MICHIGAN
STATE HIGHWAY DEPARTMENT
Charles H. Ziegler
State Highway Commissioner

62

RECOMMENDATIONS FOR THE DESIGN

OF

CONCRETE PAVEMENT

Project 39F-7 -1

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RESEARCH LABORATORY
TESTING AND RESEARCH DIVISION
November 20, 1944

MICHIGAN
STATE HIGHWAY DEPARTMENT
LANSING 13

CHARLES M. ZIEGLER
STATE HIGHWAY COMMISSIONER

HARRY T. WARD
CHIEF DEPUTY COMMISSIONER

HARRY C. COONS
DEPUTY COMMISSIONER,
CHIEF ENGINEER

November 20,1944

Mr. K. B. 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 the Road Division a report has been prepared which presents material and recommendations essential to the design and construction of concrete pavements relevant to the Michigan post war highway construction program. The report submitted herewith covers certain design and construction features such as principles of design, cross section thickness, joint spacing and joint design.

The work is in the nature of a preliminary progress report covering briefly the more important factors related to concrete pavement construction which have been disclosed over a period of years by experience, observations and investigations. Therefore, it is proposed to supplement the work from time to time by additional material to be collected from current investigations and studies by the Department and by other highway organizations.

Very truly yours,

E. A. Finney

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

EAF:CT

RECOMMENDATIONS FOR THE DESIGN OF CONCRETE PAVEMENTS

This report presents data and recommendations essential to the design and construction of concrete pavements relevant to the post war highway construction program in Michigan.

The material and recommendations set forth in the report are based upon the results of studies by the Public Roads Administration on concrete pavement design conducted over a great number of years, on the experience of other State Highway Departments and on the results of various investigations conducted by the Department in the same field.

Two types of reinforced concrete pavement construction are presented in the report. They are described as follows:

(1) With a break in reinforcement at every joint which shall be called "Continuous Reinforced Pavement".

(2) With a break in reinforcement at some of the joints and with intermediate joints where the reinforcement is not broken, which shall be called "Hinged Reinforced Pavement".

In analyzing both types of construction consideration has been given to such factors as principles of concrete pavement design, cross section thickness, joint spacing and joint design. The report contains supporting data in the form of charts, tables and illustrations. Several recommendations for future design are presented at the end of the report.

PRINCIPLES OF DESIGN

1. The crack expectancy of concrete slabs when designed to proper thickness and constructed upon a suitable foundation should be not less than twenty years.

2. When cracks occur they must be kept closed by adequate reinforcement. Therefore, stresses in the reinforcement set-up by subgrade friction forces should not cause excessive elongation of the steel.

3. Dummy and contraction joints when considered should not open sufficiently to affect riding qualities, or allow infiltration of foreign matter.

4. Provision for expansion is considered necessary at bridge structures, at special locations such as sharp curves and points where it may be necessary to neutralize excessive horizontal thrust to prevent blowups, and at points convenient to design or construction progress. On construction where joints at breaks in reinforcement are expected to open more than 1/4 inch, expansion joint construction must be utilized in order to prevent the infiltration of foreign matter and to insure normal functioning of the joint.

5. In the analysis, only slabs of uniform thickness without load transfer at breaks in reinforcement are considered.

6. In the analysis, contraction joints or dummy joints with continuous reinforcement through them are not supposed to transmit any bending moment or to be ideal joints.

CROSS SECTION THICKNESS

In determining slab cross section thickness, two types of concrete pavement construction were given consideration. They are:

1. Continuous reinforced pavement of uniform thickness with no intermediate joints. Consideration was given to continuous slab lengths of 10, 20, 30, 40, 60, 100, 140, 200, 300 and 400 feet.

2. Hinged reinforced pavement of uniform thickness with reinforcement running continuous through the intermediate joints. Under hinged slab construction the following possibilities were considered: 2 slabs of 15 feet, 2 slabs of 20 feet, 3 slabs of 20 feet, 2 slabs of 30 feet, 5 slabs of 20 feet and 10 slabs at 20 feet which would constitute placing contraction joints at 30, 40, 60, 100 and 200 foot intervals with intermediate dummy joints at 15 or 20 feet.

Assumptions: The following assumptions were considered in the design of slab thickness:

1. Westergaard's relationships for load and warping stresses were employed for determining slab thickness.

2. All slab thickness computations have been based on the assumption that no cracks should occur in the slab before 20 years. This value is believed reasonable and one possible to attain under modern construction methods.

3. Westergaard's analysis considers loads applied either in the interior, or at the edge, or corner of the slab. With the advent of wider pavements the possibility of the wheel loads reaching the extreme edge or corner positions is no doubt materially reduced. Thus consideration has been given to this fact by reducing wheel load applications 50 percent.

4. In continuous slab construction the reinforcement is considered continuous from one end of the slab to the other and sufficient to withstand the subgrade friction forces without exceeding the yield point of the steel.

5. The subgrade friction stresses for slabs of equal length and thickness are considered identical for both types of construction.

6. Warping stresses in continuous slabs are based on the total length of the slab. Whereas, in hinged construction only the length between two consecutive joints is considered in the analysis.

7. For either type of construction sufficient reinforcement is provided so that the width of transverse cracks, if they should appear, and the opening of intermediate joints should remain very small in order to prevent the infiltration of foreign matter and to provide a certain amount of edge support.

8. Under present construction methods dowels or other devices are considered necessary at contraction and expansion joints to prevent faulting only. Their ability to reduce edge stresses by load transfer is not considered in the design analysis. Consequently, an impact factor of 1.5 is utilized in computing slab thickness at transverse edges and at corners.

9. Recognizing such possibilities as, the imposition of heavy loads to the slab at the end of the curing period, the reduction in flexural strength caused by air-entraining agents and the natural increase in strength of concrete with age, a value of 750 pounds per square inch was assumed for the ultimate flexural strength of concrete for design purposes.

10. Westergaard's analysis assumes that the subgrade reaction is proportional to the deflection of the slab at a point. The reaction of the sub-

grade per unit area at a given point being the product of the slab deflection at that point and a coefficient of subgrade stiffness "k" which has been termed the modulus of subgrade reaction. Therefore, in order to make practical use of the Westergaard analysis it is necessary to know the approximate modulus of subgrade reaction of the particular subgrade on which the pavement is to be built. Preliminary subgrade studies by the Department indicate that the modulus of subgrade reaction for subbases of a sandy or granular nature are in the order of 100 to 300 pounds per cubic inch. Since granular subbases are utilized in Michigan the extreme values of 100 and 300 p. c. i. have been assumed for subgrade modulus "k" in computing slab thicknesses.

11. Laboratory and field studies by the Department and other highway organizations indicate that the subgrade friction coefficient varies between approximately 1.0 for light granular soils to 2.0 for heavier clay soils. A friction coefficient of 1.0 was used with "k" equal to 100 and a value of 2.0 with "k" equal to 300 for the determination of slab thicknesses. An average of these two slab thicknesses was assumed to correspond to the calculated thickness for the combination of "k" equal to 200 and a friction coefficient of 1.5.

12. The modulus of elasticity and Poisson's ratio for concrete are also required in Westergaard's analysis. Modern concrete has a modulus of elasticity varying between 5×10^6 to 6×10^6 pounds per square inch. The common value of 0.15 was assumed for Poisson's ratio. However, in computing the warping stresses Poisson's ratio was assumed to be zero.

13. The thermal coefficient of expansion for concrete was assumed to be 5.5×10^{-6}.

14. In all calculations the width of the pavement was assumed to be 22 feet.

Calculations:

The slab thickness for both types of construction has been determined on the basis of combined load, warping and subgrade friction stresses.

