140

MICHIGAN
STATE HIGHWAY DEPARTMENT
Charles M. Ziegler
State Highway Commissioner

PROGRESS REPORT ON DESIGN PROJECT
MICHIGAN TEST ROAD

By

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INVESTIGATIONAL CONCRETE PAVEMENTS IN MICHIGAN
DESIGN PROJECT - MICHIGAN TEST ROAD

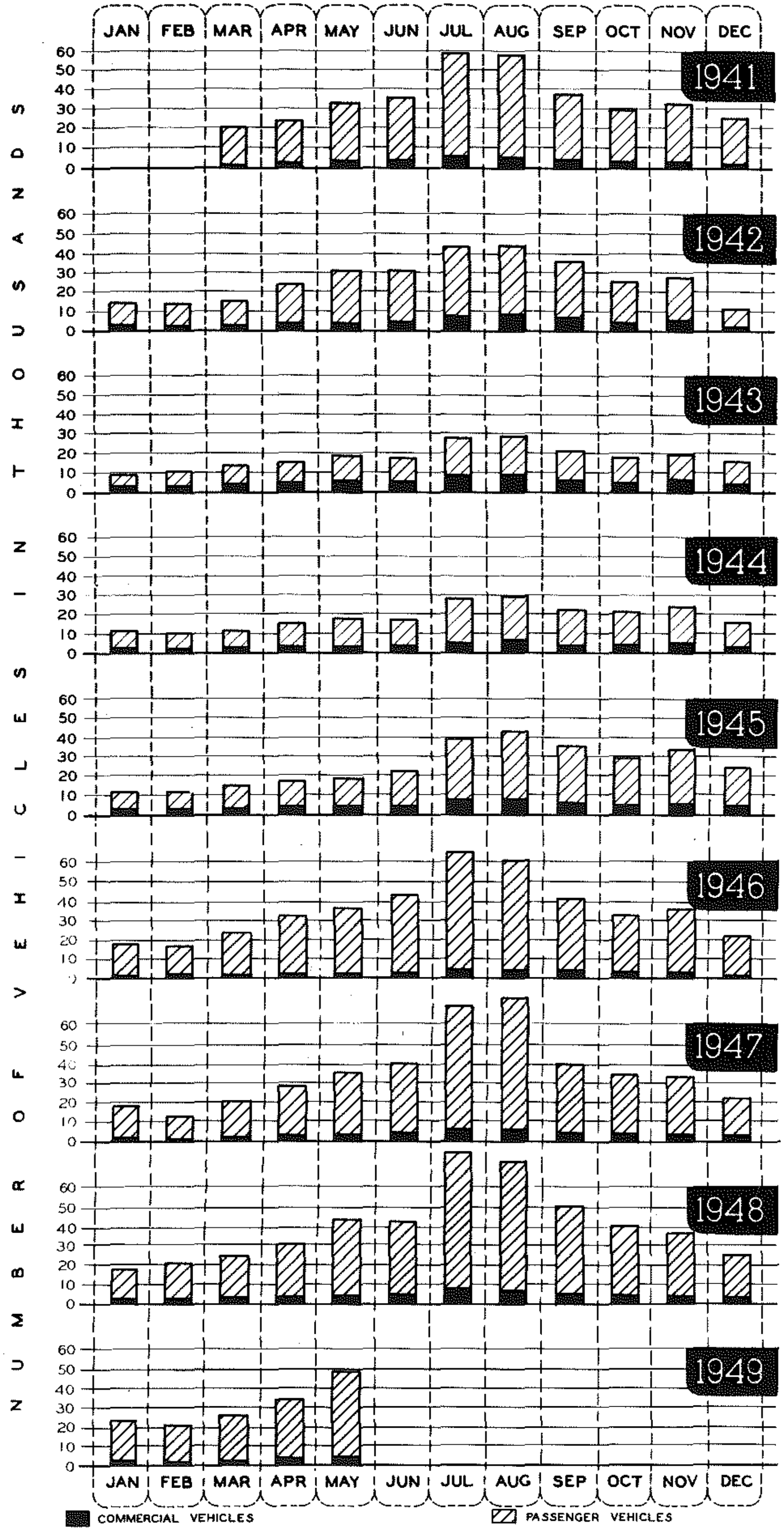
The Michigan Test Road was constructed in 1940 by the Michigan State Highway Department in cooperation with the Federal Bureau of Public Roads. It is one of a group of six such Test Roads built throughout the United States, the others being in California, Kentucky, Minnesota, Missouri, and Oregon. One 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 the various State Highway Departments in 1940, but is more comprehensive in its scope.

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.

This report presents briefly the more important developments and trends that have become evident since the last report in 1945, especially in regard to joint width movement, section movement, and general behavior of the pavement. Since basic information has been thoroughly covered in previous reports, no attempt will be made to repeat such material in this report.

Traffic Characteristics

The amount and character of the traffic on the Test Road for the years 1940 to 1949 is presented graphically in Figure 1. Values representing the percentages of different types of vehicles are given in Table I. Annual



MONTHLY TRAFFIC RECORD

MICHIGAN TEST ROAD

Figure 1

TABLES I AND II

TABLE I

CLASSIFICATION OF ANNUAL AVERAGE DAILY TRAFFIC

Michigan Test Road

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	1.9
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

TABLE II

ANNUAL AVERAGE WHEEL LOAD DISTRIBUTION

Based on Twenty, 6-Hour Samples Combined per Year*
Michigan Test Road, Traffic Station 69

Wheel Load	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)	
	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		594		270		200		214	
Ratio Axles to Vehicles	2.85		2.79		2.65		2.75		1.20		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.

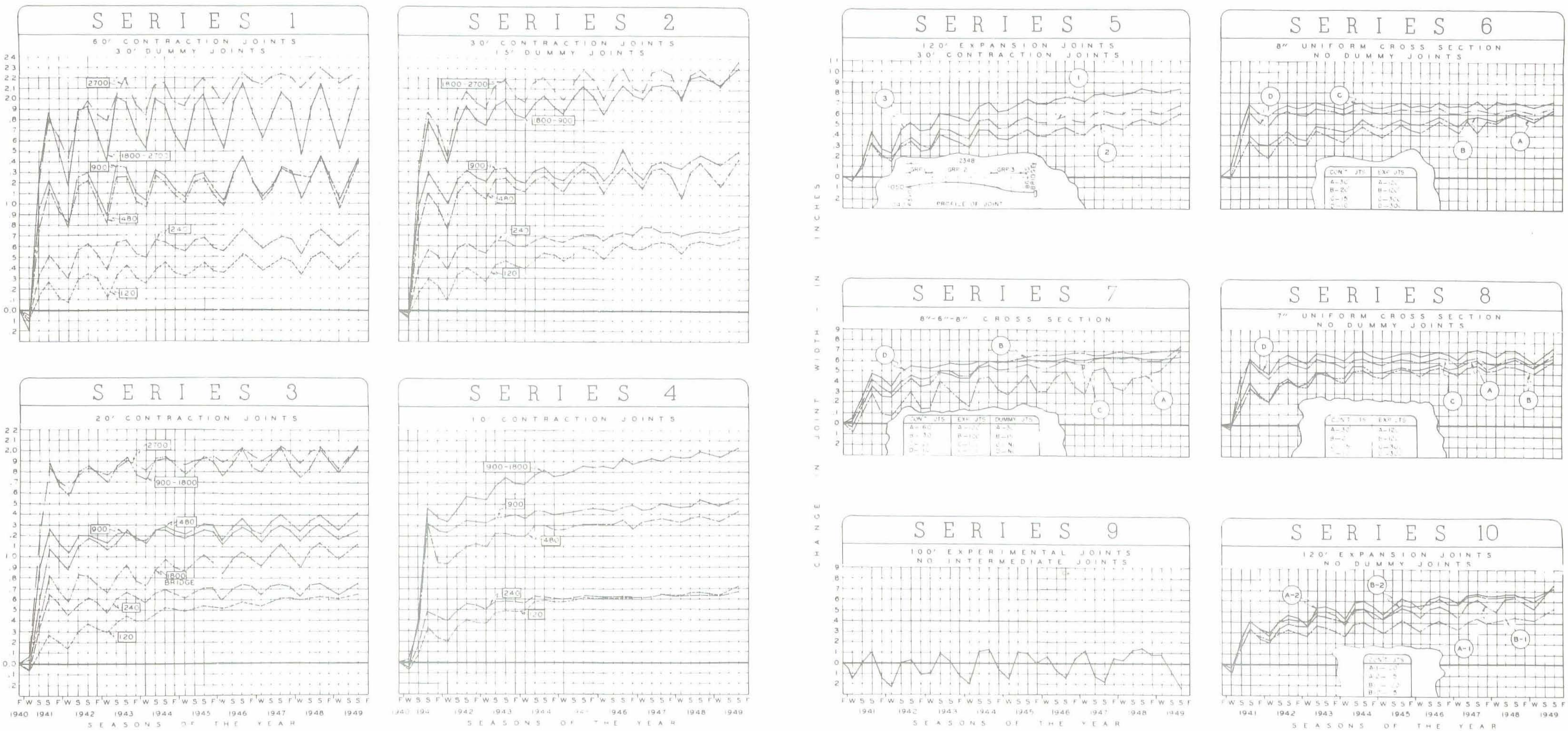
average wheel load distribution values by direction of travel are presented in Table II. With the exception of the war years, traffic has been fairly constant on the Test Road.

Joint Width Movements

The joint width changes in 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 for the past 9 years. They include seasonal and daily joint width changes for expansion, contraction, and dummy joints.

