIGHWAY COMMISSIONER

MICHIGAN TEST ROAD
CONCRETE DESIGN STUDY

RESEARCH DIVISION

PROJECT 18-20C3 & 67-37C4	RESEARCH PROJECT 39-B-11
LOCATION M-115	SCALE 1" = 100 FEET
LENGTH - 10.1 MILES	DATE 2-15-41
CONSTRUCTED 1941	DRAWN BY R.W.S.

Figure 1

General Soil Conditions:

The subgrade and subbase materials supporting the concrete slab in the design project are primarily composed of well drained sandy or gravelly soils with the exception of two areas, between Stations 83+00 to 129+00 and from Stations 170+00 to 258+00, where it was necessary to construct a 12 inch sand subbase on the existing subgrade material. The physical properties of the soil immediately under the concrete pavement at four representative locations are given in table II.

Subgrade resistance: Laboratory friction studies were made on soil material imported from the test road site to determine the coefficient of friction between the sand subbase and the pavement slab. Preliminary tests were made with a 4 foot square and 6 inch thick slab 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 the test until movement of the slab took place. The procedure was repeated several times both in a forward and backward direction. Coefficient of friction values of 0.875, 1.125 and 0.848 were obtained, which would indicate the horizontal resistance of the subgrade to slab movement to be low as compared to subgrades composed of heavier soils whose coefficient of friction may be as high as 1.5 or more.

Subgrade moisture: In order to obtain a progressive record of the amount of moisture in the pavement concrete and in the soil underneath the slab, the electrical resistance method of Bouyoucos and Mick (1) was used.

(1) G. J. Bouyoucos and A. H. Mick - "Electrical Resistance Method for Continuous Measurement of Soil Moisture Under Field Conditions" - Michigan State College Agricultural Experiment Station, Technical Bulletin No. 172, April 1940.

TABLE II

SUBBASE SOIL INFORMATION AT MOISTURE CELL STATIONS

Michigan Test Road
Design Project

	Station 772+10	Station 851+80	Station 1056+75	Station 61+05
Gravel, percent retained, No. 10 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	2.65
Shrinkage Limit, %	No Shrinkage	No Shrinkage	No Shrinkage	No Shrinkage
Loss on Ignition, %	0.87	0.80	1.59	0.61
Organic Content, %	0.82	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	25.9	25.0	20.2
Moisture, top inch of rise %	6.7	4.7	5.4	5.0
Coefficient of Permeability Feet per day	28	52	38	40
Weight on Sample lbs. per square inch	0.8	0.8	0.8	0.8
Voids, %	30.8	32.0	32.0	30.8

Plaster of paris cells were imbedded in the concrete at the top, middle and bottom of the slab, and in the subgrade at depths of 1 inch, 6 inches and 12 inches below the pavement. Corresponding iron-constantan thermocouples were installed at the same time for temperature measurements. There were four of these installations made at convenient points throughout the design project so that temperature and moisture observations might be made concurrently with displacement measurements. The installations are located at Stations 772+10, 851+80, 1055+75 and 61+05.

The data given in table III for moisture cell readings at the four stations show that the moisture content of the subbase normally varies from about 4.5 to 8 percent at the four locations observed and that there is a reasonably close correlation with the seasonal and cumulative precipitation. The data also indicate that the subbase is in general well drained, which condition would tend to maintain a relatively stable moisture content in the bottom of the slab throughout the year. Moisture values during the winter are omitted since this method cannot be used at sub-freezing temperatures.

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. Complete concrete mix design data are presented in table IV.

TABLE III

SUMMARY OF SUBGRADE MOISTURE DATA

Michigan Test Road
Design Project

Year	Season*	Soil Moisture Percent					Precipitation Inches	Cumulative Precipitation
		772+10	881+20	1035+75	61+05	Average		
1941	Winter	—	—	—	—	—	3.60	3.60
	Spring	6.8	-	8.6	7.3	6.9	9.12	12.72
	Summer	10.9	-	7.9	7.7	8.8	8.73	21.45
	Fall	7.2	7.0	3.5	8.9	6.9	9.58	31.03
1942	Winter	-	-	-	-	-	1.80	1.80
	Spring	4.4	7.1	6.2	6.9	6.1	9.09	10.89
	Summer	4.7	5.9	5.5	6.8	6.0	9.15	20.04
	Fall	7.1	9.0	7.4	7.2	7.4	8.77	28.81
1943	Winter	-	-	-	-	-	6.08	6.08
	Spring	7.7	13.7	6.2	7.4	8.8	11.76	17.84
	Summer	9.9	11.3	6.9	8.1	8.8	6.73	24.57
	Fall	6.5	7.3	8.3	7.4	8.9	4.92	29.49
1944	Winter	-	-	-	-	-	3.53	3.53
	Spring	4.8	-	5.5	6.7	5.7	7.95	11.48
	Summer	4.7	-	5.3	-	5.0	8.07	19.55

* Winter - January, February, March

Spring - April, May, June

Summer - July, August, September

Fall - October, November, December

TABLE IV

CONCRETE MIX DESIGN DATA

Michigan Test Road

Basic Concrete Mix Portion	Cement	94 pounds
	Water	52.4 pounds
	Fine Aggregate	228 pounds
	Coarse Aggregate, 10A	190.5 pounds
	Coarse Aggregate 4A	190.5 pounds
Cement per cubic yard	5.5 sacks	
Percent sand of total mix	37	
Water, Gallons per sack cement	6.5	

Physical Properties of Concrete.

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

Modulus of elasticity: The modulus of elasticity values presented in table V were determined from stress-strain measurements on 6x12 inch compression cylinders cast at different stations of the test road during pouring operations in 1940.

Coefficient of Thermal Expansion: In determining the coefficient of thermal expansion, measurements were made on 3"x6"x18" concrete specimens in both the saturated and oven dry conditions. This was done to differentiate 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 1/2" 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. average 0.0000053. In a saturated condition the specimens contained approximately 4.1 percent 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 0.000248" per inch of length. This value is equivalent to a change in temperature of 46 degrees. Assuming same linear contraction in [illegible] of the specimen, the change in volume [illegible] for [illegible] .0[illegible] % which [illegible] for concrete with [illegible] aggregate. (PCA Pavement Design [illegible] .079)

[illegible] volume of only [illegible]

TABLE V

PHYSICAL PROPERTIES OF CONCRETE

STRENGTH

	Compressive		Flexural	
	6"x12" cylinders	6" dia. cores	6"x8"x24" beams	
	28 days	21 months	7 days	28 days
	p.s.i.	p.s.i.	p.s.i.	p.s.i.
Low	4890	5780	439	518
High	5580	7195	718	949
Average	5203	5843	578	697

MODULUS OF ELASTICITY, in 10^6 pounds per square inch.

	at 500 p.s.i.	at 1000 p.s.i.
Low	6.38	6.05
High	7.22	6.59
Average	6.69	6.30

COEFFICIENT OF THERMAL EXPANSION 0.0000055

CONSISTENCY - Slump Cone Method - 1 to 3.5 inches - Average 2.08 inches.

WEIGHT PER CUBIC FOOT 153 pounds.

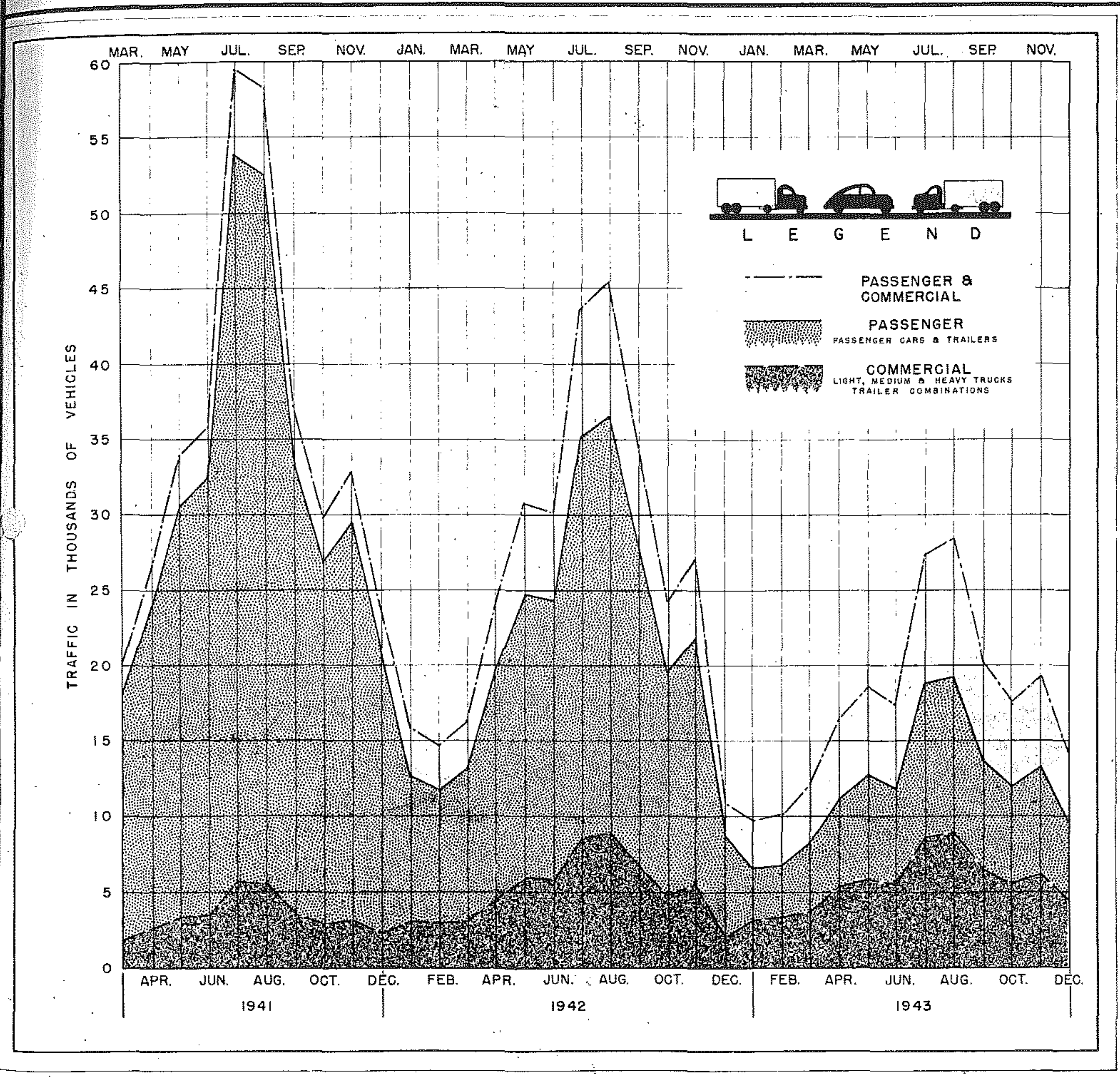
Moisture Content of Slab: Preliminary calibration of moisture cells in concrete indicates that the moisture in the top of the slab varies between about 4 and 5.5 percent. In the middle the variation is somewhat less, moisture ranging from approximately 5 to 6 percent, while the bottom maintains a fairly stable state at about 5.7 to 6.3 percent moisture content.

The overall moisture content of the slab was noticeably higher during the spring immediately following the construction of the pavement. During the summer of 1941 however, the bottom of the slab seems to have attained a relatively stable moisture equilibrium which has not changed appreciably with time. On the other hand, there has been a steady decline of moisture content at the center of the slab amounting to about 0.4% since the end of the first summer. This will probably continue until a more stable moisture gradient is established throughout the slab. It was to be expected of course that the moisture content of the top of the pavement would fluctuate between wider limits due to its direct contact with a more variable environment.

Traffic Data.

Automatic equipment was installed on the test road to obtain a continuous daily record of traffic. Periodically the daily traffic flow is sampled to screen out and classify the various types of vehicles. From this work it is possible to estimate quite closely, for any period of time, the frequency of those wheel loads which are of sufficient magnitude to warrant consideration in the future behavior of the pavement slabs. In this category it is customary to consider loads in excess of 4000 pounds.

The monthly traffic record presented graphically in figure 2 illustrates quite clearly total traffic characteristics on the test road for the years



MONTHLY TRAFFIC RECORD – MICHIGAN TEST ROAD 1941 – 43

1941, 1942 and 1943. It is interesting to note how the influence of the war has caused an appreciable drop in passenger traffic with a corresponding increase in commercial vehicles.

During the summers of 1941 to 1944 classification was made of daily traffic. Values representing the percentages of different types of vehicles traveling the test road on an average summer day are given in table VI.

The wheel load distribution by direction of travel is shown in table VII. It is to be noted that these data in tables VI and VII are representative of average summer traffic only. Authentic figures for all year traffic conditions will eventually be established for the test road. It may be seen from table VIII that the percent of wheel loads in excess of 4000 pounds which pass over the test road is 17.8 as compared to values as high as 47.8 percent occurring on certain trunk lines in Michigan. From this fact it would be natural to expect that certain structural failures attributable to heavy traffic conditions may not appear in the immediate future.

Climatological Data.

Complete records of temperature and precipitation for the test road are presented in figures 3 and 4 respectively, covering the four year life of the project.

The graph in figure 3 shows that the average mean temperature in winter is approximate 25 degrees F. while in summer it is 75 degrees, making an average temperature differential of 50 degrees F. Also, it may be observed that daily temperature fluctuations in winter are very small as compared with those occurring during the summer.

Figure 4 gives the precipitation by month as well as the total value for each year.

