THE MICHIGAN TEST ROAD

PREFACE

This bulletin presents a summary of the essential features of design and construction pertinent to the Michigan Test Road. It has been prepared as a reference study for the convenience of those interested in the project. Included in this summary are all of the important factual data relevant to the project; such as location, description, purpose and scope of study, descriptive outline of the test sections and detail layout of the design and durability studies.

The bulletin consists of four parts: the first, presents an introduction to the problem which describes the purpose and scope of the project, preliminary studies and a brief review of subsequent studies. The second and third outline and define, with the aid of illustrations, the scope of the design and durability projects respectively. Included in these parts are described features of design, incidental methods of construction and methods of measurements. The fourth and last part outlines the various subsequent studies which will be conducted throughout the next few years.

The appendices include: (1) the Public Roads Administration outline of "Proposed Experimental Concrete Pavement Construction", (2) the physical characteristics of materials involved in the construction of the Michigan Test Road, (3) sources of materials and equipment, (4) miscellaneous information and (5) a bibliography of literature pertaining to the important studies included in the design and durability projects.

For the convenience of those wishing to visually inspect the experimental project, concrete markers bearing appropriate identification numbers have been installed at the beginning and end of each test area. The key to the identification numbers on the concrete markers will be found in the "Summaries of the Design and Durability Projects," tables 1 and 2 respectively.

The design project of the Michigan Test Road coincides in a general way with the Public Roads Administrations' plans and procedure for construction of experimental roads which were submitted to various state highway organizations in 1940*. The purpose of the Public Roads Administration experimental work, as outlined, was to study the desired spacing of transverse expansion joints in concrete pavements and the amount of expansion space required per unit pavement length, and to study the efficiency of dummy contraction joints with and without dowels or other devices for the transfer of load.

It will be noted, upon further analysis, that the Michigan Test Road is more comprehensive in its scope than the outline of the Public Roads Administration.

The Michigan Test Road was constructed under regular contract and construction procedure using the Michigan State Highway Departments' 1940 plans and specifications with necessary supplementals.

*See Appendix I.

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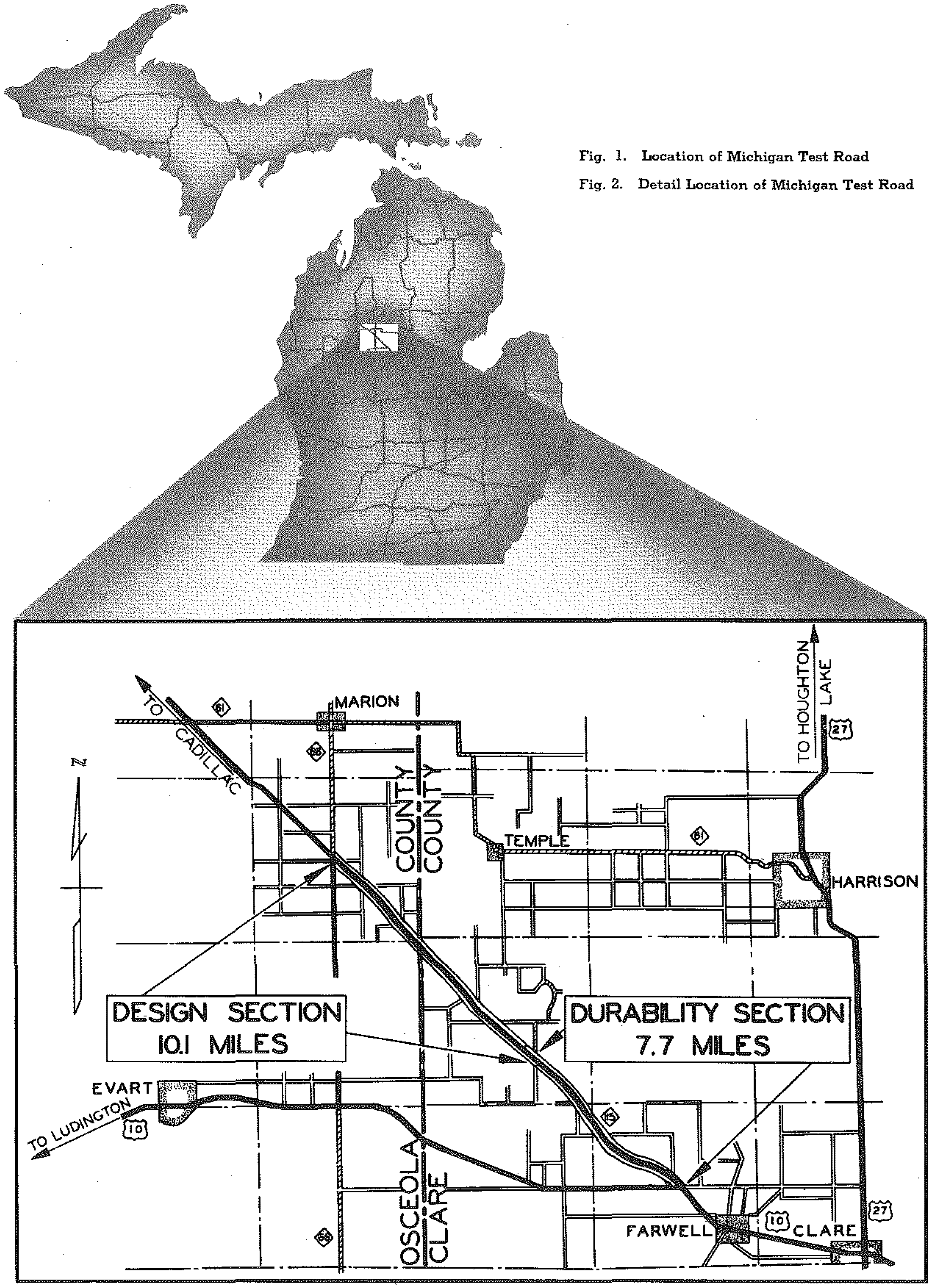


Fig. 1. Location of Michigan Test Road

Fig. 2. Detail Location of Michigan Test Road

PART I

INTRODUCTION

In May 1940, the administration of the Michigan State Highway Department, realized the need for a comprehensive evaluation of modern theories of design and construction practice in concrete pavements. Therefore, it was decided to let contracts for the construction of an experimental concrete pavement project embodying certain controversial and development features which could be used as a study in establishing criteria for concrete pavement design and construction. To this end, the Michigan Test Road was constructed on M-115, between US-10 and M-66, in Clare and Osceola counties, (figures 1 and 2) consisting of 17.8 miles of 22 foot concrete pavement. The test road is further identified as State projects F 18-20, C3; F 18-20, C4; and F 67-37, C6 or Federal Aid Projects 337-D (2); 337-E (2) and 337-F (4) respectively. The test road is essentially divided into two test projects. One project 10.1 miles in length is devoted to a study of the many principles and factors incidental to design and construction. The other 7.7 mile project is utilized for a study of durability factors particularly in regard to scaling.

The primary purpose of the Michigan Test Road is to establish certain fundamental principles in concrete pavement design and to correlate laboratory studies with construction methods in order to develop more durable concrete pavement.

The location of the test road is ideal from the standpoint of grade, alignment and average weather conditions. The maximum grade is 0.65 percent, the maximum curvature 0°-45′ with an approximate average curve length of 3500 feet. The length of the entire project is sufficient to reduce the variables of construction to a minimum for each feature investigated. With the exception of a few thousand feet of clay underlying a one-foot sand cushion, the entire project was placed on a uniform sand subgrade previously constructed in 1937. This subgrade condition insured a uniformity in density and friction which should introduce few variables in the analysis of the problems.

A meteorological station has been established from which a complete continuous record of local weather conditions will be obtained for the duration of the study.

It is estimated that it will require four to five years to make a complete analysis of all of the factors involved, including the subsequent investigations which follow the completion of the construction of the project. Periodic reports will be made as the work progresses.

PRELIMINARY STUDIES

Prior to the construction of the Michigan Test Road, it was necessary to make a number of preliminary studies and develop certain equipment in order to determine procedure, layout, materials to be used and types of measurements to be included in the complete study.

This work was divided into three phases namely the study of stresses in concrete pavements, development of tests and equipment, and a study of available materials.

The study of stresses in concrete pavements necessitated a review of previous work by other investigators together with a correlation of this information to the end that a definite hypothesis might be set up for the determination of certain unknown factors important to concrete pavement design. This study also determined what types of measuring devices were needed and the proper location for their installation.

A number of new testing methods and devices were investigated or developed which included—

1. Subgrade tests and equipment.
2. Moisture determination and calibration of equipment.
3. Stress determination and calibration of equipment.
4. Development of slab movement measuring device.
5. Sonic apparatus for measuring modulus of elasticity.

The description and development of these methods or devices is not pertinent to this report and will be discussed in other reports.

A number of materials have been offered to the Highway departments for the improvement of concrete pavements. Such materials include blends of cements, additives, aggregates and joint sealers. The preliminary study of such materials comprised an evaluation by freezing and thawing methods, accelerated scaling tests and other tests for characteristics of application and durability. Studies were made upon a number of proprietary additives, natural sands and mineral fillers together with determination of proper proportioning. Various types of joint seals were studied and a special oil latex sealer was developed.

SCOPE OF THE PROJECT

Included in the test road are many of the latest ideas of modern concrete road construction. The important design studies considered with respect to modern practices are—

1. Spacing of expansion and contraction joints.
2. Expansion and contraction joint design.
3. Uniform slab thickness versus balanced cross sections.
4. Amount of reinforcing steel necessary.
5. Relation of pavement cross section to subgrade supporting value.
6. Pavement cross section thickness.
7. Prestressing of concrete slabs during curing.

The construction features incidental to the design project are—

1. Mechanical versus manual handling of concrete on subgrade.
2. Mechanical versus hand tamping of forms.
3. The use of different types of seals.

On the durability project, the constituents of concrete which might affect the durability of concrete pavement have been varied to include—

1. The grading of aggregates.
2. Various types of admixtures with Portland cement.
3. The use of various finishing methods.
4. The application of different methods of curing.

MEASURING DEVICES. Throughout the entire project special measuring devices have been installed including—

1. Electrical strain gages for measuring stresses.
2. Thermocouples for temperature studies.
3. Moisture cells for determining moisture content of concrete and subgrade soil.
4. Reference monuments for detecting slab movement.
5. Reference points for measuring changes in joint width.
6. Elevation points for measuring vertical displacement of concrete pavement slabs at joints.

In addition to the many observations made during the construction of the Michigan Test Road, a series of subsequent studies will be made following the completion of construction operations.

SUBSEQUENT STUDIES

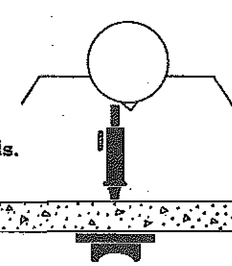
The evaluation of the many factors included in the Michigan Test Road will be determined from these subsequent studies which will be carried on over a period of years or until such time that sufficient data will be obtained to warrant drawing ultimate conclusions. These subsequent studies include pavement condition surveys, physical and displacement measurements, and special scaling studies.

PAVEMENT CONDITION SURVEYS. Twice each year a complete visual condition survey will be conducted throughout the entire length of the Michigan Test Road to observe and record the changes occurring in the physical structure of the pavement slabs.

PAVEMENT STUDIES. On the design project, daily, seasonal and permanent measurements will be made with the various measuring devices embedded in the concrete to determine the changes in physical characteristics of the concrete with age, temperature and moisture conditions.

SCALING STUDY. The durability project will be subjected to a series of controlled calcium chloride treatments each winter season for several years to determine the relative ability of the various concrete mixtures to resist scaling and disintegration. The scaling study will be augmented by extensive laboratory work.

The general phases of the studies embodied in the Michigan Test Road have been discussed in the introduction, the balance of the report will explain the principles and factors embodied in the design and durability projects respectively and describe briefly the work which will be carried on in the subsequent studies.



PART II

THE DESIGN PROJECT

The structural adequacy of a concrete pavement slab from the standpoint of strength and permanency is influenced by the features of design which determine its continuity and dimensions.

The importance and the need of development of principles for adequate design in concrete pavement construction is demonstrated by the fact that three important test roads have been built to study factors of design; viz., Pittsburg (California) Test Road[1], Bates (Illinois) Test Road[2], and Arlington (Virginia) Test Road[3]. As will be shown, all of these projects have contributed many needed principles, but certain questions remain unanswered. The first two were built and tested between 1920 and 1923, the purpose of the tests being to determine the reaction of various types and designs of pavements under the accelerated action of frequent traffic loadings. These studies included measurements of such factors as —

Subgrade moisture
Subgrade bearing power
Subgrade uniformity
Impact and cross section.

In most cases, these factors showed definite relationships to failures and the results obtained assisted materially in developing the early empirical formulae for design of pavement slabs.

In 1925, the Public Roads administration began the theoretical study of pavement design at which time the Westergaard formulae[4] were developed. In order to check these formulae and obtain other pertinent data, the Public Roads Administration constructed the Arlington Test Road. The results from this research provided the basis for a report "Application of the Results of Research to the Structural Design of Concrete Pavements", by E. F. Kelley[5]. In the summary of this report, Mr. Kelley states: "The discussion that has been presented leads inevitably to certain conclusions which, if accepted, require a rather drastic revision in some of the accepted ideas concerning the structural design of concrete pavements. These conclusions are open to attack principally on the ground that practical experience in certain localities or under certain conditions does not always support them."

If it be true that there is disparagement between these conclusions and practical observations of certain localities — then before any locality can accept such conclusions, it is necessary to determine the causes for such differences and where necessary determine the proper principles of design for the given conditions.

It would seem necessary then for the need of further research to determine whether the modified Westergaard analyses of stress is the only adequate basis for concrete slab design; and further, to determine the limits of physical characteristics in subgrade and concrete to be used for design as well as to determine practical methods for their measurement.

Little attention to warping stresses has been given by the Michigan State Highway Department. Study should be made of their importance and how these stresses are affected by various joint spacings. A method of evaluating slab strengthening at joints by various methods should be determined. The economical value of reinforcing steel versus various joint spacings should also be considered.

(1), (2), (3), (4) and (5) — See bibliography.

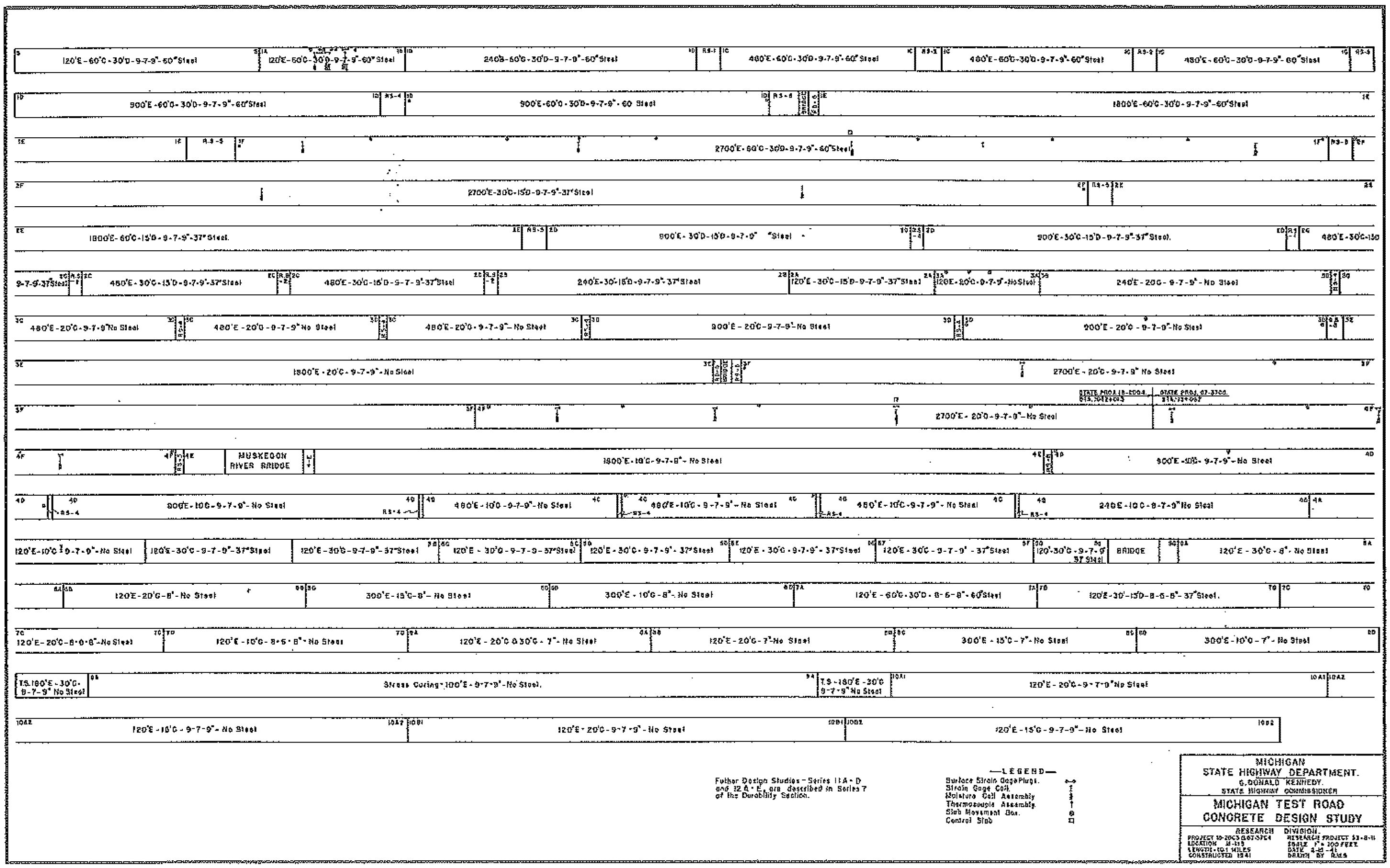


FIG. 3. SCHEMATIC DIAGRAM OF DESIGN PROJECT

In order to include for study the many important design features previously discussed, it was necessary to divide the design project of the Michigan Test Road into ten test areas. Each test area, has been established for the purpose of studying a certain design feature under controlled conditions. The test areas, designated as series 1 to 10 and described in "Summary of Test Areas of Design Project", table 1, have been further subdivided into divisions and sections in order to facilitate the study of a particular design feature under different conditions of slab construction. The divisions and sections are designated in table 1 by letters and numerals respectively.

In addition to table 1, which includes important information pertinent to each test series and division, a schematic "Diagram of Design Project" (figure 3) has been prepared to show the relative location of the various features with respect to the entire design project.

The primary features of pavement design included in the design project and discussed briefly in the following text are the spacing and design of expansion and contraction joints, pavement cross section and steel reinforcement.

The methods of measuring physical conditions relevant to the above studies will be described as well as the several incidental studies carried on in conjunction with the construction of the design project.

DELIMITATIONS. The pavement on this project was constructed for the most part on a subgrade in which the standard practice of the Michigan State Highway Department has been used. Inasmuch as no control of the subgrade

*RS = Relief Section, numeral designates type.
**Load transfer device in first joint of each series is consistent with load transfer device of preceding series.

EXPANSION JOINTS:

DB-1 = Standard Dowel Bar Expansion Joint Assembly.
DB = Standard Dowel Bar Contraction Joint Assembly.
Translode = Translode Base Expansion Joint Assembly.
Translode Angle = Translode Angle Unit Expansion Joint Assembly.
TE = Thickened Edge with Corner Bars.

CONTRACTION JOINTS:

Type 1-B = DB, with groove and poured filler.
Type 2-A = DB, with premolded filler and metal parting strip at bottom.
Type 2-B = DB, with groove and poured filler, parting strip at bottom.
Type 3 = DB, with groove and poured filler with metal divider plate.
Type 4 = Continuous plate dowel with groove and poured filler.
Type 5 = Keylode contraction joint, poured filler.

DUMMY PLANE OF WEAKNESS JOINTS:

R = Steel mesh reinforcement continuous through joint.

CURING—Wetted straw was used throughout design project.

EXPANSION JOINT WIDTH—One inch throughout design project.

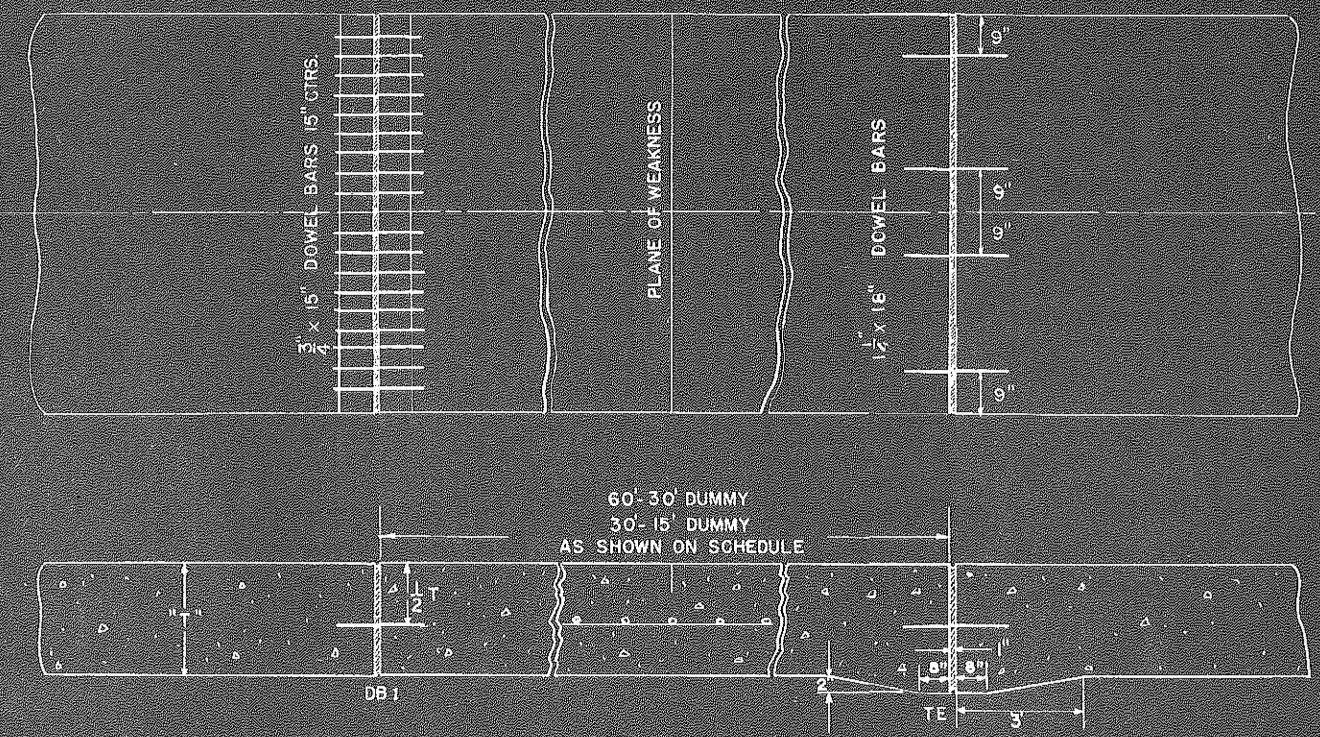
FURTHER DESIGN STUDIES—Series 11A-D and Series 12A-E were constructed in conjunction with Series 7 of Durability Project because of insufficient space on Design Project.