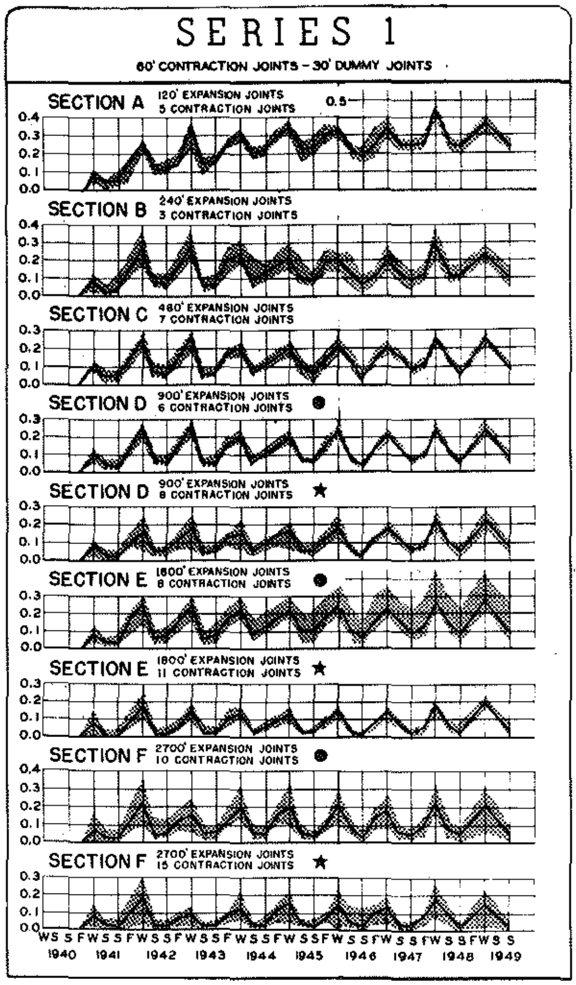
Seasonal Movement: Seasonal changes in expansion joint width, together with their progressive or permanent change, are presented graphically in Figure 2. In the same manner, the seasonal changes in contraction joints are presented in Figure 3 and dummy joints in Figure 4. In addition to the significant facts already stated in previous reports, the data is now sufficient to disclose that progressive permanent displacement of the slab ends is greatest during the first 5 to 6 years and levels off thereafter. However, after that time the amplitude of the seasonal movement apparently remains fairly constant. This is true for all three types of joints.

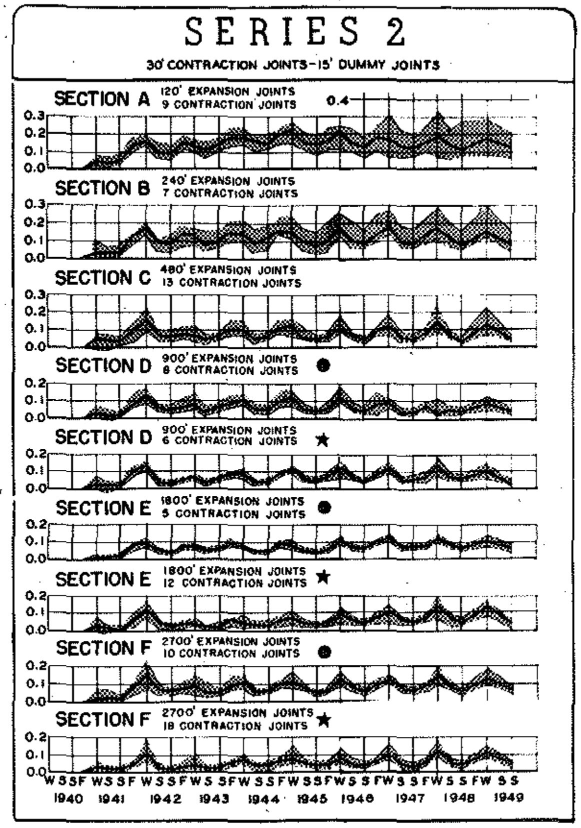
Daily Movement: The daily movement of expansion, contraction, and dummy joints is presented graphically in Figures 5, 6, and 7 respectively. In general, the data disclose several significant facts. First, daily joint width is influenced to a certain extent by the degree of pavement restraint which normally increases with age. Second, joint spacing has a decided effect upon daily joint movement. Third, the movement is greatest during the spring and least in the fall seasons, while summer and winter seasonal readings are about comparable.

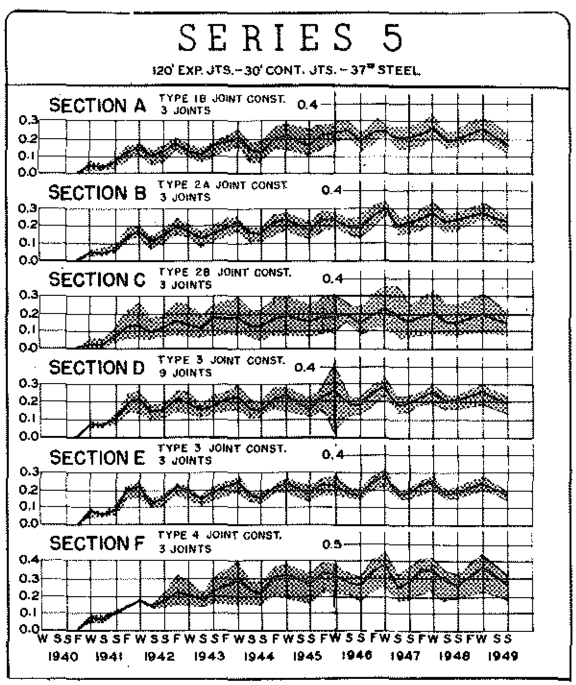


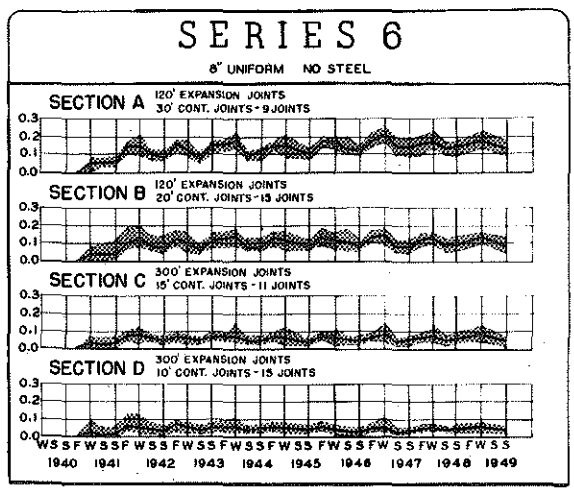
SEASONAL CHANGES IN EXPANSION JOINT WIDTH

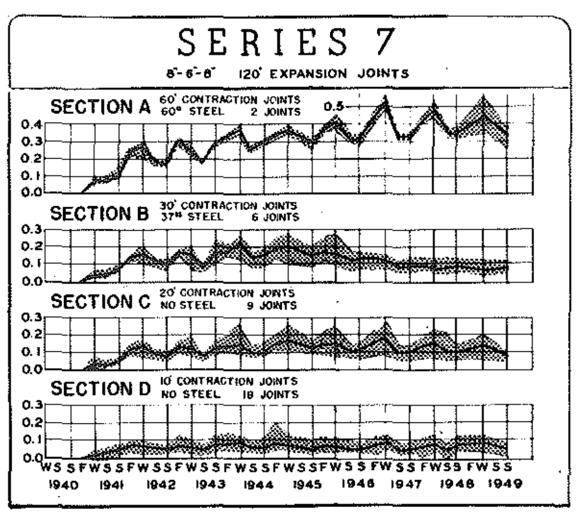
FIGURE 2

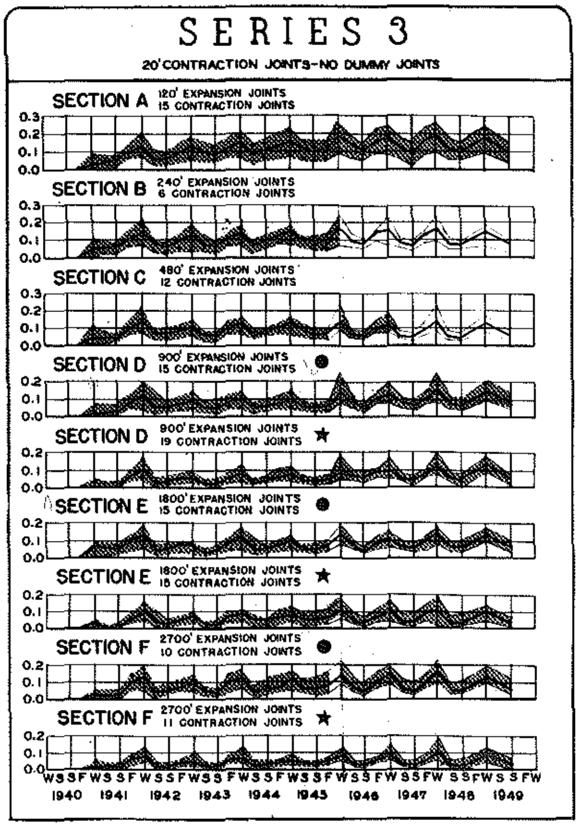

SERIES 1
60' CONTRACTION JOINTS - 30' DUMMY JOINTS
SECTION A 120' EXPANSION JOINTS 5 CONTRACTION JOINTS
SECTION B 240' EXPANSION JOINTS 3 CONTRACTION JOINTS
SECTION C 480' EXPANSION JOINTS 7 CONTRACTION JOINTS
SECTION D 900' EXPANSION JOINTS 6 CONTRACTION JOINTS ●
SECTION D 900' EXPANSION JOINTS 8 CONTRACTION JOINTS ★
SECTION E 1800' EXPANSION JOINTS 8 CONTRACTION JOINTS ●
SECTION E 1800' EXPANSION JOINTS 11 CONTRACTION JOINTS ★
SECTION F 2700' EXPANSION JOINTS 10 CONTRACTION JOINTS ●
SECTION F 2700' EXPANSION JOINTS 15 CONTRACTION JOINTS ★
1940 1941 1942 1943 1944 1945 1946 1947 1948 1949