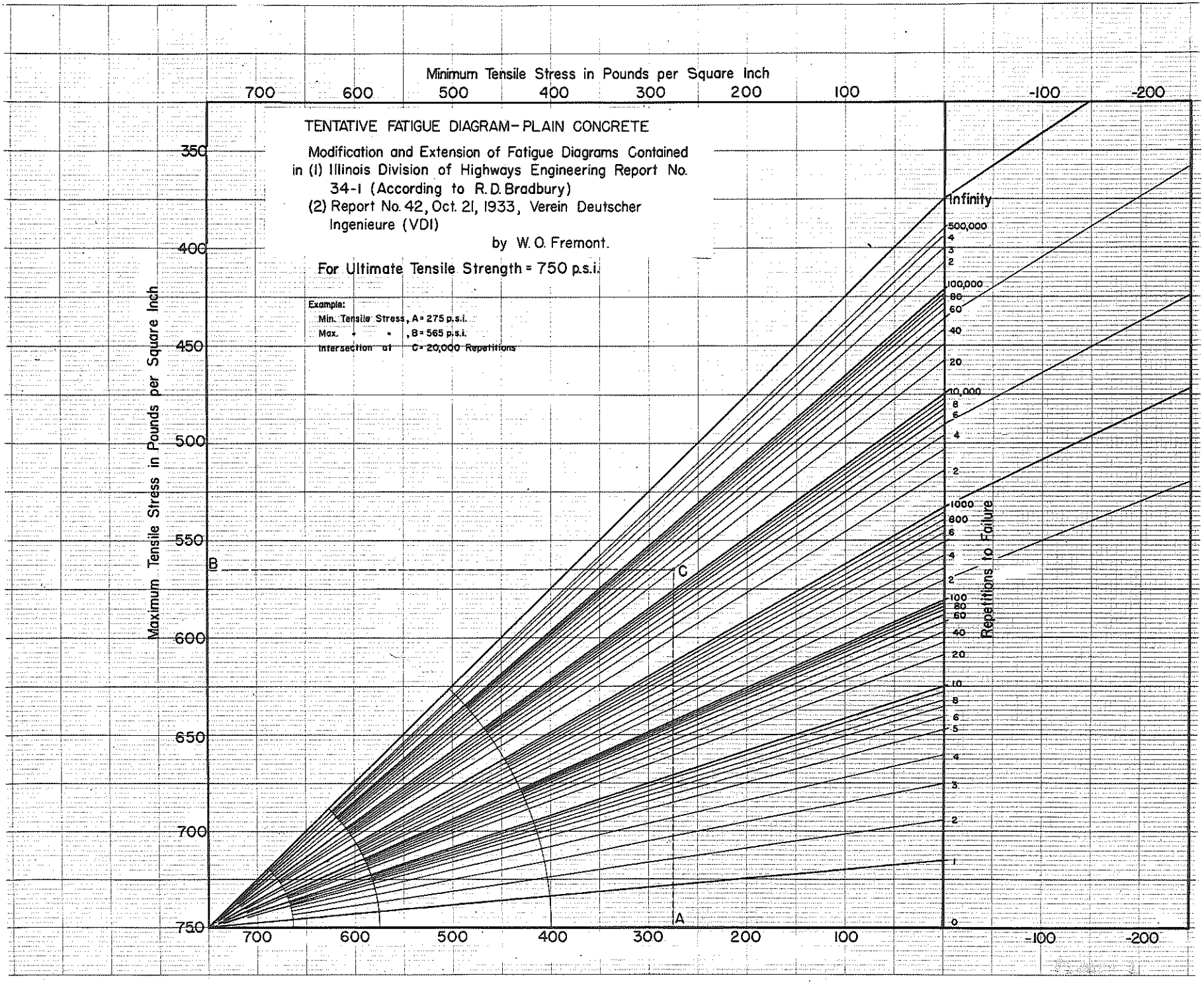
Since the volume and wheel load frequency of the traffic to which the pavement is to be subjected can be reliably anticipated over an extended period of time, it is possible to employ the principle of fatigue for predicting the age at which cracks may be expected to occur in pavements of different thicknesses. The principle of fatigue was utilized in the analysis for computing slab thickness in accordance with the relationships established in the fatigue chart, Figure 1.

The highways in the State trunk-line system have been grouped into four classes with respect to traffic and service. They have been designated by the Design Division as:

Class I	Expressway	Divided lane
Class II	Heavy Primary	Two lanes
Class III	Light Primary	Two lanes
Class IV	Secondary	Two lanes

Traffic characteristics for each class of highways are summarized by Tables I and II. Figure 2 contains a graphic presentation of wheel load frequencies occuring on certain highways in Michigan included in the above four classes. These curves are based on data from traffic surveys conducted by the Planning and Traffic Division in 1946. A projected curve is shown which was utilized for future design purposes.

The computed slab thicknesses for the four classes of highways under consideration, including both continuous and hinged slab construction, may be


TENTATIVE FATIGUE DIAGRAM—PLAIN CONCRETE
Modification and Extension of Fatigue Diagrams Contained in (1) Illinois Division of Highways Engineering Report No. 34-1 (According to R. D. Bradbury)
(2) Report No. 42, Oct. 21, 1933, Verein Deutscher Ingenieure (VDI)
by W. O. Fremont.
For Ultimate Tensile Strength = 750 p.s.i.
Example:
Min. Tensile Stress, A = 275 p.s.i.
Max. " " , B = 565 p.s.i.
Intersection at C = 20,000 Repetitions
Minimum Tensile Stress in Pounds per Square Inch
Maximum Tensile Stress in Pounds per Square Inch
Repetitions to Failure
Infinity
A
B
C

CONCRETE PAVEMENT DESIGN STUDY
TABLE NO. 1
COMPUTATION OF CRITICAL WHEEL LOAD FREQUENCY, PER DAY

Class	Highway Type	Total Daily Traffic Capacity per Lane	Commercial Traffic Percent	Commercial Traffic Per Lane	Estimated Com. Traffic per Lane	Ratio of Axles to Vehicles	Total Daily Axle Loads	Daily Wheel Load Frequency for Each Class						
								4000-4400 4200 4 %	4500-5400 5000 9%	5500-6400 6000 10%	6500-7400 7000 9.5%	7500-8400 8000 7.5%	8500-9400 9000 4%	Over 9400 10,000 1%
I	Express Way Divided Lane	12,000	15	1800	2000	2.6	5200	208	468	520	494	390	208	52
II	Heavy Primary 2 Lane	12,000	8	960	1000	2.6	2600	104	234	260	247	195	104	26
III	Light Primary 2 Lane	12,000	2	240	250	2.6	650	26	59	65	62	49	26	6.5
IV	Secondary 2 Lane	12,000	1	120	125	2.6	325	13	29	33	31	24	13	3

TABLE NO. 2
COMPUTATION OF CRITICAL WHEEL LOAD FREQUENCY, PER YEAR

Class	Highway Type	Critical Wheel Load Per Year						
		4200	5000	6000	7000	8000	9000	10,000
I	Express Way - Divided Lane	75,920	170,820	189,800	180,310	142,350	75,920	18,980
II	Heavy Primary - 2 Lane	37,960	85,410	94,900	90,155	71,175	37,960	9,490
III	Light Primary - 2 Lane	9,490	21,353	23,725	22,539	17,794	9,490	2,373
IV	Secondary - 2 Lane	4,745	10,677	11,863	11,270	8,897	4,745	1,187