JOINT FILLER AND SEAL:

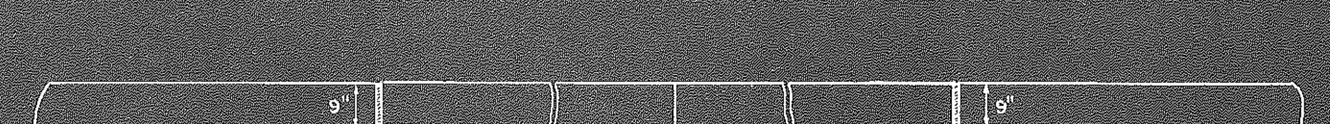
Type 1—Fiber filler with asphalt-latex seal.
Type 2—Fiber filler with asphalt-vultex seal.
Type 3—Special type using removable forms and seal top, bottom and sides with asphalt-latex.
Type 4—Asphalt-latex bottom premolded rubber seal.
Type 5—Fiber filler with thermoplastic seal.
Type 6—Fiber filler with asphalt SOA seal.

TABLE I.
SUMMARY OF TEST AREAS ON DESIGN PROJECT

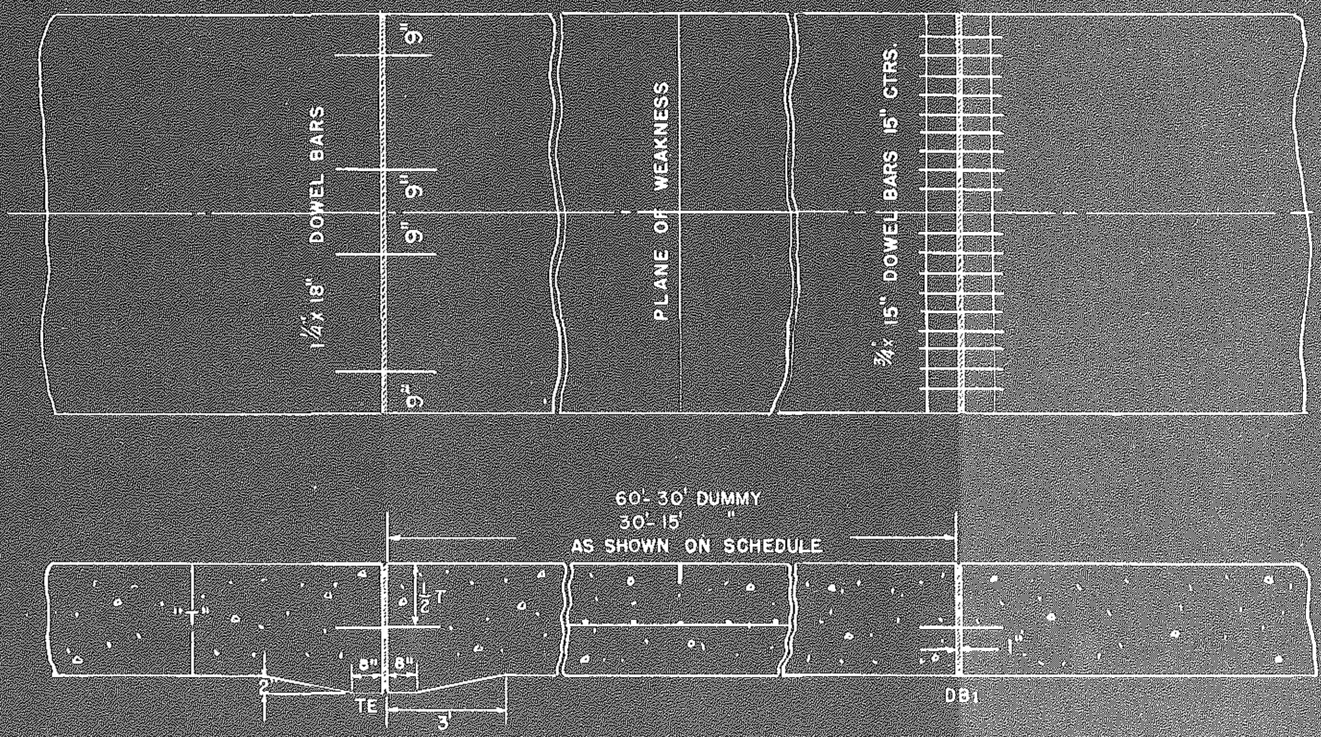
Series	Division	No. of Sects.	Station Begin	Station End	Pavement Thickness	Steel lbs. per 100 Sq. Ft.	Spacing Exp.	Spacing Contr.	Spacing D'my	Joint Filler and Seal	Type Load Transfer Exp.	Type Load Transfer Contr.	Type Load Transfer D'my	Width of Exp. Joint	Length, in Feet	Nomenclature Section Markers
S			764+00	770+00	9-7-9	60	120'	60'	30'	Type 1	DB-1	DB	R	1"	600'	8B/S
1	A	3	770+00	773+60	9-7-9	60	120'	60'	30'	Type 1	DB-1	DB	R	1"	360'	S/1A
	B	3	773+60	780+80	9-7-9	60	240'	60'	30'	Type 1	DB-1	DB	R	1"	720'	1A/1B
	*RS-1	1	780+80	781+40	9-7-9	60	60'	None	30'	Type 1	DB-1 and TE	—	R	1"	60'	1B/RS-1
	C	1	781+40	786+20	9-7-9	60	480'	60'	30'	Type 1	TE	DB	R	1"	480'	RS-1/1C
	*RS-2	1	786+20	786+80	9-7-9	60	60'	None	30'	Type 1	TE	—	R	1"	60'	1C/RS-2
	C	1	786+80	791+60	9-7-9	60	480'	60'	30'	Type 1	TE	DB	R	1"	480'	RS-2/1C
	*RS-2	1	791+60	792+20	9-7-9	60	60'	None	30'	Type 1	TE	—	R	1"	60'	1C/RS-2
	C	1	792+20	797+00	9-7-9	60	480'	60'	30'	Type 1	TE and DB-1	DB	R	1"	480'	RS-2/1C
	*RS-3	1	797+00	797+60	9-7-9	60	60'	None	30'	Type 1	DB-1	DB	R	1"	60'	1C/RS-3
	D	1	797+60	806+60	9-7-9	60	900'	60'	30'	Type 1	DB-1	DB	R	1"	900'	RS-3/1D
	*RS-4	1	806+60	807+20	9-7-9	60	60'	None	30'	Type 1	DB-1	DB	R	1"	60'	1D/RS-4
	D	1	807+20	816+20	9-7-9	60	900'	60'	30'	Type 1	DB-1	DB	R	1"	900'	RS-4/1D
	*RS-5	1	816+20	817+40	9-7-9	60	60'	None	30'	Type 1	DB-1	DB	R	1"	120'	1D/RS-5
	E	1	817+40	835+40	9-7-9	60	1800'	60'	30'	Type 1	DB-1	DB	R	1"	1800'	RS-5/1E
	*RS-5	1	835+40	836+60	9-7-9	60	60'	None	30'	Type 1	DB-1	DB	R	1"	120'	1E/RS-5
	F	1	836+60	863+60	9-7-9	60	2700'	60'	30'	Type 1	DB-1	DB	R	1"	2700'	RS-5/1F
	Total length of Series 1—(Sections A, B, C, D, E, and F)														9360'	
2	*RS-5	1	863+60	864+20	9-7-9	60	30'	None	15'	Type 1	DB-1	.....	R	1"	60'	1F/RS-5
	F	1	864+20	891+20	9-7-9	37	2700'	30'	15'	Type 1	DB-1	DB	R	1"	2700'	RS-5/2F
	*RS-5	1	891+20	891+80	9-7-9	37	30'	None	15'	Type 1	DB-1	—	R	1"	60'	2F/RS-5
	E	1	891+80	909+80	9-7-9	37	1800'	30'	15'	Type 1	DB-1	DB	R	1"	1800'	RS-5/2E
	*RS-5	1	909+80	910+40	9-7-9	37	30'	None	15'	Type 1	DB-1	—	R	1"	60'	2E/RS-5
	D	1	910+40	919+40	9-7-9	37	900'	30'	15'	Type 1	DB-1	DB	R	1"	900'	RS-5/2D
	*RS-4	1	919+40	919+70	9-7-9	37	30'	None	15'	Type 1	DB-1	.....	R	1"	30'	2D/RS-4
	D	1	919+70	928+70	9-7-9	37	900'	30'	15'	Type 1	DB-1	DB	R	1"	900'	RS-4/2D
	*RS-1	1	928+70	929+00	9-7-9	37	30'	None	15'	Type 1	DB-1 and TE	—	R	1"	30'	2D/RS-1
	C	1	929+00	933+80	9-7-9	37	480'	30'	15'	Type 1	TE	DB	R	1"	480'	RS-1/2C
	*RS-2	1	933+80	934+10	9-7-9	37	30'	None	15'	Type 1	TE	—	R	1"	30'	2C/RS-2
	C	1	934+10	938+90	9-7-9	37	480'	30'	15'	Type 1	TE	DB	R	1"	480'	RS-2/2C
	*RS-2	1	938+90	939+20	9-7-9	37	30'	None	15'	Type 1	TE	—	R	1"	30'	2C/RS-2
	C	1	939+20	944+00	9-7-9	37	480'	30'	15'	Type 1	TE	DB	R	1"	480'	RS-2/2C
	*RS-3	1	944+00	944+30	9-7-9	37	30'	None	15'	Type 1	TE and DB-1	.....	R	1"	30'	2C/RS-3
	B	3	944+30	951+50	9-7-9	37	240'	30'	15'	Type 1	DB-1	DB	R	1"	720'	RS-3/2B
	A	3	951+50	955+10	9-7-9	37	120'	30'	15'	Type 1	DB-1	DB	R	1"	360'	2B/2A
	Total length of Series 2—(Sections F, E, D, C, B, and A)														9150'	
3	A	3	955+10	958+70	9-7-9	None	120'	20'	None	Type 1	DB-1	DB	None	1"	360'	2A/3A
	B	3	958+70	965+90	9-7-9	None	240'	20'	None	Type 1	DB-1	DB	None	1"	720'	3A/3B
	*RS-4	1	965+90	966+10	9-7-9	None	20'	—	None	Type 1	DB-1	...	None	1"	20'	3B/RS-4
	C	1	966+10	970+90	9-7-9	None	480'	20'	None	Type 1	DB-1	DB	None	1"	480'	RS-4/3C
	*RS-4	1	970+90	971+10	9-7-9	None	20'	—	None	Type 1	DB-1	—	None	1"	20'	3C/RS-4
	C	1	971+10	975+90	9-7-9	None	480'	20'	None	Type 1	DB-1	DB	None	1"	480'	RS-4/3C
	*RS-4	1	975+90	976+10	9-7-9	None	20'	...	None	Type 1	DB-1	—	None	1"	20'	3C/RS-4
	C	1	976+10	980+90	9-7-9	None	480'	20'	None	Type 1	DB-1	DB	None	1"	480'	RS-4/3C
	*RS-4	1	980+90	981+10	9-7-9	None	20'	...	None	Type 1	DB-1	...	None	1"	20'	3C/RS-4
	D	1	981+10	990+10	9-7-9	None	900'	20'	None	Type 1	DB-1	DB	None	1"	900'	RS-4/3D
	*RS-4	1	990+10	990+30	9-7-9	None	20'	—	None	Type 1	DB-1	...	None	1"	20'	3D/RS-4
	D	1	990+30	999+30	9-7-9	None	900'	20'	None	Type 1	DB-1	DB	None	1"	900'	RS-4/3D
	*RS-5	1	999+30	999+70	9-7-9	None	20'	—	None	Type 1	DB-1	—	None	1"	40'	3D/RS-5
	E	1	999+70	1017+70	9-7-9	None	1800'	20'	None	Type 1	DB-1	—	None	1"	1800'	RS-5/3E
	*RS-5	1	1017+70	1017+90	9-7-9	None	20'	...	None	Type 1	DB-1	—	None	1"	20'	3E/RS-5
	Bridge	1	1017+90	1018+20	9-7-9	None	Bridge over Norway Creek								30'	
	*RS-5	1	1018+20	1018+40	9-7-9	None	20'	—	None	Type 1	DB-1	—	None	1"	20'	
	F	1	1018+40	1045+40	9-7-9	None	2700'	20'	None	Type 1	DB-1	DB	None	1"	2700'	RS-5/3F
	Total length of Series 3—(Sections A, B, C, D, E, and F)														9000'	
4	*RS-5	1	1045+40	1045+60	9-7-9	None	10'	—	None	Type 2	DB-1	—	None	1"	20'	3F/RS-5
	F	1	1045+60	0-3+65.4	9-7-9	None	2700'	10'	None	Type 2	DB-1	DB	None	1"	2700'	RS-5/4F
	*RS-5	1	0-3+65.4	0-3+85.4	9-7-9	None	10'	—	None	Type 2	DB-1	...	None	1"	20'	4F/RS-5
	Bridge	1	0-3+85.4	1+20	.....	—	—	Bridge over Muskegon River				—	...	—	334.68'	
	E	1	1+20	19+20	9-7-9	None	1800'	10'	None	Type 2	DB-1	—	None	1"	1800'	RS-5/4E
	*RS-5	1	19+20	19+40	9-7-9	None	10'	....	None	Type 2	DB-1	—	None	1"	20'	4E/RS-5
	D	1	19+40	28+40	9-7-9	None	900'	10'	None	Type 2	DB-1	DB	None	1"	900'	RS-5/4D
	*RS-4	1	28+40	28+50	9-7-9	None	10'	....	None	Type 2	DB-1	—	None	1"	10'	4D/RS-4
	D	1	28+50	37+50	9-7-9	None	900'	10'	None	Type 2	DB-1	DB	None	1"	900'	RS-4/4D
	*RS-4	1	37+50	37+60	9-7-9	None	10'	—	None	Type 2	DB-1	—	None	1"	10'	4D/RS-4
	C	1	37+60	42+40	9-7-9	None	480'	10'	None	Type 2	DB-1	DB	None	1"	480'	RS-4/4C
	*RS-4	1	42+40	42+50	9-7-9	None	10'	....	None	Type 2	DB-1	—	None	1"	10'	4C/RS-4
	C	1	42+50	47+30	9-7-9	None	480'	10'	None	Type 2	DB-1	DB	None	1"	480'	RS-4/4C
	*RS-4	1	47+30	47+40	9-7-9	None	10'	—	None	Type 2	DB-1	—	None	1"	10'	4C/RS-4
	C	1	47+40	52+20	9-7-9	None	480'	10'	None	Type 2	DB-1	DB	None	1"	480'	RS-4/4C
	*RS-4	1	52+20	52+30	9-7-9	None	10'	—	None	Type 2	DB-1	—	None	1"	10'	4C/RS-4
	B	3	52+30	59+50	9-7-9	None	240'	10'	None	Type 2	DB-1	DB	None	1"	720'	RS-4/4B
	A	3	59+50	63+10	9-7-9	None	120'	10'	None	Type 2	DB-1	DB	None	1"	360'	4B/4A
	Total length of Series 4—(Sections A, B, C, D, E, and F)														8930'	
5	A	3	63+10	66+70	9-7-9	37	120'	30'	None	Type 3	DB-1	Type-1B	None	1"	360'	4A/5A
	B	3	66+70	70+30	9-7-9	37	120'	30'	None	Type 3	DB-1	Type-2A	None	1"	360'	5A/5B
	C	3	70+30	73+90	9-7-9	37	120'	30'	None	Type 3	DB-1	Type-2B	None	1"	360'	5B/5C
	D	3	73+90	77+50	9-7-9	37	120'	30'	None	Type 3	DB-1	Type 3	None	1"	360'	5C/5D
	E	3	77+50	81+10	9-7-9	37	120'	30'	None	Type 3	DB-1	Type 3	None	1"	360'	5D/5E
	F	3	81+10	84+70	9-7-9	37	120'	30'	None	Type 3	DB-1	Type 4	None	1"	360'	5E/5F
	G	3	84+70	86+57.5	9-7-9	37	120'	30'	None	Type 3	DB-1	Type 4	None	1"	187.5'	5F/5G
	Bridge		86+57.5	87+82.5	—		Bridge over Middle Branch Creek					—	....		125'	
	G	3	87+82.5	86+30	9-7-9	37	120'	30'	None	Type 3	DB-1	Type 4	None	1"	172.5'	
	Total length of Series 5—(Sections A, B, C, D, E, F and G)														2520'	
6	A	5	88+30	94+80	8" Uniform	None	120'	30'	None	Type 2	1" Cor Bars**	1" Cor Bars	None	1"	600'	5G/6A
	B	5	94+30	100+30	8" Uniform	None	120'	20'	None	Type 2	1" Cor Bars**	1" Cor Bars	None	1"	600'	6A/6B
	C	2	100+30	106+30	8" Uniform	None	300'	15'	None	Type 2	1" Cor Bars**	1" Cor Bars	None	1"	600'	6B/6C
	D	2	106+30	112+30	8" Uniform	None	300'	10'	None	Type 2	1" Cor Bars**	1" Cor Bars	None	1"	600'	6C/6D
	Total length of Series 6—(Sections A, B, C, and D)														2400'	
7	A	5	112+30	118+30	8-6-8	60	120'	60'	30'	Type 2	DB-1**	DB	R	1"	600'	6D/7A
	B	5	118+30	124+30	8-6-8	37	120'	30'	15'	Type 2	DB-1	DB	R	1"	600'	7A/7B
	C	5	124+30	130+30	8-6-8	None	120'	20'	None	Type 2	DB-1	DB	None	1"	600'	7B/7C
	D	5	130+30	136+30	8-6-8	None	120'	10'	None	Type 2	DB-1	DB	None	1"	600'	7C/7D
	Total length of Series 7—(Sections A, B, C and D)														2400'	
8	A	3	136+30	139+90	7" Uniform	None	120'	30'	None	Type 2	1" Cor Bars**	1" Cor Bars	None	1"	360'	7D/8A
	B	7	139+90	148+30	7" Uniform	None	120'	20'	None	Type 2	1" Cor Bars**	1" Cor Bars	None	1"	840'	8A/8B
	C	2	148+30	154+30	7" Uniform	None	300'	15'	None	Type 2	1" Cor Bars**	1" Cor Bars	None	1"	600'	8B/8C
	D	2	154+30	160+30	7" Uniform	None	300'	10'	None	Type 2	1" Cor Bars**	1" Cor Bars	None	1"	600'	8C/8D
	Total length of Series 8—(Sections A, B, C and D)														2400'	
9	T.S.	1	160+30	162+10	9-7-9	None	180'	30'	None	Type 4	Trans-lode**	DB	None	1"	180'	8D/TS
	A	1	162+10	180+10	9-7-9	None	180'	None	None	Type 4	Trans-lode**	DB	None	1"	1800'	TS/9A
	T.S.	1	180+10	181+00	9-7-9	None	180'	30'	None	Type 4	Trans-lode**	Type 5	None	1"	90'	9A/TS
		1	181+00	181+90	9-7-9	None		30'	None	Type 4	DB-1	DB	None	1"	90'	
10	A-1	9	181+90	192+70	9-7-9	None	120'	20'	None	Type 5	DB-1	DB	None	1"	1080'	TS/10A-1
	A-2	9	192+70	203+50	9-7-9	None	120'	15'	None	Type 5	DB-1	DB	None	1"	1080'	10A-1/10A-2
	B-1	9	203+50	214+30	9-7-9	None	120'	20'	None	Type 2	None	None	None	1"	1080'	10A-2/10B-1
	B-2	9	214+30	225+10	9-7-9	None	120'	15'	None	Type 2	None	None	None	1"	1080'	10B-1/10B-2
11			691+75	692+10	9-7-9	Series 7D of Durability Project										
	A	1	692+10	693+00	9-7-9		60	90'	None	None	Type 6	Trans-lode Angle	—	—	1"	90'	7C/7D-11A
	B	1	693+00	694+20	9-7-9	60	120'	None	None	Type 6	"	—	—	1"	120'	11A/11B
	RS	1	694+20	694+30	9-7-9	60	10'	None	None	Type 6	"	—	—	1"	10'	
	C	1	694+30	697+92	9-7-9	60	362'	None	None	Type 6	"	—	—	1"	362'	11B/11C
	RS	1	697+92	698+00	9-7-9	60	8'	None	None	Type 6	"	—	—	1"	8'	
	D	1	698+00	704+00	9-7-9	60	600'	None	None	Type 6	"	.....	—	1"	600'	11C/11D
	RS	1	704+00	704+18	9-7-9	60	18'	None	None	Type 6	"	—	—	1"	18'	
		1	704+18	721+75	9-7-9	Series 7E and 7F of Durability Project									1757'	
		1	721+75	728+10	9-7-9										635'	
12	A	1	728+10	729+00	9-7-9	None	90'	None	None	Type 6	Trans-lode Angle	.....	—	1"	90'	7E/7F-12A
	B	1	729+00	730+20	9-7-9	None	120'	None	None	Type 6	"	—	—	1"	120'	12A/12B
	RS	1	730+20	730+30	9-7-9	None	10'	None	None	Type 6	"	—	—	1"	10'	
	C	1	730+30	733+90	9-7-9	None	360'	None	None	Type 6	"	—	—	1"	360'	12B/12C
	RS	1	733+90	734+00	9-7-9	None	10'	None	None	Type 6	"	—	—	1"	10'	
	D	1	734+00	736+42	9-7-9	None	242'	None	None	Type 6	"	—	—	1"	242'	12C/12D
	RS	1	736+42	736+52	9-7-9	None	10'	None	None	Type 6	"	—	—	1"	10'	
	E	1	736+52	742+52	9-7-9	None	600'	None	None	Type 6	"	—	—	1"	600'	12D/12E
	RS	1	742+52	742+62	9-7-9	None	10'	None	None	Type 6	"	—	—	1"	10'	
			742+62	763+46	9-7-9	Series 8A of Durability Project									1084'	12E-7F/8A