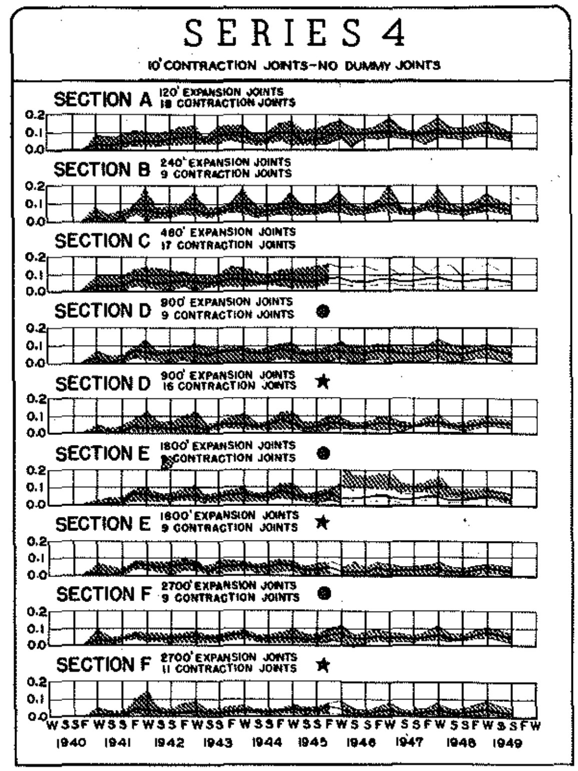

SERIES 2
30' CONTRACTION JOINTS-15' DUMMY JOINTS
SECTION A 120' EXPANSION JOINTS 9 CONTRACTION JOINTS
SECTION B 240' EXPANSION JOINTS 7 CONTRACTION JOINTS
SECTION C 480' EXPANSION JOINTS 13 CONTRACTION JOINTS
SECTION D 900' EXPANSION JOINTS 8 CONTRACTION JOINTS ●
SECTION D 900' EXPANSION JOINTS 6 CONTRACTION JOINTS ★
SECTION E 1800' EXPANSION JOINTS 5 CONTRACTION JOINTS ●
SECTION E 1800' EXPANSION JOINTS 12 CONTRACTION JOINTS ★
SECTION F 2700' EXPANSION JOINTS 10 CONTRACTION JOINTS ●
SECTION F 2700' EXPANSION JOINTS 18 CONTRACTION JOINTS ★
1940 1941 1942 1943 1944 1945 1946 1947 1948 1949

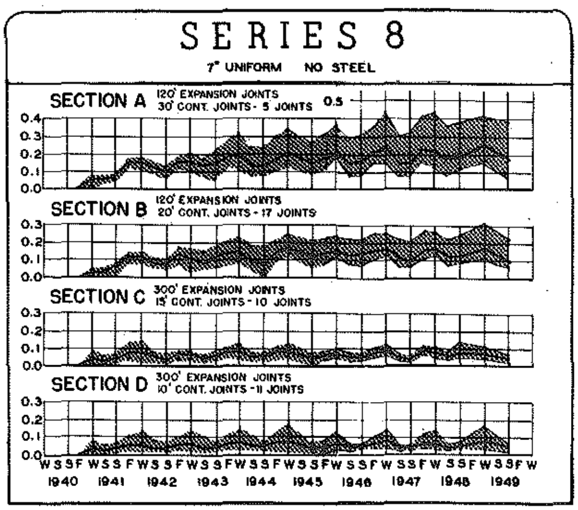

SERIES 5
120' EXP. JTS.-30' CONT. JTS.-37" STEEL
SECTION A TYPE 1B JOINT CONST. 3 JOINTS
SECTION B TYPE 2A JOINT CONST. 3 JOINTS
SECTION C TYPE 2B JOINT CONST. 3 JOINTS
SECTION D TYPE 3 JOINT CONST. 9 JOINTS
SECTION E TYPE 3 JOINT CONST. 3 JOINTS
SECTION F TYPE 4 JOINT CONST. 3 JOINTS
1940 1941 1942 1943 1944 1945 1946 1947 1948 1949

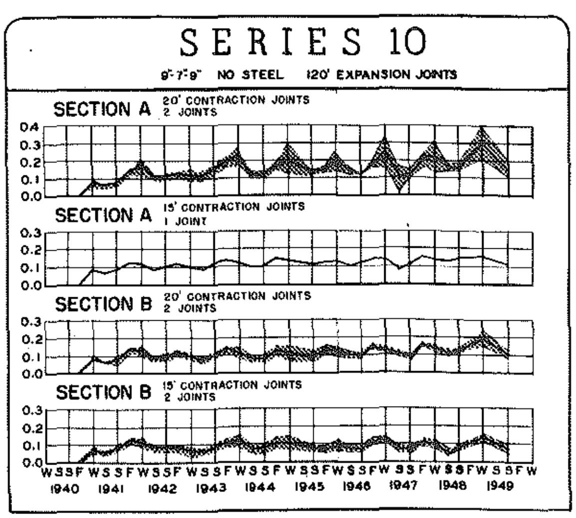

SERIES 6
8" UNIFORM NO STEEL
SECTION A 120' EXPANSION JOINTS 30' CONT. JOINTS - 9 JOINTS
SECTION B 120' EXPANSION JOINTS 20' CONT. JOINTS - 15 JOINTS
SECTION C 300' EXPANSION JOINTS 15' CONT. JOINTS - 11 JOINTS
SECTION D 300' EXPANSION JOINTS 10' CONT. JOINTS - 15 JOINTS
1940 1941 1942 1943 1944 1945 1946 1947 1948 1949


SERIES 7
8"-6"-8" 120' EXPANSION JOINTS
SECTION A 60' CONTRACTION JOINTS 60" STEEL 2 JOINTS
SECTION B 30' CONTRACTION JOINTS 37" STEEL 6 JOINTS
SECTION C 20' CONTRACTION JOINTS NO STEEL 9 JOINTS
SECTION D 10' CONTRACTION JOINTS NO STEEL 18 JOINTS
1940 1941 1942 1943 1944 1945 1946 1947 1948 1949