GRAPHIC PRESENTATION OF WHEEL LOAD FREQUENCY BASED ON 1936 TRAFFIC COUNT

FROM REPORT TO PUBLIC ROADS ADMINISTRATION
BY PLANNING AND TRAFFIC DIVISION 1938

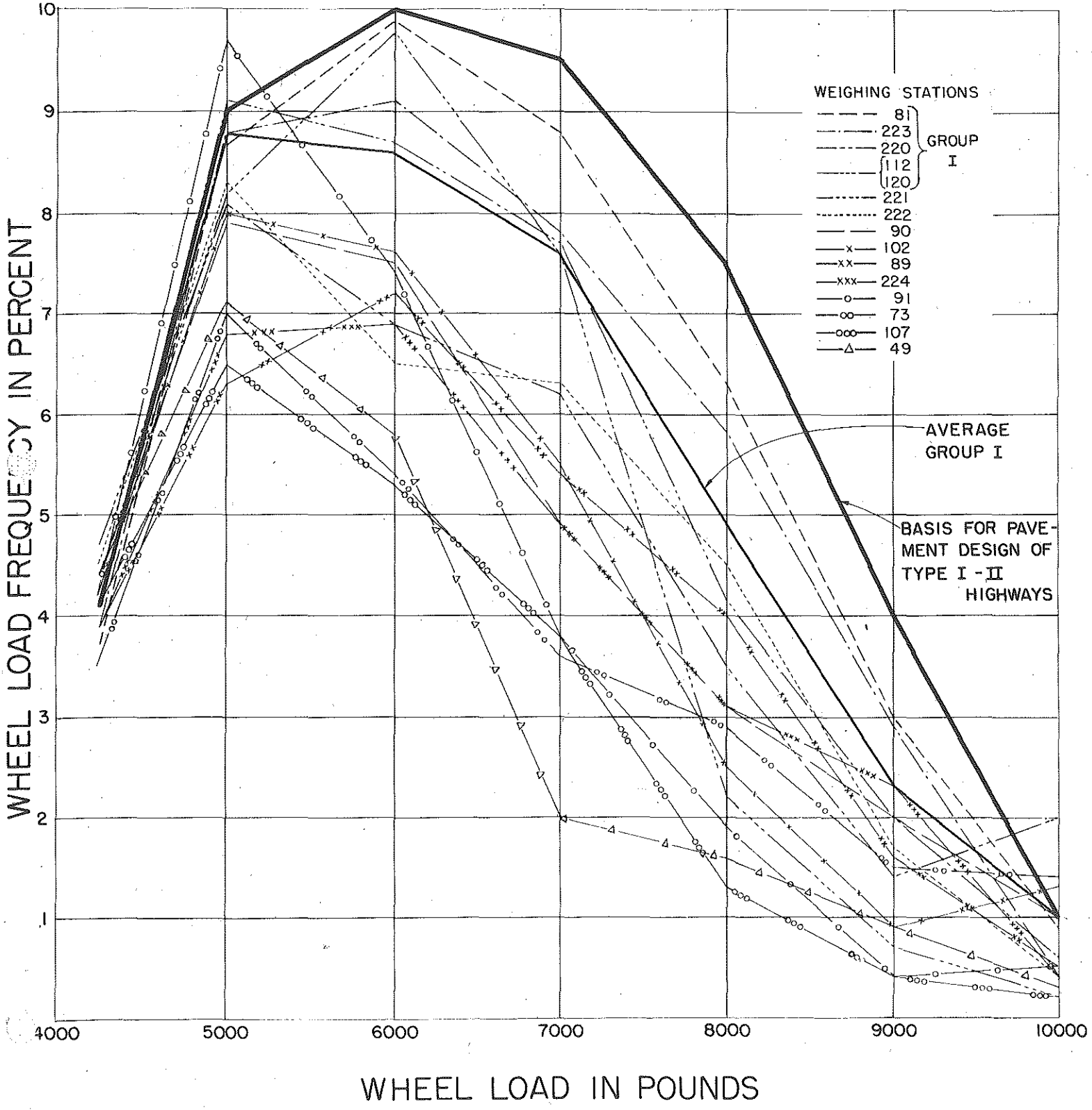


Figure 2

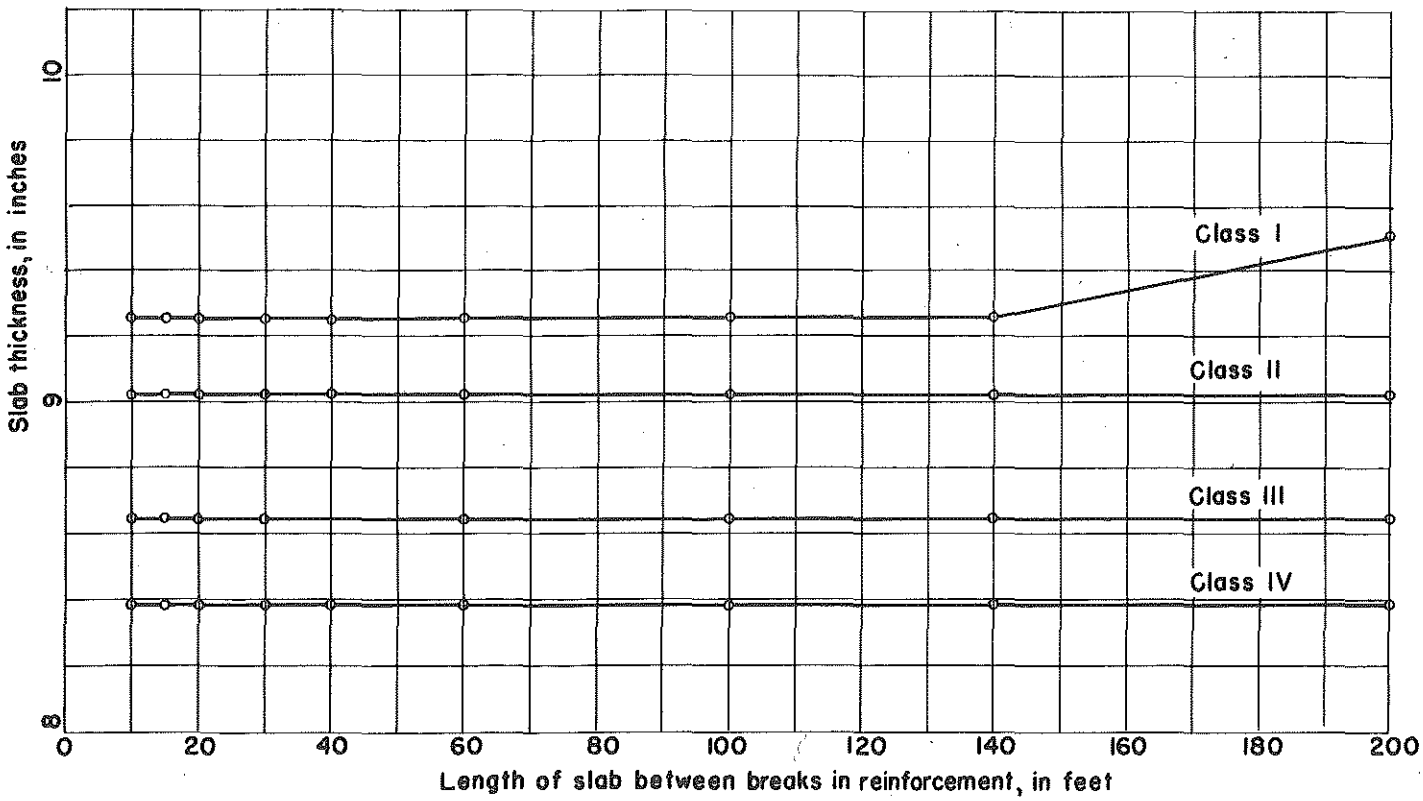
obtained from the curves in Figure 5. It was found that when no load transfer is considered the corner stresses are the governing factor in slab design. The maximum combined stresses at all other points in the slab being less than those at the corner in most cases.

The curves in Figure 5 indicate that continuous slab lengths of 200 feet or less have very little effect upon slab thickness. Whereas in the case of hinged slab construction, the slab thickness increases slightly with slab length. This is caused by the influence of subgrade friction stresses which must be combined with warping and load stresses at the corners occuring at all intermediate joints between the contraction joints.

Furthermore, the variation in slab thickness between Class I and IV highways is very small amounting to approximately one inch in thickness. This appears true for both types of pavement construction.

DESIGN DIAGRAM FOR CONTINUOUS REINFORCED SLABS

For Highway Classes I-II-III-IV



DESIGN DIAGRAM FOR HINGED REINFORCED SLABS

For Highway Classes I-II-III-IV

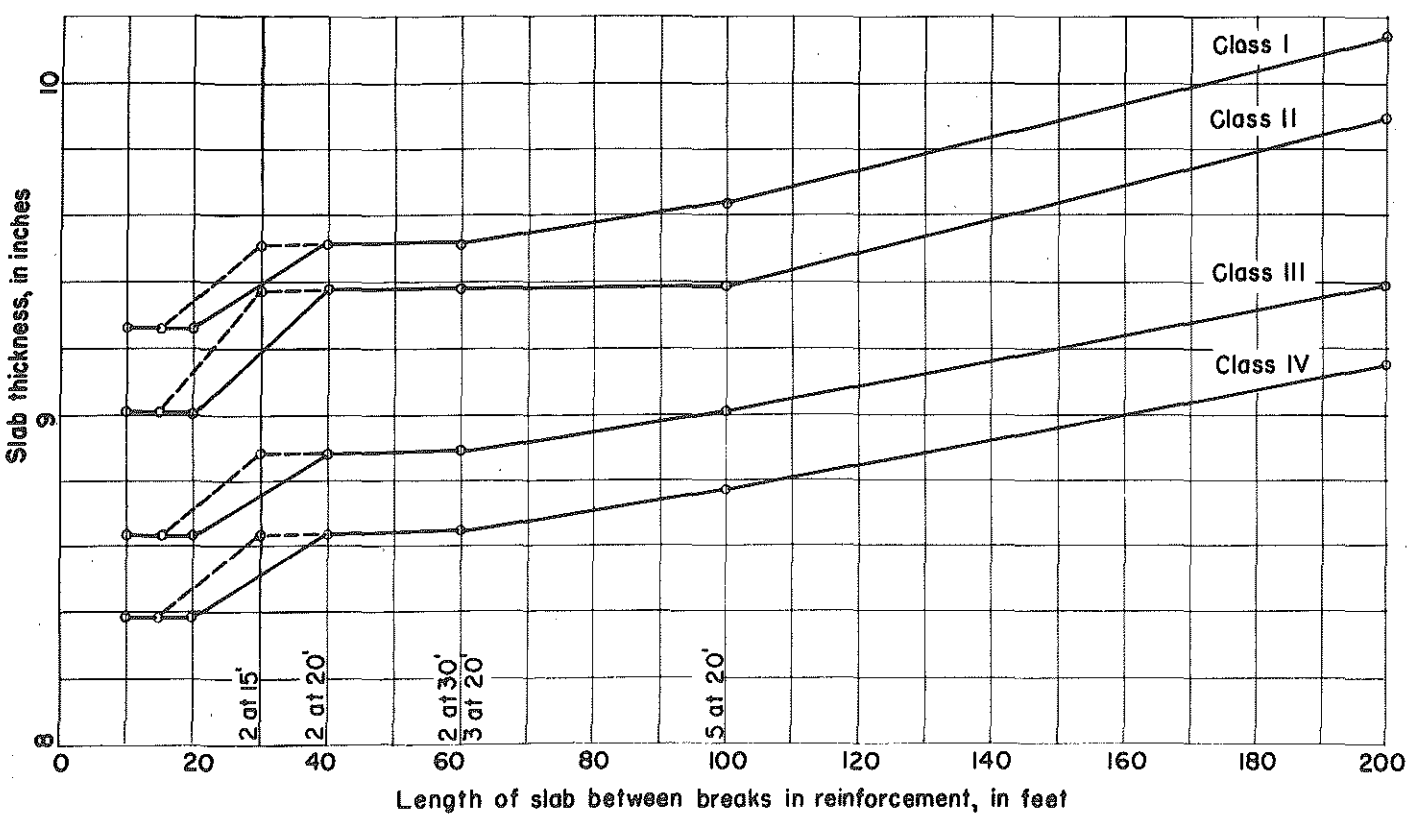


Figure 3

JOINT SPACING

Joints are normally provided in concrete pavements to reduce to safe values the stresses caused by expansion, contraction and warping of the concrete and by subgrade friction forces. Joints in this category are expansion, contraction and dummy joints.