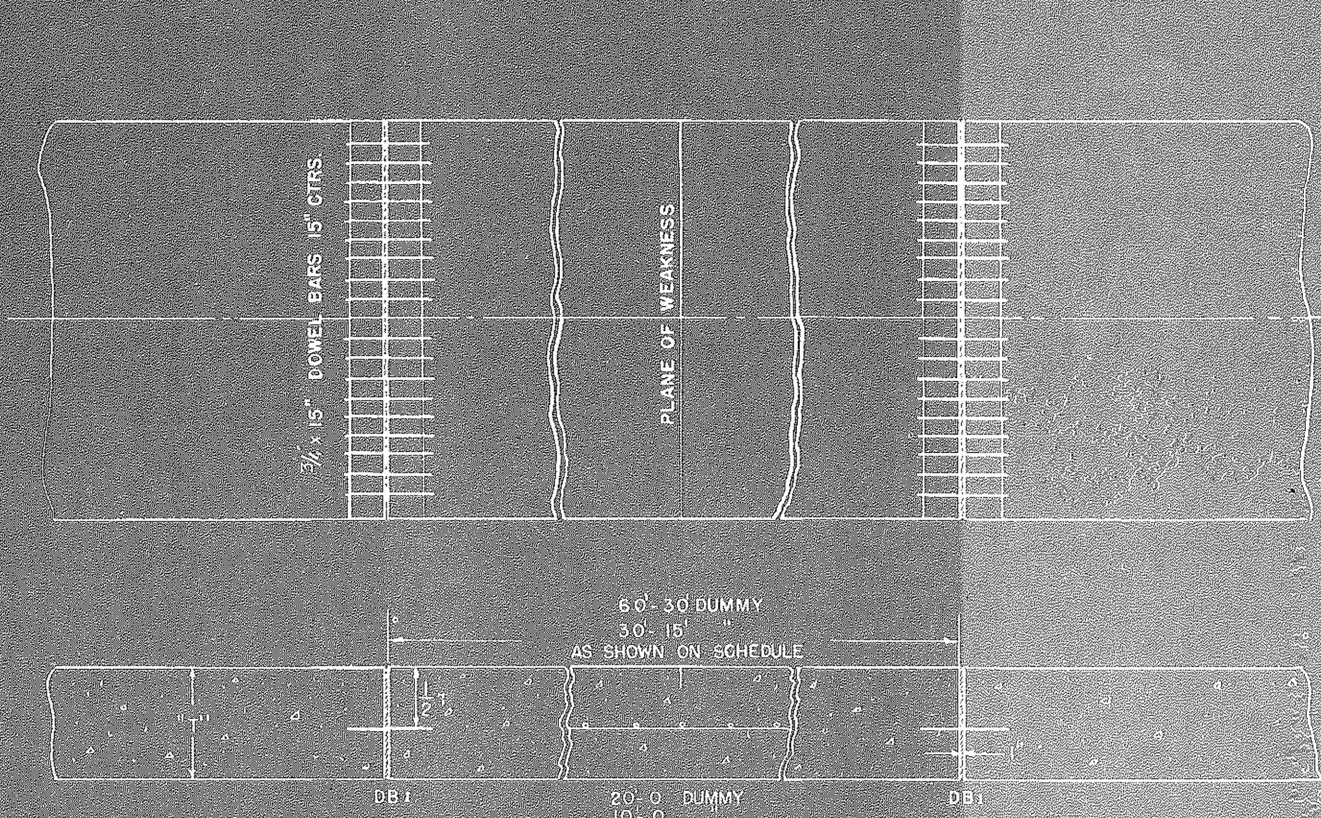
TYPE RS 1
FIG. 4. DETAIL SKETCH OF EXPANSION RELIEF SECTION



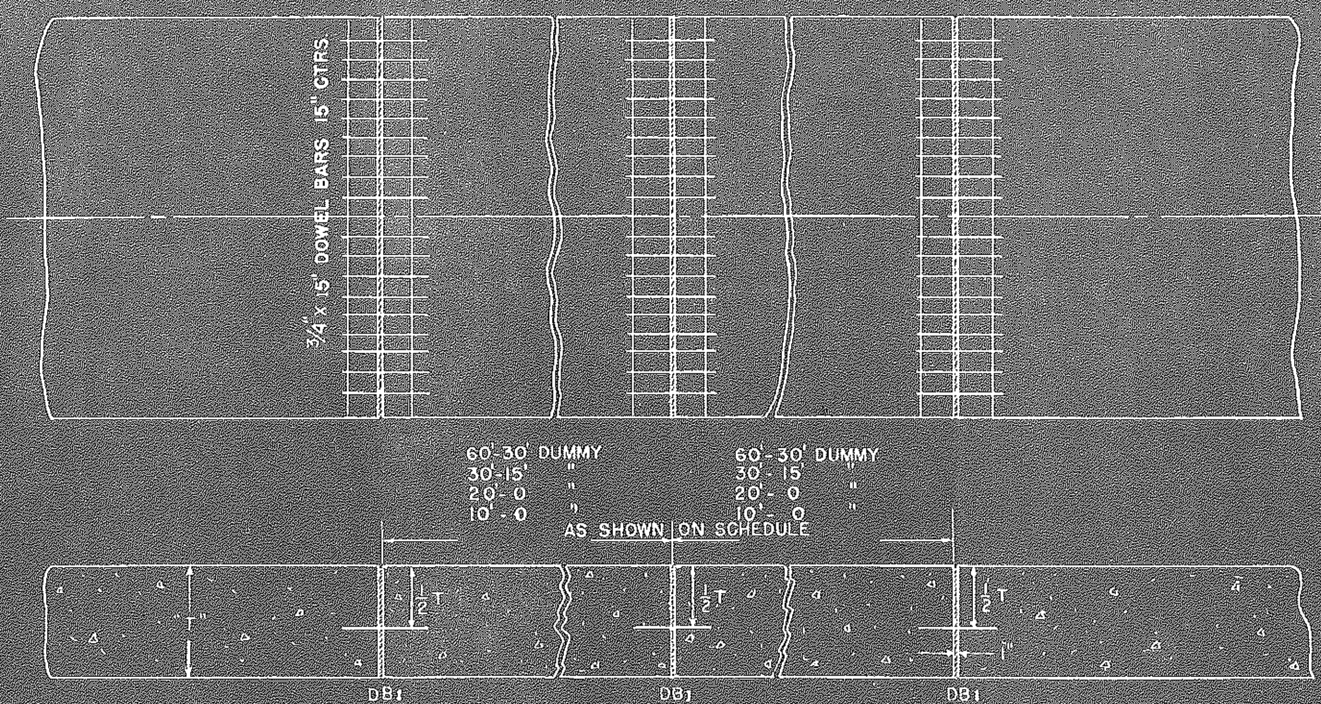
TYPE RS 2
FIG. 5. DETAIL SKETCH OF EXPANSION RELIEF SECTION



TYPE RS 3
FIG. 6. DETAIL SKETCH OF EXPANSION RELIEF SECTION



TYPE RS 4
FIG. 7. DETAIL SKETCH OF EXPANSION RELIEF SECTION



TYPE RS 5
FIG. 8. DETAIL SKETCH OF EXPANSION RELIEF SECTION

supporting value has been made in the construction of the subgrade, it will be necessary to use the subgrade modulus values found. It is hoped that in the comparison of various sections, subgrades having the same modulus will be encountered.

In order to eliminate excess costs in the construction of this experimental pavement, it has seemed advisable to maintain a standard cross section of 9-7-9 as much as possible, in accordance with the Michigan State Highway Department 1940 Specifications and Plans. However, to obtain comparison of equivalent uniform thickness slabs and reduced cross section, it has been necessary to introduce a few thousand feet of these types.

As has been pointed out in the scope of the Test Road, the spacing and design of transverse joints is one of the three main design features included in the design project, therefore, the subject will be given considerable attention and study.

JOINT SPACING AND DESIGN

In the study of joints, especially those for expansion and contraction purposes, the proper spacing will be determined by permissible maximum stress intensities induced by linear frictional restraint and flexural weight restraint, but the detailed design features of the joint itself are determined by the desired structural interaction between jointed slab units.

The design of tranverse joints necessitates consideration of structural features which enable the joint to perform the function for which it is intended, including: movement for expansion or

Fig. 10A. Standard Expansion Joint Assembly with $3/4$ inch Dowel Bars for Load Transfer and 1 inch Fiber Filler

Fig. 10B. Expansion Joint Assembly with $1\frac{1}{4}$ inch x 18 inches Corner Bars

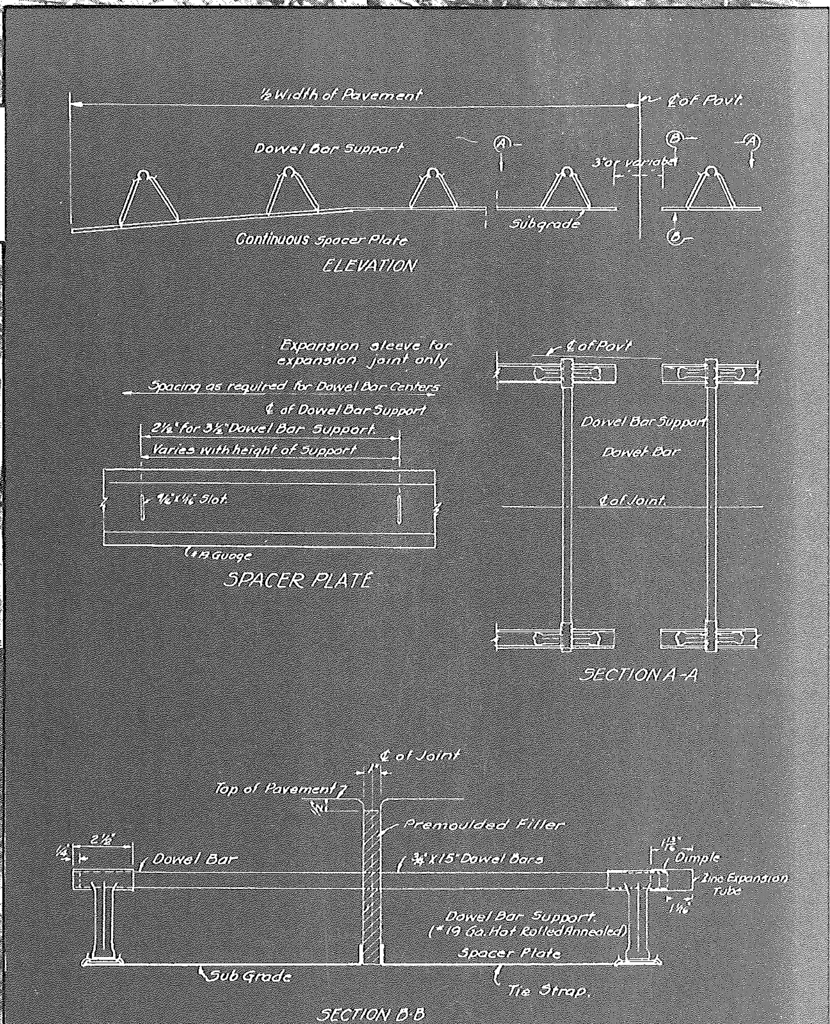


FIG. 9. DETAIL SKETCH OF TRUSS-ASSEMBLY FOR HOLDING DOWEL BARS AT EXPANSION AND CONTRACTION JOINTS

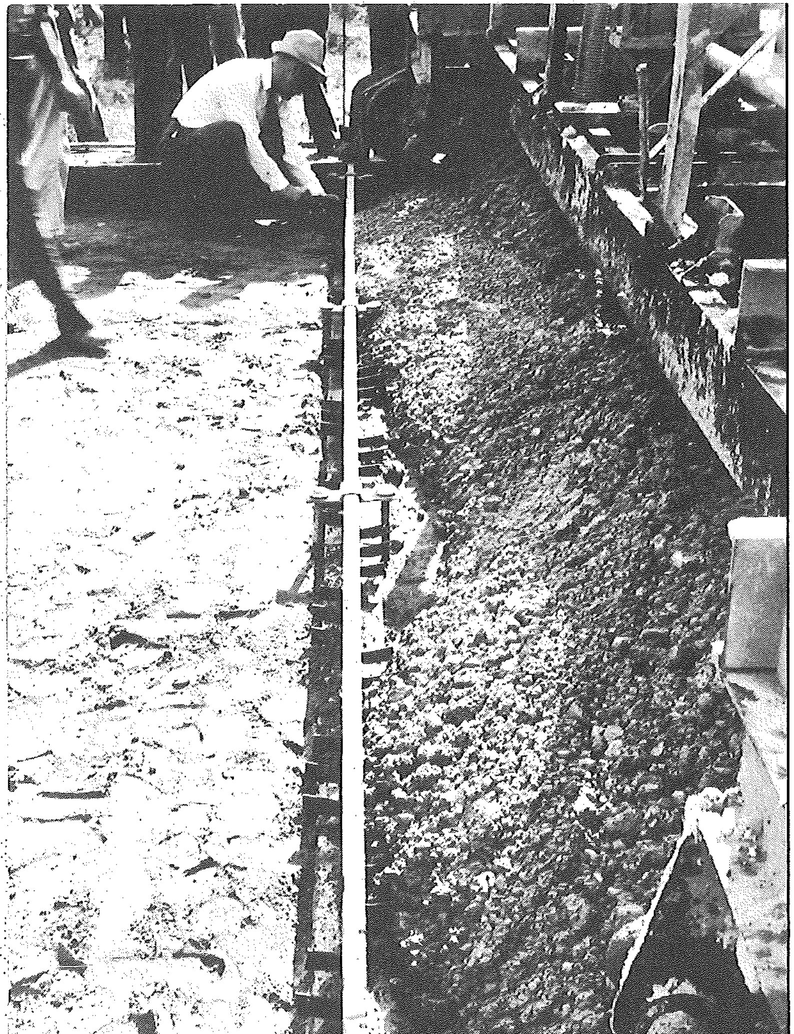


Fig. 12. Translode Expansion Joint Assembly Used on Stress Curing Section

contraction, load transfer where necessary and flexibility for warping and adequate seal against infiltration of water and foreign matter. In order to study these features, several units of various types of expansion and contraction joints were installed. With respect to expansion joints, the efficiency of dowel bars and other load transfer devices will also be compared with thickened edge joints.

In conjunction with the contraction joint spacing investigation, four major types of load transfer will be studied; first, aggregate interlock with load transfer; second, aggregate interlock only; third, load transfer without aggregate interlock; and fourth, continuous plate dowel.

In some cases, both in expansion and contraction joints, corner bars $1\frac{1}{4}$ inch in diameter and 18 inches in length were used to maintain mutual elevation of the slabs and the efficacy of this method is to be studied.

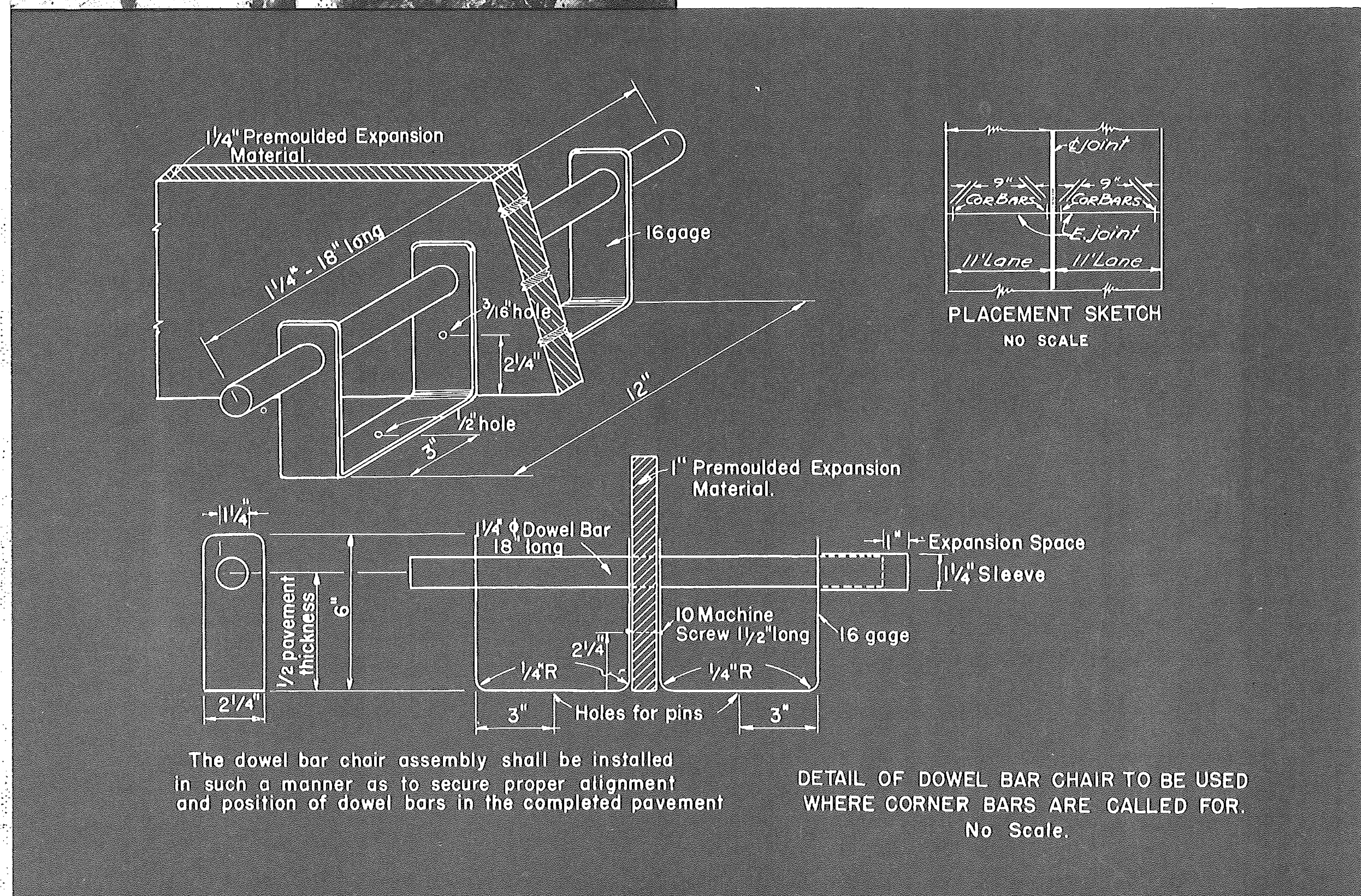


FIG. 11. DETAIL SKETCH OF $1\frac{1}{4}''$ x 18″ DOWEL CORNER BAR ASSEMBLY

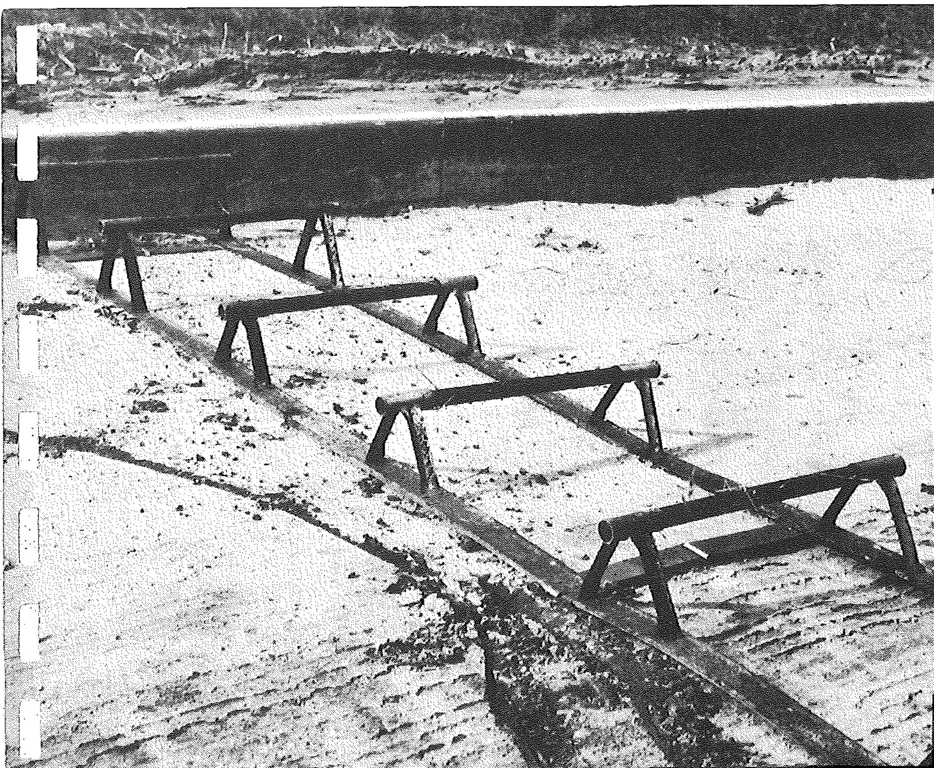
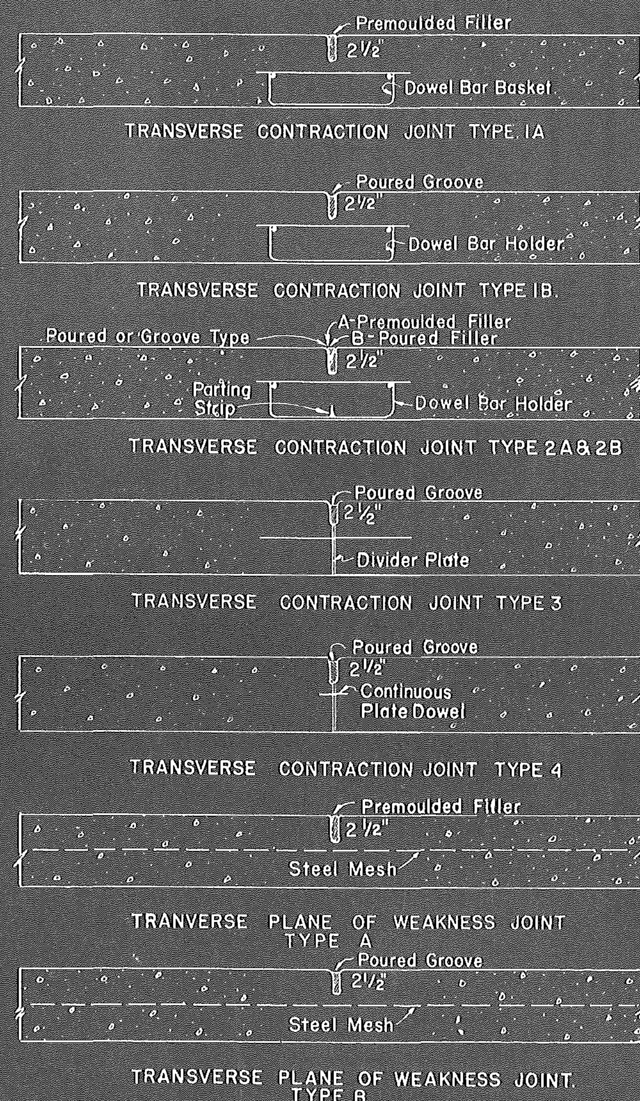


Fig. 14. Type I Contraction Joint Assembly

Fig. 13. Detail Sketch of Contraction and Plane of Weakness Joints Used on Project



EXPANSION JOINTS

In the design project, considerable emphasis has been placed upon the study of joint spacing, expansion space, joint design and joint construction. The expansion joints have been spaced to give sections of 120, 360, 480, 600, 900, 1800 and 2700 foot lengths for various cross sections and various amounts of reinforcing steel. In addition, sections with 300 foot expansion joint spacings were constructed in the 7 and 8 inch uniform pavement without reinforcing steel.