SEASONAL CHANGES IN
CONTRACTION JOINT WIDTH

Figure 3

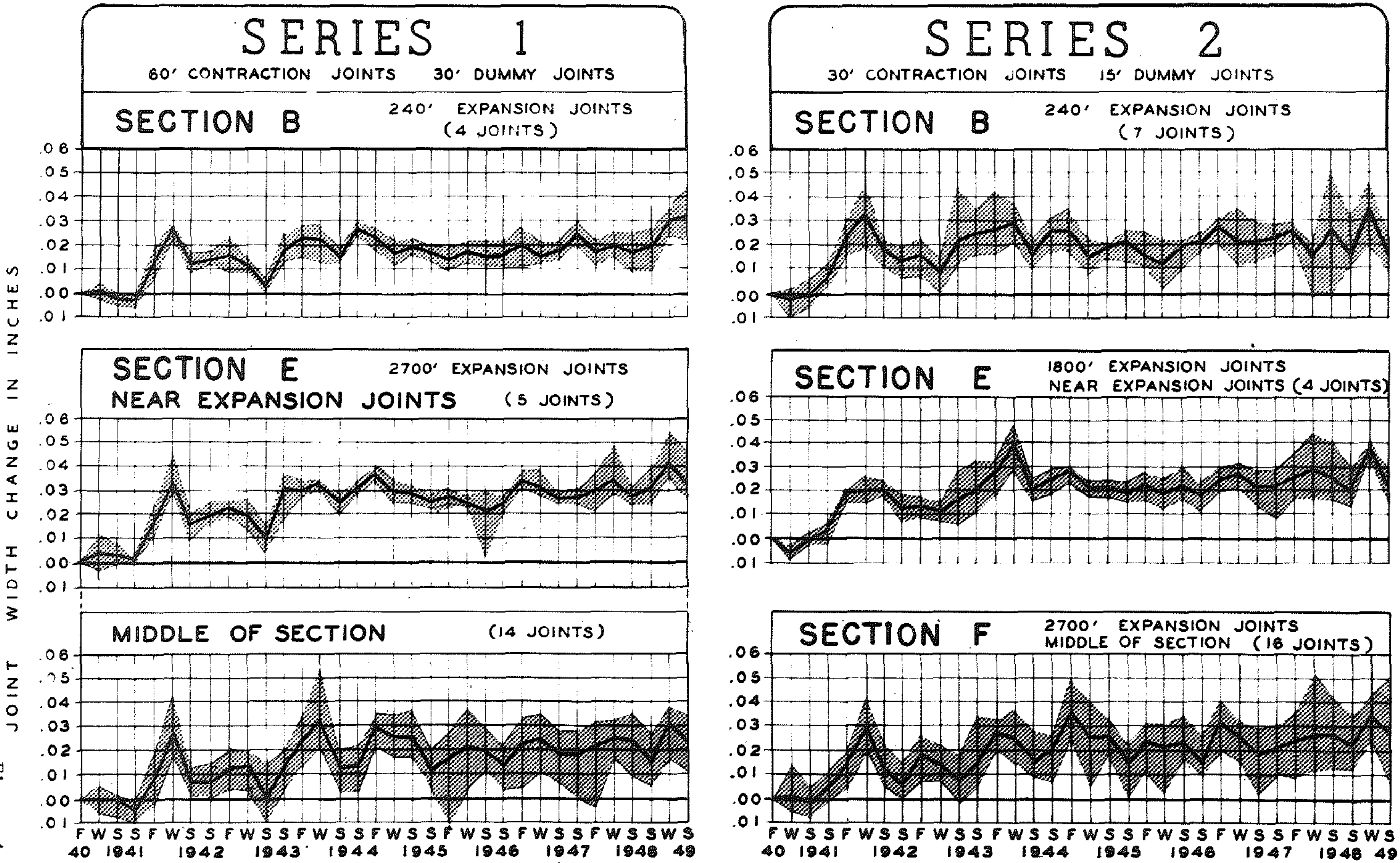
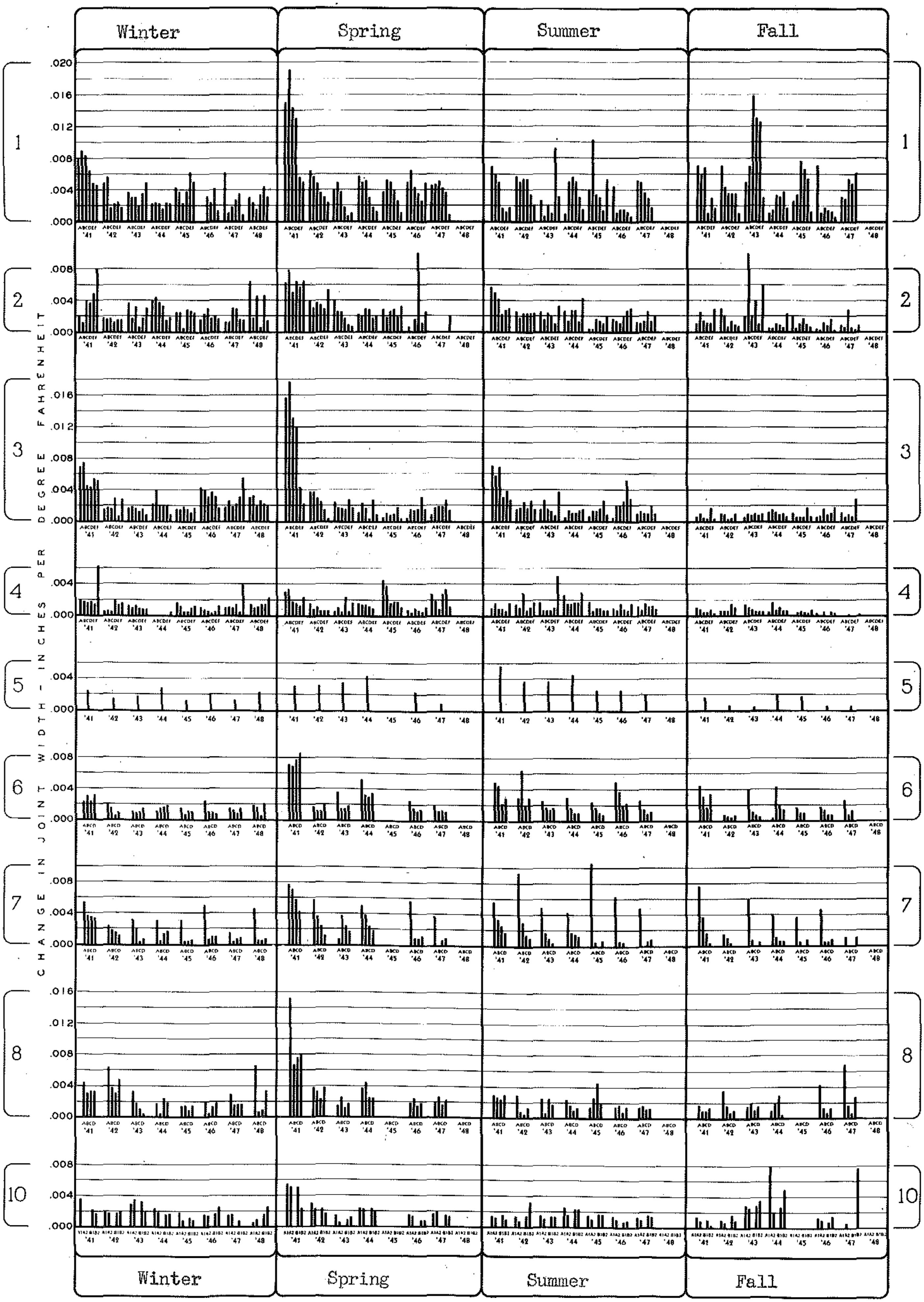
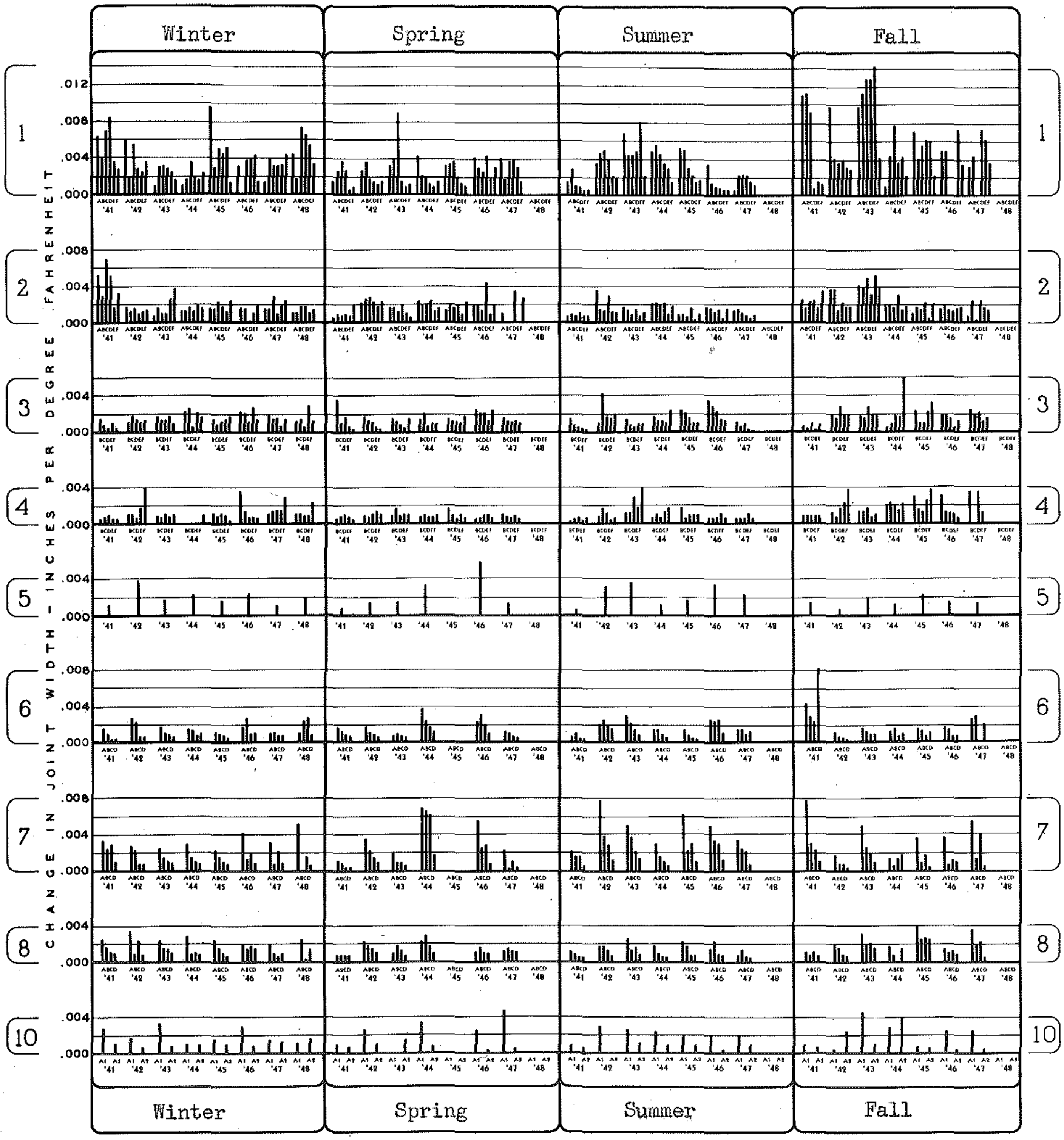

SERIES 1
60' CONTRACTION JOINTS 30' DUMMY JOINTS
SECTION B 240' EXPANSION JOINTS (4 JOINTS)
SECTION E 2700' EXPANSION JOINTS
NEAR EXPANSION JOINTS (5 JOINTS)
MIDDLE OF SECTION (14 JOINTS)
SERIES 2
30' CONTRACTION JOINTS 15' DUMMY JOINTS
SECTION B 240' EXPANSION JOINTS (7 JOINTS)
SECTION E 1800' EXPANSION JOINTS
NEAR EXPANSION JOINTS (4 JOINTS)
SECTION F 2700' EXPANSION JOINTS
MIDDLE OF SECTION (16 JOINTS)
JOINT WIDTH CHANGE IN INCHES
.06 .05 .04 .03 .02 .01 .00 .01
F W S S F W S S F W S S F W S S F W S S F W S S F W S S F W S S F W S S W S
40 1941 1942 1943 1944 1945 1946 1947 1948 49

Figure 4

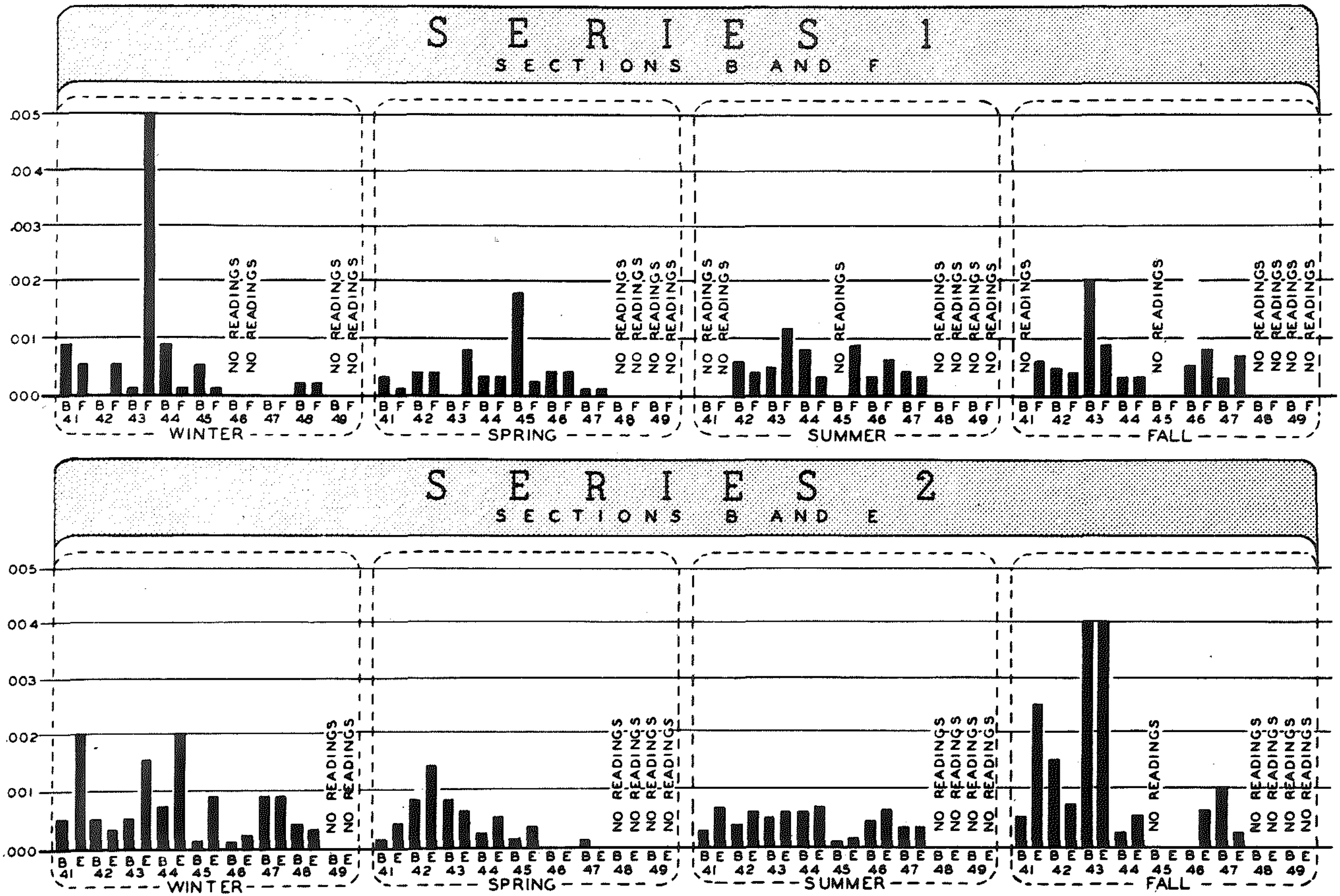


DAILY MOVEMENT OF EXPANSION JOINTS FIGURE 5



DAILY MOVEMENT OF CONTRACTION JOINTS

FIGURE 6



DAILY MOVEMENT OF DUMMY JOINTS

FIGURE 7

Pavement Movement: The seasonal changes of Sections A, C, D, and F of Series 1, 2, 3, and 4 are presented graphically in Figures 8 and 9 for the years 1940 to 1949. In general, the data discloses that the sections are still undergoing a very slight increase in length after 9 years. The curves presented in Figure 10 indicate that the bulk of the section movement took place during the first 5 years.