Expansion Joints:

The spacing of expansion joints should be dependent on the allowable compressive stress in the concrete and on the maximum compressive stress created by the expansion of the slab.

The average compressive strength of pavement concrete in Michigan is approximately 4000 to 5000 pounds per square inch at 28 days. Compression tests on pavement cores at ages of one year or more indicate compressive strength values consistently between 4000 to 6000 pounds per square inch. It will be shown later that such unit compressive strength values are in excess of any that might be caused by extreme temperature fluxations common to Michigan.

For example, assume as an extreme case a pavement laid during an air temperature of 40°F and the concrete reached a temperature of 140°F. the following summer which is quite possible in Michigan. If the slab is in full restraint at both ends, the maximum possible unit compressive stress which could occur under a temperature differential of 100°F would be 2500 pounds as computed by the following equation:

$$S_c = E.e.t.$$

Where

S_c = Unit compressive stress in pounds per square inch
E = Modulus of elasticity ($5x10^6$ p.s.i.)
e = Coefficient of expansion (.000005)
t = Temperature differential (100°F.)

This value is approximately 50% of the ultimate compression strength of the concrete.

At the plane of weakness joints the unit compressive stress may increase from 2500 pounds to approximately 3800 pounds per square inch due to reduction in cross section area caused by the groove or bituminous parting strip.

Furthermore, such high unit compressive stresses are not likely to occur only after the pavement has attained a great age. This fact is obvious because the hardening shrinkage factor of concrete is approximately .02%. Such a shrinkage factor is equivalent to a temperature differential of 40°F. Thus in reality the compressive stresses set up in a fully restrained slab under extreme temperature conditions would be equivalent to those caused by a 60°F temperature differential amounting to 2250 pounds per square inch at plane of weakness joints. This condition would still allow an ample safety factor for a future increase in compressive stresses caused by moisture and chemical growth as well as infiltration of foreign matter at cracks and joints which tend to increase the length of concrete slabs with age.

It has been observed that compression failures are of two types (1) those manifested by slow crushing of the concrete and (2) those manifested by sudden blowing up of the pavement. See Figure 4. Failures of both types most generally occur on pavements at least 15 years or more in age. Those of the first type occur only when the concrete, especially at transverse joints, has been over-stressed because of the unequal distribution of the compression force along the joint face. Such conditions are not likely to occur so frequently on modern pavements employing the non-extending type of joint filler. In general such blow ups are manifested by crushing of the concrete in a localized area with the crushed mass usually displaced slightly above the surrounding surface. A failure of this type does not necessarily cause a very severe hazard to traffic and then can be easily and quickly repaired.

A. Illustrating type one compression failure.

B. Illustrating type two compression failure.

Figure 4

Compression failures of the second type materialize by sudden rupture of the slab in tension and compression resulting in the pushing up of large sections of slab in the form of a roof section. Such a failure may constitute a serious traffic hazard since it is difficult for the driver of a fast moving vehicle to visualize the height to which the peak of the blow up area has risen. Consequently any attempt to ride the blow up may result in a serious accident.

It is an inherent characteristic of long concrete pavement slabs to break eventually into shorter units and in the light of present knowledge there seems to be no means available at the present time to prevent entirely this phenomenon.

Survey data show that the number of slab units developing in any one 100 foot slab may, over a period of years and under normal traffic conditions, range from 0 to 9 or more. The rate of cracking on any project is apparently a function of the characteristics of the subbase material and age, all other factors assumed comparable.

Cracking will occur much sooner and be more pronounced in a slab constructed on clays, heavy loams or sandy loam soils than on well-drained granular materials.

In order to control cracking of concrete slabs steel reinforcement is usually considered as an alternative for short slabs. When steel reinforcement is employed it must be designed to limit the maximum width of cracks that may develop to a very small dimension thus minimizing the possibility of creating edge weakness at cracks.

A relationship between slab length, slab thickness and quantity of longitudinal reinforcement necessary for proper design is shown in Figure 5. This relationship is based on the Department's 1942 specification requirements for

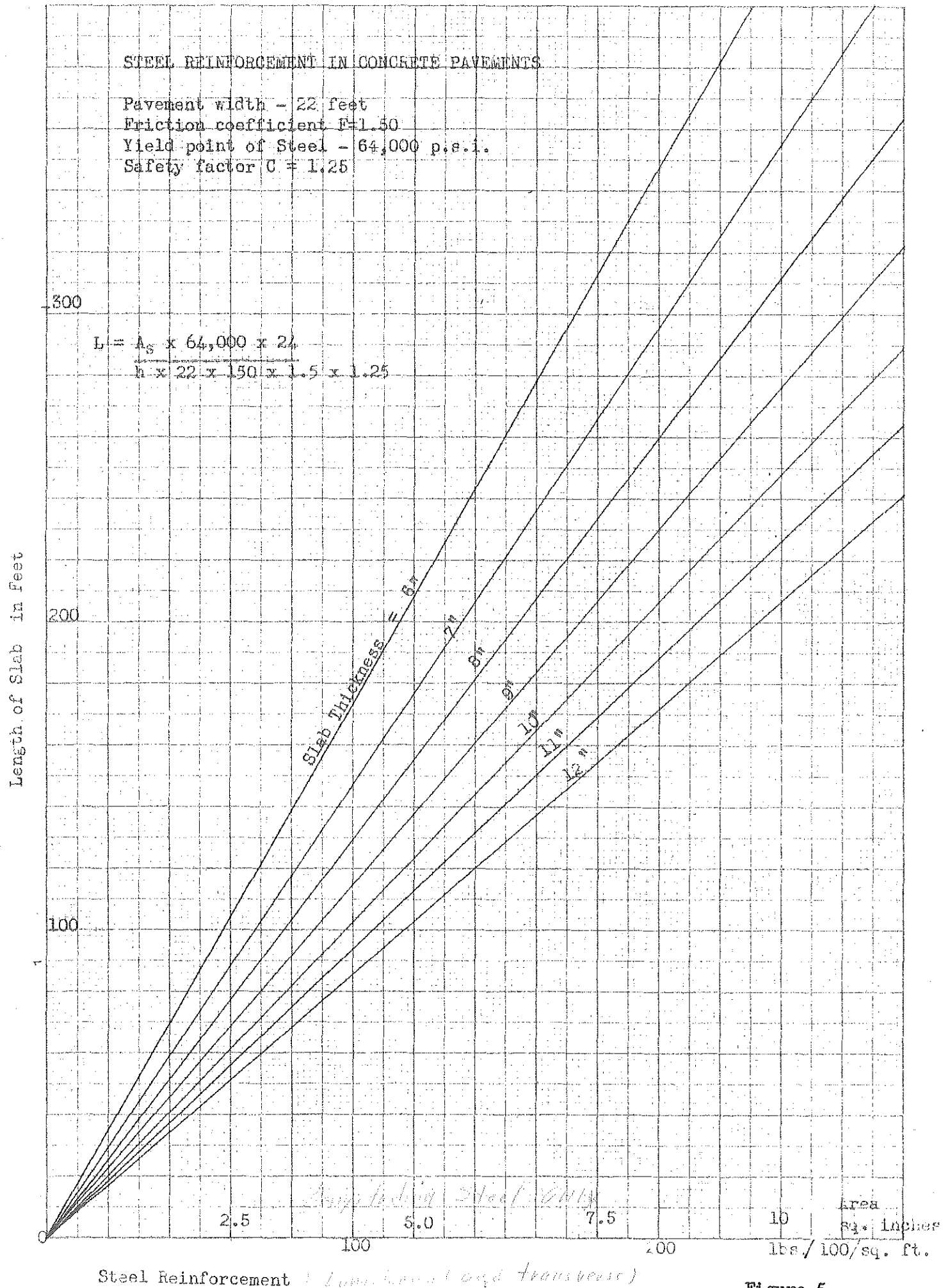

STEEL REINFORCEMENT IN CONCRETE PAVEMENTS
Pavement width - 22 feet
Friction coefficient F=1.50
Yield point of Steel - 64,000 p.s.i.
Safety factor C = 1.25
L = As x 64,000 x 24 / h x 22 x 150 x 1.5 x 1.25
Slab Thickness = 6"
7"
8"
9"
10"
11"
12"
300
200
100
0
Length of Slab in Feet
2.5
5.0
7.5
10
Area sq. inches
100
200
lbs./100/sq. ft.
Steel Reinforcement

Figure 5

mesh reinforcement 7.05.03 in accordance with A.S.T.M. Designation A 185. From Figure 5 it is possible to determine quickly the proper amount of reinforcement for use with a given slab thickness and slab length.