A one inch joint width was maintained for the various lengths of slabs. In the case of long expansion joint intervals, relief sections, shown in figures 4 to 8, have been placed between each series of slab sections in order to relieve any movement in excess of the amount provided for in the regular one inch expansion joint opening. Tests on joint width movement will be a primary factor in determining the necessary expansion opening.

Load transfer at expansion joints throughout the entire test road with the exception of series 1-C, 2-C, 6, 8 and 9A of the design project consist of standard ¾ inch dowel bars, 15 inches long, spaced 15 inches apart. The dowel bars were held in position by a Truss-Assembly shown in figures 9 and 10A.

In series 1-C and 2-C the expansion joints were constructed with thickened edge using four

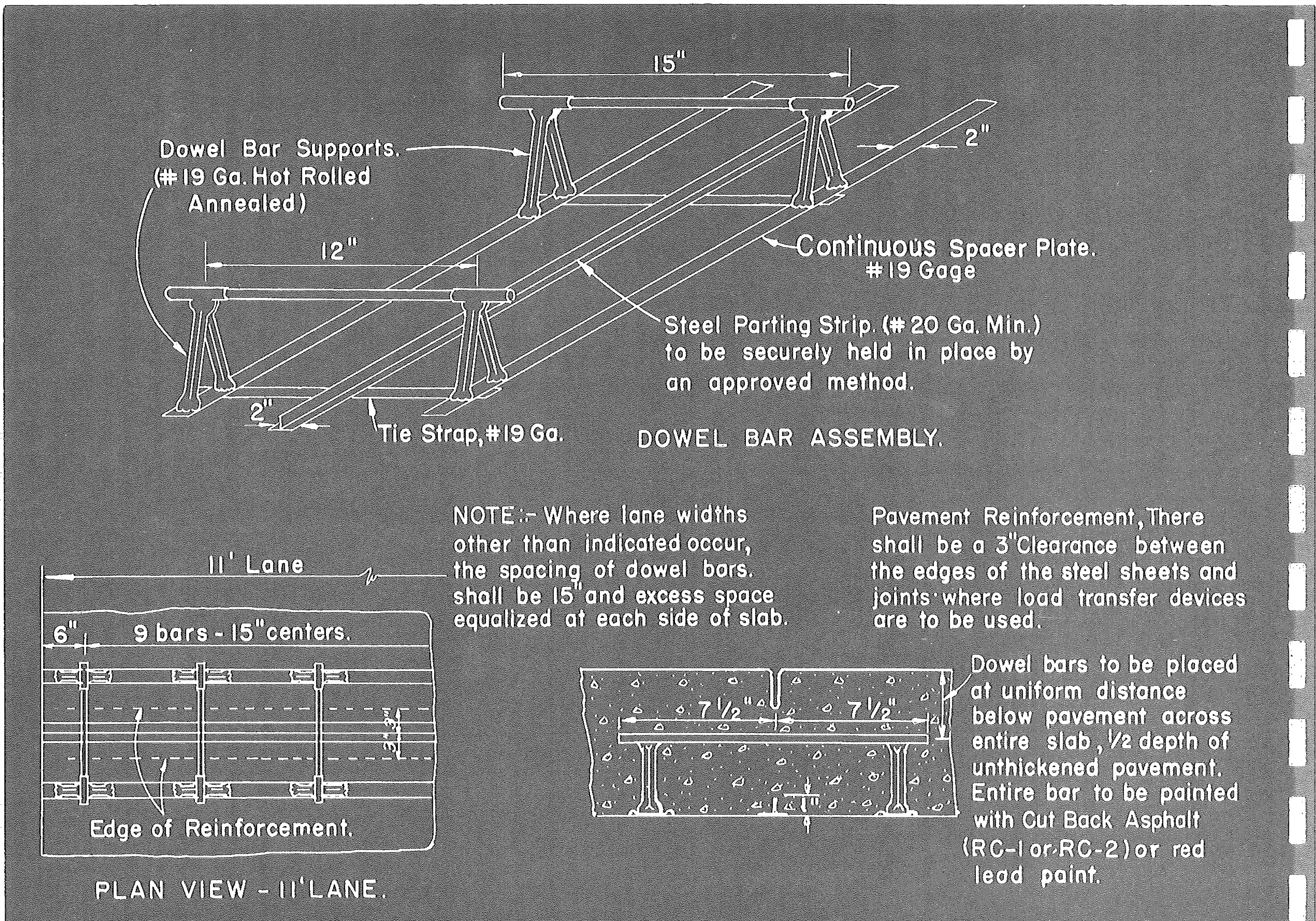


FIG. 15. DETAIL SKETCH OF TYPES 2A AND 2B CONTRACTION JOINT WITH LOAD TRANSFER DEVICE AND PARTING STRIP

1¼ inch diameter dowel bars, 18 inches long. Each bar was placed 9 inches from the corner of the slab (figure 5). The corner bar assembly is illustrated in figures 10B and 11.

The corner dowel bars were used in series 6 and 8, uniform cross section pavement in order to maintain mutual elevation of slabs due to changes in subgrade.

Throughout the stress curing section, series 9A, "Translode" units were used, because an open joint was necessary for this particular section as discussed further in this bulletin, (figure 12).

Five different combinations of joint fillers and sealers were installed in the expansion joints throughout the design section. They are described as types 1, 2, 3, 4, and 5, in table 1. The different joint sealers are described in detail under incidental studies.

CONTRACTION JOINTS WITH LOAD TRANSFER

Consistent with the spacing of expansion joints at specified intervals and amount of reinforcing steel, contraction joints have been constructed at 10, 15, 20, 30 and 60 foot intervals. These various spacings have been included in the construction of the various cross sections and expansion joint spacing as described in "Summary of Design Project", table 1.

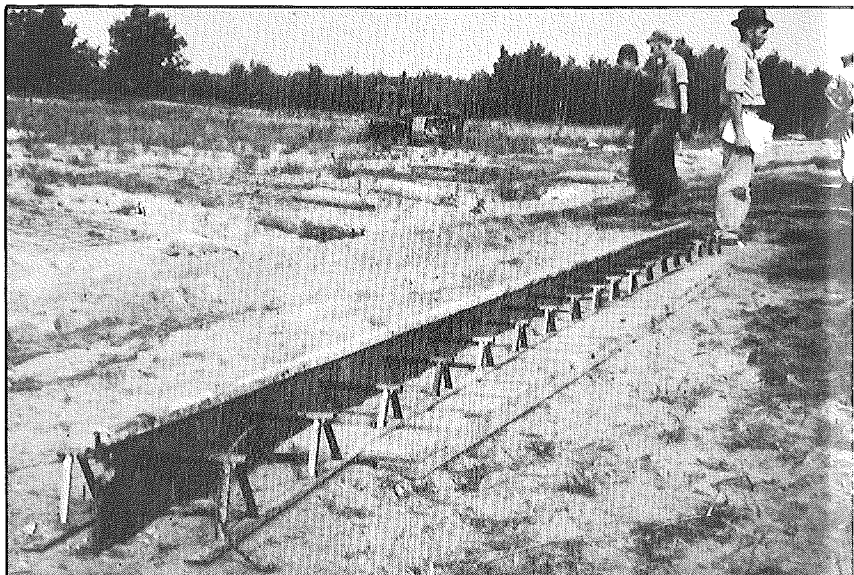
In general, the contraction joints were constructed in accordance with Michigan State Highway Department standard practice and designated as type 1A (figure 13). Several installations of the other types shown in figure 13 are included in the design project for comparative study. They are designated as types 1, 2, 3, 4 and 5 as described below.

1/8" material for placing weakened joint.

STANDARD CONTRACTION JOINT—Type 1A—1B. This type of joint consists of ¾ inch diameter by 15 inch dowel bars spaced 15 inches center to center and held in place by an approved installing device. The bars are coated entirely with asphalt paint (RC2) to break the bond. Directly over the center of the dowel bar assembly a 2½ inch weakened plane is formed in the surface of the pavement. In type 1A joint, the weakened plane is formed by inserting a ¼ inch by 2½ inch premolded bituminous felt at the time of finishing operation. In type 1B joint, the weakened plane is formed by a special plate grooving device and the groove is poured full of joint sealing compound (figures 13 and 14).

CONTRACTION JOINT WITH PARTING STRIP—Type 2A-2B. This joint is essentially the same as type 1A and 1B described above, except that a piece of metal 1 inch high is installed in the bottom of the slab and made to coincide vertically with the weakened plane in the top of the slab. The purpose of this strip of metal is to insure cracking of the slab in a vertical plane (figure 15).

Fig. 16. Contraction Joint Assembly with Dowel Bars and Steel Dividing Plate



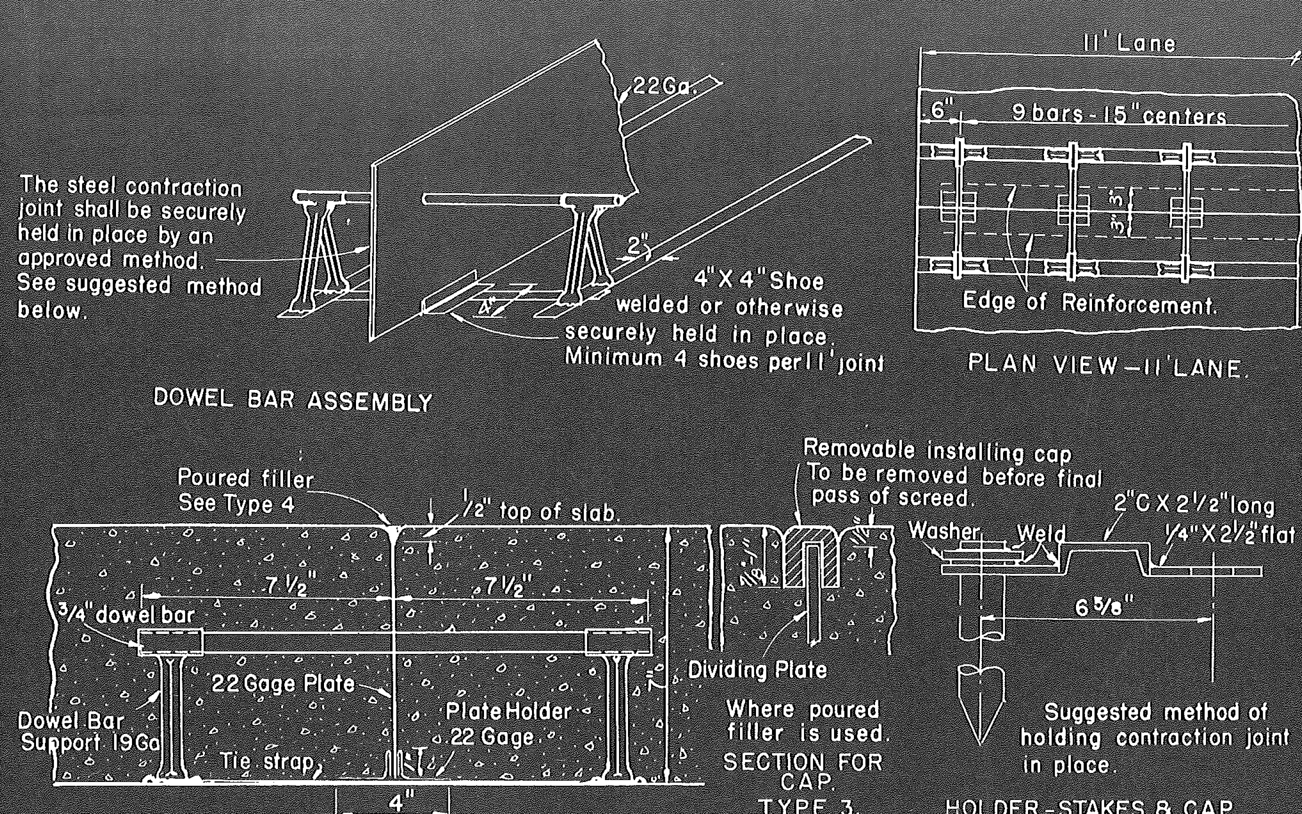


FIG. 17. DETAIL SKETCH OF TYPE 3 CONTRACTION JOINT WITH LOAD TRANSFER DEVICE AND STEEL DIVIDING PLATE

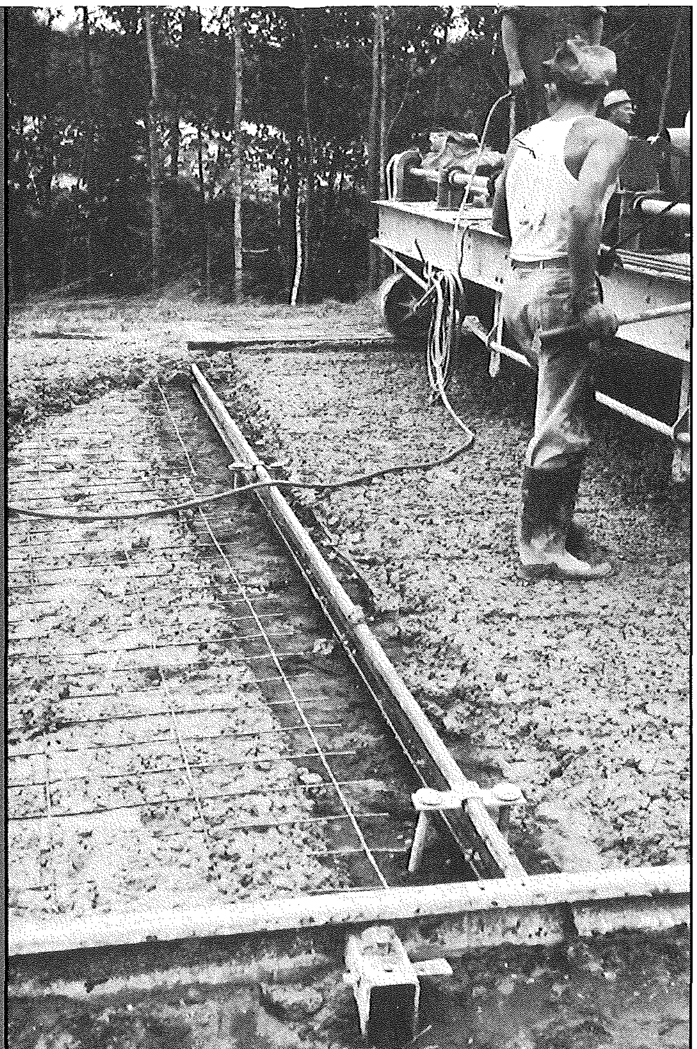


Fig. 19A. Continuous Plate Dowel Contraction Joint Assembly

CONTRACTION JOINT WITH FACE PLATE — DB Type 3. The contraction joint consists of the same dowel bar assembly as described for the two previous joints with the exception of including a 22 gage metal face plate extending the full length of the joint and from the bottom of the slab to within ½ inch of the surface (figure 16). The surface of the joint was prepared as shown in figure 17, and eventually sealed with suitable joint sealing compound.

CONTINUOUS DOWEL PLATE — Type 4. The continuous plate dowel illustrated in figures 18 and 19A consists of a continuous No. 10 gage metal plate running the entire length of the joint and supported in proper position by two vertical web members.

The joint is designed to provide continuous load transfer across the joint and prevent passage of water through the joint. A few installations of this type of contraction joint device were made in the design project at the locations shown in the "Summary of Design Project", table 1.

KEYLODE CONTRACTION JOINT UNIT— Type 5. The Keylode Contraction joint unit is also a continuous plate dowel contraction joint similar to type 4, except that the two vertical web members which support the plate dowel are fabricated in such a manner as to allow interlocking action of concrete across the joint. The joint is fully illustrated in figures 19B and 20.

WEAKENED PLANE "DUMMY" JOINTS. In standard Michigan practice, the "dummy" type of joint illustrated as type A (figure 13) is placed midway between the expansion and contraction joints. In order to evaluate this type of joint with contraction joints at close spacing, the dummy joints were placed at 15 and 30 foot spacings for 8-6-8 and 9-7-9 cross section pavement using 37 and 60 pounds per 100 square feet of reinforcing steel.

Another important factor in the construction of concrete pavements, in addition to proper joint design and spacing, is the adequate design of the pavement cross section for proper stress distribution.

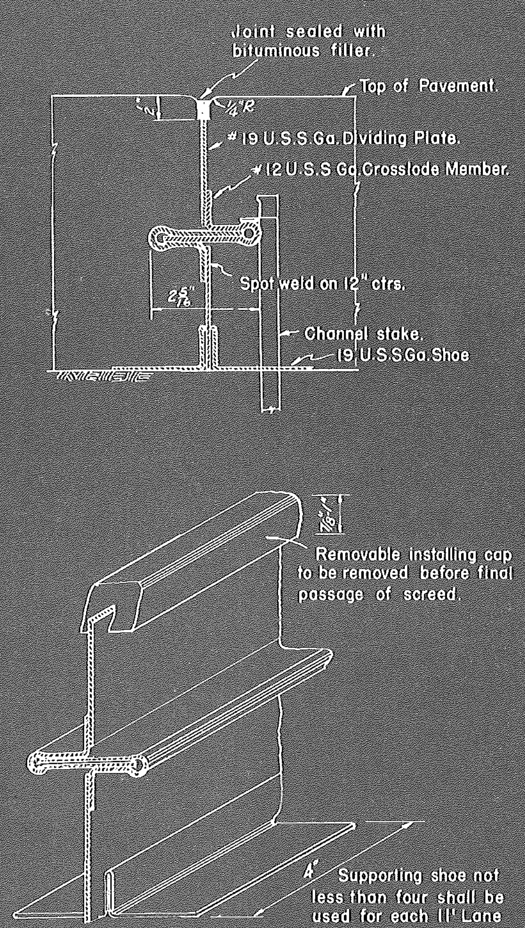
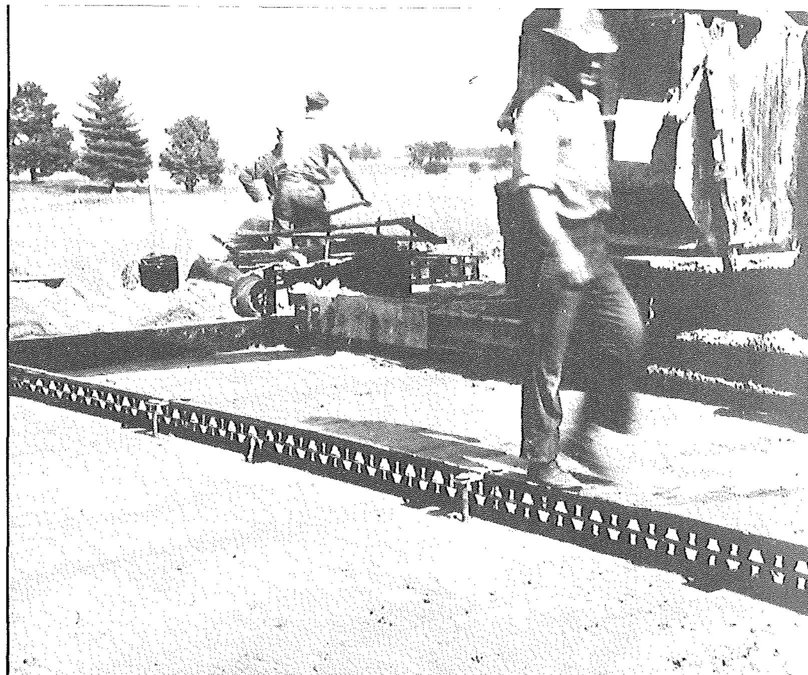


Fig. 18. Detail Sketch of Type 4, Contraction Joint with Continuous Plate Dowel Load Transfer Device

Fig. 19B. Keylode Contraction Joint Assembly



PAVEMENT CROSS SECTION

In the feature of structural strength, the concrete pavement cross section can be designed to meet practically any requirement. By thickening certain sections of the slab which may be subjected to more severe stresses than other parts, and by limiting the horizontal dimensions of slab units through the use of joints, uniformity of structural strength may be economically balanced throughout all parts of the pavement. Also, adequate and uniform subgrade support is necessary to insure and maintain uniform stress distribution throughout the pavement slab.