TABLE VI

CLASSIFICATION OF ~~AVERAGE SUMMER~~ Annual Average DAILY TRAFFIC
Michigan Test Road

Classification of Annual Average Daily Traffic

Classification	1941 Amount	1941 Percent	1942 Amount	1942 Percent	1943 Amount	1943 Percent	1944 Amount	1944 Percent
Total Traffic	1590	100.0	829	100.0	578	100.0	735	100.0
Passenger Cars	1361	85.6	657	78.9	376	65.0	554	75.6
Passenger Cars with Trailers	76	4.8	31	3.7	18	3.2	29	3.9
Total Passenger Cars	1437	90.4	688	80.8	394	68.2	583	79.5
Light Trucks (3/4 tons and under)	43	2.7	44	5.3	14	2.4	32	4.4
Medium Trucks (1 to 2 1/2 tons)	26	1.6	37	4.4	56	9.7	51	7.0
Heavy Trucks (3 tons and over)	43	2.7	12	1.5	13	2.2	5	0.7
Trailer Combinations	41	2.6	68	8.2	101	17.5	62	8.4
Total Commercial	153	9.6	161	19.4	184	31.8	150	20.5

TABLE VII
AVERAGE SUMMER WHEEL LOAD DISTRIBUTION
By Direction of Travel

Michigan Test Road

Annual Average Wheel load distribution

Wheel Load*	Southbound (West Lane)		Northbound (East Lane)		Total	
	Number	Percent	Number	Percent	Number	Percent
Under 4000	79	84.93	78	79.60	157	82.20
4000 - 4400	1	1.08	0		1	0.52
4500 - 4900	0		2	2.04	2	1.05
5000 - 5400	1	1.08	1	1.02	2	1.05
5500 - 5900	1	1.08	1	1.02	2	1.05
6000 - 6400	3	3.22	0		3	1.57
6500 - 6900	4	4.29	2	2.04	6	3.14
7000 - 7400	1	1.08	2	2.04	3	1.57
7500 - 7900	0		4	4.08	4	2.09
8000 - 8400	1	1.08	2	2.04	3	1.57
8500 - 8900	1	1.08	2	2.04	3	1.57
9000 - 9400	1	1.08	4	4.08	5	2.62
9500 & Over	0		0		0	
Total Axles	93	100.00	98	100.00	191	100.00
Total Vehicles	37		39		76	
Ratio Axles to Vehicles	2.51		2.51			

* One wheel weighed per Axle.

TABLE VIII

COMPARISON OF WHEEL LOAD FREQUENCY ON TEST ROAD WITH OTHER TRUNKLINES IN MICHIGAN

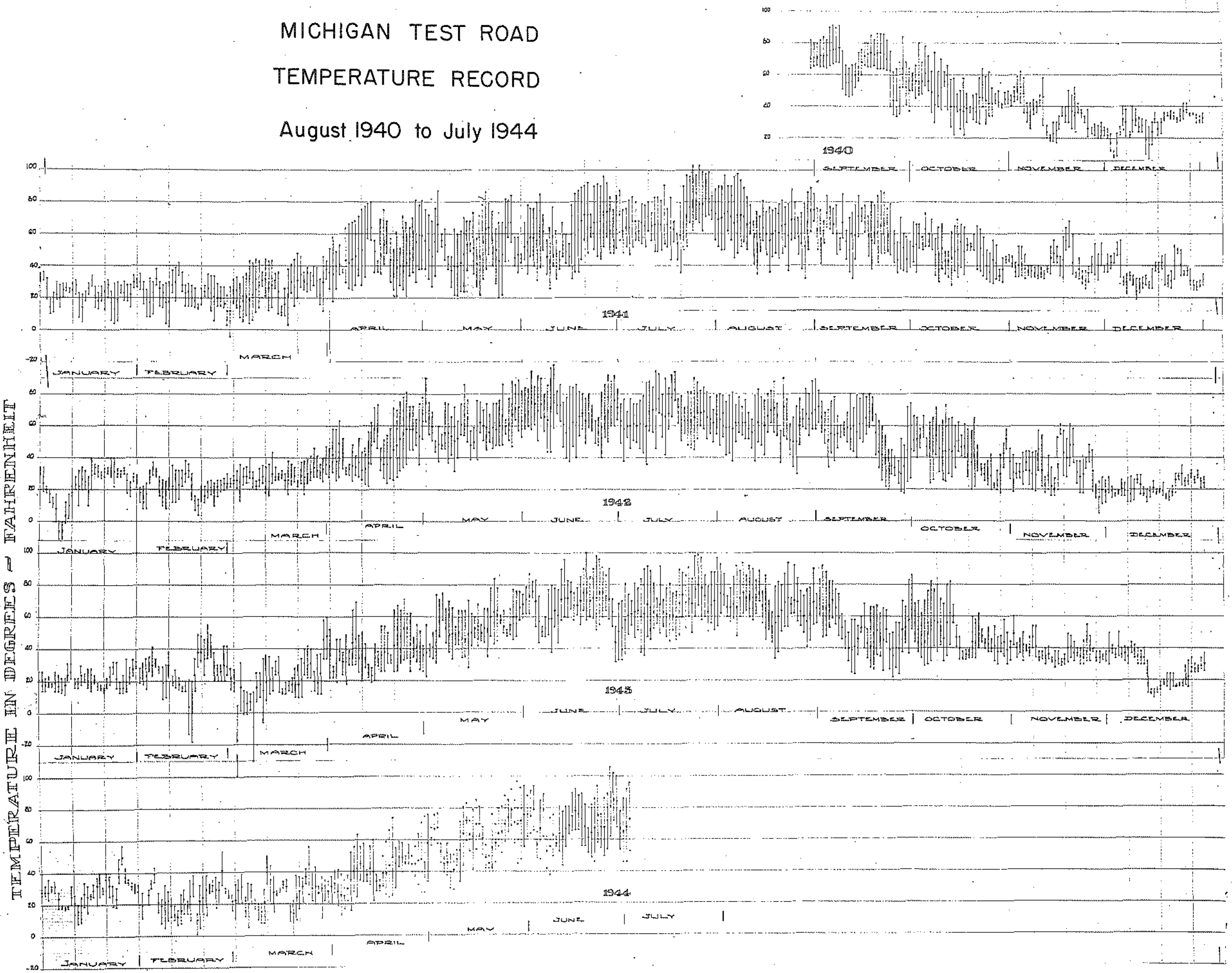
Weight Station	Route	Percent Wheel Loads over 4,000 pounds for summer 1943
118	US 112 - US 131	47.6
81	US 24 - US 25	44.0
112	US 12	43.2
89	US 10 - M 15	37.6
109	US 131	34.2
82	US 25 - M 97	33.7
108	US 16	33.7
27	US 131	28.8
52	US 27	26.8
40	US 31	25.5
Test Road	M 115	*17.8

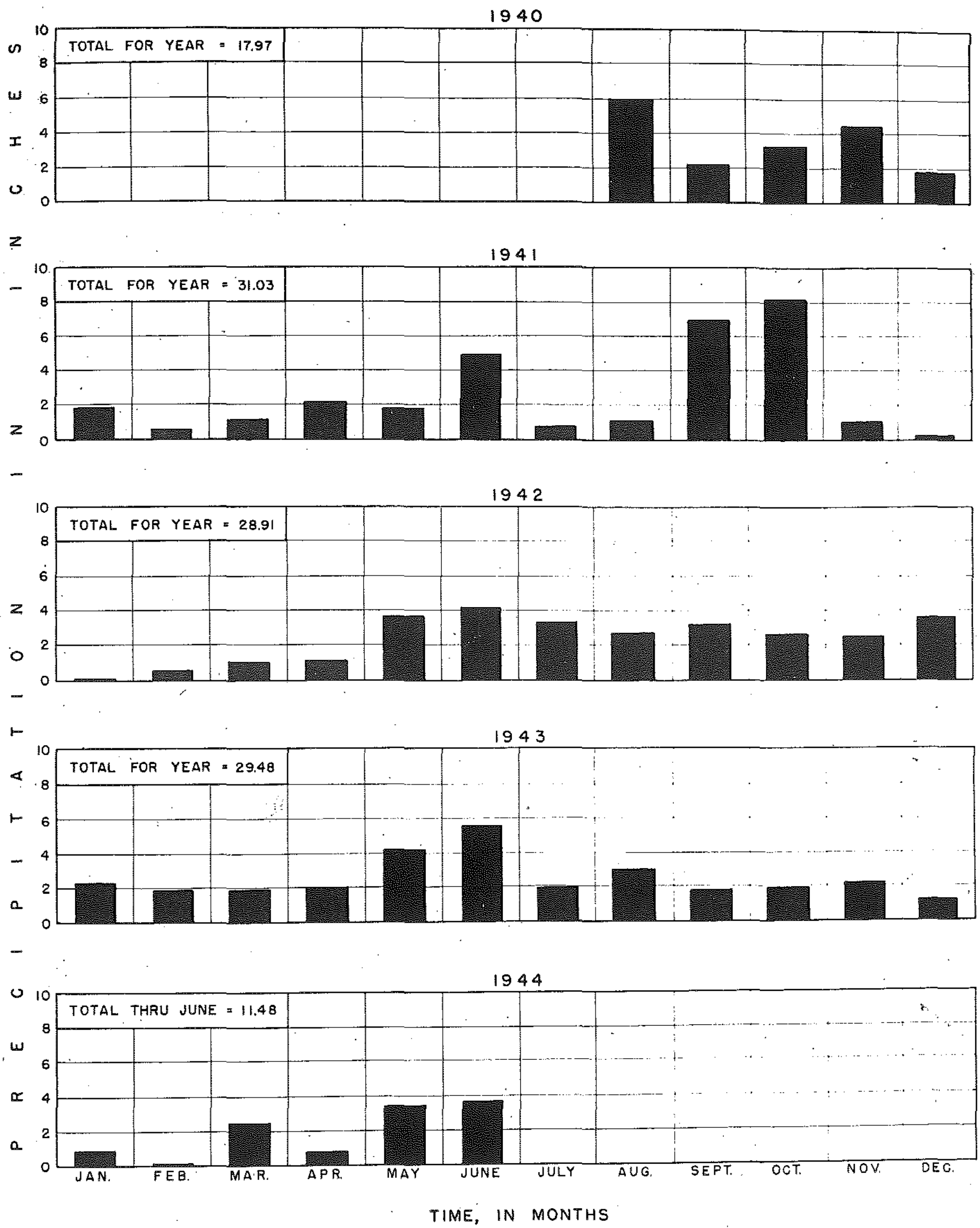
*Summer 1944

MICHIGAN TEST ROAD

TEMPERATURE RECORD

August 1940 to July 1944





MICHIGAN TEST ROAD

PRECIPITATION RECORD

Figure 4

One of the three primary factors of concrete pavement design and construction included in the design project pertains to the design and spacing of transverse joints. In connection with the special considerations being given to the spacing of the transverse joints, seasonal, and daily movements of joint widths and slabs have been recorded for comparative study.

JOINT SPACING AND PAVEMENT MOVEMENT

In series 1, 2, 3 and 4 special emphasis has been placed upon the study of joint spacing. Expansion joints have been spaced to give sections of 120, 240, 480, 900, 1800 and 2700 foot lengths. In these sections of various length, contraction joints have been spaced at 60, 30, 20 and 10 foot intervals. Dummy or plane of weakness joints are included in the sections containing 60 and 30 foot contraction joint spacing.

Initial measurements of joint width and slab position were made immediately upon completion of each series in the fall of 1940 and these readings have been used as a reference in determining subsequent displacements.

Because of the vast amount of data accumulated over the past four years, it has seemed desirable for the purpose of this report to condense the data into a more compact, convenient form; for example, the joint width movements in the different test sections have been reduced to composite curves which are representative of the average annual maximum and minimum joint widths for all of the joints under observation in any given section. The observed annual winter and summer readings have been chosen for comparative study because it is during these seasons of the year that the maximum and minimum limits of joint movement are apt to occur.

The change in joint width or section length was compiled from data obtained in the morning of a winter day and the morning of a summer day. 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 measurement between series to a certain extent. The effect of these day-to-day changes in temperature during the observation period has not been considered in the presentation and interpretation of the data in this report.

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

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, or relief sections composed of two or more one-inch expansion joints, contraction joints, and dummy or plane of weakness joints.

Expansion Joints: Changes in expansion joint width for the several sections together with their progressive or permanent change, are presented graphically in figure 5 for the years 1941 to 1944. This graph also shows the relationship between change in joint width and length of section. 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 joint movements were combined algebraically to form a single value representative of one joint of equivalent width.

The temperature values shown on the graph represent the mean temperature of the concrete slab at time that the readings were taken. Summer readings include those taken in July and August, winter readings taken in January, February or March. Readings were taken in the winter when temperatures were seasonable and the pavement surface was sufficiently clear to permit measurements.