Contraction and Dummy Joint Spacing

Several factors govern the spacing of contraction and dummy joints in reinforced pavements. They are:

1. The joints should not open sufficiently to affect riding qualities, or allow infiltration of foreign matter.

2. The allowable stress in the concrete to prevent cracking.

3. And the cost of steel reinforcement.

Results from the joint movement study on the Michigan Test Road indicate that contraction joints must be spaced less than 60 feet apart if joint width openings are to be kept within satisfactory limits. Relationships between contraction joint openings, spacing of contraction joints and length of pavement sections are presented in Figure 6.

Experience indicates that dummy joint spacings of 20 feet or less are required in order to eliminate cracking of concrete pavements.

Further it is generally believed that reinforcement is not necessary when contraction joints are spaced at twenty feet or less.

Comparative Costs

For the purpose of comparing the relative costs of continuous versus hinged types of pavement construction, comparative cost figures have been prepared for different joint spacings. The relative cost values are presented in Table III. For the purpose of computing relative costs a value of 1000 feet has been assumed for the probable expansion joint spacing to be used in the case of hinged slab construction. Expansion joint spacings

DESIGN PROJECT SERIES I, II, III, IV

RELATIONSHIP BETWEEN AVERAGE MAXIMUM CONTRACTION JOINT OPENING AND SPACING OF CONTRACTION JOINTS

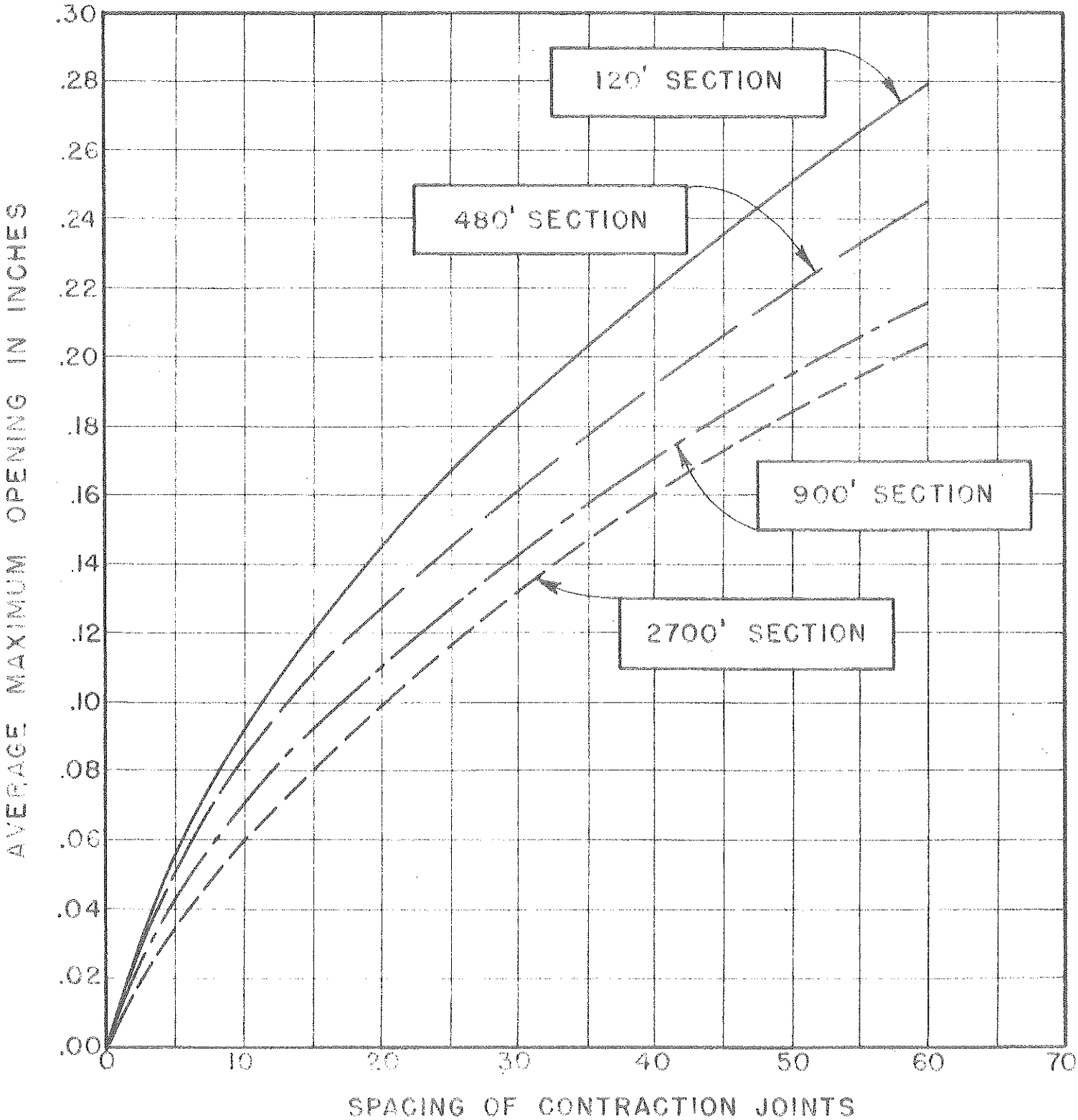


Figure 6

TABLE 3

Summary of Relative Pavement Costs for Different Joint Spacings and Reinforced Slabs.

TYPE I HIGHWAY

Load transfer not considered - Shear bars provided to prevent faulting.

10 Inch Uniform Slab Construction

Design Designation	Expansion Joint Spacing Feet	Contraction Joint Spacing Feet	Dummy Joint Spacing Feet	Longitudinal Reinforcement per 100 sq. ft. Pounds	Cost Per Mile Dollars	Relative Cost	No.
A	200	none	none	195	49,878	1.305	1
B	100	none	none	98	43,553	1.140	2
D	120	60	20	59	41,852	1.095	3
F	1000	60	20	59	41,556	1.087	4
C	120	60	30	59	41,464	1.085	5
E	1000	60	30	59	41,169	1.077	6
I	1000	60	none	59	40,782	1.067	7
N	1000	10	none	none	40,542	1.061	8
G	1000	40	20	39	40,356	1.056	9
H	1000	30	15	29	40,239	1.053	10
J	1000	40	none	39	39,775	1.041	11
L	1000	20	none	20	39,612	1.036	12
K	1000	30	none	29	38,465	1.033	13
M	1000	20	none	none	38,218	1.000	14

ESTIMATED PRICES FOR COMPUTING COSTS

Class A Concrete, including center joint finishing and curing per cubic yard	$10.00
Reinforcement, mesh per pound	.06
Expansion Joint, complete at 75 cents per foot	16.50
Contraction Joint, complete at 40 cents per foot	8.80
Dummy Joint, complete at 20 cents per foot	4.40

less than 1000 are not anticipated. If greater expansion joint spacings are preferred the relative pavement costs would be affected but little. All relative cost values have been based on the cheapest construction which consists of contraction joint spacings of 20 feet and no reinforcement.

Field Experiments

On the Michigan Test Road pavement sections up to 2700 feet in length were constructed without expansion joints. No unusual developments have occurred on these sections during the past four years. The data present in Figure 7 and 7a indicate that sections of pavement up to 1800 feet in length may be constructed with the pavement still retaining its normal expansion properties when a minimum space of 2 inches is provided for expansion. The 900 to 1000 foot lengths of pavement within the central portion of the same 2700 sections have been under restraint comparable to that of a pavement with no expansion joints for the last four years without any noticable detrimental effect.

Results from Indiana's experiments with continuous reinforcement in concrete slabs indicate that there is a definite limitation as to slab length and amount of reinforcement which will reduce cracking to a minimum. The crack pattern on the Indiana experimental road would indicate that this optimum slab length is some value between 100 and 200 feet.