In the construction of the pavement in the design project, consideration has been given to such controversial factors as load capacity of subgrade versus slab thickness, also the balanced cross section versus equivalent uniform thickness. Consequently, four different types of cross sections were set up for study, namely 9-7-9 Michigan State Highway Department standard cross section, 8 inch uniform, the approximate equivalent of 9-7-9; 8-6-8 and its approximate equivalent 7 inch uniform. The various cross sections are illustrated in figure 21.

In addition to the studies of joint spacing and pavement cross section, the use of steel reinforcement in pavement construction has been given consideration.

STEEL REINFORCEMENT

The use of steel in concrete pavements has been considered necessary only for the purpose of controlling cracks in slabs after the cracks have been formed. However, with the modern trend towards longer expansion joint spacing and shorter slabs and better subgrade conditions it is believed, by many engineers, that steel reinforcement may be dispensed with. The present shortage of construction materials has made it even more necessary to give consideration to the problem of pavement design without steel.

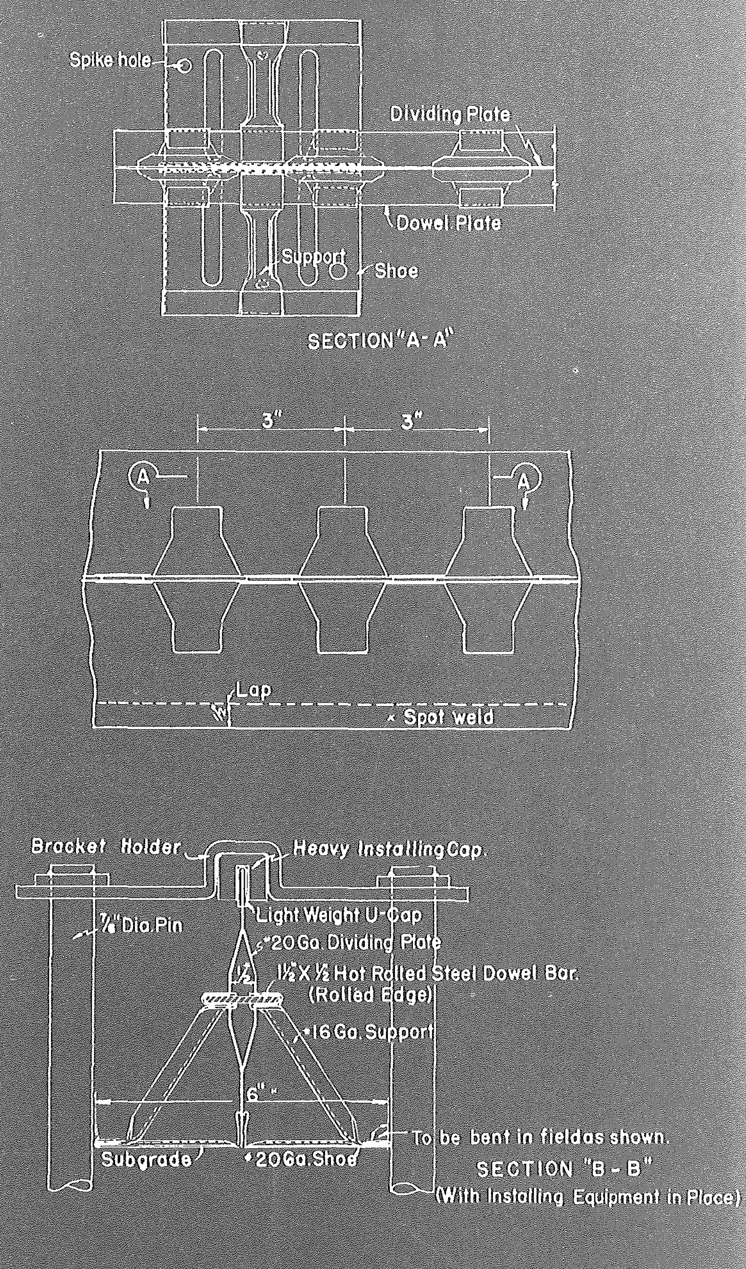


Fig. 20. Detail Sketch of Keylode Contraction Joint Assembly, Type 5

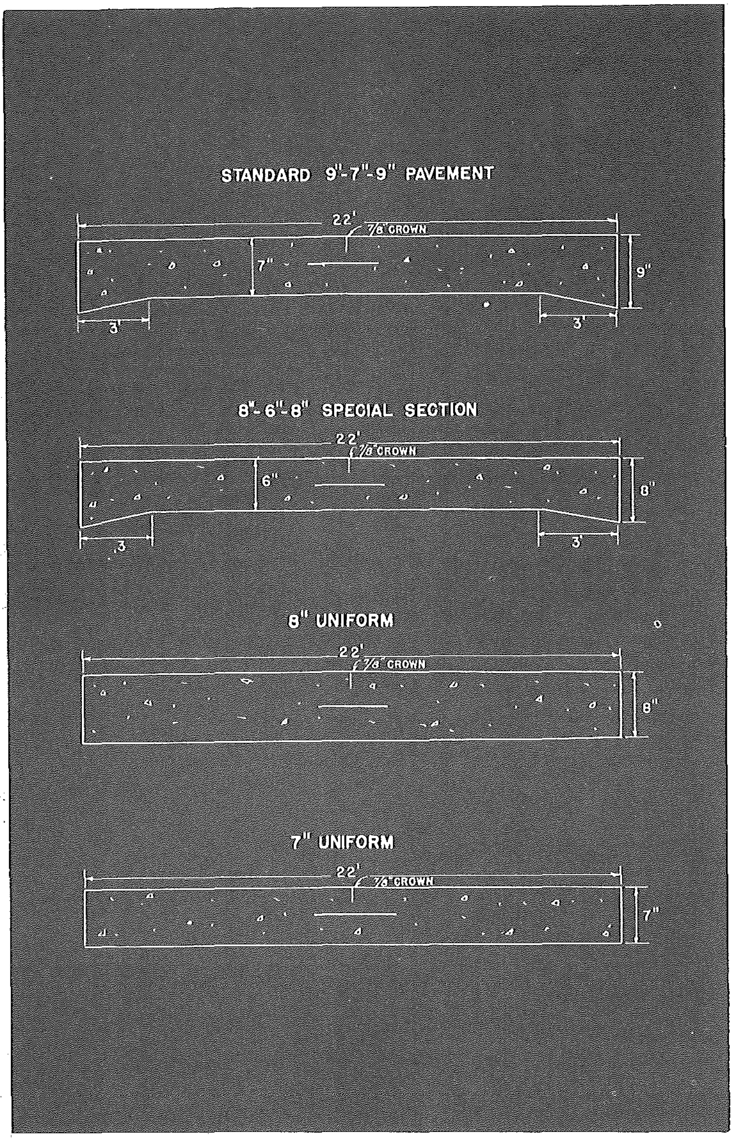


Fig. 21. Detail Sketch of Pavement Cross-Sections

In order to obtain more pertinent data relative to such questions as —

1. The relationship of plain uniform cross section to reinforced "balanced" cross section.
2. Economies of reinforced cross sections of both types versus plain cross sections with adequate jointing.
3. The adequate amount of reinforcing steel versus various designs. Several test sections were constructed using 9-7-9, 8-6-8, 8 inch and 7 inch uniform cross section consisting of plain concrete, and reinforced concrete with 60 pounds per hundred square feet and 37 pounds per hundred square feet. Joints were spaced in the manner as described under joint spacing and design.

In addition to the various design problems previously described, it was necessary to give considerable attention to design and construction of suitable measuring equipment for installation in the design project.

METHODS OF MEASUREMENT

For the proper appraisal of the structural efficiency of the elements of design considered in this project, periodic visual examinations together with measurement of displacements and physical conditions must be made. The program of observations as set up by the Public Roads Administration* will be adhered to.

DISPLACEMENT MEASUREMENTS

The displacement of the slab which will occur due to volume change of concrete, superimposed loads and subgrade differentials will be determined by change in joint width and slab movement horizontally and vertically.

JOINT WIDTH MEASUREMENTS. Joint width is measured by change in position of reference points located one on each side of the joint, as shown in figure 22. The reference points consist of holes drilled in heads of galvanized roofing nails. A Starrett micrometer caliper reading to 1/1000 inch was adapted for taking measurements.

To insure accuracy of the readings and avoid any criticism of the results in the use of roofing nails as reference points, in one section consisting of a day's work, a series of brass plugs held in place with sulphur were installed. If variations develop that have been caused by corrosion of the nail heads, the entire project will be replaced with brass plugs set in sulphur.

Initial readings were taken the morning following the placing of the concrete pavement and subsequent readings for daily, seasonal and permanent joint width determinations will be made for the duration of the study (figure 23).

LEVEL MEASUREMENTS. Concurrent with the establishment of reference points for joint width study, 5/16 inch by 2½ inch carriage bolts were embedded in the fresh concrete adjacent to the joint to serve as elevation points for subsequent level readings to determine the vertical displacement of the pavement at the joint (figure 22). The day following the placement of the concrete, the initial elevation of all level points were established

*See Appendix I.

by precise level measurements. Subsequent level readings will be repeated during the summer and winter seasons of the first year after construction and at longer periods thereafter (figure 24).

In conjunction with the vertical displacements, horizontal displacements will be measured at definite locations (figure 23) throughout the design project, provisions having been made to measure the horizontal movement of the concrete slabs of various lengths.

SLAB MOVEMENT MEASUREMENT. The slab movement is determined with respect to a fixed point in the subgrade. The fixed reference monument in the subgrade consists of an 8 inch pipe casing, 6 feet long, set to grade, the interior of which is excavated. Centered in the casing is a 2 inch pipe to a depth of 12 feet below the concrete pavement, on top of which is placed a chrome plated pipe cap having reference marks etched in the surface. In this manner the shifting of subgrade soil due to frost action or slab movement will not affect the original position of the reference pipe. Directly over this assembly and cast in the concrete is a specially designed monument box containing a machined brass bushing to accommodate a brass ring containing a glass plate having etched cross hairs. By means of a special telescopic measuring device constructed to permit longitudinal and transverse movement, the increments of relative movement of the slab with respect to the reference monument in the subgrade can be measured to 0.1 mm. Seventy-nine slab movement monuments have been established at special locations throughout the project. The reference monuments are illustrated in figures 25 and 26. For complete evaluation of slab movement measurements certain data concerning physical conditions must be obtained.

PHYSICAL MEASUREMENTS

Physical conditions to be measured are those which affect slab movements and those which are the result of slab movement such as temperature of concrete, moisture content of concrete and subgrade, strain in concrete and meteorological conditions.

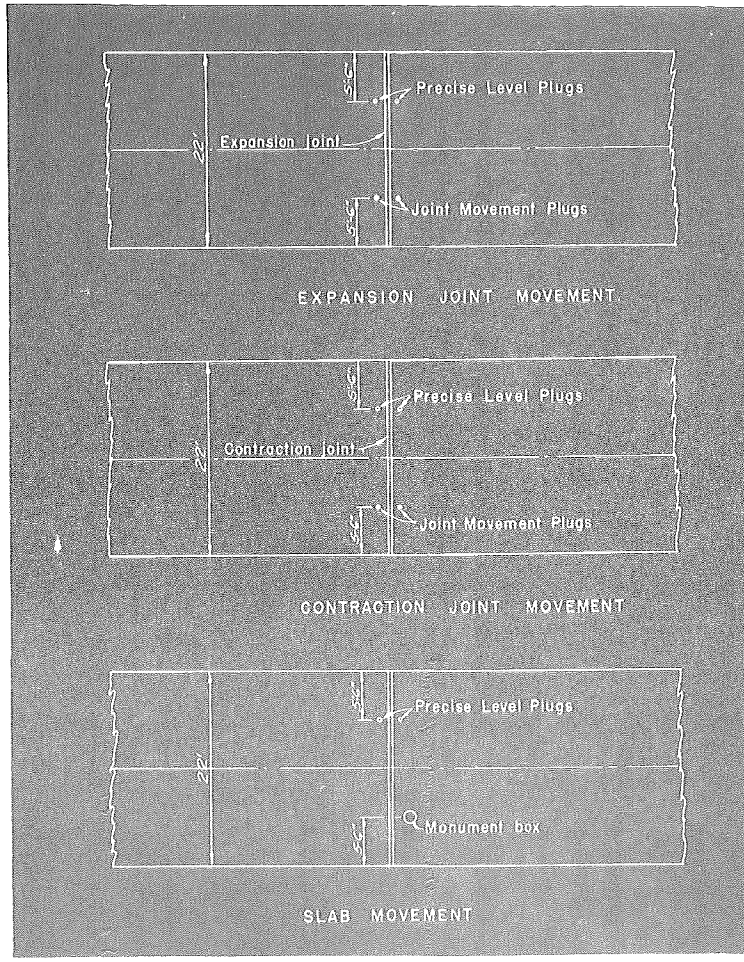


Fig. 22. Detail Sketch Showing Relative Location of Reference Points

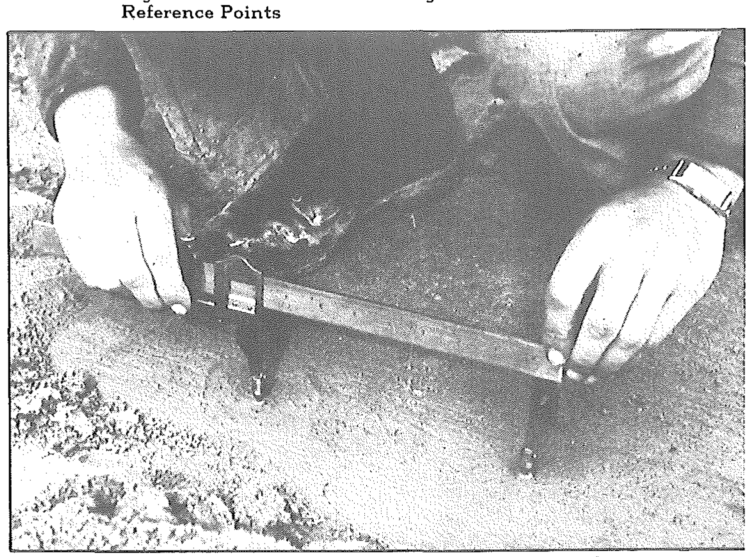


Fig. 23. Starrett Micrometer caliper used to measure joint widths

Fig. 24. Elevation points to determine vertical displacement of pavement at the joint

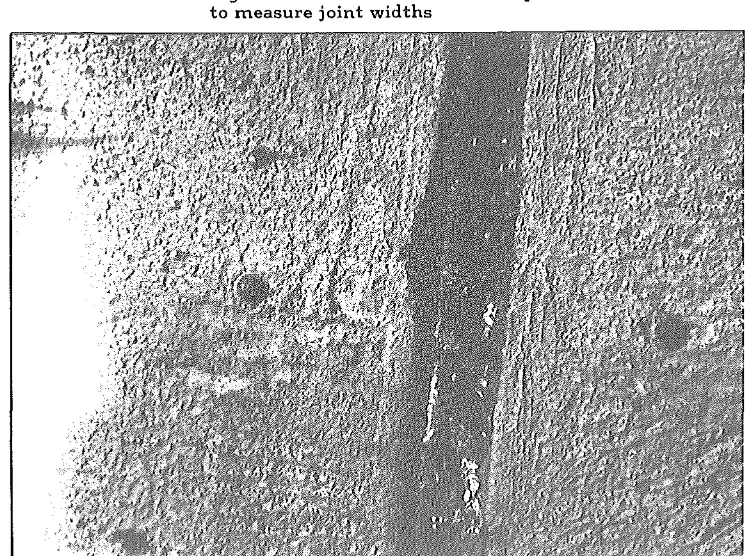


Fig. 25A. View of telescopic measuring device

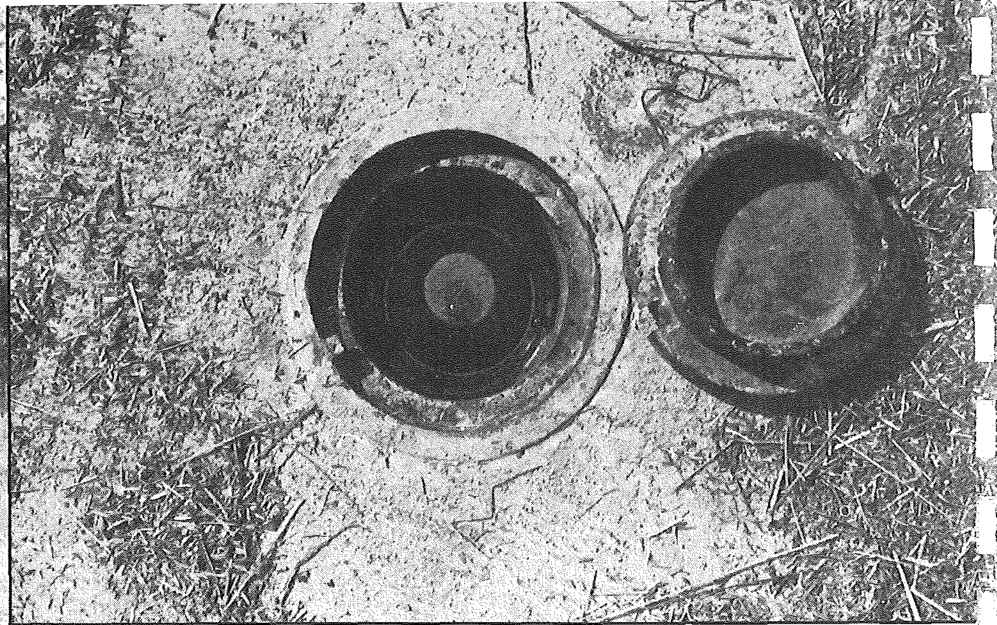


Fig. 25B. View of reference monument

TEMPERATURE. The temperature of the concrete and subgrade are determined by means of iron and constantan wire thermocouples embedded in the concrete and subgrade at time of construction. The location of the various types of the thermocouple assemblies are shown in the "Schematic Diagram of Design Project" (figure 3). The thermocouple assemblies are illustrated in figures 27, 28 and 29.

MOISTURE CONTENT. At the same location of the thermocouples, moisture cell assemblies were also installed in the concrete pavement and subgrade to measure moisture content concurrent with displacement measurements and as desired for other studies. The moisture cells consist of two bare wire terminals separated 1 inch apart and cast in chemically pure plaster of Paris to form blocks ½ inch by 1½ inches by 2½ inches. An electrical bridge is used to measure the resistance in ohms of potential between the two terminal wires embedded in the plaster of Paris cell. The relationship between resistance and moisture content must be determined from laboratory calibration tests. The moisture cell assemblies are shown in figures 27, 28 and 29.

STRAIN MEASUREMENTS. The measurement of strain in the concrete slab is being made at the neutral axis and at the surface of the slab. These measurements are being conducted at special locations to determine differences in tensile, compressive and warping stresses for various spacings of expansion and contraction joints.

The interior strains at the neutral axis are being measured by means of the Carlson electric strain meter. The strain meters, illustrated in figure 30, are approximately 10 inches long and 1½ inches in diameter. They were embedded in the fresh concrete during construction operations. The principle of the Carlson strain meter is based upon the linear relationship between change in resistance of a wire with change in tension. The strain meter contains two coils of wire under tension. The resistance ratio of the two coils, which changes in direct proportion to the change in gage length of the meter, is measured directly by a portable Wheatstone bridge. Twenty-six Carlson strain meters have been placed at desired locations in the design project. The locations of the electric strain meters are noted on the "Schematic Drawing of Design Project" (figure 3).

Immediately over the strain meters and at a few additional locations, surface strain measurements will be determined by use of an 8 inch Berry strain gage with 1/10,000 inch dial micrometer (figure 31). In this manner, stress differentials between the surface and interior of the pavement can be analyzed for temperature and moisture changes in the concrete. The relative location of the Carlson and Berry strain gages in the pavement are illustrated in figure 32.