ANNUAL AND PROGRESSIVE CHANGES IN EXPANSION JOINT WIDTH

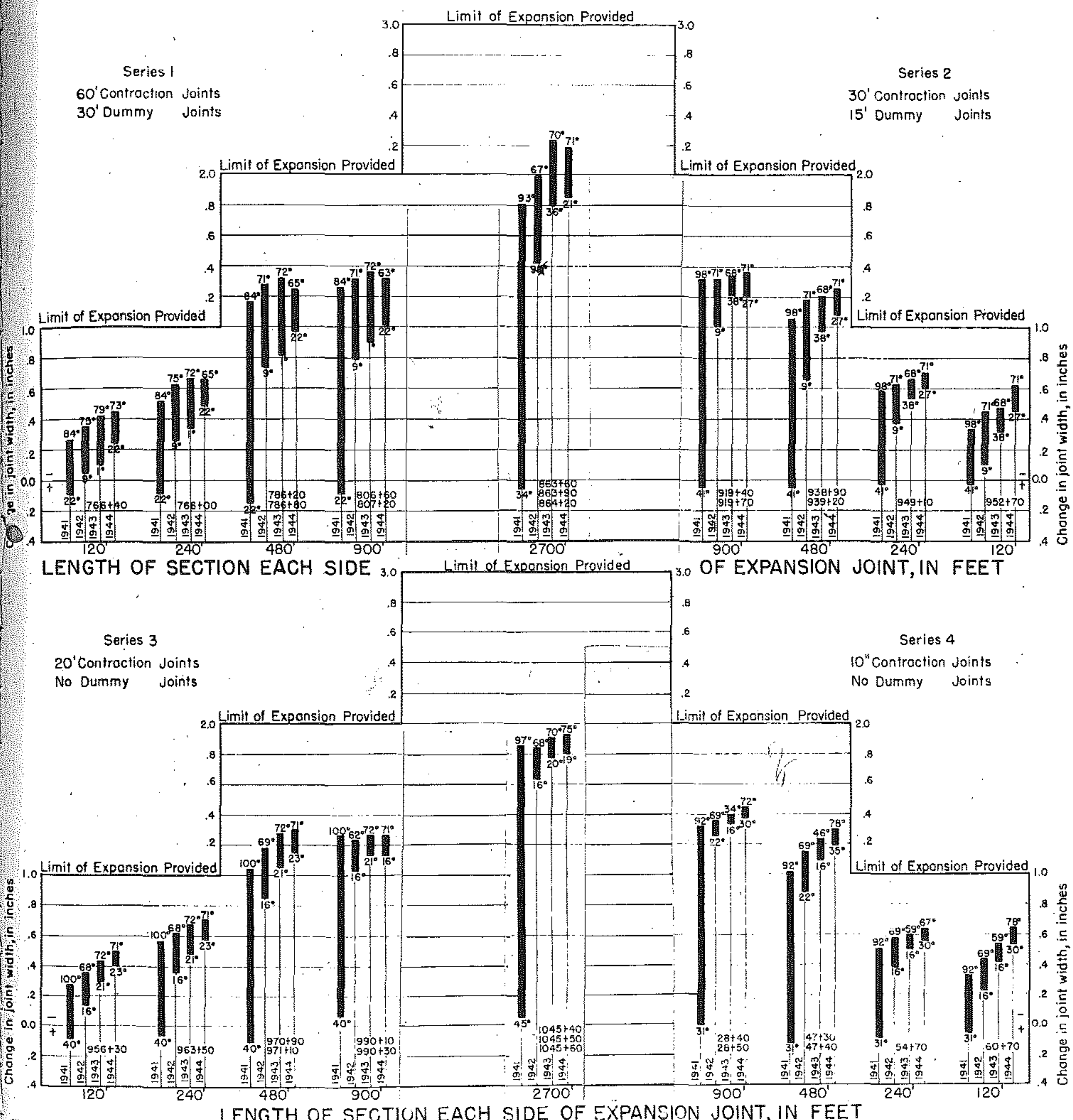


Figure 5

Several significant facts are revealed by the graph in figure 5. 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 1 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 four years the sections have absorbed approximately 50 to 70 percent of the expansion space provided. There is no doubt that this rate of permanent change will diminish rapidly in the future, since the joint filler material 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 curves presented in figures 6, 7, 8 and 9 show graphically the average annual maximum and minimum movement of the contraction joints in series 1, 2, 3 and 4 respectively for the four year life of the project.

OMPOSITE SEASONAL CONTRACTION JOINT MOVEMENT
RELATIONSHIP BETWEEN CHANGES IN JOINT WIDTH AND LENGTH OF SECTION
SERIES I 60' SPACING – 30' DUMMIES