Condition surveys on many pavements in Michigan over 10 years of age and constructed with 100 foot slab lengths revealed that many of the slabs were in perfect condition, especially so in those areas where the pavement was constructed on a granular subgrade material. At that time very little attention was given to certain subgrade refinements such as the removal of frost heave material or to the use of sand subbases. Because of the fact that it appears possible to construct slabs 100 feet in length without them develop-

RELATIONSHIP BETWEEN SECTION MOVEMENT AND DISTANCE FROM CENTER OF SECTION

SERIES I-F - LENGTH 2700'

SPACING OF CONTRACTION JOINTS 60'

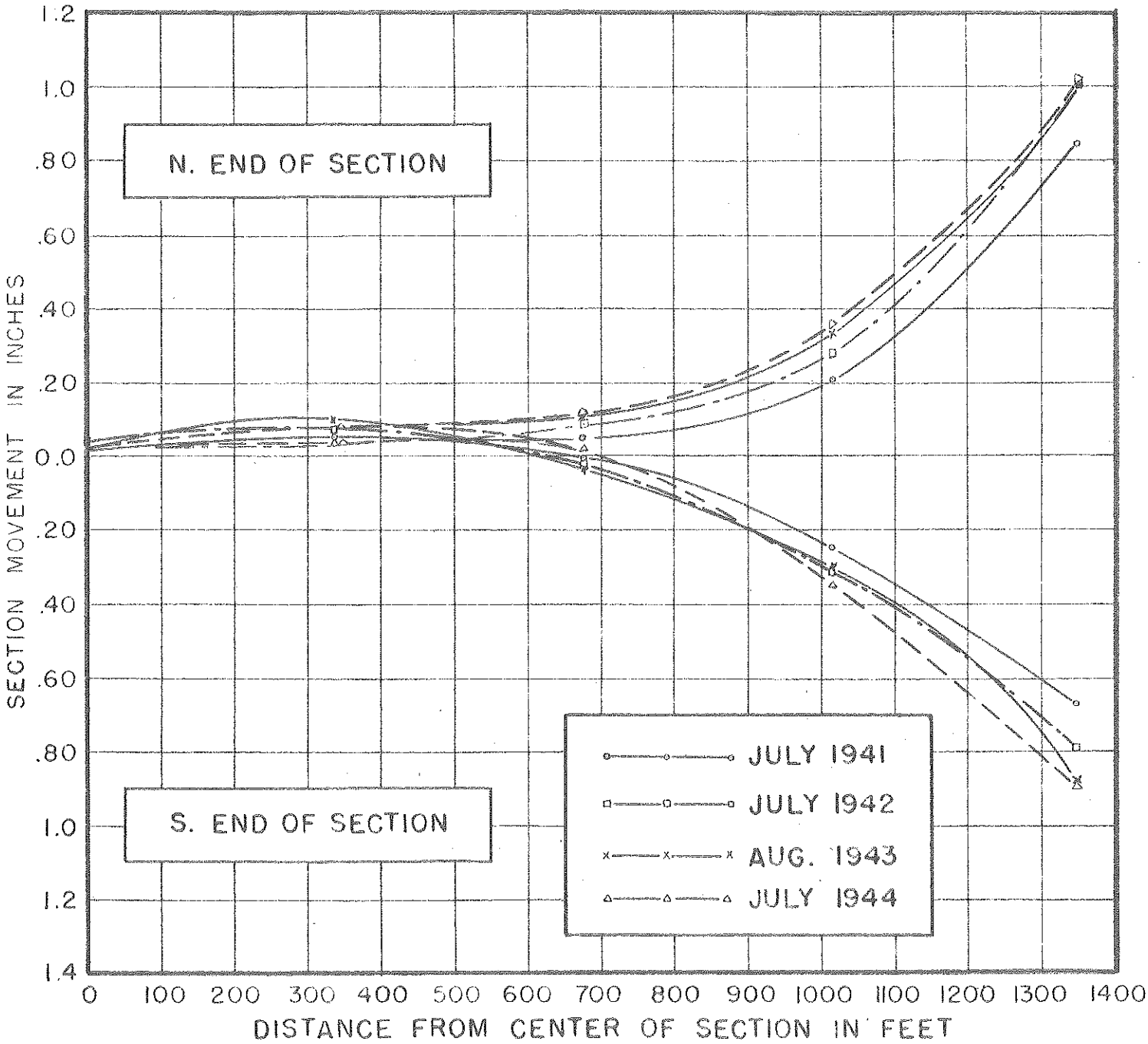


Figure 7

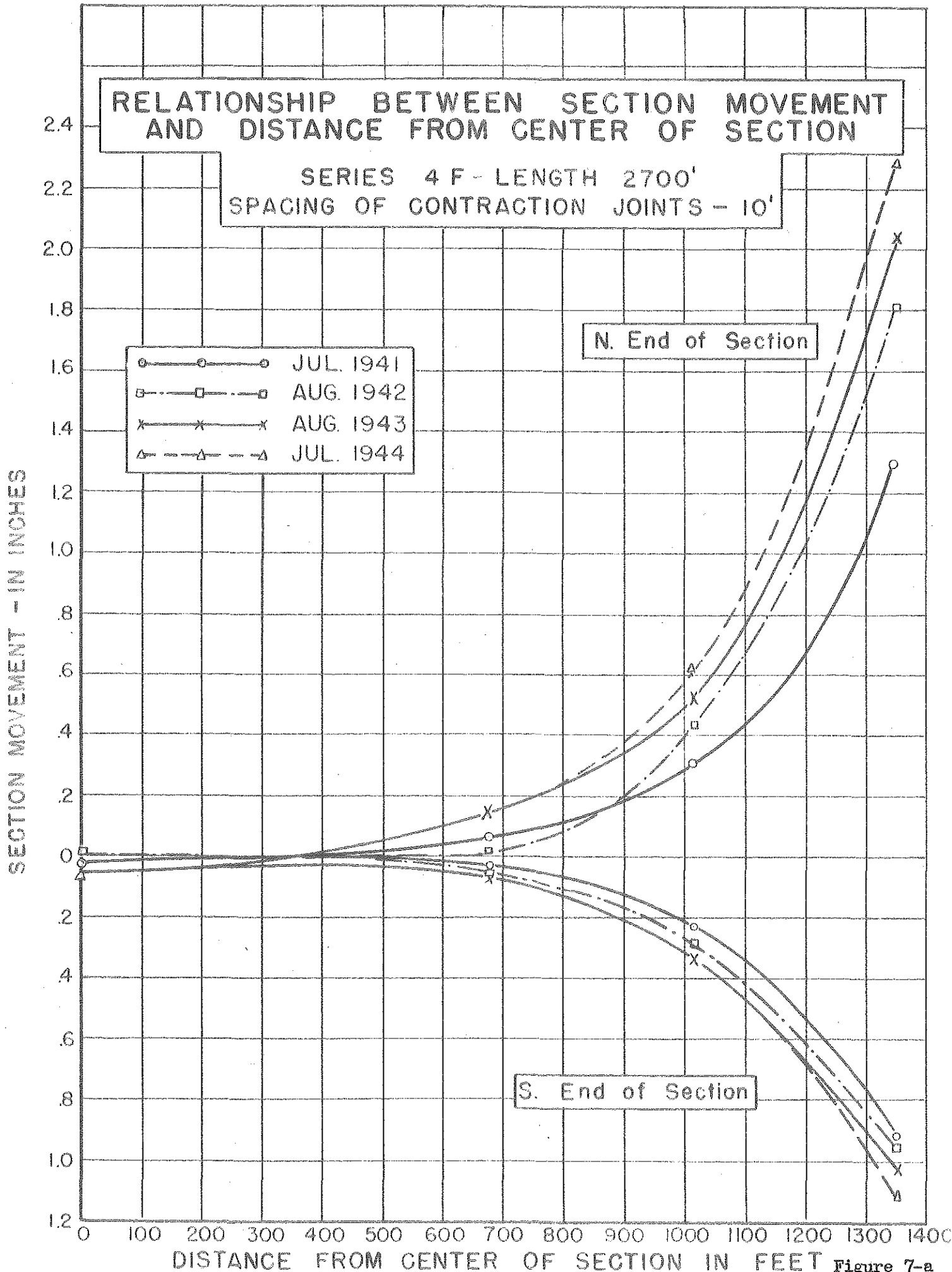

RELATIONSHIP BETWEEN SECTION MOVEMENT AND DISTANCE FROM CENTER OF SECTION
SERIES 4 F - LENGTH 2700'
SPACING OF CONTRACTION JOINTS - 10'
JUL. 1941
AUG. 1942
AUG. 1943
JUL. 1944
N. End of Section
S. End of Section
SECTION MOVEMENT - IN INCHES
DISTANCE FROM CENTER OF SECTION IN FEET
2.4
2.2
2.0
1.8
1.6
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

Figure 7-a

ing serious cracking at least within 10 years, one is prone to speculate on the service behavior of this type of pavement when built under modern design and construction methods. Such a plan would require that the slabs be reinforced adequately to resist cracking, with expansion joints 3/4 inch or less in width and the joints adequately designed to resist faulting, infiltration of water and inert material. The initial cost per mile of such construction may be slightly higher than the hinged construction, but the criticisms against the use of short slabs and frequent joints would be greatly overcome.