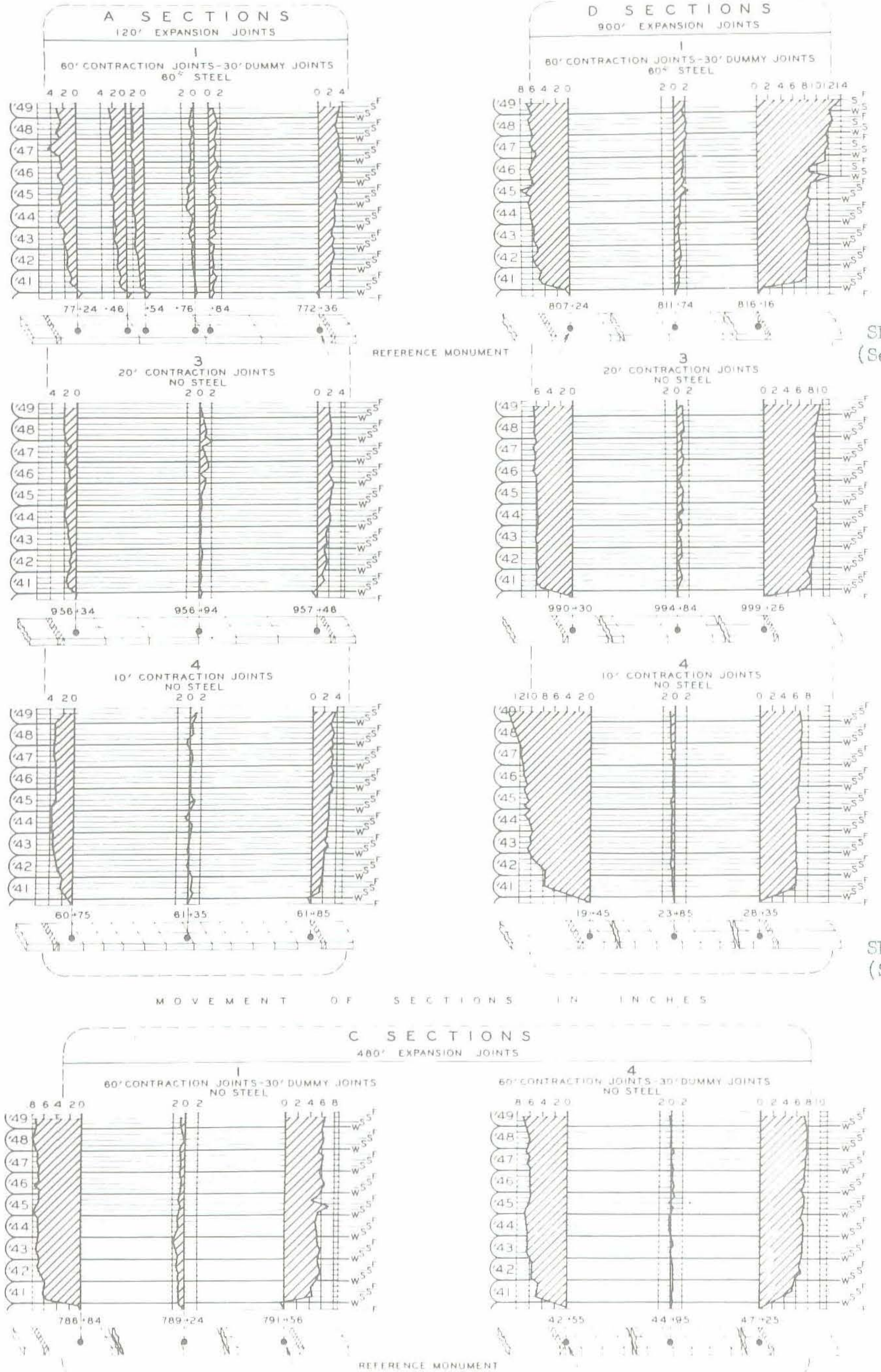
Pavement Cross Section

The cross sections set up for comparative study include the 9-7-9-in. and its approximate equivalent, 8-in. uniform; the 8-6-8-in. and its approximate equivalent, 7-in. uniform. The portions of the Design Project devoted to this study are Section 3A, Series 6, 7, and 8.

In general, nothing has developed so far from which conclusive data can be derived. The joints and respective slabs have, after 9 years, shown no marked difference in behavior traceable to cross section design. The cracking which has occurred in Series 6 can be attributed directly to a faulty subbase and volume changes in the subgrade. Joint width changes in Series 6, 7, and 8 duplicate very closely the magnitude, annual amplitude, and progressive displacement of the joints located in other series with similar joint spacings.

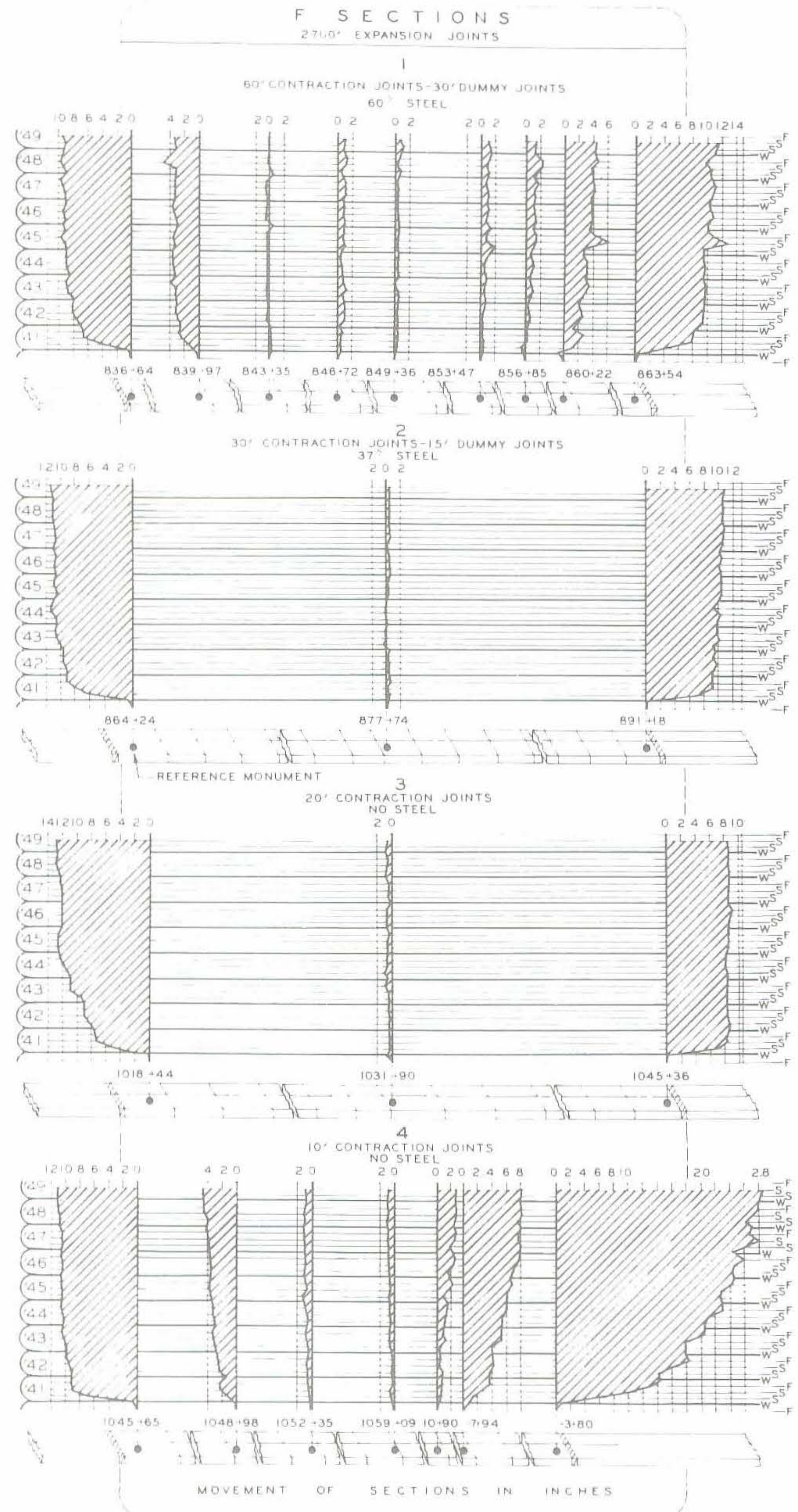
Stress Cured Concrete

In Series 9A, 1800 ft. of concrete pavement were constructed employing the stress curing method. The slab lengths are 100 ft. The concrete was subjected to controlled compressive forces during the 7-day curing period, or until such time as the flexural strengths reached the 7-day specification requirement of 550 lb. per sq. in. 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



SEASONAL CHANGES IN SECTION LENGTH
(Sections A,C,D of Series 1,3 and 4)

Figure 8



SEASONAL CHANGES IN SECTION LENGTH
(Sections F of Series 1,2,3 and 4)

Figure 9

determinations of strength increase in test specimens up to a maximum of 200 lb. per sq. in.

At the end of 9 years, 10 of the slabs, as against 14 in the 1945 report, are apparently still in perfect condition. The cracking in four of the slabs is known to have been caused by undesirable subgrade conditions.

Unlike expansion joints in other series, the joints separating uncracked slabs in this series have not undergone a progressive closure but the openings oscillate about the original width.