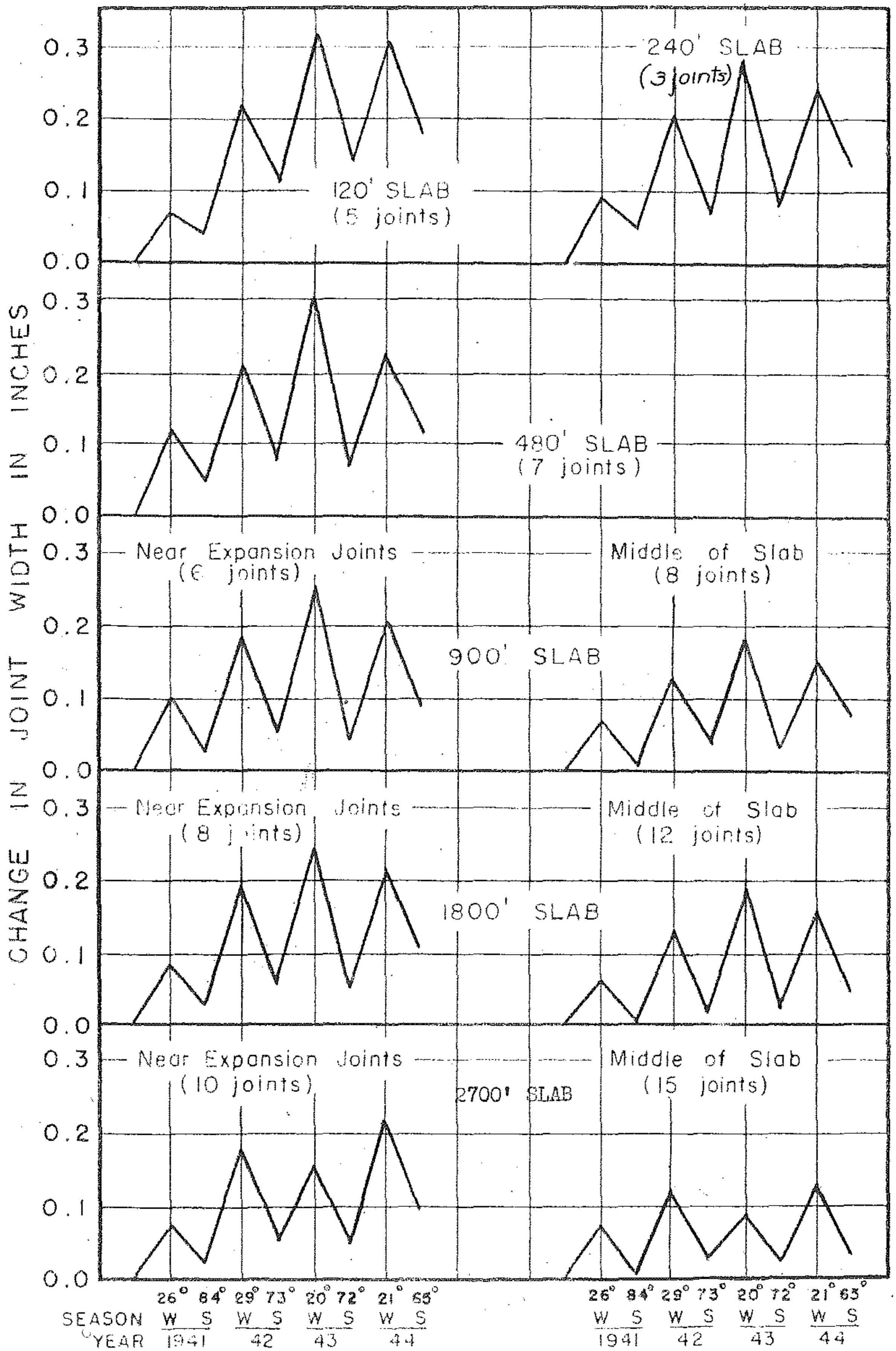


Figure 6

COMPOSITE SEASONAL CONTRACTION JOINT MOVEMENT

RELATIONSHIP BETWEEN CHANGES IN JOINT WIDTH AND LENGTH OF SECTION

SERIES 2 30ft. spasing 15' Dummy joints

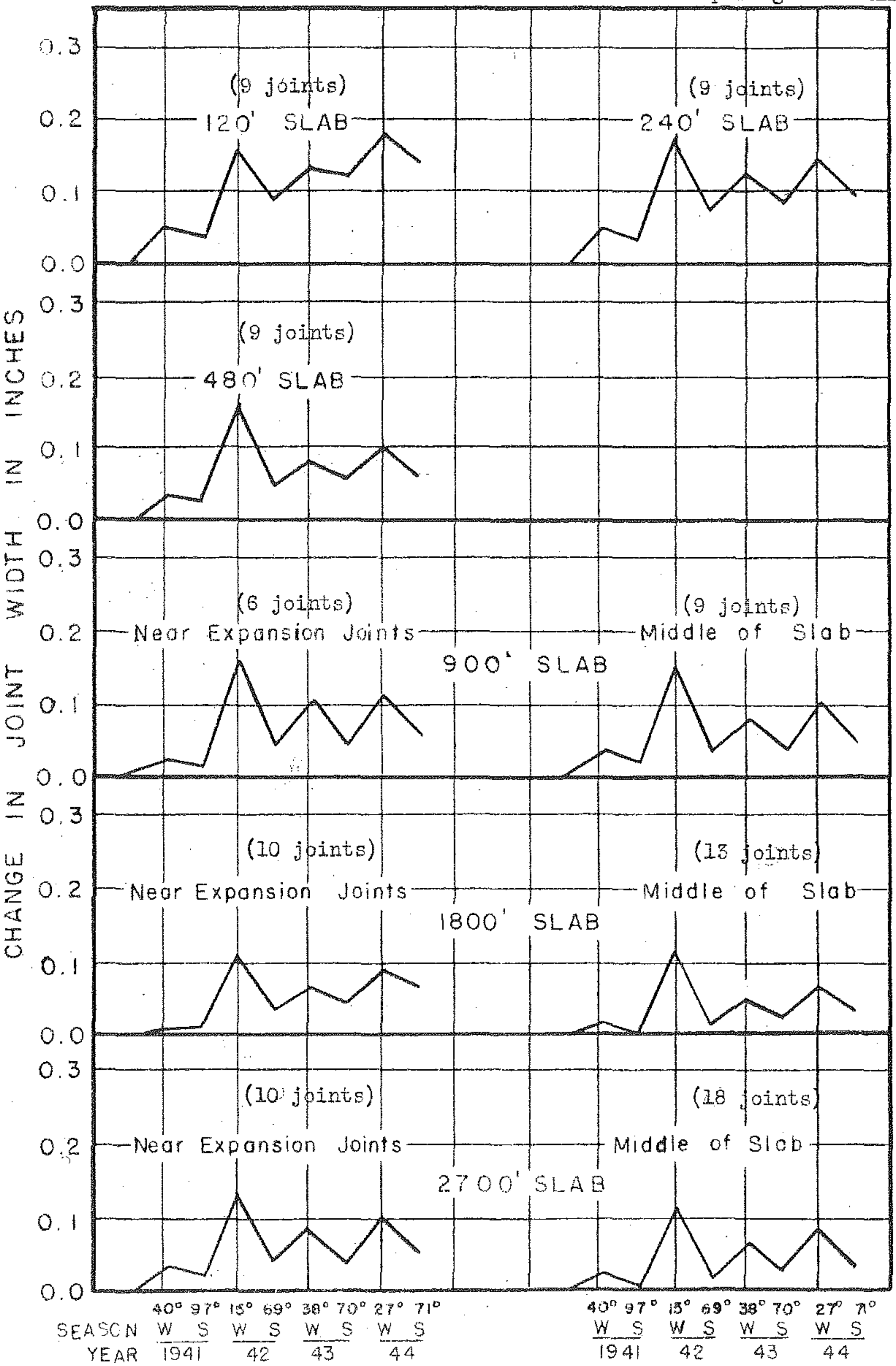


Figure 7

COMPOSITE SEASONAL CONTRACTION JOINT MOVEMENT
RELATIONSHIP BETWEEN CHANGES IN JOINT WIDTH AND LENGTH OF SECTION
SERIES 3

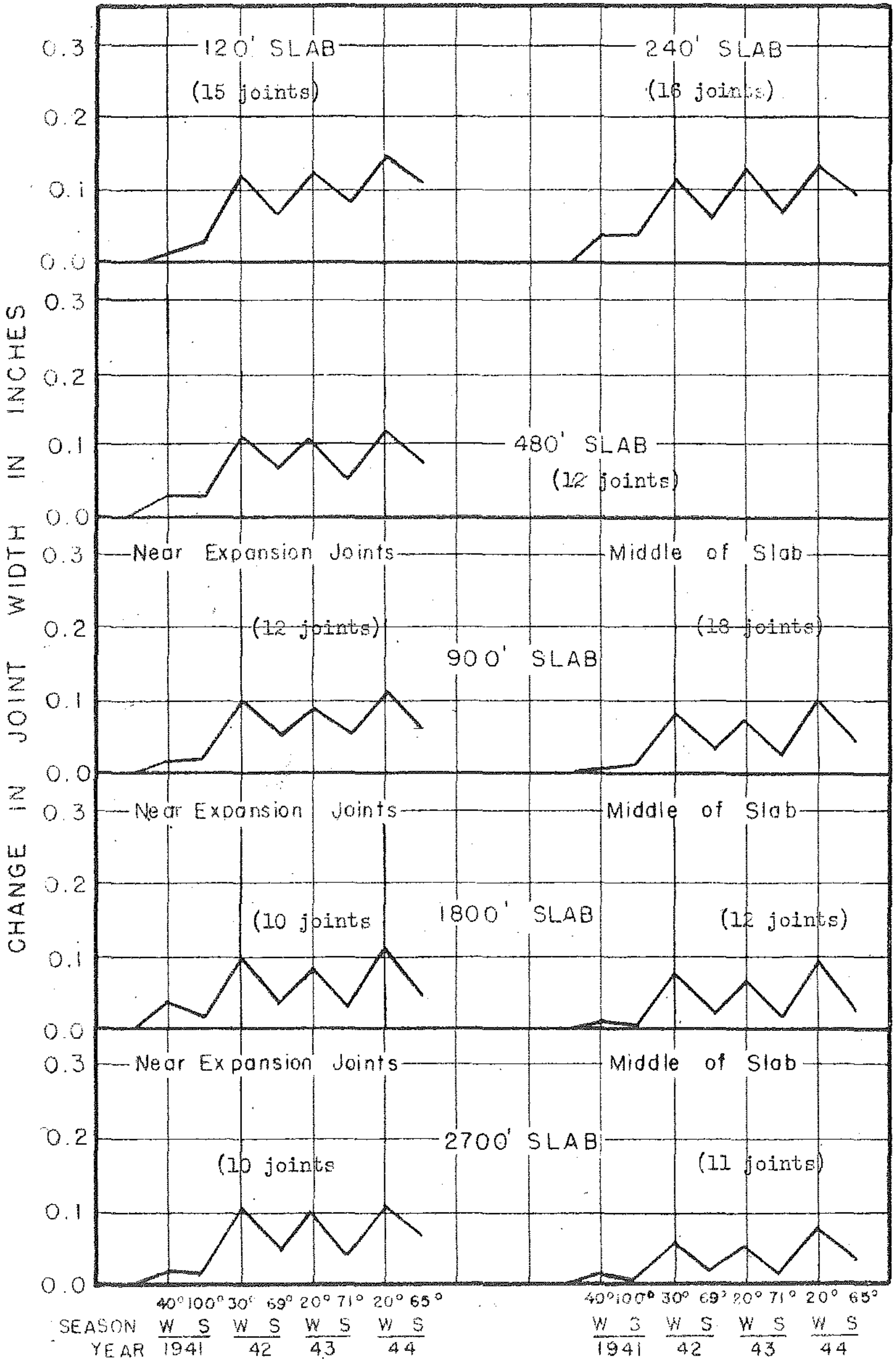


Figure 8

COMPOSITE SEASONAL CONTRACTION JOINT MOVEMENT

RELATIONSHIP BETWEEN CHANGES IN JOINT WIDTH AND LENGTH OF SECTION

SERIES 4 10' SPACING

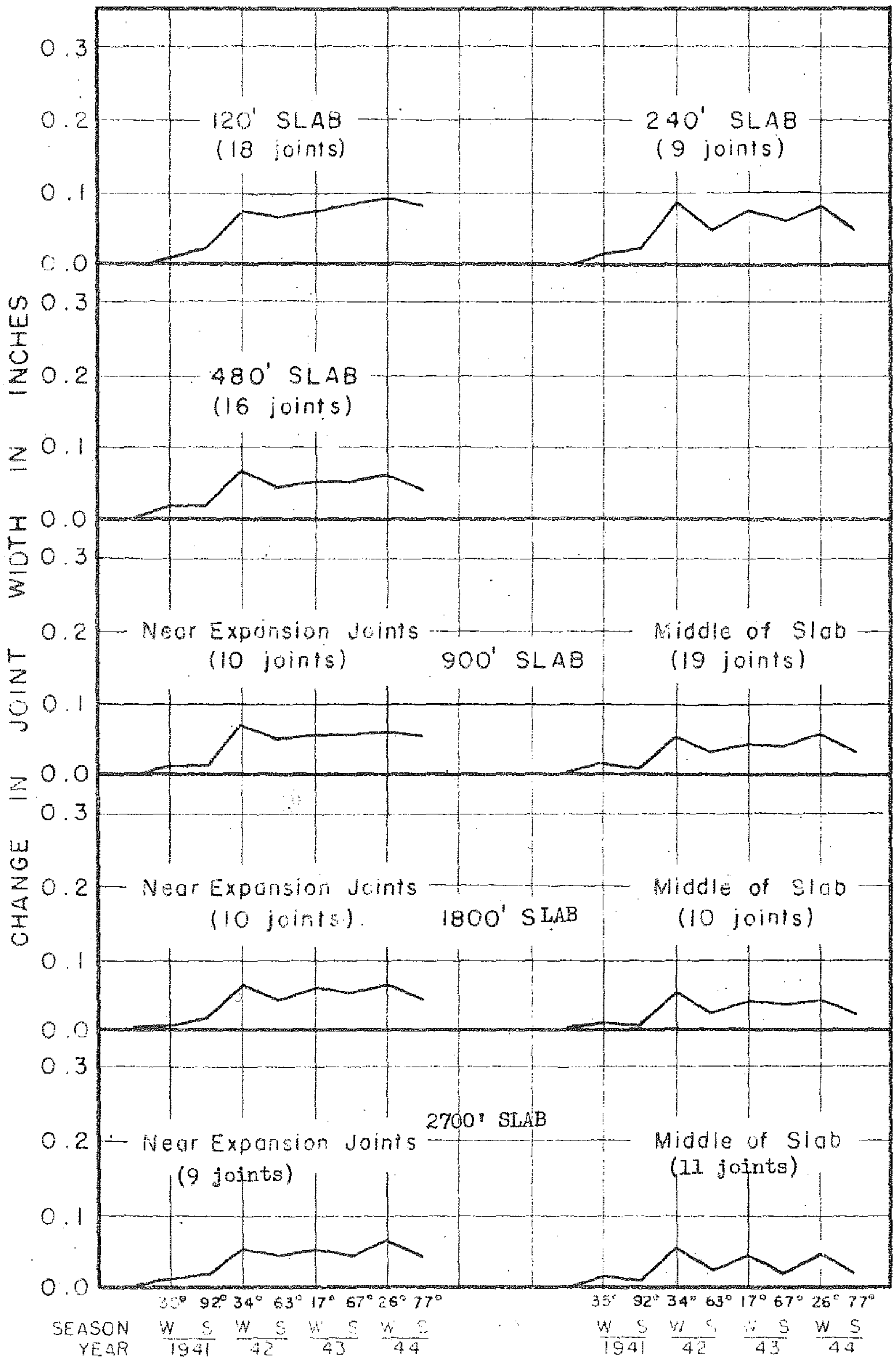


Figure 9

In order to illustrate more clearly the general relative change in widths of the joints in their respective sections, the maximum and minimum joint width values have been summarized into representative composite graphs which depict quite accurately the behavior of the contraction joints with respect to their spacing and length of section in which they are located. The following significant facts are disclosed by the graphs in figures 6,7,8 and 9; first, that the movement of the 60 foot contraction joints is approximately 5 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; fifth, all contraction joints experience a gradual progressive opening with time.

Average maximum and minimum contraction joint width values in relation to section length and distance between contraction joints are summarized further in figure 10. By means of the bar graphs in figure 10 the various facts previously discussed are clearly illustrated.

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 locations throughout series 1 and 2 to study the effect of the reinforcement upon joint behavior. Composite graphs showing the width changes of these joints are presented in figure 11.

AVERAGE SEASONAL CONTRACTION JOINT MOVEMENT RELATIONSHIP BETWEEN SEASONAL CHANGES IN JOINT WIDTH AND SPACING BETWEEN JOINTS

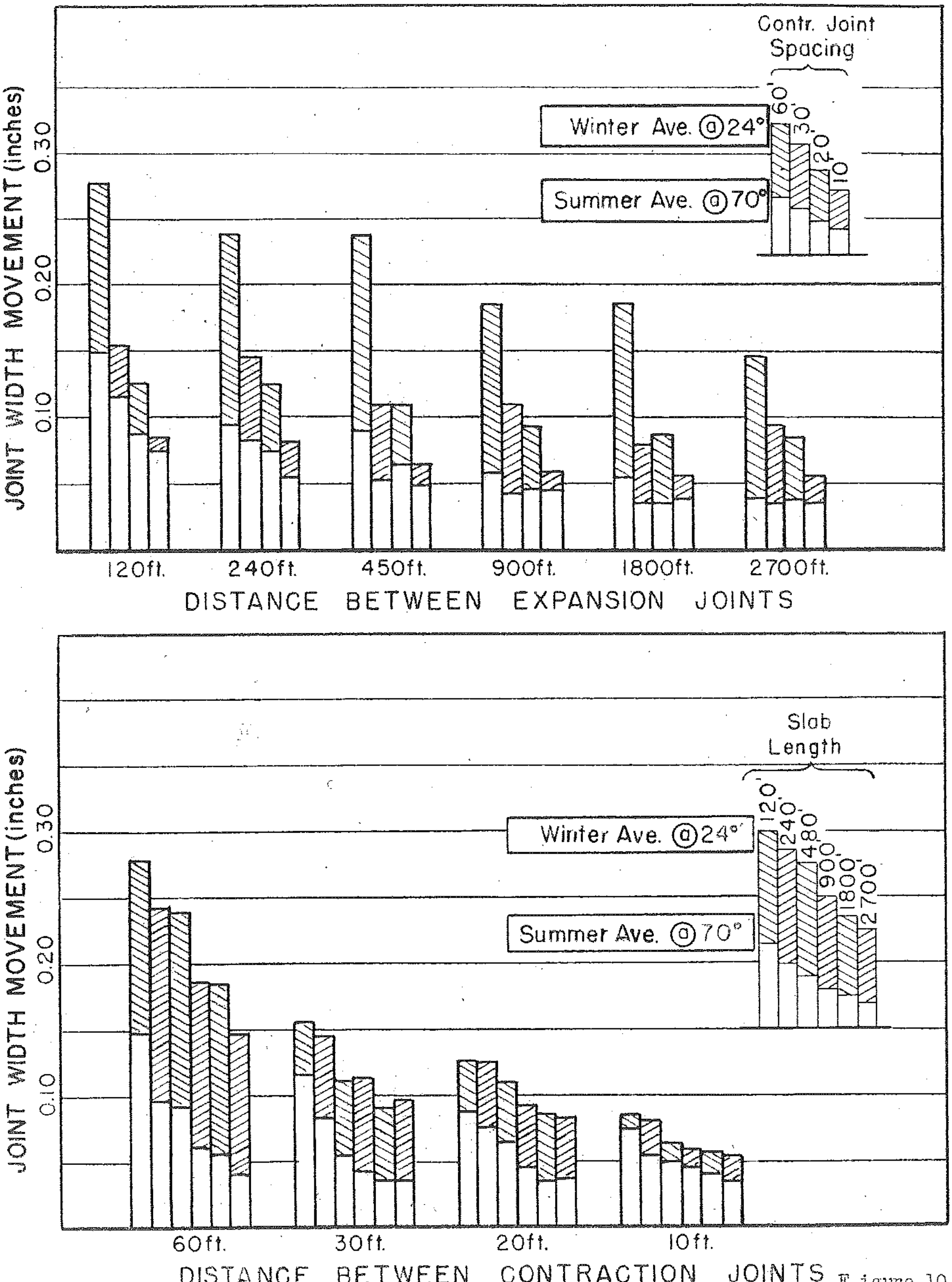


Figure 10

COMPOSITE SEASONAL DUMMY JOINT MOVEMENT RELATIONSHIP BETWEEN SEASONAL CHANGES IN JOINT WIDTH AND LENGTH OF SECTION

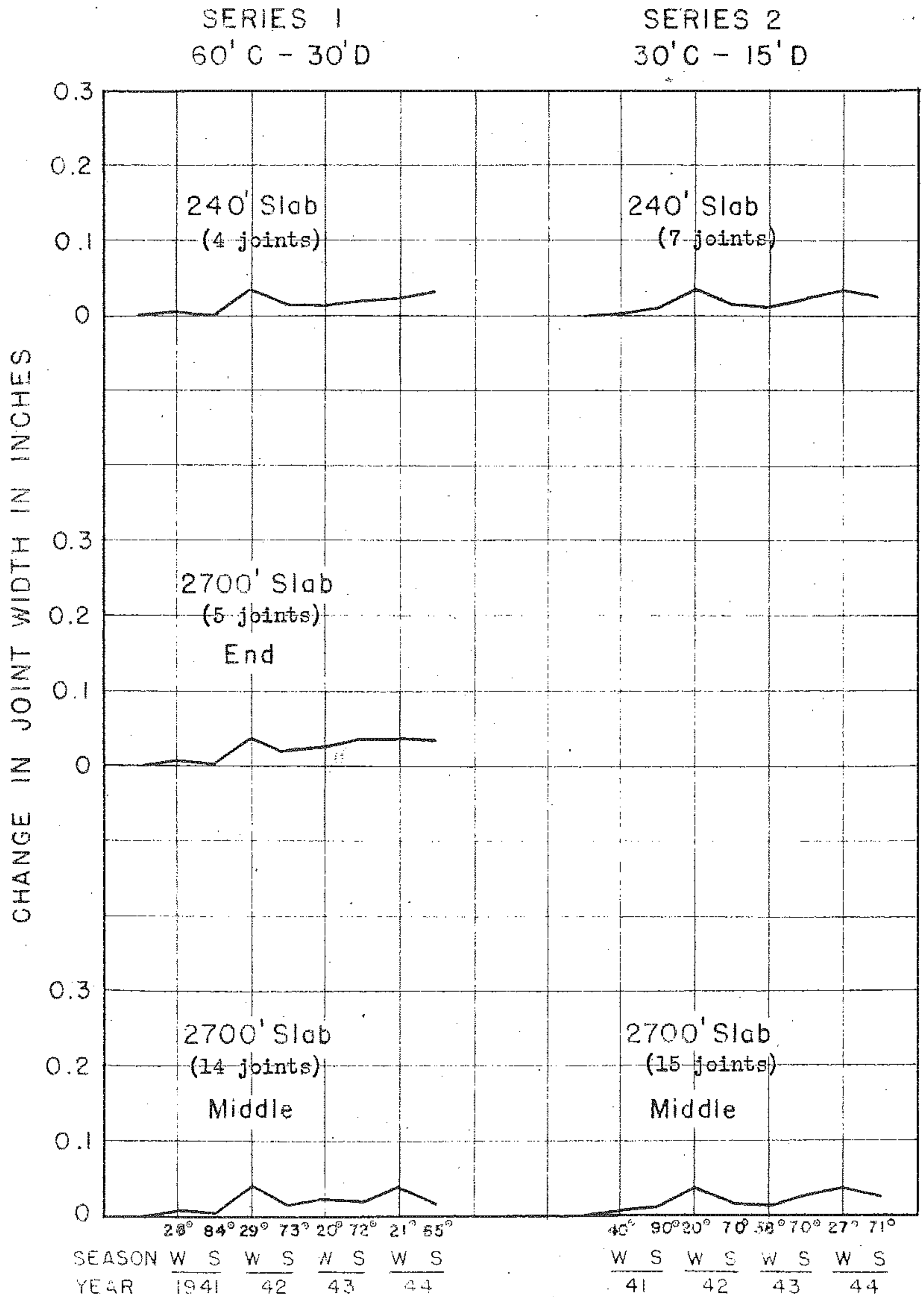


Figure 11

The graphs show that the maximum opening of joints in the longer sections is less than 0.05 inches, approaching 0.1 inch in the short sections. 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, progressive and permanent displacement with time.