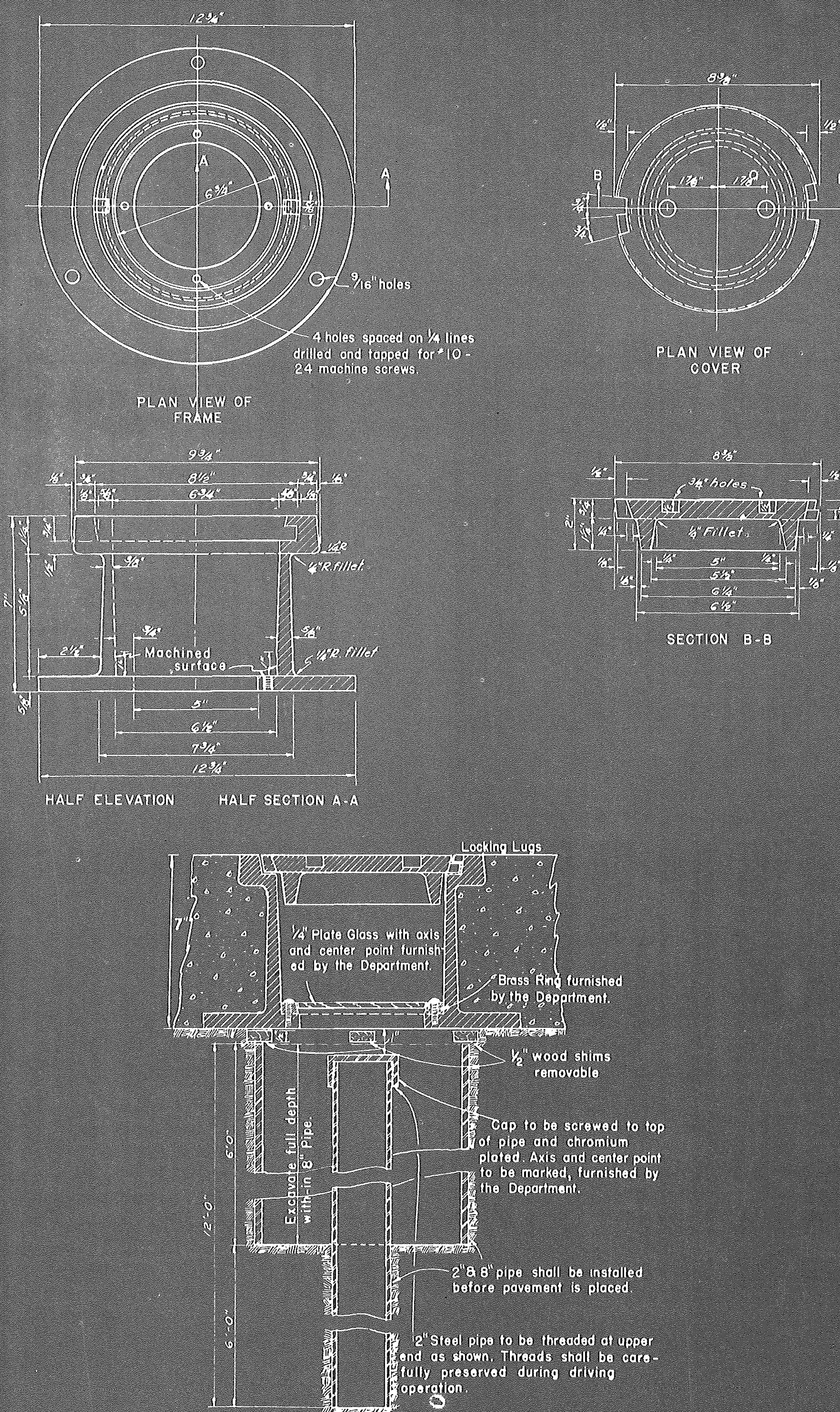
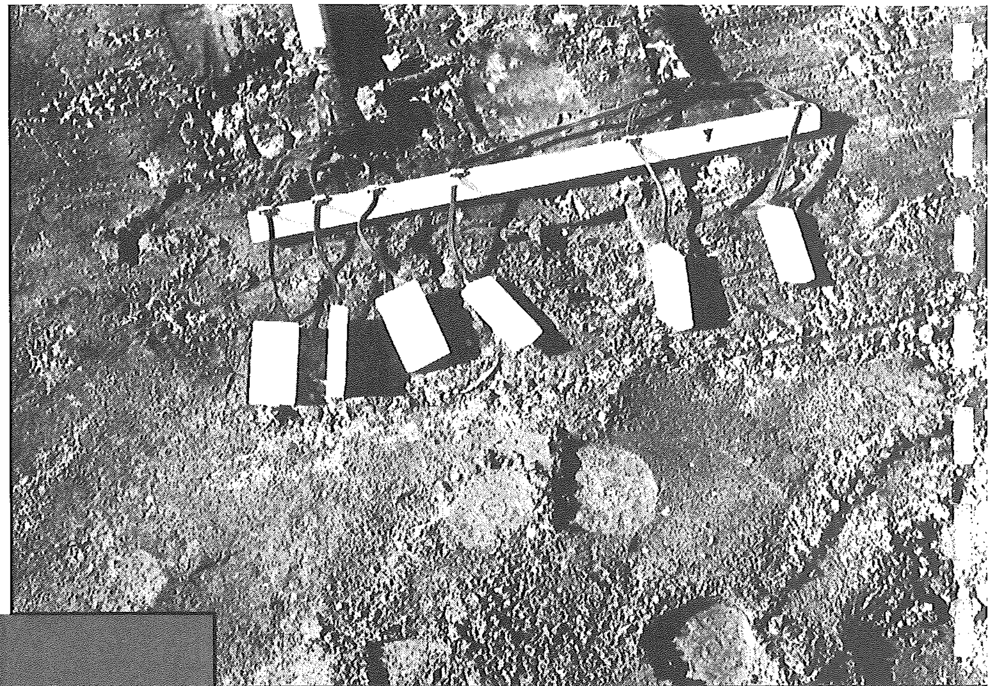


FIG. 26. DETAIL SKETCH OF REFERENCE MONUMENT

Fig. 27A. Moisture Cell Assembly



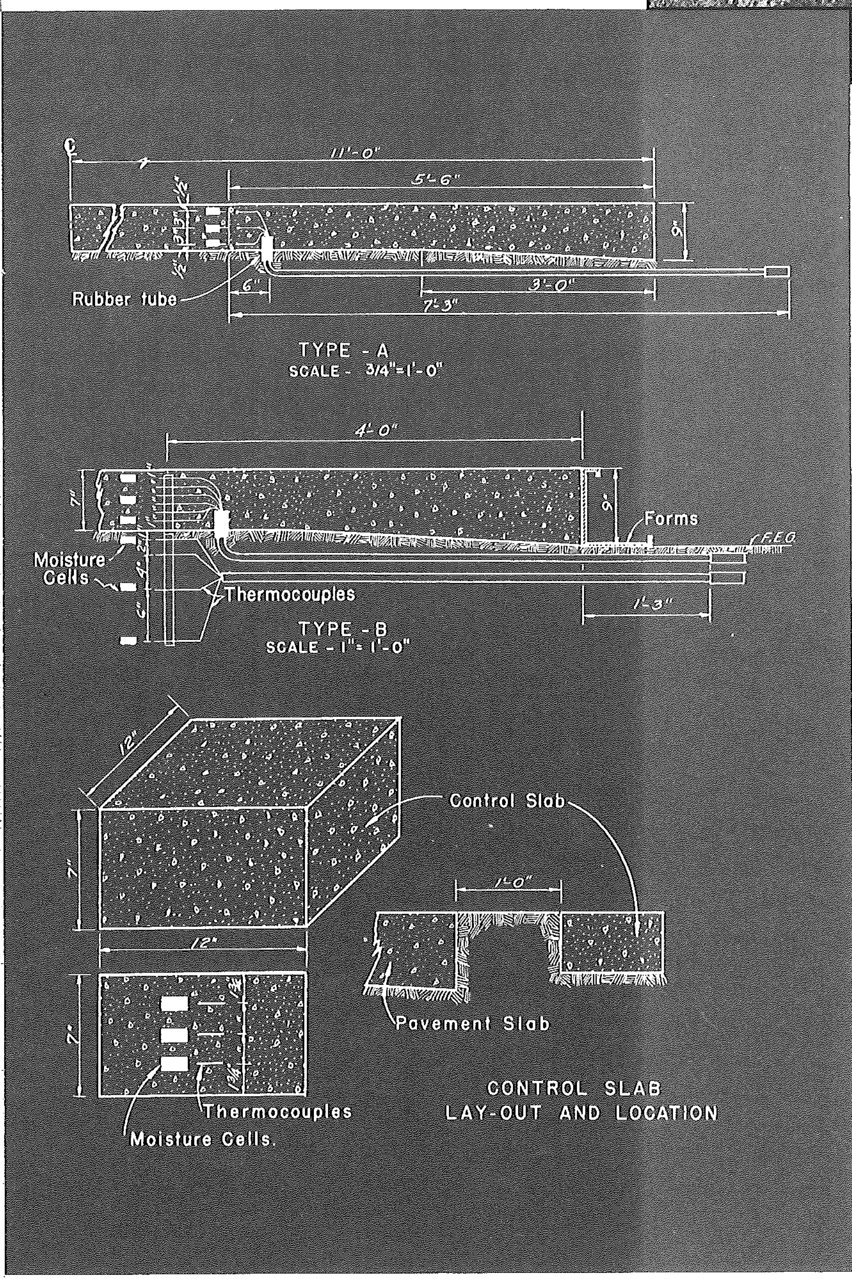


Fig. 28. Detail Sketch of Moisture Cell and Thermocouple Assemblies for Special Studies

SUBGRADE BEARING CAPACITY. During the construction of the project and prior to the placing of the pavement, subgrade bearing tests were conducted to determine the Modulus of Subgrade Reaction "k", which is employed in Westergaards formulae[4] for the computation of thickness of concrete pavements.

Bearing tests were made on 3 sizes of circular bearing plates, 10, 50 and 100 square inches in area. Static load was applied to the bearing plates by means of a hydraulic jack mounted under a loaded truck.

To simulate conditions which might exist under a slab, the tests were conducted with and without a surcharge on the subgrade around the bearing plates. The resisting load was determined by a ring dynamometer with 1/10,000 inch dial. The penetration of the plates was measured by averaging the readings of three 1/1,000 inch dials, spaced equally around the edge of the plate. The equipment and test set up are shown in figure 33.

In connection with the subgrade bearing tests, undisturbed soil samples were obtained by penetrating a 16 ounce metal sample can into the subgrade. Soil samples were taken directly under the bearing plate after the completion of each test and also at a short distance away from the plate. The soil samples were sealed in the cans and submitted to the laboratory for moisture and natural density tests. Finally all of the samples from a bearing test station were combined into one composite sample for further study with respect to gradation and compaction characteristics. The

([4]) — See Appendix IV.)

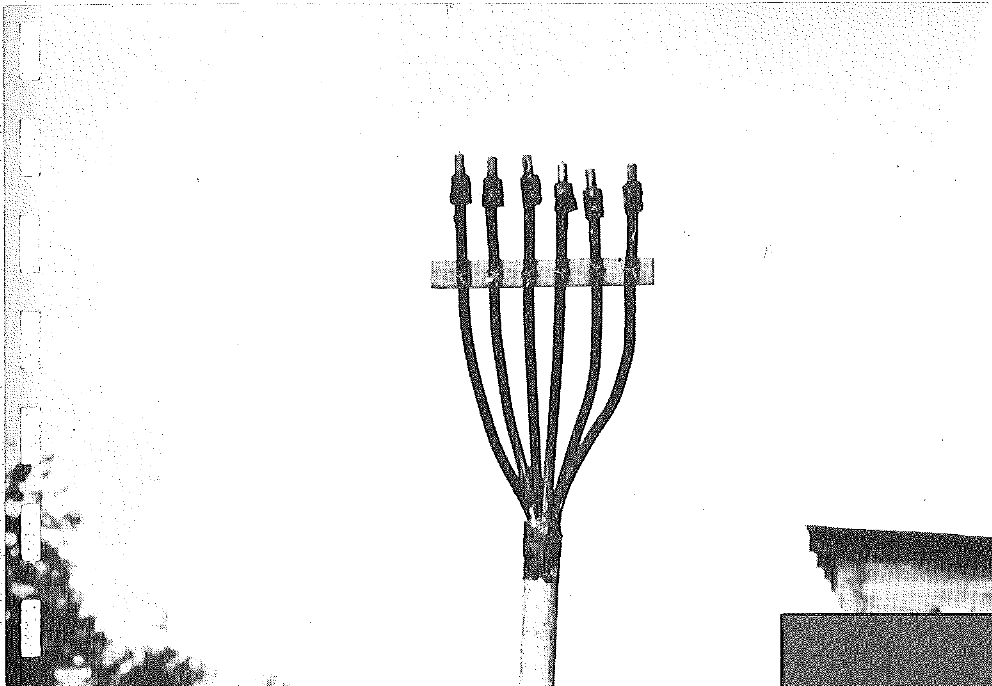


Fig. 27B. Thermocouple Assembly

later test consisted of compacting the soil on a vibrating table to its maximum density at the natural moisture content for the purpose of obtaining the porosity, percentage of voids (loose and compacted), and percentage of consolidation.

It has been pointed out that the subgrade bearing tests were conducted on the subgrade prior to construction of the slab. Eventually, at the same location of the bearing tests, the pavement slab will be subjected to loadings and the deflections determined. By means of Westergaards formulae the modulus of subgrade reaction "k" will be computed. The purpose of this work is an attempt to correlate these determinations of subgrade modulus with actual subgrade bearing tests in the field.

METEOROLOGICAL DATA. Throughout the construction of the test road, meteorological data was obtained including, temperature, relative humidity, precipitation, evaporation, and wind movement. The weather observation station has been permanently established and the gathering of this information will be continued for the entire period of the Test Road investigation. The meteorological equipment is illustrated in figure 34.

TRAFFIC COUNTER. An International Traffic Recorder has been installed near the center of the Test Road for the purpose of studying traffic conditions relative to the project. A record of total traffic flow will be maintained throughout the duration of the test project and the record will be tabulated in such a manner as to have available a

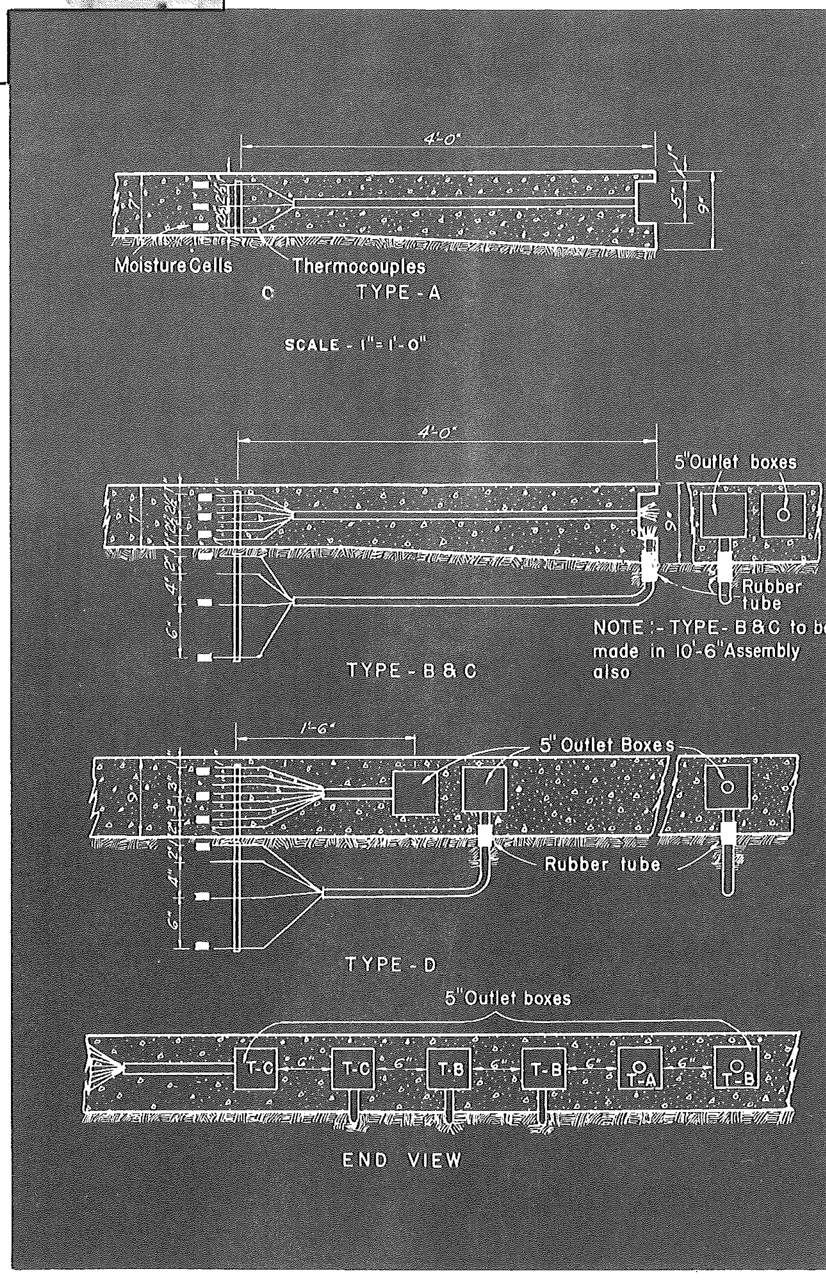


Fig. 29. Detail Sketch of Moisture Cell and Thermocouple Assemblies for Regular Installations