Joint Faulting

Results of a 1944 survey on faulting of expansion and contraction joints constructed in Series 10 with and without load transfer devices were presented in the 1945 report. The results of a similar survey conducted in 1949 are presented together with the 1944 data in Table III. Faulting measurements on contraction joints in Series 3D, 4D, 3E, and 4E are also included in Table III.

The data show, in all cases, a gradual increase in faulting with time. The value of load transfer on the prevention of faulting at expansion joints is clearly indicated. In the case of contraction joints, the influence of slab restraint is apparent. Aggregate interlock is not effective in preventing faulting, irrespective of any slab restraint effected by omission of expansion joints.

The absence of transverse dowels has created a weakness in the pavement structure at the junction of longitudinal and transverse joints. This weakness is manifested by noticeable differential movement of the slab corners at the junction which has resulted in spalling of the concrete at the intersection of the two joints. Since 1945, however, this same phenomenon has begun to develop more noticeably, especially at doweled joints where

FAULTING OF EXPANSION JOINTS
WITH AND WITHOUT LOAD TRANSFER DEVICES
(Two Lanes)

Series	Number of Joints Having Maximum Fault of: 1/8 inch		3/16 inch		1/4 inch		Over 1/4 inch		Total Joints Faulted		Total No. of Joints in Two Lanes	Percentage of Total Faulted		Load Transfer
	A	B	A	B	A	B	A	B	A	B		A	B	
10 A-1	2	1	0	0	0	0	0	0	2	1	20	10	5	3/4- by 15 in. dowels, 15 in. spacing
10 A-2	0	0	0	0	0	0	0	0	0	0	18	0	0	" " " "
10 B-1	5	6	5	4	0	3	0	0	10	13	18	56	72	None
10 B-2	5	5	4	1	5	5	0	2	14	13	18	78	72	"

A = Survey August 1944

B = Survey July 1949

FAULTING OF CONTRACTION JOINTS
WITH AND WITHOUT LOAD TRANSFER DEVICES
(Two Lanes)

Series	Number of Joints Having Maximum Fault of: 1/8 inch		3/16 inch		1/4 inch		Over 1/4 inch		Total Joints Faulted		Total No. of Joints in Two Lanes	Percentage of Total Faulted		Load Transfer
	A	B	A	B	A	B	A	B	A	B		A	B	
10 A-1	7	9	0	1	1	1	0	2	8	13	90	9	15	3/4-by 15 in. dowels, 15 in. spacing
10 A-2	4	6	1	3	0	0	0	1	5	10	126	4	8	" " "
10 B-1	23	26	7	11	4	9	0	0	34	46	90	38	51	No dowels, agg. interlock
10 B-2	22	37	5	4	6	12	0	1	33	54	126	28	43	" " "
3 D	0	5	0	0	0	0	0	0	0	5	176	0	3	3/4-by 15 in. dowels, 15 in. spacing
4 D	1	5	0	0	0	0	0	1	1	6	179	1	3	" " "
3 E	15	32	0	7	1	1	0	0	16	40	178	9	22	No dowels, agg. interlock
4 E	3	9	0	0	0	0	0	0	3	9	358	1	3	" " "

A = Survey August 1944

B = Survey July 1949

TABLE III. FAULTING OF JOINTS

premolded joint seal material was used to form the joint. See Figure 10.

Continuous Slabs With and Without Reinforcement

Two test sections, designated Series 11 and 12 of the Design Project, included continuous slabs of different lengths with and without reinforcement. The dimensional details of the two sections as well as their present physical condition in regard to cracking will be found in Figure 11.

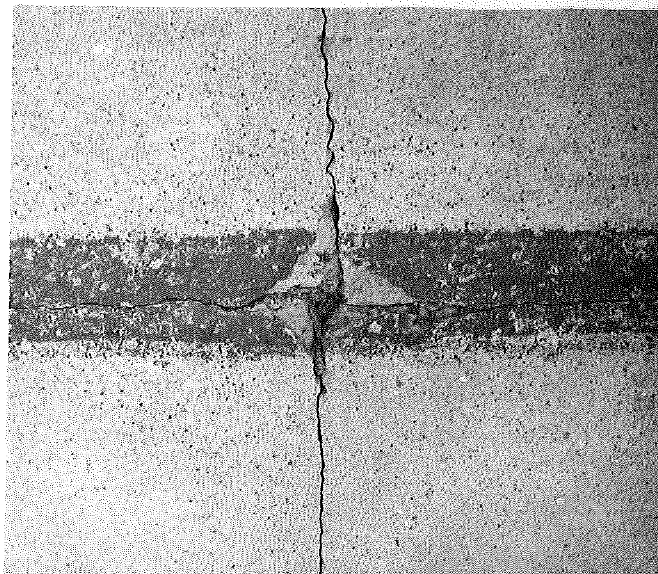
The concrete in both sections is in excellent condition today. It will be noted that the crack pattern is very similar in both sections. With few exceptions, the cracks formed first at the monument boxes which were set in the slabs at the 1/4 and 1/8 points to measure slab movement. The maximum width of crack opening varied from 1/4 to 1/2 inch. It is apparent that the steel mesh in Series 11 has broken at the cracks. Perhaps the most remarkable thing noted from this study so far is the continued resistance of the long slabs, both reinforced and unreinforced, to further break-up.

Unfortunately, the subsequent cracking of the long sections has interfered with the original purpose of observing the movement of the long slabs. However, seasonal readings have been continued and the movement of the sections is shown in Figures 12 and 13.

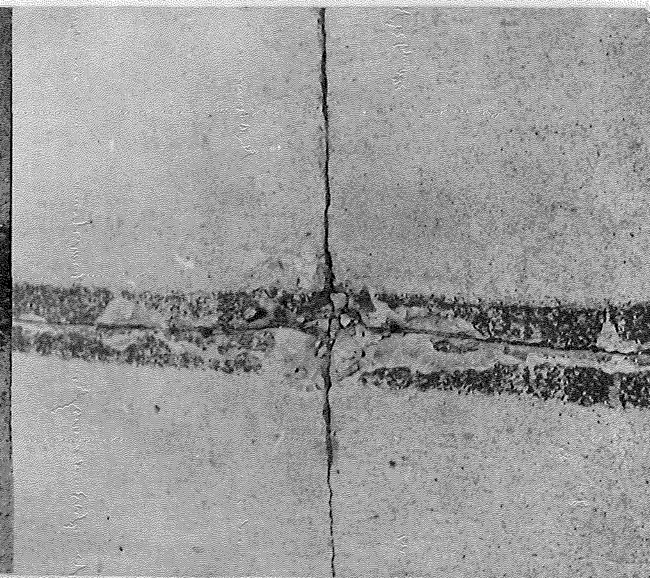
Since the 120-foot slabs of Section 11B and 12B have not broken, it is possible to observe the net change in their length. The net seasonal and progressive changes for the 9-year period are shown in Figure 14.

Pavement Roughness

In September, 1941, and again in August, 1949, a series of pavement roughness tests were conducted on the entire Test Road by personnel and equipment of the Federal Bureau of Public Roads. The study was made primarily to compare the riding quality of the various sections of the pavement and to determine change in roughness with time. Roughness values for

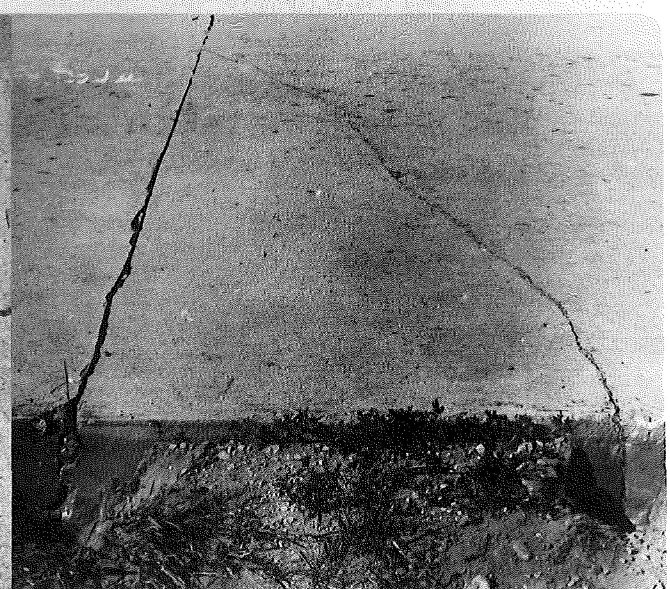


SHOWING TYPICAL SPALLING AT INTERSECTION OF LONGITUDINAL AND TRANSVERSE JOINTS AND OPENING OF JOINTS INDICATING DIFFERENTIAL SLAB MOVEMENT. SECTION 3E, 20-FOOT JOINT SPACING. NO DOWELS.



TYPICAL SPALLING ALONG LONGITUDINAL JOINT. SECTION 3E.