Daily Changes in Joint Widths:

The average daily changes in expansion joint widths for series 1, 2, 3 and 4 are presented in figure 12. The relationships for the daily 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 contraction joints. The graphs in figure 12 disclose that the expansion joints of the short sections have a greater reaction to daily temperature changes than those of the long sections. Also that the sections with the 80 foot contraction joints have considerably more daily movement than the sections with the 10 foot contraction joints. As a matter of interest daily temperature limits upon which the individual averages were based are also given in the graph.

Further information concerning the daily movement of the slabs was obtained by a special study in which the movement of the joints and slabs in selected series 3, 1A, 1F and 2F were observed continuously for a 24 hour period. Curves indicating the movements which took place during this period are shown in figures 13 and 14. The temperature curve in the graph represents the mean temperature of the concrete slab.

It may be noted from the curves in figure 13 that all the joints responded in the same manner to the temperature change throughout the 24 hour period.

AVERAGE DAILY CHANGE IN EXPANSION JOINT WIDTH PER DEGREE FAHRENHEIT

RELATION BETWEEN JOINT WIDTH MOVEMENT AND LENGTH OF SECTION

JULY, 1942

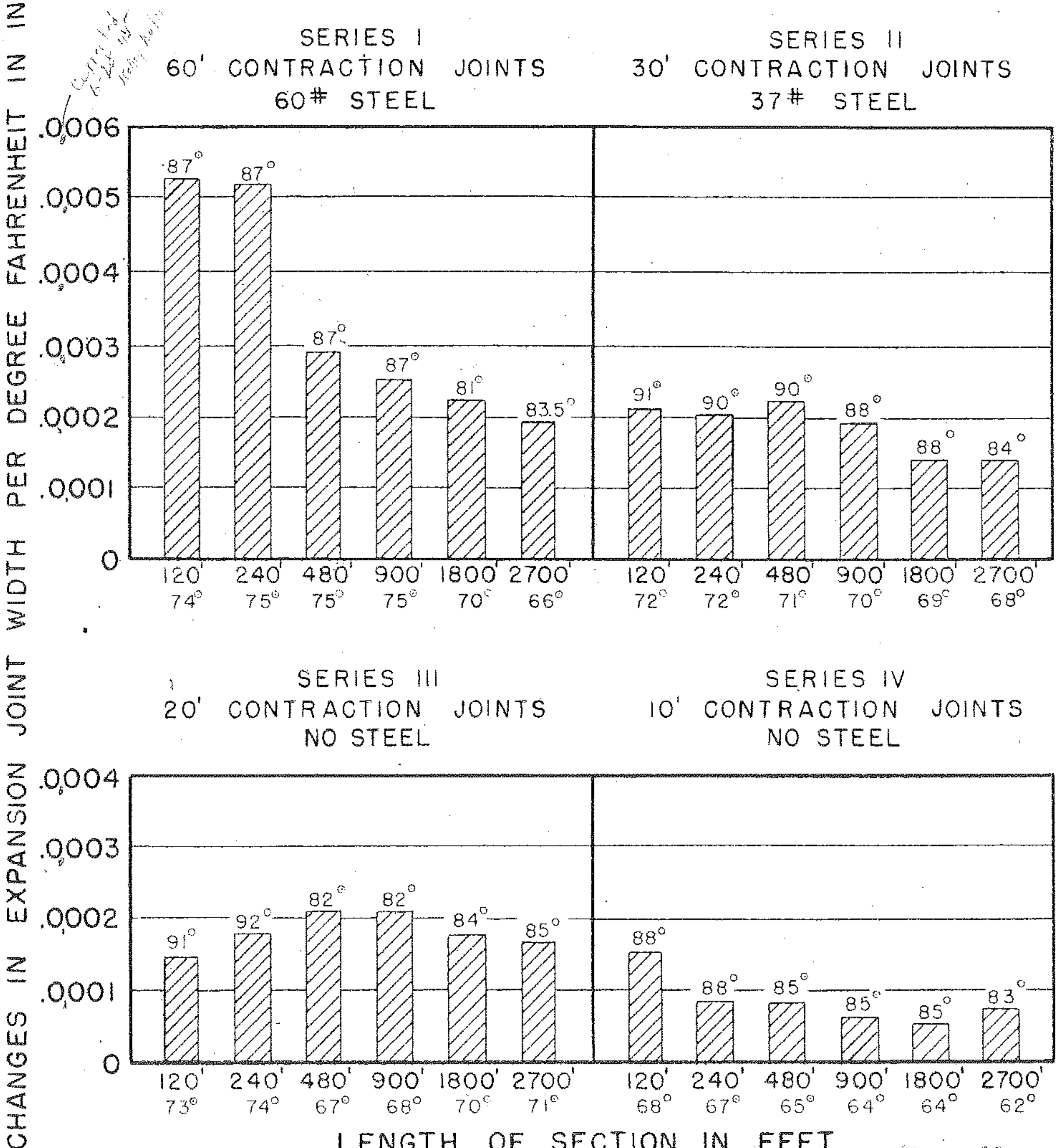


Figure 12

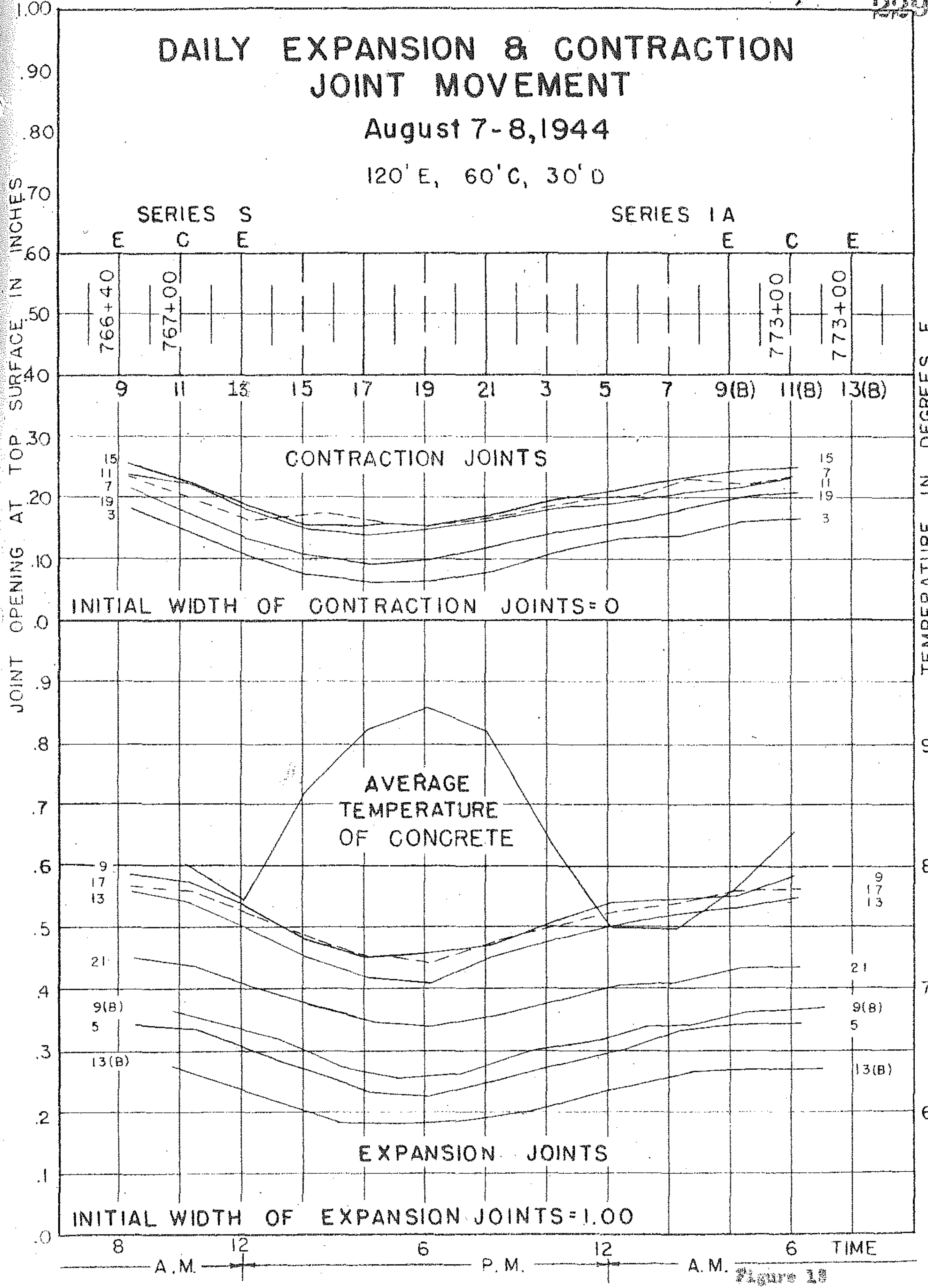

DAILY EXPANSION & CONTRACTION JOINT MOVEMENT
August 7-8, 1944
120' E, 60' C, 30' D
SERIES S
SERIES IA
E C E
766+40
767+00
773+00
773+00
9 11 13 15 17 19 21 3 5 7 9(B) 11(B) 13(B)
CONTRACTION JOINTS
INITIAL WIDTH OF CONTRACTION JOINTS = 0
AVERAGE TEMPERATURE OF CONCRETE
EXPANSION JOINTS
INITIAL WIDTH OF EXPANSION JOINTS = 1.00
JOINT OPENING AT TOP SURFACE IN INCHES
TEMPERATURE IN DEGREES F.
8 12 6 12 6 TIME
A.M. P.M. A.M.

Figure 18

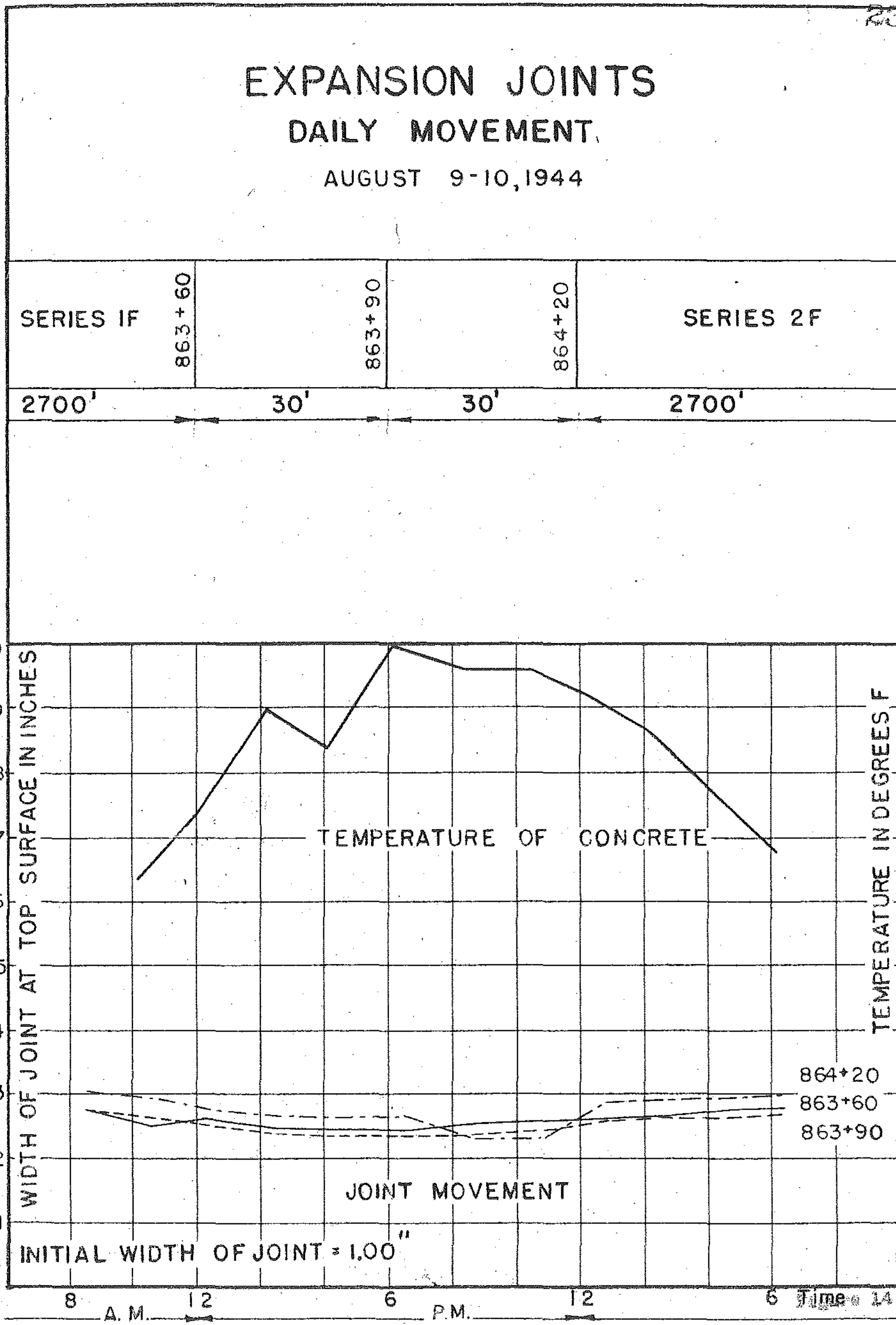

EXPANSION JOINTS
DAILY MOVEMENT
AUGUST 9-10, 1944
SERIES 1F
863+60
863+90
864+20
SERIES 2F
2700'
30'
30'
2700'
WIDTH OF JOINT AT TOP SURFACE IN INCHES
TEMPERATURE IN DEGREES F
1.00
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
90
80
70
60
TEMPERATURE OF CONCRETE
864+20
863+60
863+90
JOINT MOVEMENT
INITIAL WIDTH OF JOINT = 1.00"
8
12
6
12
6
A. M.
P.M.