FIG. 30. EQUIPMENT FOR MEASURING STRESS IN PAVEMENT SLAB

1. Electric Strain Gage Assembly Ready for Installation
2. Electric Strain Gage
3. Electric Bridge used with strain gage

FIG. 31. METHOD OF MEASURING SURFACE STRAIN

1. Strain Gage Reference Point Lay-Out
2. Berry Strain Gage in Operation

FIG. 33. METHOD OF MEASURING SUBGRADE MODULUS

1. Installation of Bearing Plate
2. View of Test Set-Up
3. Equipment in Position Prior to Conducting Test

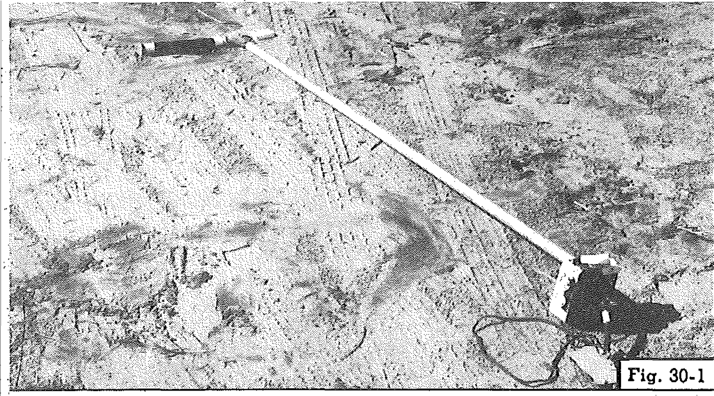


Fig. 30-1

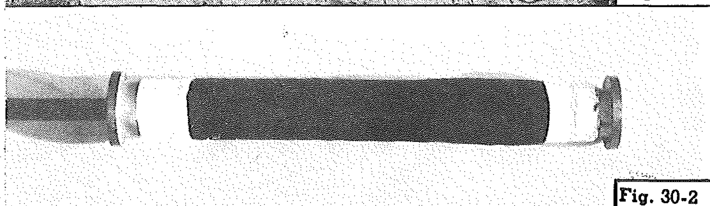


Fig. 30-2

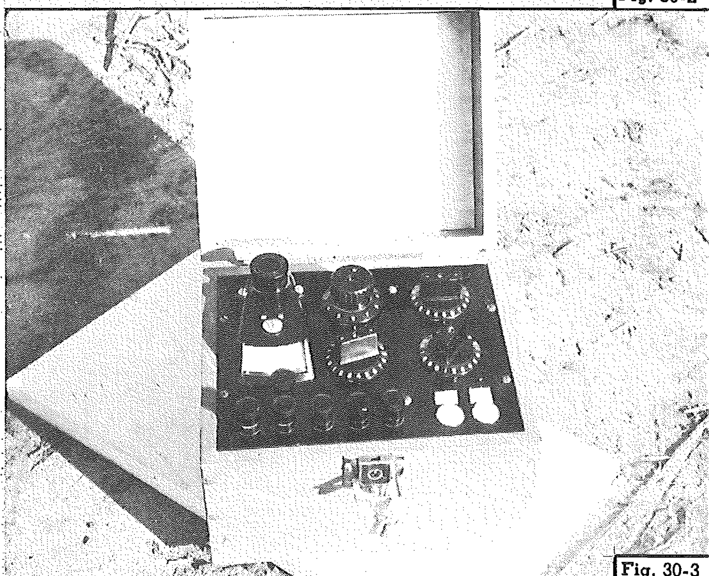


Fig. 30-3

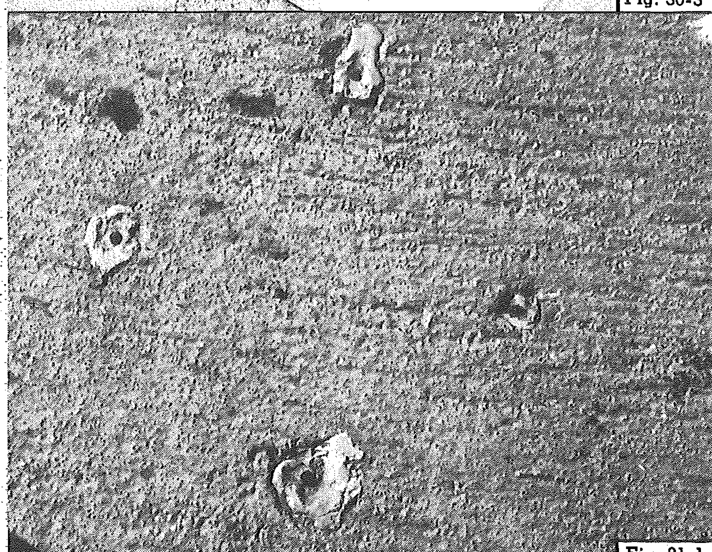


Fig. 31-1

Fig. 31-2

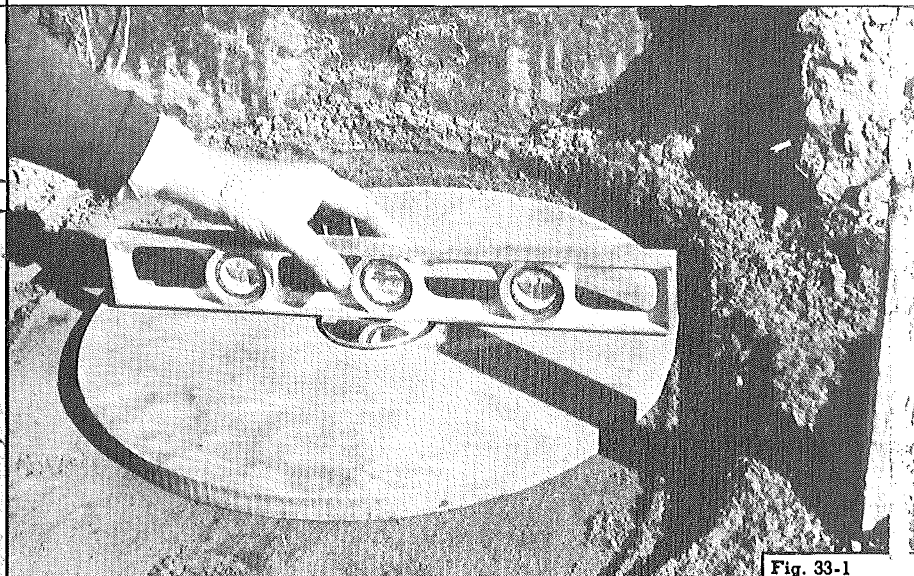


Fig. 33-1

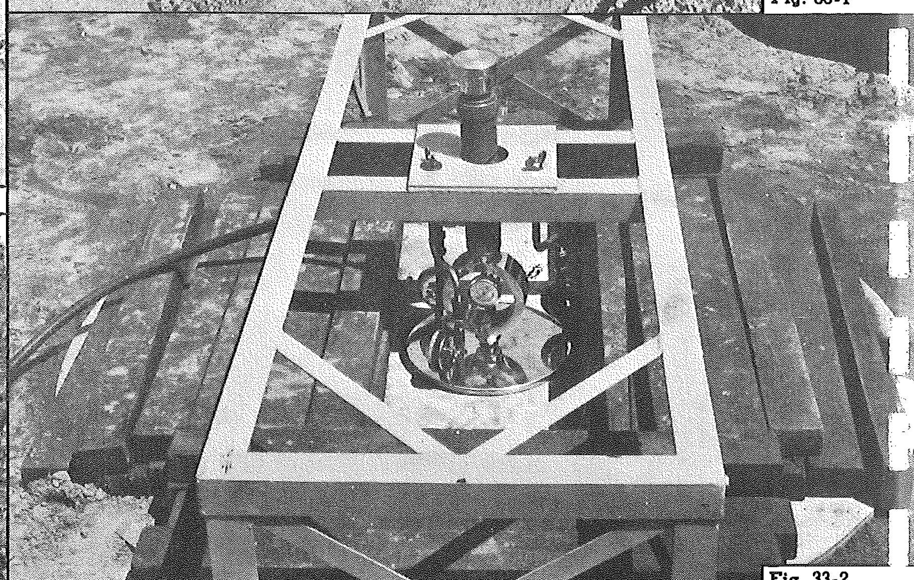


Fig. 33-2

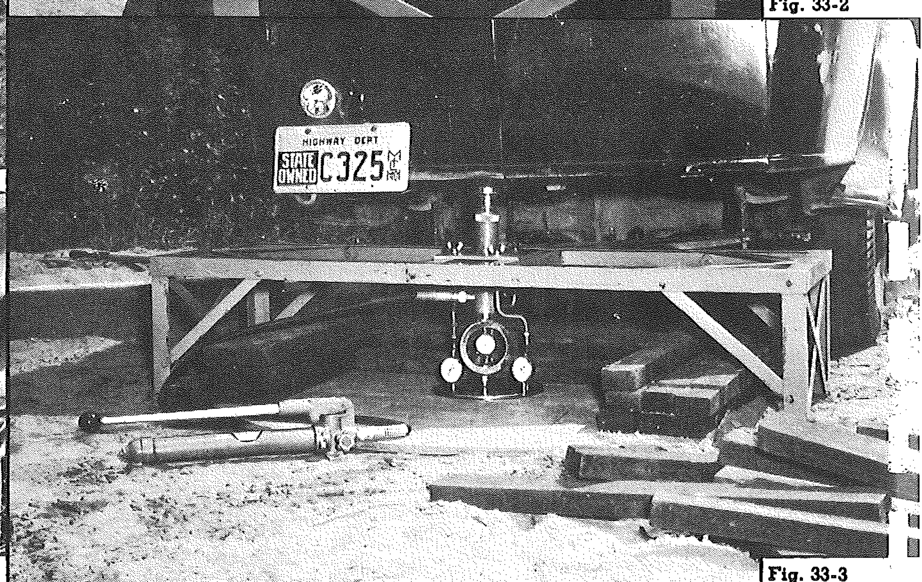


Fig. 33-3

traffic summary including, hourly, daily, weekly, monthly and yearly vehicle count. Also, periodically the total traffic will be sampled to obtain the various percentages of different types of traffic included in the count of the traffic recorder. The purpose of the traffic study is to obtain a knowledge of the loads being imposed upon the various slab sections.

In connection with the studies on joints, pavement cross section and reinforcements previously described, a number of incidental studies pertinent to pavement design and construction were included in the design project.

INCIDENTAL STUDIES

A few incidental studies were introduced into the Michigan Test Road which were of particular interest to the Michigan State Highway Department and pertinent to the improvement of concrete slab construction. These sub-investigations comprised a study of various construction methods including: the stress curing of concrete, mechanical spreading of concrete, the use of various joint sealers and the mechanical tamping of forms.

STRESS CURING. Eighteen hundred feet of concrete pavement was placed by the stress curing method of construction which eliminates steel reinforcement and transverse joints other than expansion. The purpose of the experiment was to determine the economic and physical value of stress curing. The slabs were laid in 100 foot lengths and the prestressing of the concrete accomplished by use of canvas covered rubber hose pressure cells inserted in the joint openings. These were expanded to exert pressures based on results of tests on representative specimens 7 by 9 by 14 inches cast throughout the period of construction of the stress curing section (figure 35). The pressures were increased at a rate controlled by determinations of strength increase in specimens up to a maximum of 200 pounds per square inch. This pressure was maintained until the standard modulus of rupture beam tests reached the 7 day specification strength requirement of 550 pounds per square inch. The stress curing experiment is illustrated in figure 36.

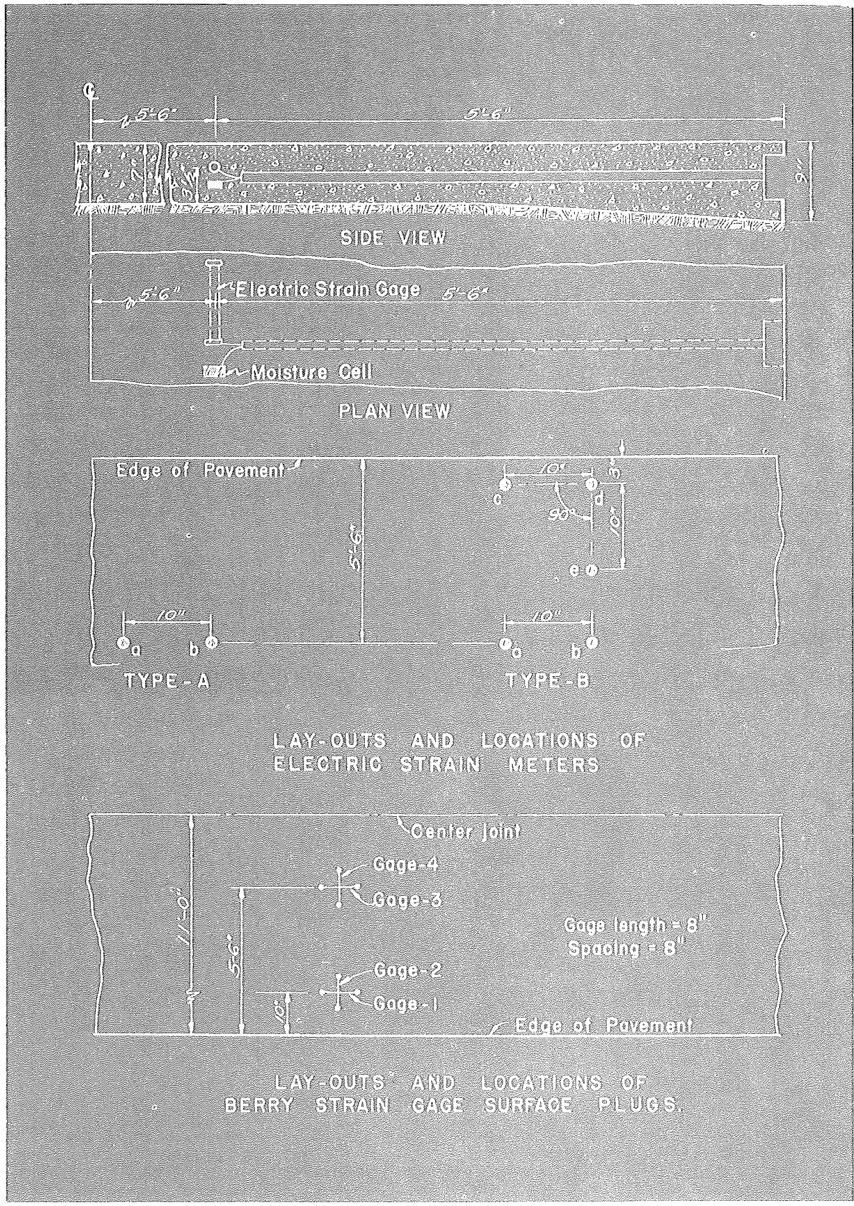


Fig. 32. Detail Sketch of Strain Gage and Moisture Cell Assembly

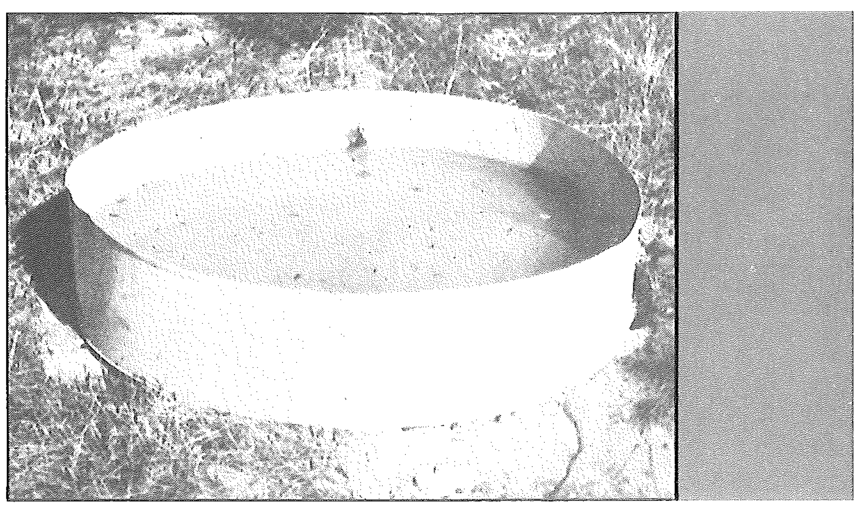


Fig. 34-1. Evaporation Pan with Measuring Device

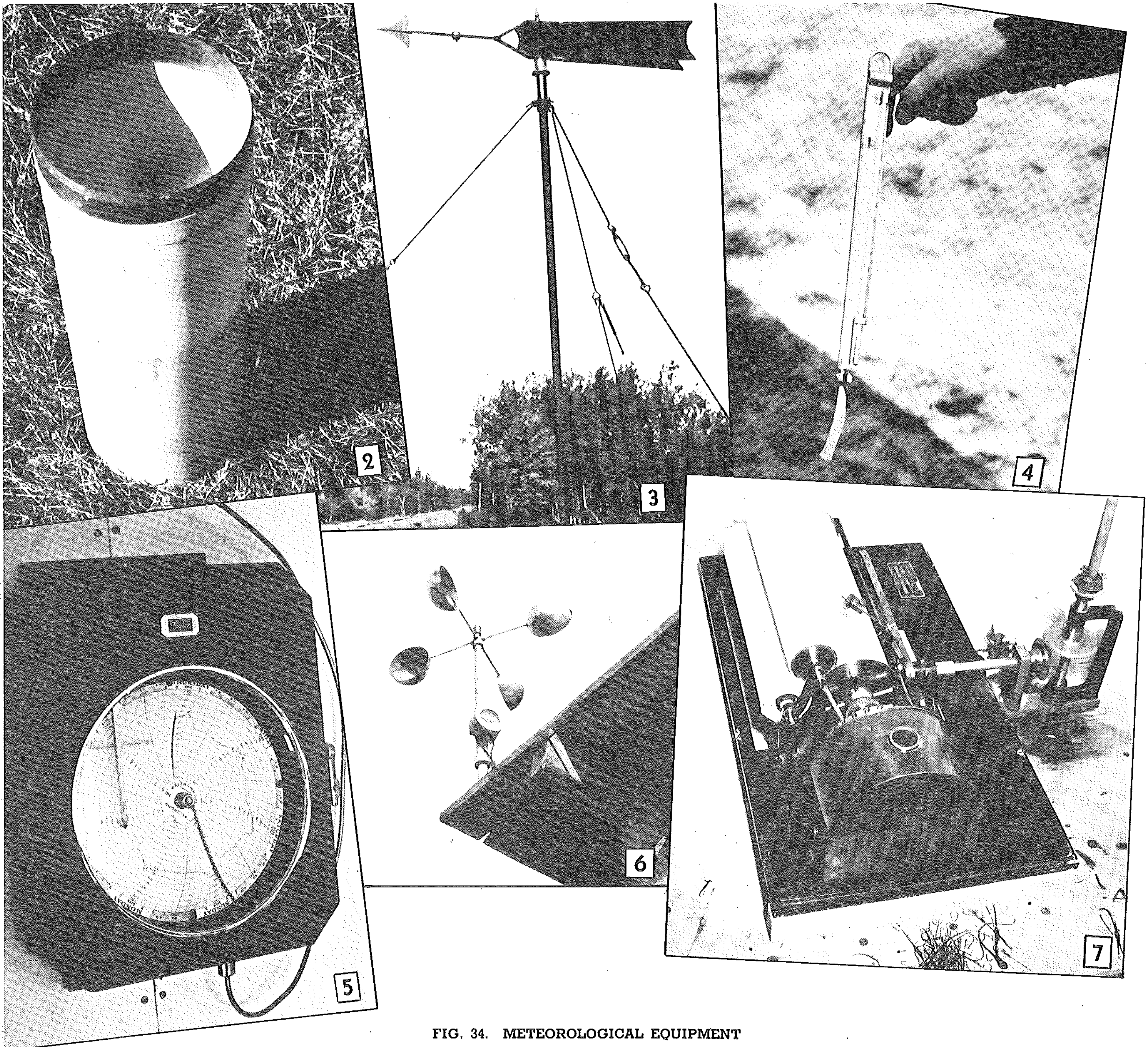


FIG. 34. METEOROLOGICAL EQUIPMENT

2. Rain Gauge
3. Wind Direction Indicator
4. Sling Hygrometer
5. Recording Thermometer
6. Wind Anemometer
7. Automatic Wind Direction Recorder

Another phase of highway construction considered important enough for trial and study is the mechanical handling of concrete on the subgrade.

MECHANICAL CONCRETE SPREADER. With the exception of 600 lineal feet, the concrete on the design project of the test road was placed and consolidated by means of a mechanical concrete spreader. The purpose of this study was to compare the relative merits of mechanical spreading versus hand spreading of concrete. Comparative observations were made on the uniformity of distribution and placing of the concrete, its strength characteristics, the segregation of aggregates, relative water content and effect on finishing operations.

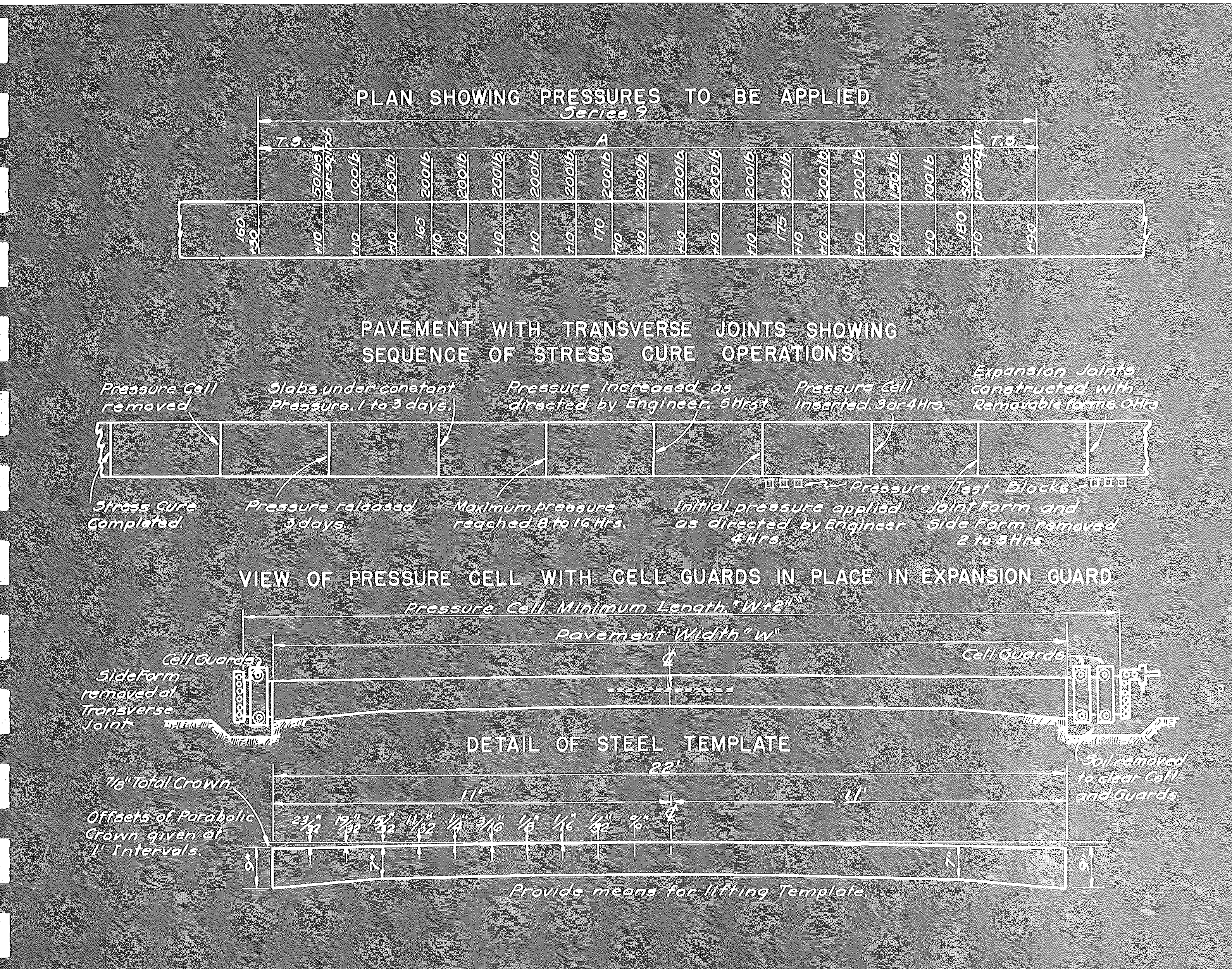


Fig. 36A. Detail Sketch of Stress Curing Test Section

The mechanical concrete spreader is a power-driven four-wheel frame with suitable forward and reverse speeds, on which is mounted a reversible 14 inch spiral screw which manipulates the concrete to one side or the other at the will of the operator. The screw may be quickly adjusted vertically so that the strike-off plate, which is located behind the screw, may be used to obtain the desired height of concrete on the subgrade. The spreader was designed to handle the concrete for the full 22-foot width of the slab and to operate on the pavement forms. The pictures in figure 37 illustrate the unit in operation on the design project.