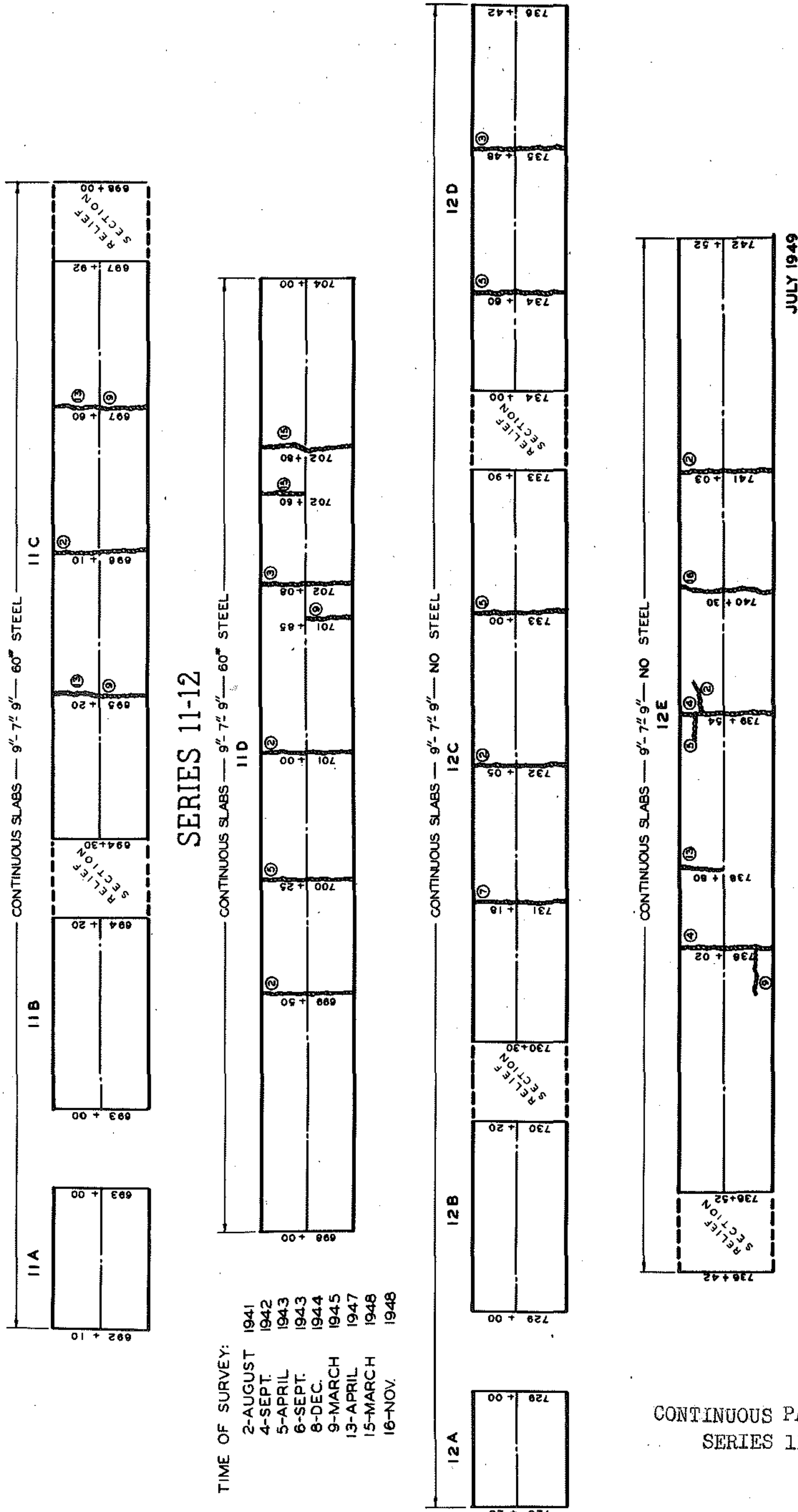
TYPICAL SPALLING OCCURRING ON SECTIONS WITH DOWELS. SERIES 1F, STATION 839+60.



CORNER BREAK AT STATION 1000+70. SECTION 3E. NO DOWELS.

CONTRACTION JOINT PERFORMANCE, WITH AND WITHOUT DOWELS

FIGURE 10



CONTINUOUS PAVEMENT STUDY
SERIES 11 AND 12

Figure 11

SECTION MOVEMENT, SERIES 11

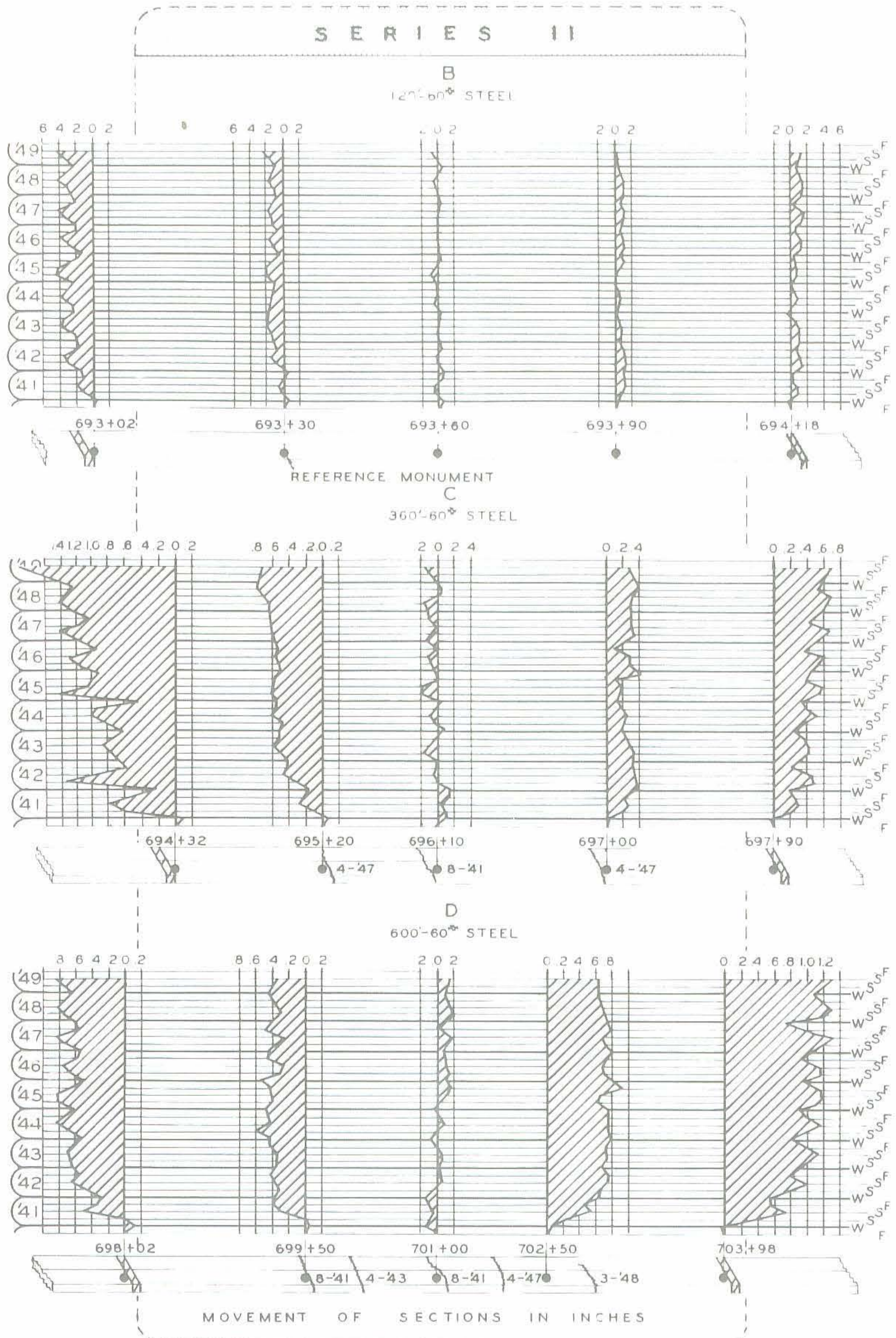
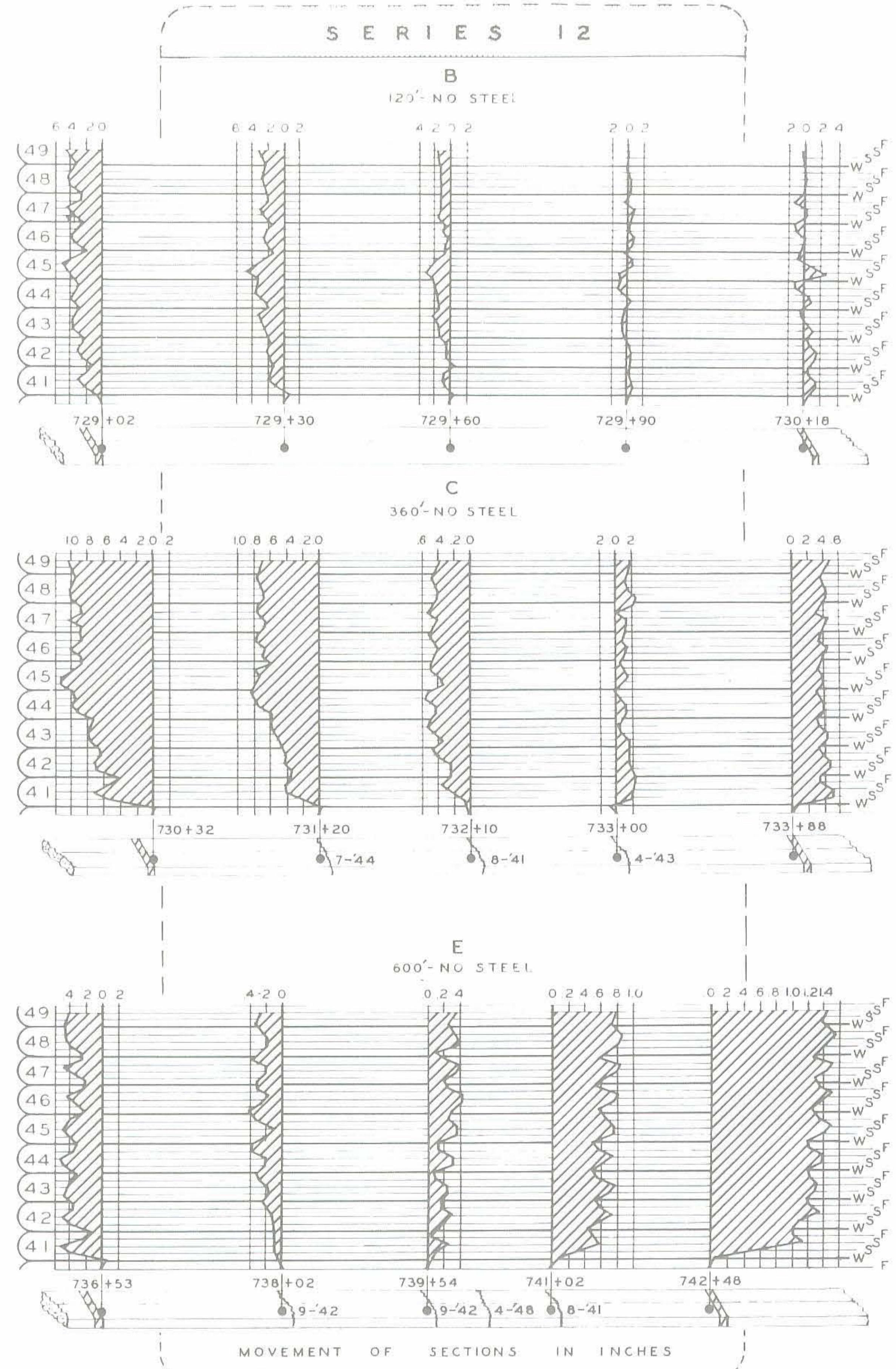
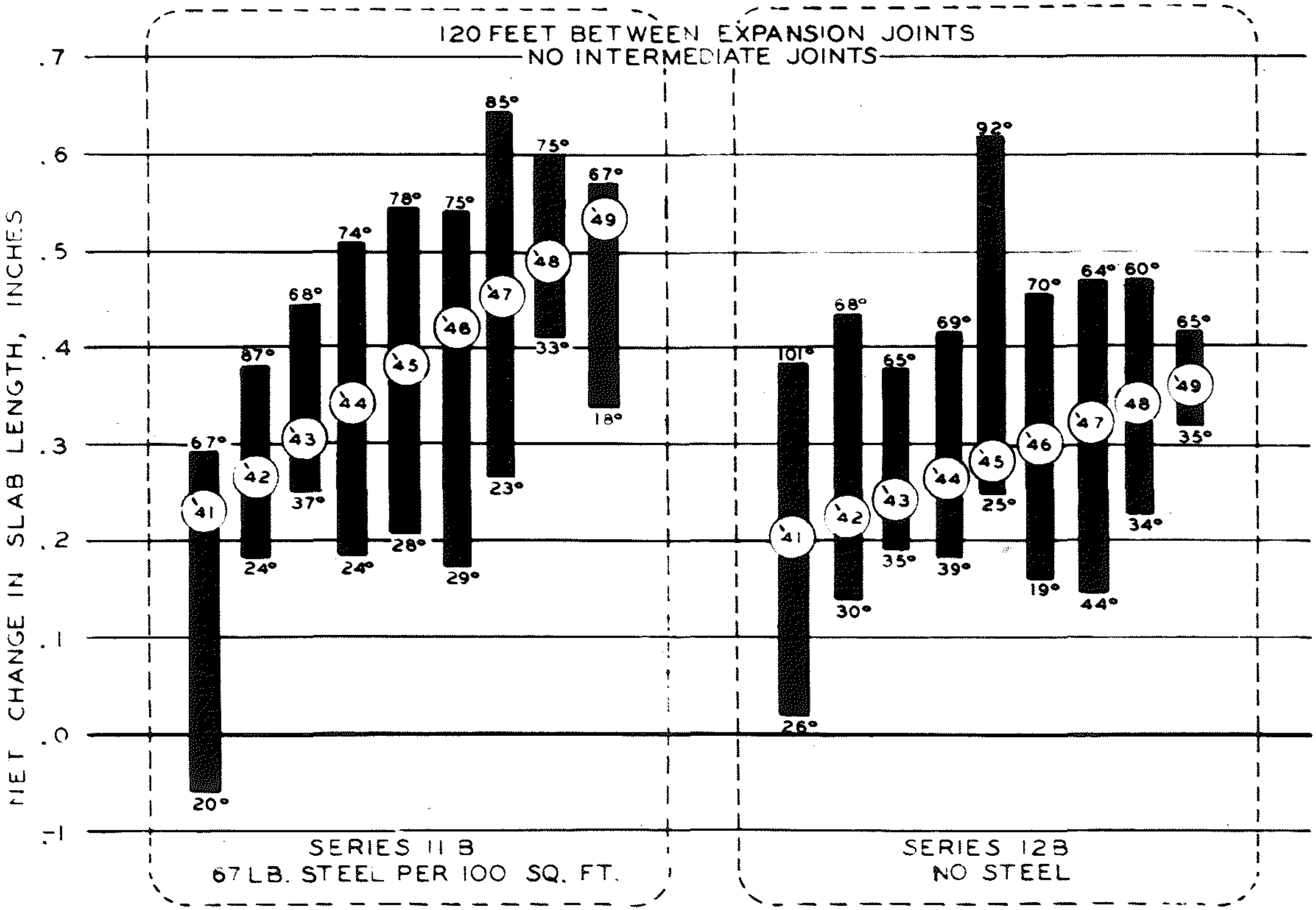