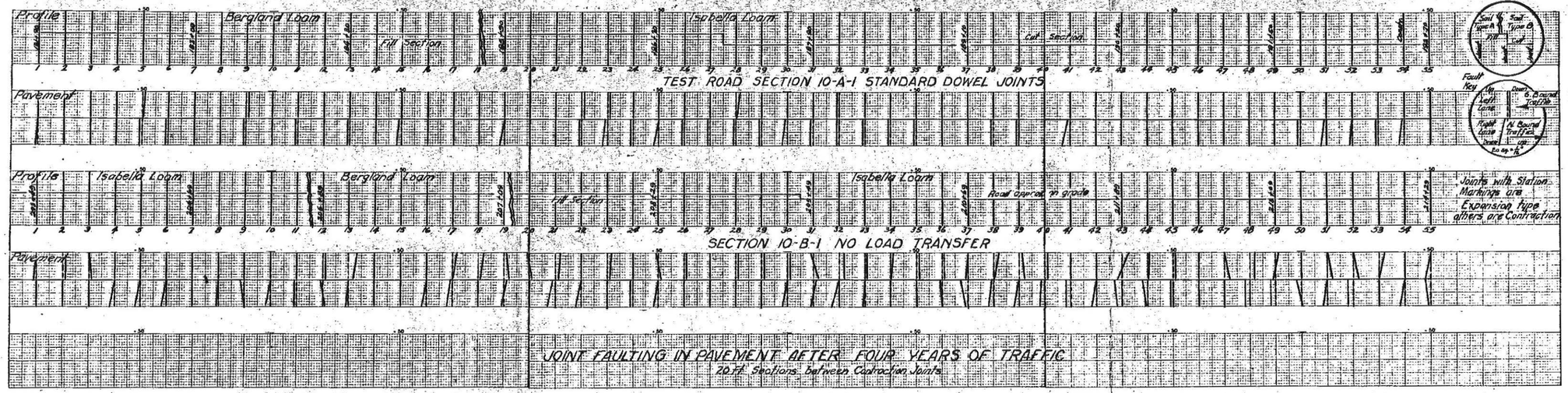
JOINT DESIGN

The design of transverse joints necessitates consideration of certain structural features which enable the joint to perform the function for which it is intended, including movement for expansion or contraction, load transfer where necessary, flexibility for warping and adequate seal against infiltration of water and foreign matter.

Visual surveys of many miles of concrete pavements in Michigan reveal that considerable faulting has occurred at expansion and contraction joints constructed either with or without dowels or other devices. This situation is more pronounced in pavements located on trunklines carrying heavy commercial traffic. Also, faulting is becoming quite noticeable on wartime pavements in which the reinforcement and dowel bars have been eliminated as part of the war effort to save steel.

A recent condition survey of series 10A and 10B of the design project (Michigan Test Road), which have been established for the purpose of studying joint design, revealed considerable faulting at both expansion and contraction joints. The faulting was more pronounced in those sections constructed without dowels. These sections of pavement were constructed with and without 3/4"x15" dowel bars. The degree of faulting encountered during the survey is shown in Figure 8.

These data in Figure 8 indicate that in the doweled Series 10A, 5 percent of the expansion joints have faulted 1/8 inch or more as compared to 67 percent in the undoweled series 10B. Considering the contraction joints, in the doweled Series 10A, 8 percent have faulted 1/8 inch or more as compared to series 10B, without dowels, when 32 percent of all contraction joints had faulted.


Profile
Bergland Loam
Fill section
Isabella Loam
Cut section
Soil Type A
Soil Type B
Fill
Cut
TEST ROAD SECTION 10-A-1 STANDARD DOWEL JOINTS
Pavement
Fault Key
Left Lane
Right Lane
S. Bound Traffic
N. Bound Traffic
Profile
Isabella Loam
Bergland Loam
Fill section
Isabella Loam
Road approx. in grade
Joints with Station Markings are Expansion type others are Contraction
SECTION 10-B-1 NO LOAD TRANSFER
Pavement
JOINT FAULTING IN PAVEMENT AFTER FOUR YEARS OF TRAFFIC
20 ft. Sections between Contraction Joints

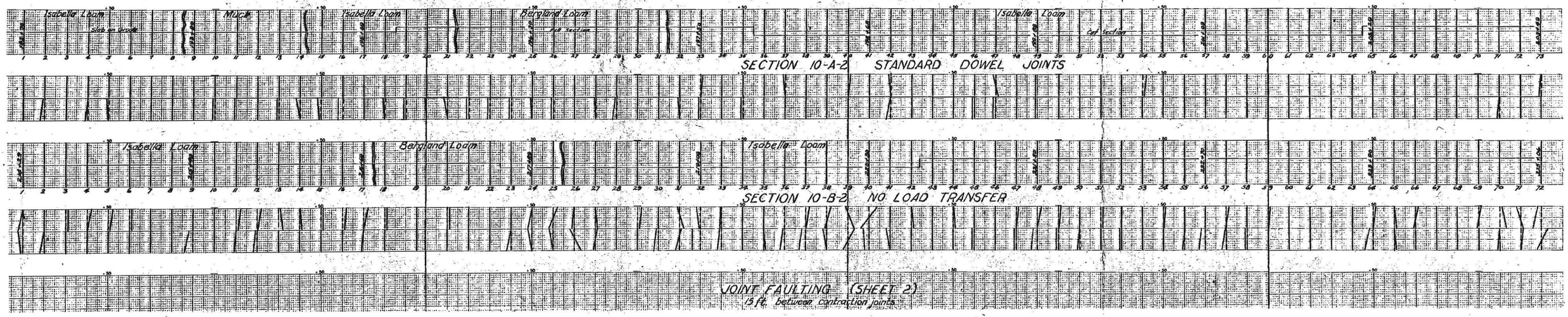

Isabella Loam
Slab on grade
Muck
Isabella Loam
Bergland Loam
Fill section
Isabella Loam
Cut section
SECTION 10-A-2 STANDARD DOWEL JOINTS
Isabella Loam
Bergland Loam
Isabella Loam
SECTION 10-B-2 NO LOAD TRANSFER
JOINT FAULTING (SHEET 2)
15 ft. between contraction joints

Figure 8

Observations of contraction joint width movement on the Michigan Test Road indicate that certain joints in the central part of the 2700 foot sections have opened as much as 0.2 to 0.3 inches during the winter season even though the slabs are under restraint similar to that of pavements constructed without expansion joints. Such joint width movements are sufficient to disrupt the structural continuity of the pavement unless dowels or other devices are provided across the joints. Under such conditions faulting at the joints may occur unless adequate subgrade support is provided.

A few years ago the Department, realizing the importance of the joint design problem, made a preliminary investigation of several available load transfer devices with the view of developing a method for evaluating joint units in terms of their load transfer ability. After developing an appropriate test procedure and performing tests on a few joint units, the investigation was temporarily suspended because of the help situation. Consequently, the subject has not been completely investigated.

The investigation included several types of commercial joint units and two sizes of dowel bars. The dowel bars were tested with and without devices for distributing the stress uniformily throughout the concrete surrounding the joint unit. The various joint units tested are described in Tables IV and V. The joint units which have been thoroughly tested are evaluated in Table V on the basis of their relative spacing in the joint in order that the unit stress in the concrete surrounding the unit does not exceed the assumed design value of 375 pounds per square inch. Joint unit (LBC-G) with the greatest permissable spacing of 24 inches was taken as 100 percent for comparative purposes. The two most efficient joint units tested are illustrated in Figure 9.

TABLE IV

LOAD TRANSFER DEVICES INCLUDED IN STUDY

SYMBOL	TRADE NAME AND MANUFACTURER COMMERCIAL DEVICES		TEST
A	Translode Angle Unit	Highway Steel Products	NC
B	Translode	Highway Steel Products	C
C	Double Dowel	Highway Steel Products	NC
CC	New Double Dowel	Highway Steel Products	C
E	Dowel Bucket	American Steel & Wire	NC
EE	Ringed Dowel	American Steel & Wire	C
EFS	Fabricated Unit	American Steel & Wire	C
F	Godwin Truss Unit	W. S. Godwin Inc.	NC
I	Wing Bearing	National Joint Co.	C
	3/4"x15" DOWEL BARS WITH STRESS DISTRIBUTING DEVICE		
GRS	Grade (SAE 1020) with welded rotor sleeve		NC
HDW	Intermediate Grade (A15-39) with washer		NC
GRC	Grade (SAE 1020) with cast rotor sleeve		C
GRW	Grade (SAE 1020) with washer		NC
	3/4"x15" PLAIN DOWEL BARS		
U	Rail Steel		NC
H	Intermediate Grade (A15-39)		C
	1 1/4" x 15" DOWEL BARS WITH STRESS DISTRIBUTING DEVICE		
LRC	Grade (SAE 1020) with cast rotor sleeve		C
LRS	Grade (SAE 1020) with welded rotor sleeve		NC
	1 1/4"x15" PLAIN DOWEL BARS		
L	Grade (SAE 1020)		NC

Test Code:

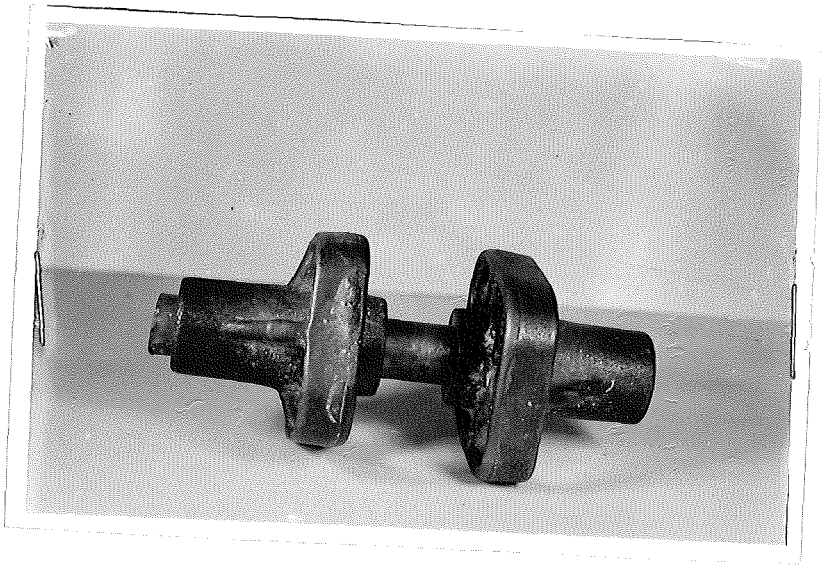
NC = Tests have not been completed.
C = Tests have been completed.