Figure 14

The maximum average expansion joint change in width for the 24 hour period and for a mean slab temperature variation of 27 degrees Fahrenheit was observed to be 0.12 inches or the equivalent of 0.0044 inches per degree Fahrenheit. It is of interest to note that during this study the maximum slab movement occurred at approximately 6:00 P. M. Eastern War Time and not at 1:00 to 3:00 P. M. as might be expected.

With respect to the behavior of contraction joints under similar field conditions, it may also be observed in figure 13 that the average opening of the contraction joints was 0.103 inches or the equivalent of 0.0039 inches per degree Fahrenheit.

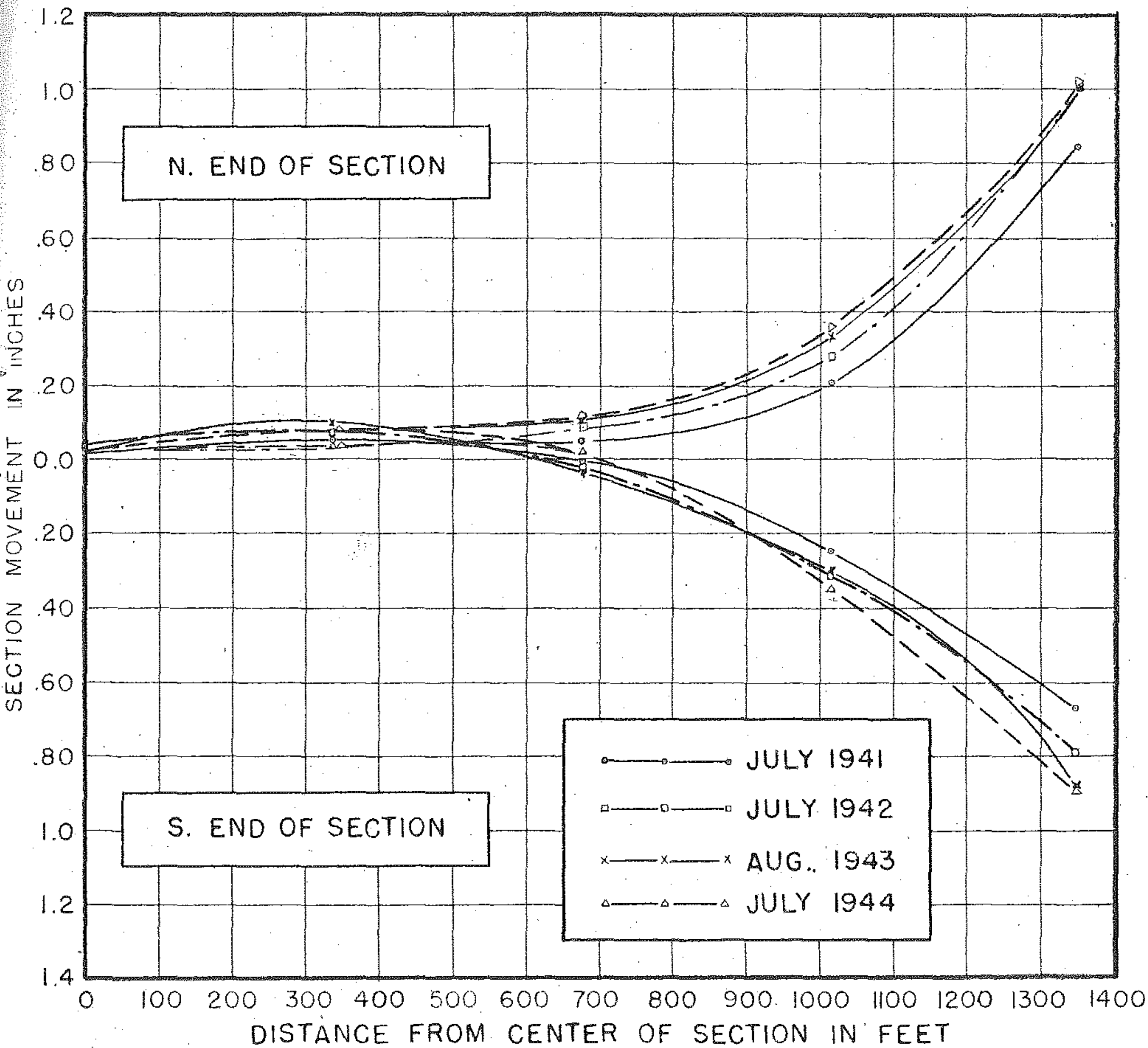
Similar observations were made on the expansion joints at the ends of the 2700 foot sections designated series 1F and 2F. From figure 14 it is evident that the daily expansion joint width variations in this case were much less than those observed in the 120 foot sections. For a mean slab temperature change of 17 degrees the maximum movement of the joint was 0.043 or the equivalent of 0.0025 inches per degree Fahrenheit.

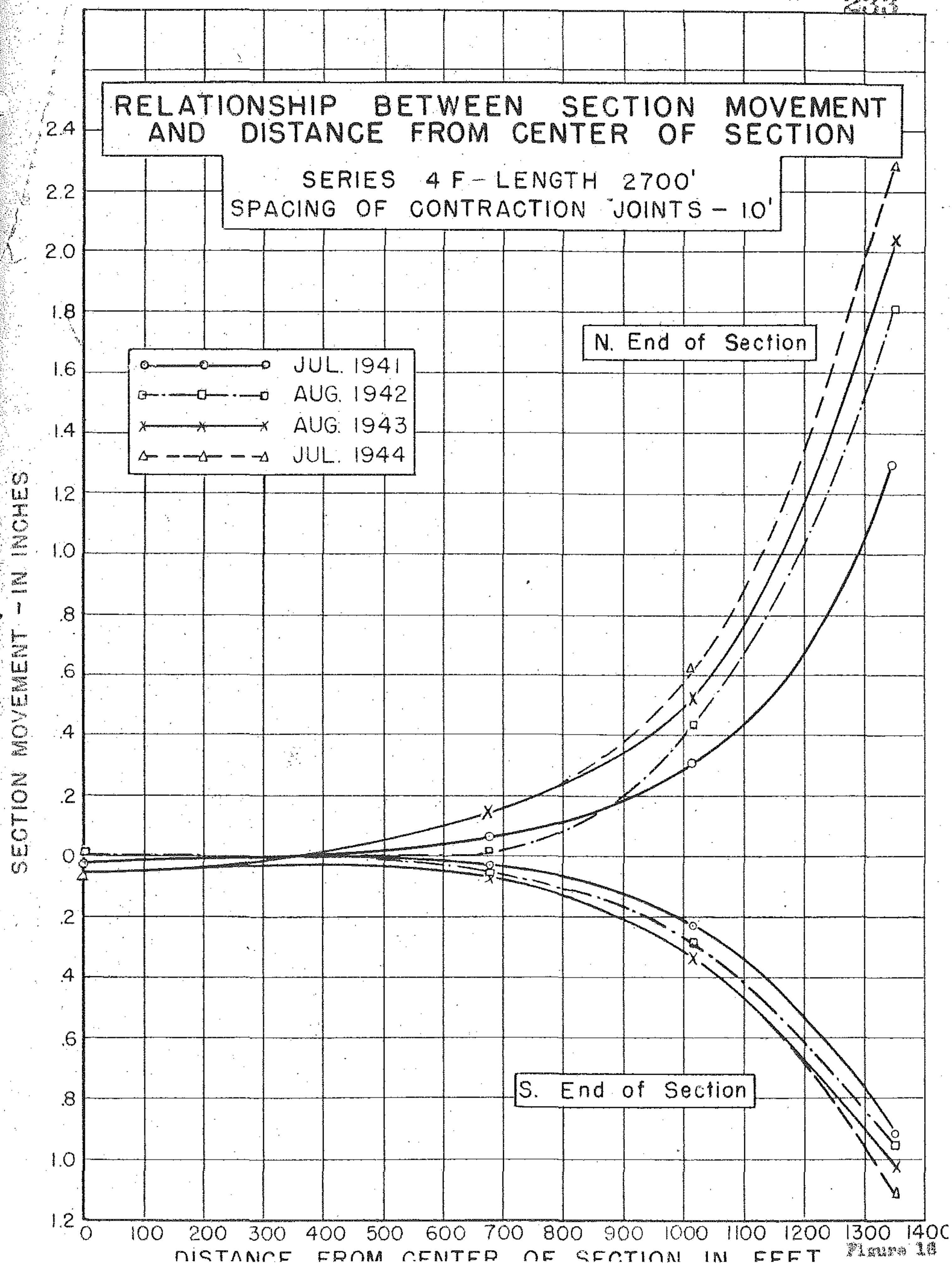
Pavement Movements.

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 series 1A, 1F and 4F. The curves in figures 15, 16 and 17 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. The graphs

RELATIONSHIP BETWEEN SECTION MOVEMENT AND DISTANCE FROM CENTER OF SECTION

SERIES I-F – LENGTH 2700'
SPACING OF CONTRACTION JOINTS 60'





RELATIONSHIP BETWEEN SECTION MOVEMENT AND DISTANCE FROM CENTER OF SECTION
SERIES 4 F – LENGTH 2700'
SPACING OF CONTRACTION JOINTS – 10'
JUL. 1941
AUG. 1942
AUG. 1943
JUL. 1944
N. End of Section
S. End of Section
SECTION MOVEMENT – IN INCHES
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
.2
.4
.6
.8
1.0
1.2
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
DISTANCE FROM CENTER OF SECTION IN FEET

Figure 18

RELATIONSHIP BETWEEN SECTION MOVEMENT AND DISTANCE FROM CENTER OF SECTION SERIES IA-LENGTH 120'

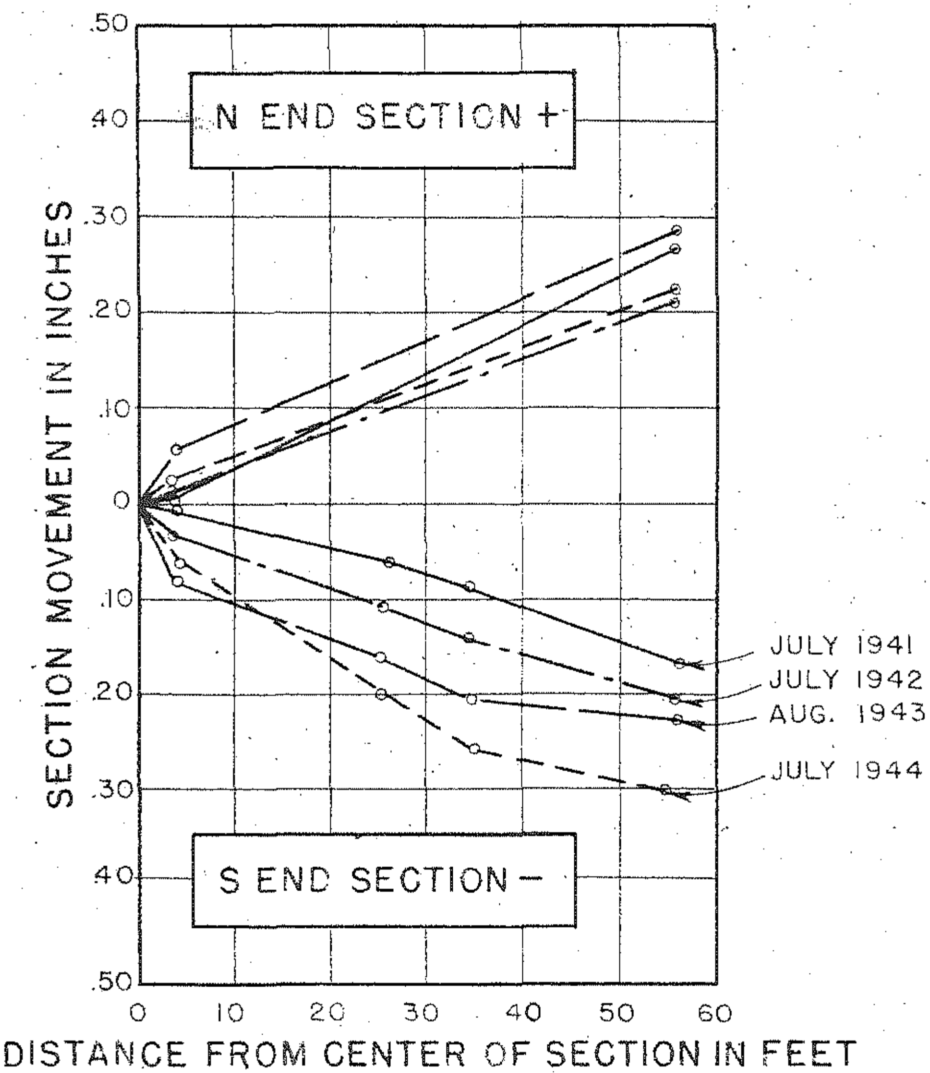


Figure 17

in figures 15 and 16 show that this point of zero longitudinal movement is approximately between 700 and 900 feet from the ends of the section. Thus there exists in the central part of the 2700 foot sections in series 1, 2, 3 and 4, portions of pavement approximately 1000 feet long which, at elevated temperatures are under restraint similar to that of a continuous slab without expansion joints. Therefore, in the case of sections whose lengths are less than 1800 feet, it may be expected that every point in each half of the section will display some movement with respect to the center of the section. For short sections, such as illustrated in figure 17 the movement of any point in either half of the section is approximately proportional to its distance from the center of the section.