FIGURE 12



SECTION MOVEMENT SERIES 12

FIGURE 13



120 FEET BETWEEN EXPANSION JOINTS
NO INTERMEDIATE JOINTS
NET CHANGE IN SLAB LENGTH, INCHES
.7
.6
.5
.4
.3
.2
.1
.0
-.1
SERIES 11 B
67 LB. STEEL PER 100 SQ. FT.
SERIES 12 B
NO STEEL
'41
'42
'43
'44
'45
'46
'47
'48
'49
67°
20°
87°
24°
68°
37°
74°
24°
78°
28°
75°
29°
85°
23°
75°
33°
67°
18°
101°
26°
68°
30°
65°
35°
69°
39°
92°
25°
70°
19°
64°
44°
60°
34°
65°
35°

Figure 14

the two series of tests are presented graphically in Figure 15.

The 1949 roughness tests show that all sections have increased in roughness approximately to the same degree, the general increase in roughness for the entire Design Project being approximately 56 per cent in 8 years. Series 4 with the 10-foot joint spacing had the greatest increase in roughness.

General Pavement Condition

Some physical changes of rather broad significance have begun to appear in the pavement of the Design Project. The area at the beginning of the project between Stations 764+00 and -3+65.4, which includes Series 1, 2, 3, and Section F of Series 4, is in excellent condition with very little evidence of scaling or spalling at the joints. The remainder of the project, however, is characterized by a quite general scaling of the concrete surface, with marked localization at the joints in many instances. This latter part of the project was built first and observations during construction plainly indicate poorer workmanship and wetter concrete here than in the remainder of the project.

Incidence of cracking in the first four series is following a course pretty much to be expected on the basis of the slab lengths involved. In Series 1, seven full transverse cracks and nine half cracks have formed. In Series 2, one complete crack and four half cracks have appeared. No transverse cracks have shown up in Series 3 and 4 so far.

There are five complete transverse cracks in Series 10, two of which are in the doweled sections and three in the undoweled sections.

General Summary

Important indications are reviewed and presented as a supplement to those already established in Highway Research Board Report No. 3-B.

1. The limit of pavement movement has not been reached in 9 years.

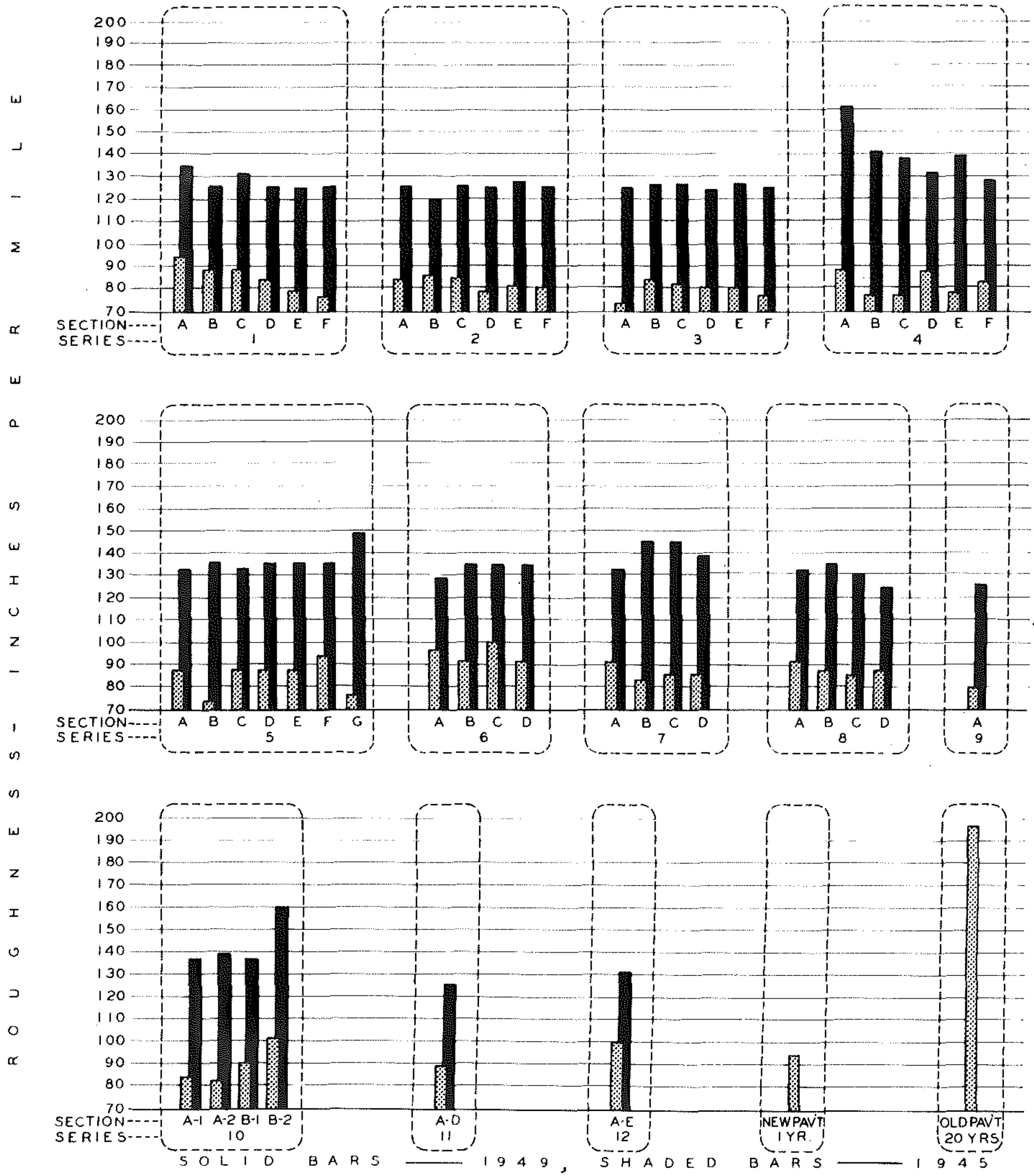
2. Aggregate interlock is not sufficient to prevent faulting, even though slabs are partially restrained at joints due to purposeful omission of expansion joints.

3. The four inside corners created by the intersection of the longitudinal and transverse joints are in need of further strengthening through mechanical interlock to prevent excessive differential vertical movement of the slabs due to warping and loads.

4. The results of inadequate design or workmanship or both evidently come to light within a period of 8 to 10 years after construction to the extent that major maintenance operations are necessary.

5. Concrete pavements gradually increase in roughness with age. This phenomenon does not appear to be associated with modern pavement design features. It apparently is directly associated with the inherent character of modern concrete when exposed in thin slabs to climatic conditions and soil.

6. All sections of the Test Road are beginning to show signs of stress due to age and traffic. In the following years, differences in slab performance as related to the design features under study should be more pronounced.



ROAD ROUGHNESS

FIGURE 15