TABLE V

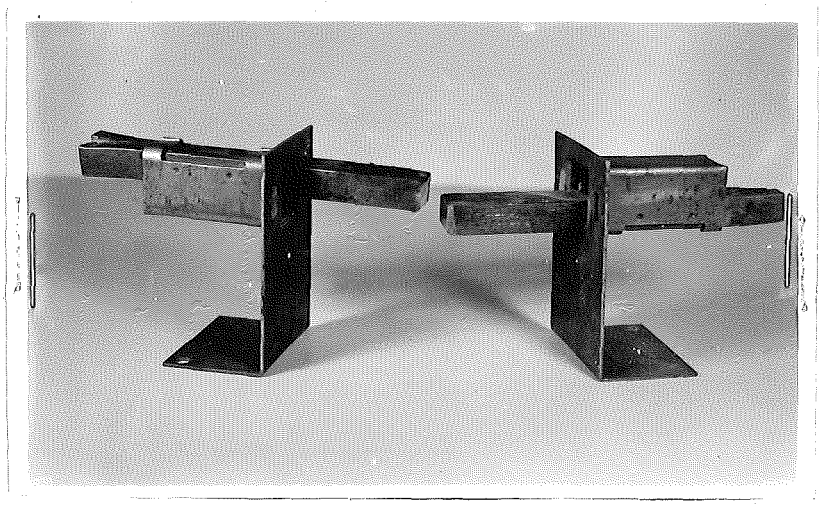
EVALUATION OF LOAD TRANSFER UNITS ON WHICH TESTS HAVE BEEN COMPLETED

Symbol	Ultimate Shear Strength of unit V - in lbs.	Tested to Max. repeated Shear of V - lbs.	Deflection in 10^{-4} inches at V= 1000 lbs.	When total combined stress in concrete at edge due to load, warping and impact does not exceed 375 p.s.i. for h=7" and k=100 p.c.i. Max. Shear V - lbs.	Joint Spacing in inches (a)	Rating %
LBC-0	17,000	3000	17.5	2930	24	100
CC-0	7,500	2250	23.1	2470	20	83
1-EPS-0	9,000	2000	37.7	1850	16	65
H-0	7,500	1000	50.0	1400	12	50
GBC-0	12,850	2500	63.0	1190	11	46
I-0	11,500	1500	75.0	980	11	40
S-0	7,000	1250	81.1	895	9	37
2-SE-0	10,000	2000	181.0	125	2	8

$$\text{rating} = \frac{a}{24} \times 100$$



A. (LRC) 1 1/4"x15" Dowel Bar with rotor sleeve.



B. (C) Double Dowel Unit by Highway Steel Products. Company.

Figure 9

The data presented in Table V, although not conclusive, discloses several significant facts which may be helpful in setting up new specification requirements for joint units. In the first place the evaluation brings out the significance of joint spacing on performance. In other words, from an economic standpoint the better and perhaps more expensive joint units may be spaced at greater distances apart along the joint and still give the same performance as the less efficient and cheaper units which must be spaced at closer intervals. In such a case the cost of the two installations might be fairly comparable. Second, according to these data the standard 3/4"x15" dowel should not be spaced more than 12 inches apart and perhaps less. Third, the double dowel developed by the Highway Steel Products Company shows up very well among the commercial joint units. The double dowel joint unit has a rectangular cross section 3/4"x 1 1/4" with an area of 0.9375 square inches. This may account for the low deflection and high shear value of the joint. However, the joint unit has a rather low ultimate shear strength value in comparison with other more efficient units. This may be due to some inherent weakness in design or construction of the joint unit.

Another joint problem in need of serious consideration at this time concerns the forming of the plane of weakness in the pavement at dummy and contraction joints. Under careful workmanship the premolded bituminous felt strip can be installed properly and whenever this occurs the results are generally quite satisfactory. When the strip is not installed properly, or it becomes tipped during finishing machine operations, which experience proves is the general case, considerable spalling and ravelling occurs along the joint edge. Furthermore, the bituminous felt strip does not provide an adequate seal when the slabs have fully contracted.

On the other hand, the grooved joint eliminates spalling and ravelling at the joint edge and when properly filled with a good bituminous material it will maintain a satisfactory seal indefinitely. Consideration should be given to the use of the grooved joint for post war construction.

It is understood that several States are using compressed wood boards as an expansion joint filler to replace the commonly used bituminous fibre board with excellent results. The compressed board upon becoming saturated with water expands sufficiently to keep the joint sealed against foreign matter at all times. Small compressed wooden strips are also being manufactured as a substitute for the bituminous fibre strip used in place of weakness joints.

RECOMMENDATIONS

On the basis of experience and results from observations and studies several recommendations pertinent to the design and construction of concrete pavements are offered for consideration. It is believed that these recommendations are in keeping with the modern trend in concrete pavement construction practice.

Slab Cross Section and Thickness.

The uniform cross section is considered the most desirable in view of the following reasons:

1. The thickness can be computed by recognized methods.
2. The trend to wider pavements minimized the need of the thickened edge.
3. Auxiliary edge strengthening at transverse joints or cracks when they occur is not normally necessary to reduce stresses.
4. Subgrade preparation can be accomplished better and cheaper.

Slab Thickness: On the basis of the assumptions employed in the calculation of slab thickness, the dimensions given by the graphs in Figure 5 will be a minimum requirement for highways in any one of the four recognized classes.

Joint Spacing and Construction.

Three types of highway construction are offered for consideration in connection with the postwar program; they are:

A. Long Continuous Reinforced Slabs.

Slab lengths	100 feet - no intermediate joints.
Expansion joint spacing	100 feet in accordance with principle No. 4.
Longitudinal reinforcement	In accordance with graph in figure 5.
Uniform thickness	In accordance with graphs in figure 5.
Joint design	Dowels or other devices to prevent faulting should be considered.
Width	Minimum width 1/2 inch.
Filler	Compressed wood board or bituminous fibre board.

B. Hinged Reinforced Slabs.

Contraction joints	40 foot spacing.
Intermediate dummy joints	At 20 foot intervals with reinforcement running continuous through the joint.
Longitudinal reinforcement	In accordance with graph in figure 5.
Uniform thickness	In accordance with graphs in figure 5.
Expansion joint spacing	As permitted by Public Road Administration. Otherwise, not less than 1,000 feet, or entirely omitted except at critical points in accordance with principle No. 4.
Joint design	Dowels or other devices to prevent faulting at contraction and expansion joints should be considered.
Expansion joint width	Minimum width one inch.
Filler	Compressed wood board or bituminous fibre board.

C. Short Unreinforced Slabs.

Contraction joints	Spaced at 20 foot intervals, no intermediate joints.
Uniform thickness	In accordance with graphs in figure 3.
Reinforcement	None
Expansion joint spacing	In accordance with design B.
Joint design	In accordance with design B.

Joint Design

Until more conclusive information is available on joint design, it is suggested that the Department's specifications for the dowel bar assembly be continued except that the spacing of the 3/4 inch dowels be changed from 15 inches to 12 inches.

Consideration should be given to the use of wood for expansion joint filler which has been properly prepared and compressed to specified limits.

The hand finished groove should be considered in lieu of the bituminous felt strip for forming the plane of weakness at contraction and dummy joints.

Foundation

In the design and construction of the subgrade and subbase course when required, greater emphasis should be placed upon obtaining uniform consolidation and maximum density throughout the project.

Concrete Design

Consideration should be given to the possibility of increasing the flexural strength of air entrained concrete. At the present time this can be done to a certain extent by reducing the drop in unit weight to a minimum consistant with desirable durability qualities. In accordance with current practice we should revise the present Department's specifications by changing the drop in unit weight limits of 4 to 8 pounds to 3 to 6 pounds per cubic foot.