It may be noted further that movements of the ends of each section are quite similar in character. In some instances certain inherent construction features such as horizontal or vertical alignment, soil conditions and bridge structures no doubt influence the relative movement of the entire section, resulting in a general movement of the whole section to the right or left and causing the point of zero movement to occur on either side of the geometric center of the section.

<u>Summary:</u>

The study of expansion and contraction joint movement has brought out several interesting and significant facts concerning slab behavior under varying expansion and contraction joint spacing. <u>First</u>, the seasonal movements of the expansion joints indicate that there takes place during the first year after construction a considerable expansion and subsequent permanent displacement of the slab ends, using at least 50% of the space originally provided. <u>Second</u>, subsequent to the first year's movement the section ends oscillate with seasonal temperature changes, the amplitude of these seasonal movements gradually diminishes with time, and a slow, progressive permanent displacement takes place. Eventually the joint filler may become compressed to the state that no further longitudinal movement can occur. Third, contraction joint spacing has considerable influence upon the amplitude of expansion joint movement. Fourth, all contraction joints acquire a small permanent opening which increases with time. The degree of joint movement and amount of residual opening is more pronounced as the distance between contraction joints is increased. Fifth, the movement of contraction joints is greater near the expansion joints than it is near the center of the sections. Sixth, dummy joints react similarily to contraction joints but to a much smaller degree. Seventh, in sections of pavement greater than 1800 feet in length without expansion joints, there is a point of zero longitudinal movement approximately 700 to 800 feet from the ends of the section. Consequently, the central portion of such sections at elevated temperatures will be under restraint similar to that of continuous slabs in which no expansion joints have been provided.

In addition to the joint spacing study previously discussed, other features highly important to concrete pavement design and construction were given consideration in the design project. These features will be described briefly in the following text under general condition of the pavement.

GENERAL CONDITION OF THE PAVEMENT

The several features included for study in the design project in conjunction with the joint spacing study are; joint design, thickened edge versus uniform thickness slab design, plain versus reinforced pavement, and stress cured concrete. Evaluation of these features will be based upon the behavior of the respective concrete slabs under the service conditions, taking into account performance, physical irregularities and vertical alignment.

Design of Transverse Joints:

The design of transverse joints necessitates consideration of structural features which enable the joint to best perform the function for which it was intended: provision for movement due to expansion or contraction, load transfer where necessary, flexibility under warping stresses and adequate seal against infiltration of water and foreign matter.

Provision for Expansion and Contraction: At the present time nothing has developed in the pavement structure or its movement which would indicate that any of the various types of expansion joints are not behaving in a normal manner. Joint movement data show that the seasonal amplitudes of width movement for all types of joints are comparable. The air chamber expansion joints located in series 5 have developed a greater permanent displacement than joints in other series constructed with the premolded fiber filler.

Load Transfer: All expansion joints with load transfer seem to be functioning normally with the exception of the dowel bar installations in series 10, divisions A and B. In the summer of 1944 a survey was made to

TABLE IX

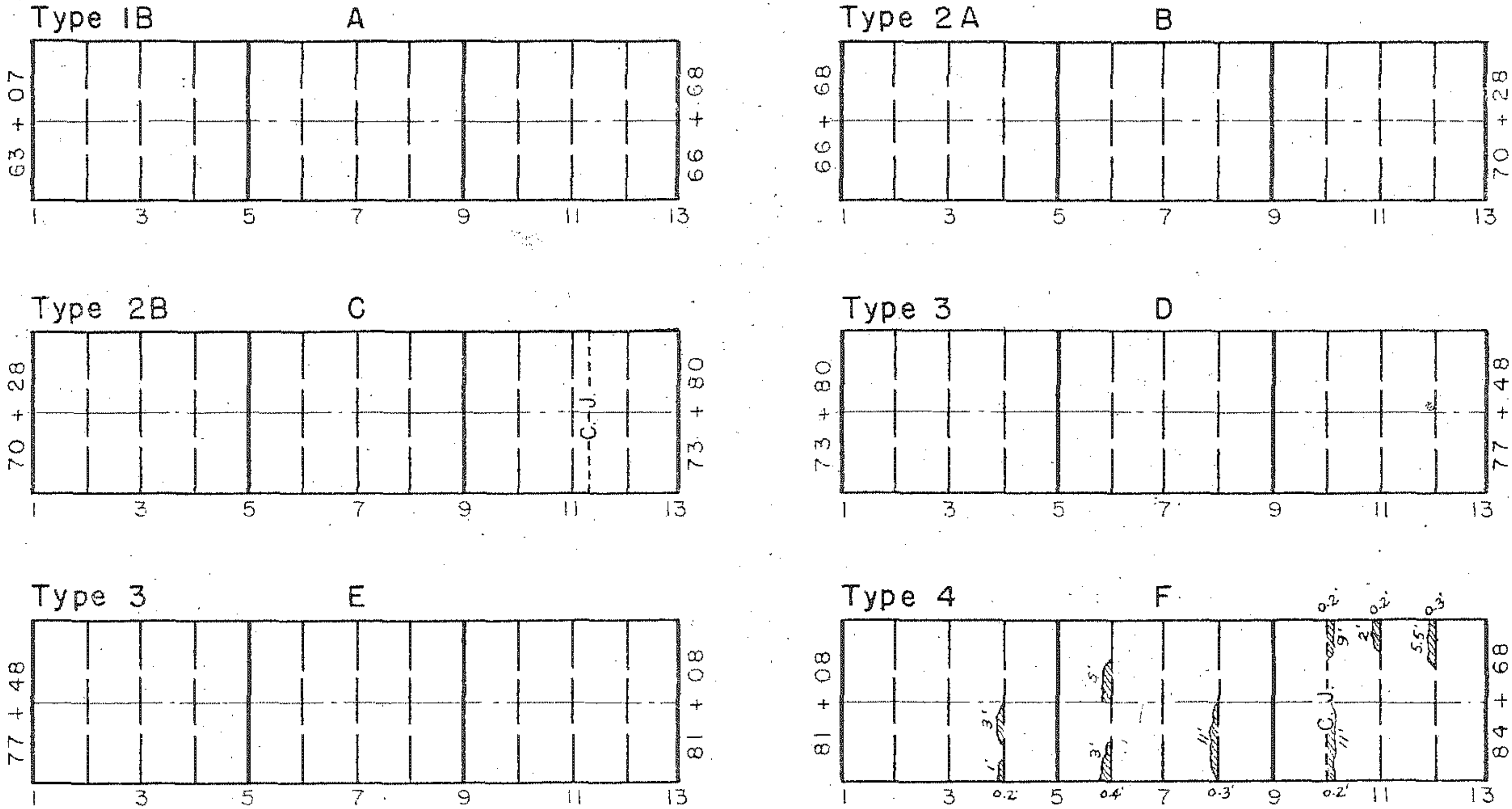
SUMMARY OF DATA ON JOINT FAULTING IN SERIES 10

EXPANSION JOINTS

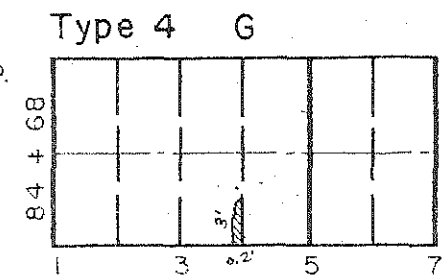
	Faulting Joints							Joints Faulted	Total No. Joints	Percent of Total Faulted
	1/8 Inch		3/16 Inch		1/4 Inch		Over			
Series	No.	%	No.	%	No.	%	1/4 Inch			
10A-1	2	10	0	0	0	0	0	2	20	10
10A-2	0	0	0	0	0	0	0	0	18	0
10B-1	5	28	5	28	0	0	0	10	18	56
10B-2	5	28	4	22	5	28	0	14	18	78
CONTRACTION JOINTS										
10A-1	8	9	1	1	0	0	0	9	90	10
10A-2	8	6	0	0	0	0	0	8	126	6
10B-1	34	38	2	2	0	0	0	36	90	40
10B-2	25	20	5	4	2	2	0	32	124	26

CONTRACTION JOINT DESIGN SERIES 5

120' E - 30' C - 9" - 7" - 9" - 37 lbs Reinforcement



Type 1B - Dowel Bars with Grooved Joint.
Type 2A - Dowel Bars with Premolded Filler.
Type 2B - Dowel Bars - Grooved Joint, Parting Strip.
Type 3 - Dowel Bars - Grooved Joint, Metal Dividing Plate.
Type 4 - Continuous Plate Dowel - Grooved Joint.
Expansion Joints, Dowel Bars, No Filler.
Sealed Top and Bottom with Asphalt - Latex.



——— Expansion Joint
— — — — Contraction Joint
----C J----- Construction Joint

Figure 18

determine the extent of faulting which was observed to be taking place in this particular section of the test road. A summary of the joint faulting data is presented in table IX.

The data indicate that 5 percent of the expansion joints with dowel bars in series 10A had faulted 1/8 inch or more, whereas in series 10B the expansion joints without dowel bars had faulted to the extent of 67 percent. Considering the contraction joints in series 10, it may be seen from table IX that 8 percent of all contraction joints in series 10A, with dowel bars, had faulted 1/8 inch or more, as compared to series 10B, without dowel bars, where 52 percent of all contracted joints had faulted. It is believed that abnormal volume changes in the subgrade are responsible for the extensive faulting in this section of the test road. Level measurements and soil surveys indicate that the subgrade is responsible for the faulting.

Another unusual type of joint failure has appeared in series 5 which is characterized by excessive spalling along the joint edge. Type 4, a continuous plate dowel contraction joint unit which was installed in series 5, sections F and G, has evidently an inherent design weakness which causes spalling adjacent to the joint edge. The extent and characteristics of the spalling which has developed so far are shown in figure 18.

<u>Contraction Joint Construction:</u> In forming the weakened plane section for contraction joints two methods were employed, the groove joint and the insertion of a premolded fiber strip. After four years of service, the concrete adjacent to the grooved joints is in excellent shape. The bituminous seal material in the grooved joint has provided a perfect seal and the joint edges have remained sound, no spalling or disintegration of the concrete having occurred. Where the premolded fiber strip was installed, considerable

spalling has occurred. The most serious type of spalling at contraction joint edges is caused by the tipping of the premolded fiber strip during placing or by subsequent finishing operations. A typical failure of this type is shown in figure 19.

Another common fault of the premolded strip is that it does not provide adequate seal at the joint, especially during the winter time when the contraction joint is at its maximum opening. This fault is naturally more serious in sections with 60 foot contraction joint spacing than it would be in the sections with 10 foot spacing. See figure 20.

Expansion Joint Seal Material: Various types of bituminous joint sealing compounds were used in the design project for comparative study in conjunction with joint design. These materials include: asphalt-latex, thermoplastic compound, premolded rubber and standard SOA asphaltic material. After four years of service, the asphalt rubber compounds such as asphalt-latex and thermoplastic are still in excellent state of preservation and giving satisfactory performance. They have weathered slightly on the surface and have become considerably more inspissated with age. However, they still retain a major portion of their original cohesive and adhesive properties. See figure 21.

It was necessary to replace the premolded rubber joint seal after two years, and the SOA material after one year.

Pavement Cross Sections:

The cross sections set up for comparative study include the 9"-7"-9", its approximate equivalent 8 inch uniform; the 8"-6"-8" and its approximate equivalent 7 inch uniform. The sections of the design project devoted to this study are series 3A, series 6, series 7, and series 8 respectively.

In general nothing has developed thus far in any of the series involved, from which conclusive comparative data can be derived. The joints and respective slabs in all sections have, after four years, shown no marked difference in their relative behavior under normal service conditions. However, in a portion of series 6 considerable cracking has gradually developed. This cracking is known to be caused by undesirable subgrade conditions. The extent of cracking is shown in figure 22.

Steel Reinforcement:

Consideration was given to the problem of designing pavements with and without steel reinforcement. To this end different sections of the design project were constructed with 80, 37 and 0 pounds of steel reinforcement per 100 square feet of pavement. The problem of reinforcement was also considered in connection with contraction and dummy joint construction as well as in the construction of continuous slabs of varying lengths without intermediate contraction or dummy joints.

With the exception of a few areas of concrete pavement which are being abnormally stressed because of existing subgrade conditions, the pavement throughout the design project is in excellent structural condition. Therefore, at this time no conclusive evidence based on performance is available for judging the relative merits of the various sections constructed with and without steel reinforcement.

Stress Cured Concrete:

In series 9A, eighteen hundred feet of concrete pavement was constructed employing the stress curing method. The slab lengths are 100 feet. The concrete was subjected to controlled compressive forces during the seven day curing

8" UNIFORM CROSS SECTION SERIES 6

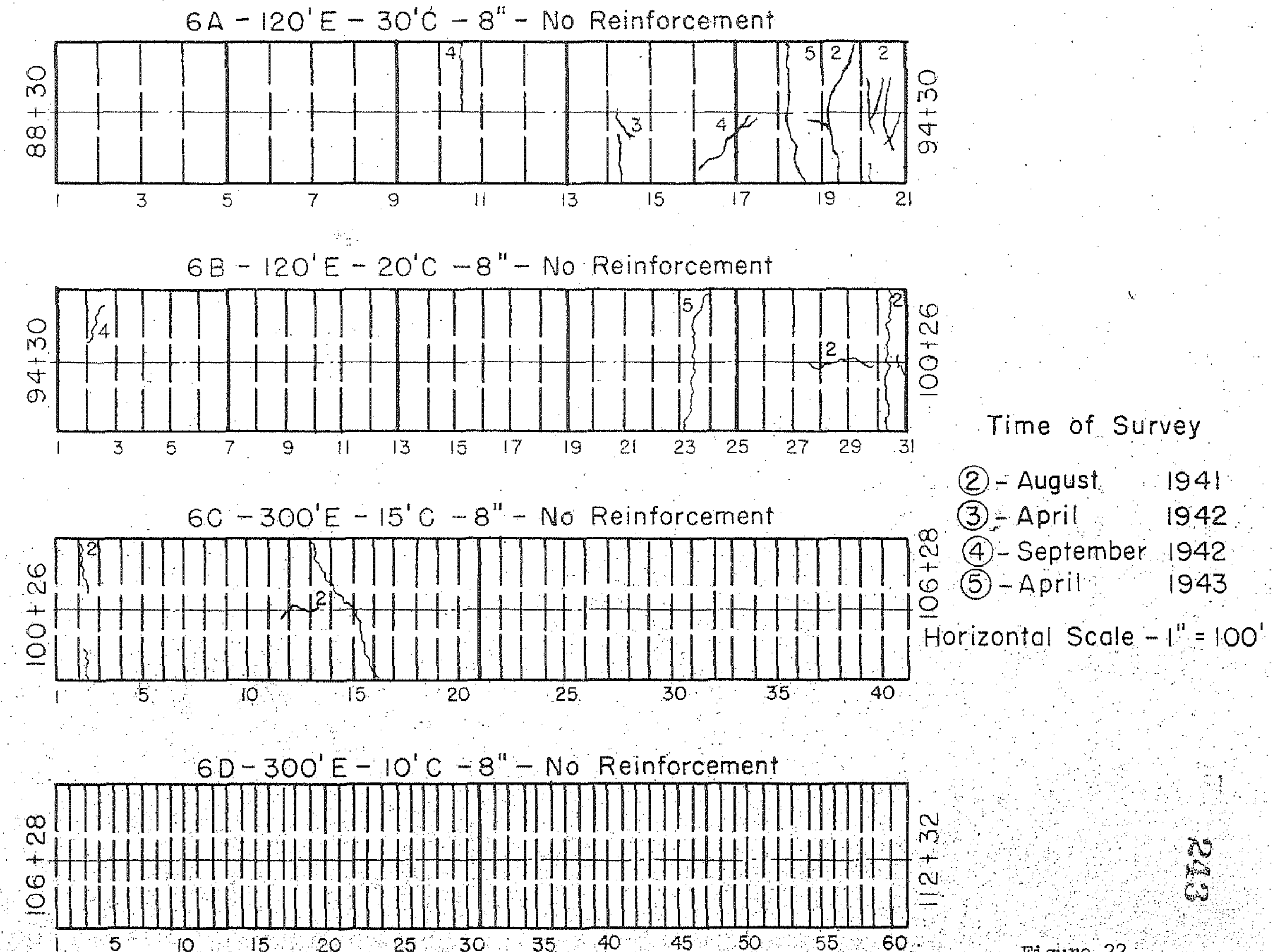


Figure 22

period, or until such time as the flexural strengths reached the 7 day specification requirement of 550 pounds per square inch. The application of pressure was accomplished by using canvas covered hose pressure cells inserted in the expansion joint openings. The pressures were increased at a rate controlled by determinations of strength increase in test specimens up to a maximum of 200 pounds per square inch.

At the end of four years, 14 of the 18 slabs are apparently in perfect condition. The remaining 4 slabs have cracked as shown in figure 23. The progressive development of cracks in this section is also shown in figure 23.

A careful survey of the subgrade under the cracked slabs has proved definitely that the cracking in all four slabs was caused by subgrade volume changes and not by any weakness in the slab structure or method of construction.

Pavement Roughness:

In September 1941 a series of pavement surface roughness tests was conducted on the entire test road by the Public Roads Administration, using that organization's specially designed machine constructed to record the number of surface irregularties in a definite distance. The study was made primarily to compare the riding qualities of the pavement, especially in those sections having varied expansion and contraction joint spacing.

The roughness factor for the entire project ranges from 73 to 101 units per mile, which is indicative of good workmanship and excellent riding qualities. See table X. The data indicate that no distinguishable difference exists in the riding qualities of the pavement with 10 foot contraction joints as compared to pavement with 60 foot contraction joints.

TABLE X

ROAD ROUGHNESS DATA

Units Per Mile

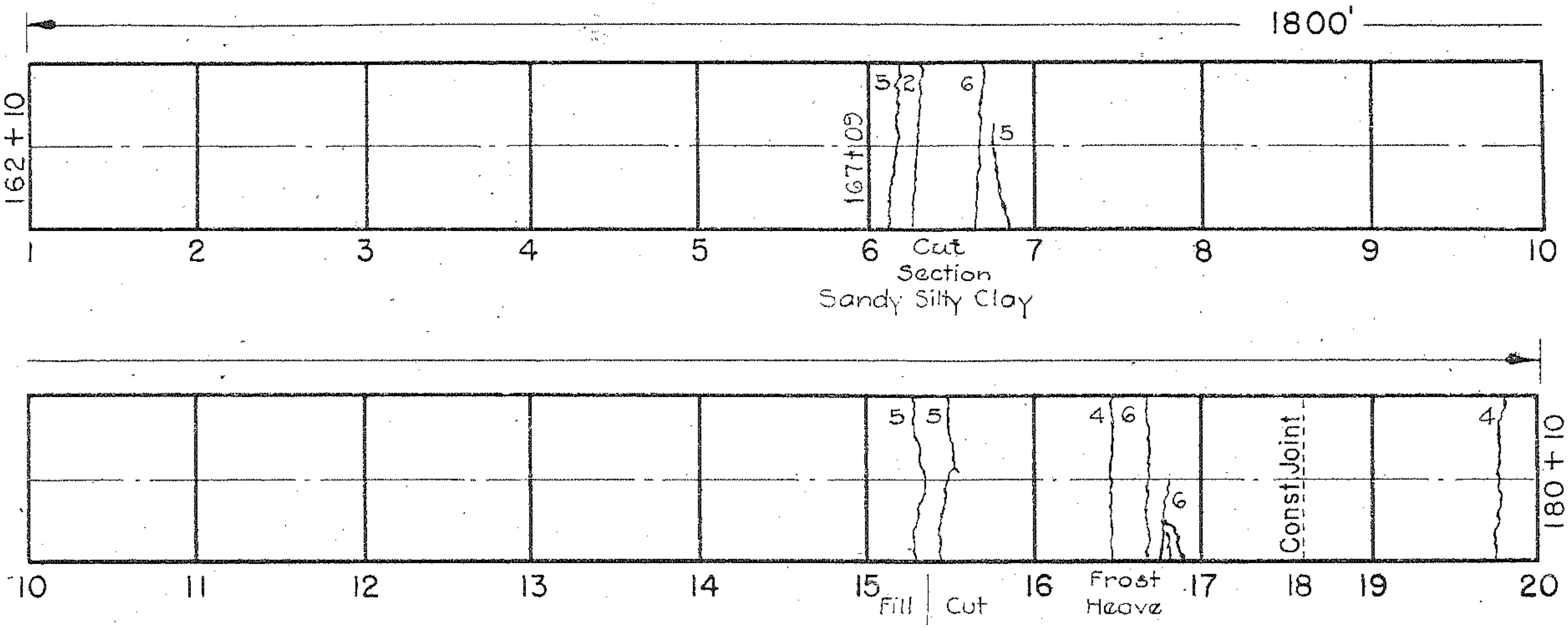
DIVISION	SERIES NUMBER											
	1	2	3	4	5	6	7	8	9	10	11	12
A	93	83	73	88	86	87	91	81	80	(A1) 85	89	93
B	83	84	83	77	73	91	82	88		(A2) 81	89	96
C	83	82	81	77	100	85	85			(B1) 90	80	93
D	83	79	80	85	82	91	85	88		(B2) 101	89	96
E	79	81	80	79	83							96
F	77	80	78	82	83							
G					78							

STRESS CURED CONCRETE

Series 9

9"-7"-9" – 100' Expansion Joints, No Contraction or Dummy Joints

No Reinforcement



TIME OF SURVEY

2 – AUGUST 1941

4 – SEPTEMBER 1942

5 – APRIL 1943

6 – SEPTEMBER 1943

Horizontal Scale 1" = 100'

Figure 23

Pavement Cracking:

In the entire portion of the project devoted to the study of joint spacing which consists of series 1, 2, 3 and 4 there have appeared only two transverse cracks. In series 1 a crack was noted at Station 831+80 in September 1943. In series 3 at Station 1000+70 a corner crack was observed in June 1941. Series 8 has one transverse crack located at Station 133+80 which was first noted in April 1943. Series 10 has two cracks, one complete transverse crack at Station 213+80, first noted in September 1942, and the other a half transverse crack at Station 219+75 which first was noticed in April 1943. No cracks have appeared in series 2, 4, 5, or 7. Cracks which have occurred in the remaining series 6, 9, 11 and 12, have been discussed previously in the report.

Changes in Elevation:

During the four year period three sets of precise elevation measurements have been made over the entire length of the experimental pavement. One set of readings representing pavement behavior under winter conditions consists of measurements taken in 1941 and 1942. A second complete set of level measurements was made in August 1941 and a third in July 1944.

All elevations are compared to the base readings which were established soon after the construction of the project in 1940. The data show that the majority of the pavement throughout the test road has not varied more than ± 1/4 inch from the base readings established in 1940. In localized areas considerable changes in elevation occurred only during the winter season, evidently caused by heaving. Such heaving caused changes in elevations as much as 1.85 inches although the majority of the elevation changes in this respect were less than 1.0 inch. Some permanent settlement has occurred, ranging from 0.25 to 1.8 inches. Settlement values of 0.4 to 0.8 inches are most common. In some cases the pavement has raised permanently approximately 0.2 to 0.4 inches with respect to base elevations.

CONCLUSIONS

In the course of this progress report certain data obtained during the four year life of the project have been presented and discussed. The investigation has furnished information on the behavior of concrete pavements under service conditions which will be of value in their design and construction. The most important conclusions are reviewed as follows:

1. Concrete pavements undergo their greatest movement during the first year after construction. The magnitude of this initial movement and the subsequent permanent displacement which is produced thereby are sufficient to deplete at least 80 percent of the expansion space provided. The amplitude of the following annual movements is comparatively small, gradually diminishing with time in conjunction with the progressively increasing permanent displacement which takes place during succeeding years.

2. Contraction joint spacing has a marked effect upon movement of pavement between expansion joints. The annual or seasonal movement of sections with 10 foot slabs is less than sections with 60 foot slabs, but the end movement of sections with 10 foot slabs is much greater than that of those with 60 foot joint spacing.

3. Contraction joints at 60 foot spacing opened approximately 3 times as much as did those at 10 foot spacing. The contraction joints acquire a slight permanent opening with time.

4. Under conditions prevailing on the Michigan Test Road the critical distance from the expansion joint within which movement of the pavement takes place appears to be approximately 700 to 900 feet. Sections of pavement having

a length of 1800 feet or less have a point of zero movement near the center of the section length. Sections longer than approximately 1800 feet have central zones between points 700 to 900 feet from the expansion joints which are held under sufficient restraint to prevent any movement within the zones. Movement increases gradually from no movement at these central zones to maximum movement at the expansion joints.

5. The moisture content of the soil immediately under a concrete pavement slab remains fairly constant throughout the year fluctuating but slightly with seasonal weather conditions. On the design project, the moisture content varied in amounts between five and eight percent.

6. The high moisture content of the subgrade is instrumental in maintaining a near saturation condition in the concrete pavement especially at the bottom. The moisture content of the top portion fluctutes slightly with weather conditions. The moisture content of the concrete does not seem to vary more than approximately one percent between top and bottom.

7. The 3/4 inch dowel bar installations used at the present time for load transfer at expansion and contraction joints are not a guarantee against faulting of slabs at joints.

8. Joint sealing compounds composed of a proper combination of asphalt and rubber materials have proved to be the best type of joint sealer so far developed.

9. The practice of grooving the pavement surface to weaken the slab at contraction joints has several advantages over the method of inserting in the concrete a strip of premolded fiber for the same purpose. The common occurrence of joint edge spalling caused by improper placing of the premolded fiber strip

cannot take place with the grooved joint and also, the grooved joint when properly filled with a bituminous material provides a satisfactory seal both in summer and winter.

10. With but few exceptions, in which frost heave and fill sections are involved, the pavement has not varied in position more than ± 1/4 inch from base elevations established in 1940. The frost heave areas, even though they rise as much as 1.9 inches in some cases, return to base elevation in the summer. Permanent settling has occurred in a few fill sections. At one fill section in particular the pavement has dropped 1.8 inches for a distance of several hundred feet.

11. Time or traffic conditions have not been sufficient so far to cause any material differences in pavement behavior from which one can evaluate all of the various studies included in the investigation.