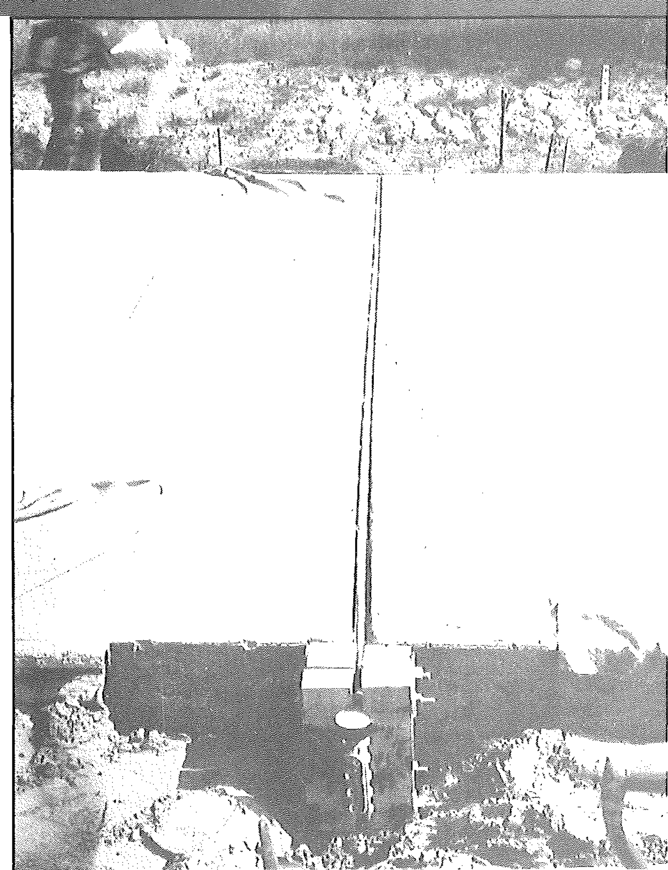


Fig. 35A. Pressure Cell in Place in Joint Opening

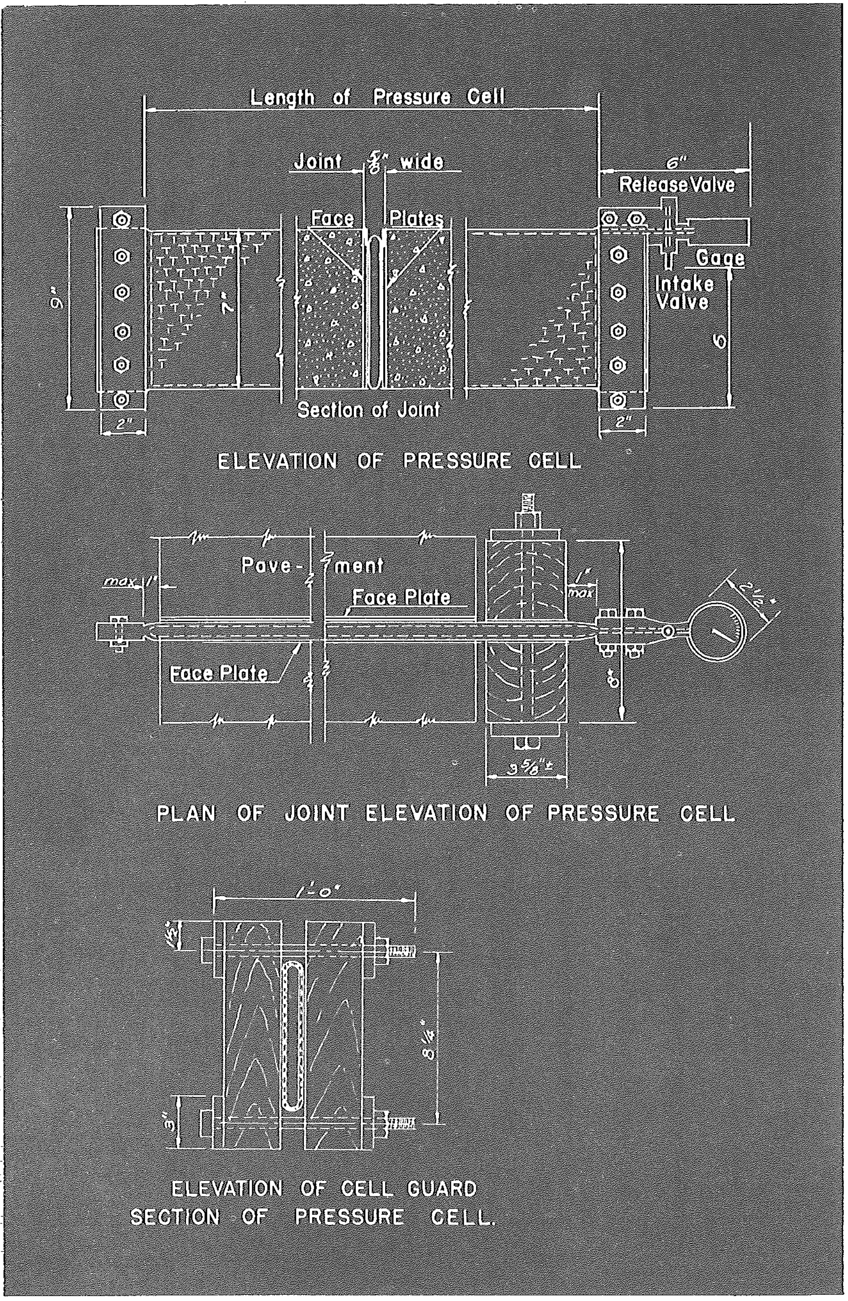


Fig. 36B. Detail Sketch of Stress Curing Test Section

Occurring with the studies of stress curing and the mechanical handling of concrete is the study of joint seals. The problem of adequately sealing a pavement joint was considered important enough to be included as one of the incidental studies in the design project.

JOINT SEALERS. Over a period of years the Michigan State Highway Department has given considerable attention to the study of various kinds of joint sealers. Several joint sealers having desirable characteristics were included in the design project for comparative study. The various joint sealers used are herein described and the location of each type is shown in the "Summary of Design Project", table 1.

ASPHALTIC OIL — LATEX SEAL, Type I. This material consists of a mixture of 70 parts of asphaltic oil SC-6A, 30 parts of normal rubber latex and 2 parts of hydrated lime. The materials are mixed together under controlled conditions prior to pouring into the joint. Two types of asphaltic oil-latex seal were included for comparative study. Type No. 1 contained the regular commercial grade of rubber latex, and type No. 2 contained a vulcanized latex known as Vultex, (figure 38).

ASPHALT-LATEX EXPANSION JOINT, Type 3. Several installations were made employing asphalt latex as a seal material at top, bottom and sides of the expansion joint. The joint was designed in such a manner as to provide a combination air and escape chamber throughout the central portion of the joint. The chamber provides a space for excess seal material caused by movement of the slabs. The joint was developed by the Michigan State Highway Department, and is illustrated in figure 39.

PREMOLDED RUBBER, Type 4. In connection with the construction of the stress curing section, the expansion joints were designed to use a

Fig. 35B. Adjusting Air Cells to Test Specimen premolded rubber expansion joint filler, (figure 40). In addition, the bottom inch of the joint was sealed with asphalt latex sealing compound. The joint is illustrated in figure 41.

RAI-SEAL, Type 5. Rai-Seal is a hot poured type rubber compound material, furnished in block form which upon heating to 450°F. transforms to a liquid which can be easily handled and poured into the prepared joints (figure 42).

CONTRACTION JOINT FILLER. The majority of the contraction joints were sealed with the regular standard $\frac{1}{4}$ inch by $2\frac{1}{2}$ inch premolded bituminous strip. Several of the contraction joints were constructed with the $2\frac{1}{2}$ inch groove in which asphaltic oil-latex material was poured to seal the joint.

Periodic observations will be made to determine the effectiveness of the various types of seals.

On account of the unusual heavy equipment used on the design project, it was essential that the sandy subgrade should be firmly tamped under the forms. In order to accomplish this purpose a mechanical tamper was employed on the design project.

MECHANICAL TAMPING OF FORMS. A mechanical form tamper was specified for use on the design project for comparative study of mechanical versus hand methods of tamping forms on sandy subgrades. In conjunction with the tamping of the subgrade under the forms the tamper applied a coating of oil to the inside surface of the forms as it moved along them (figure 43).

In Part II, this report has summarized the various details of the design section of the Michigan Test Road. The durability phase of the Test Road will be described in Part III.

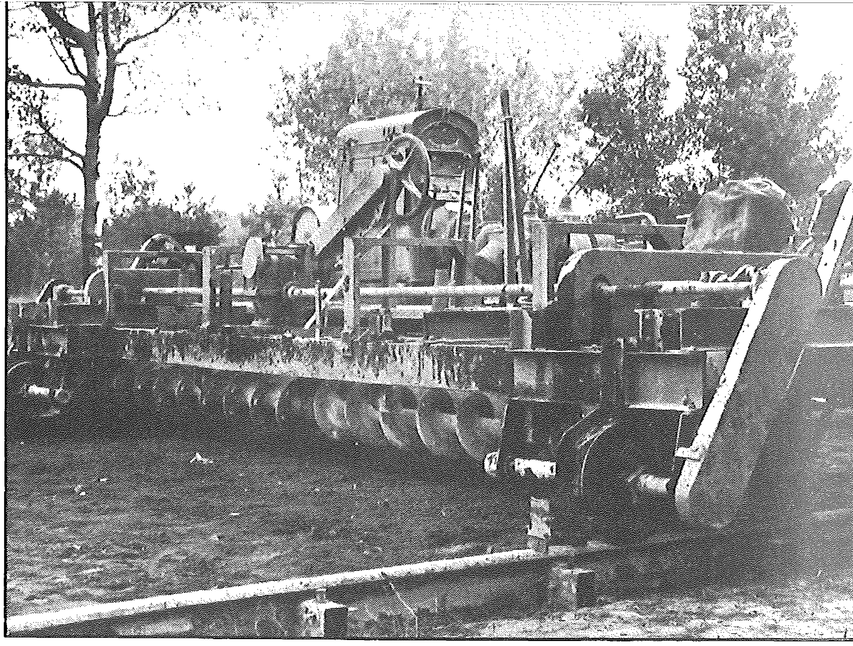


Fig. 37A. View of Mechanical Concrete Spreader

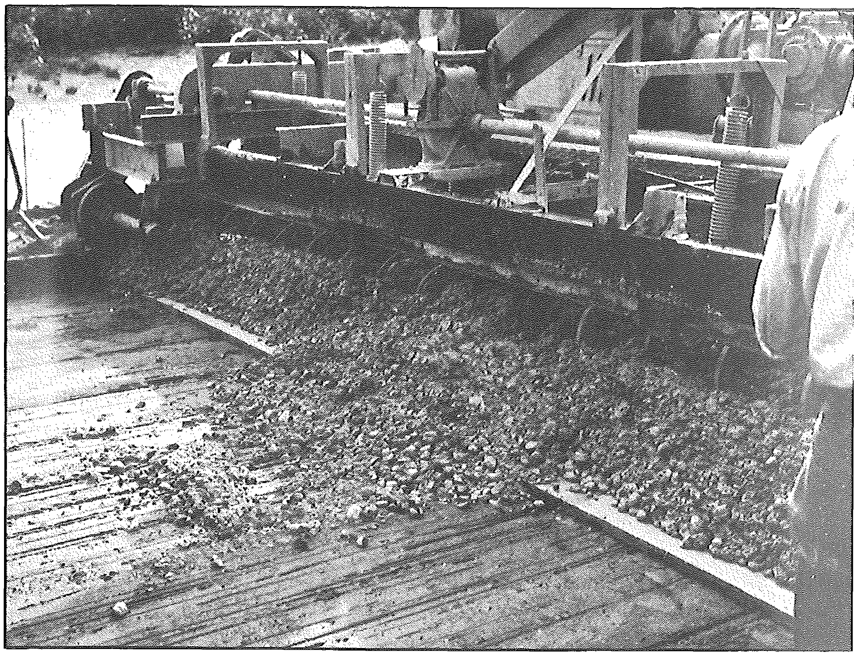


Fig. 37B. View of Mechanical Concrete Spreader

Fig. 38. Sealing Joint with Asphaltic Oil-Latex Material

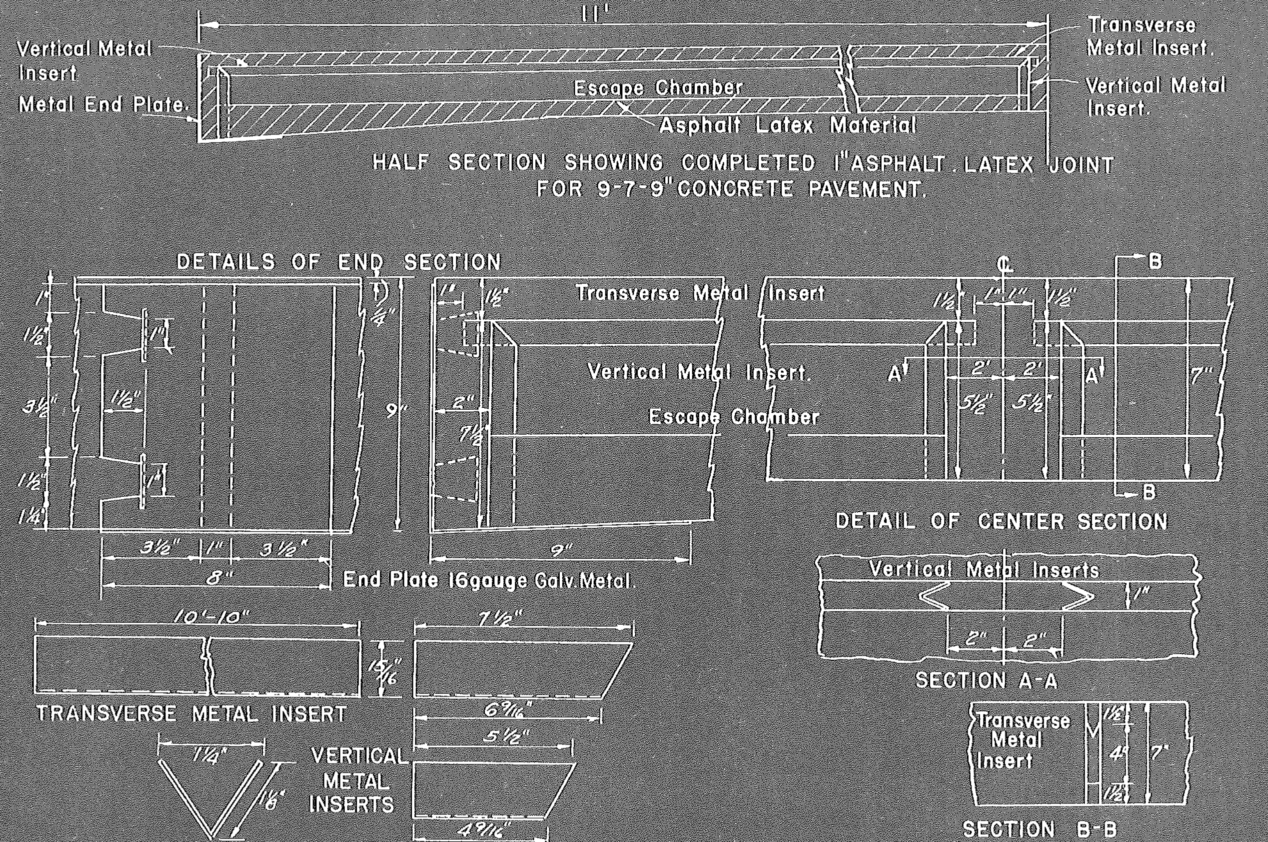
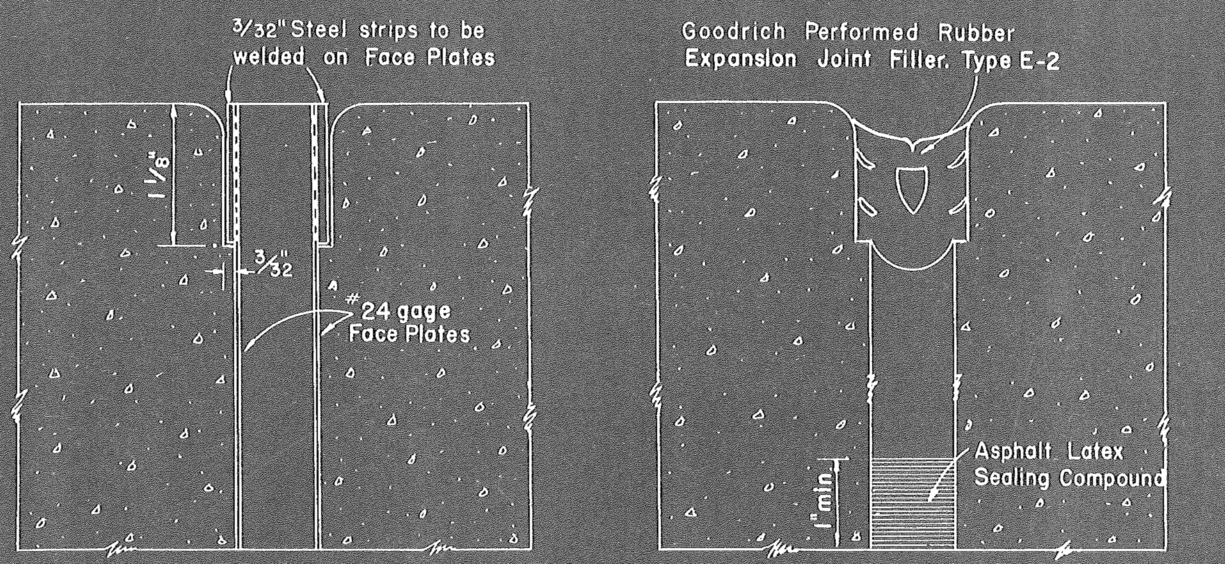


FIG. 39. DETAIL SKETCH OF ASPHALT LATEX EXPANSION JOINT



NOTE:- Face Plates shall be placed with the Expansion Joint Forms and remain in place until Stress Curing is completed. Four strips, not less than 24 gage thick, shall be used per joint. All Pressure Cells furnished longer than the required minimum length shall have their extended portion covered by Cell Guards. If more than one Cell Guard is required, place a wood strip cut to size, on each side between the Pressure Cell and Cell Guards.

FIG. 41. DETAIL SKETCH OF PREMOLDED RUBBER JOINT INSTALLATION

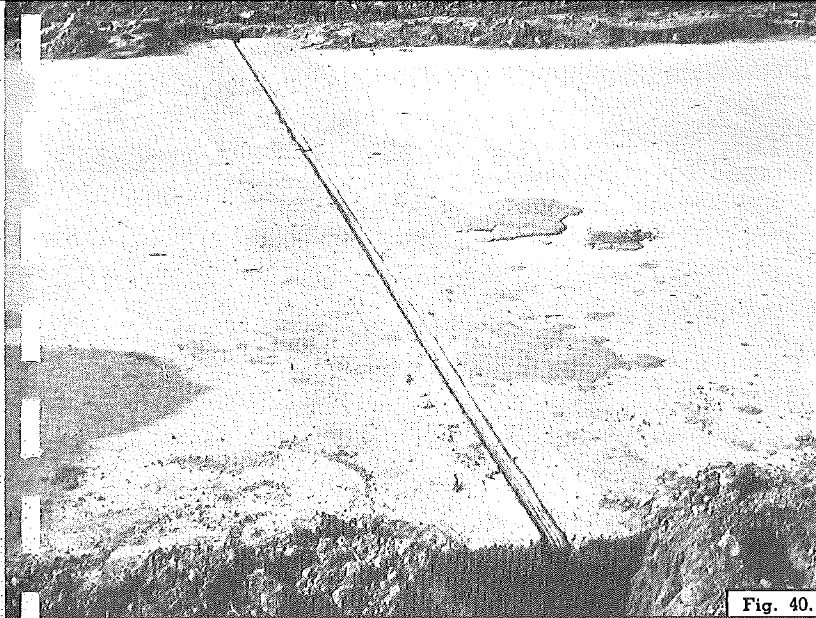


Fig. 40.

Fig. 42.

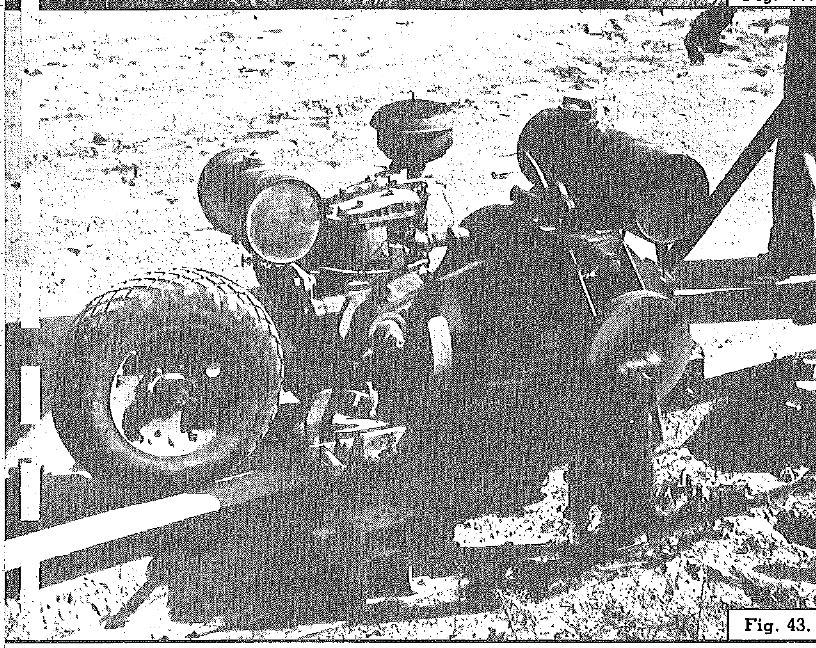


Fig. 43.

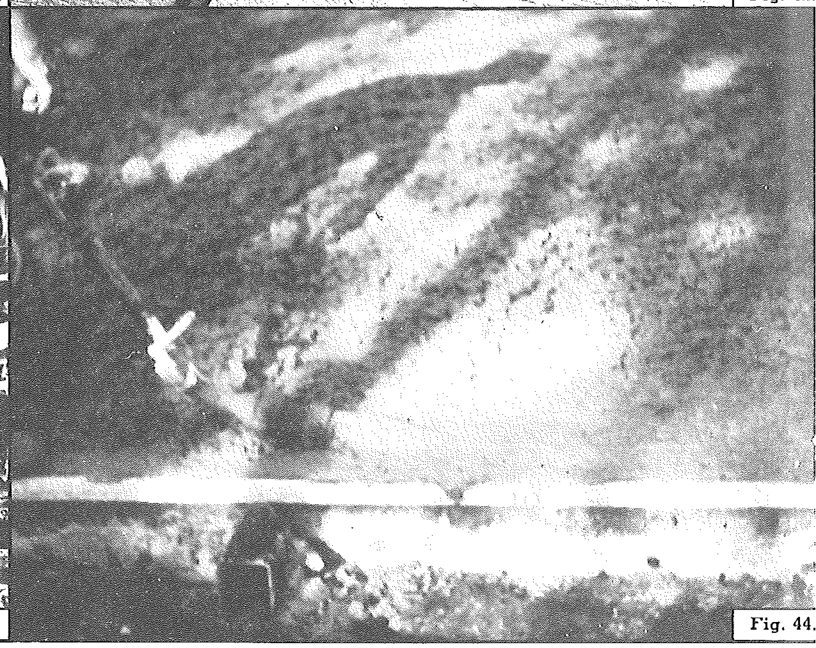


Fig. 44.

FIG. 40. PREMOLDED RUBBER EXPANSION JOINT FILLER IN PLACE

FIG. 42. SEALING JOINT WITH RAI-SEAL

FIG. 43. MECHANICAL FORM TAMPER

FIG. 44. VIBRATING CONCRETE AT FORMS AND JOINTS

PART III

THE DURABILITY PROJECT

A preliminary survey study of all concrete pavements in Michigan shows that approximately 10 percent of the surface is scaled in varying degrees. This condition has become more apparent as the use of chemical salts has increased for the removal of ice from pavements. However, the use of concrete for pavements during the last thirty years has indicated its many desirable properties as paving material. At the present time, scaling has not become a serious problem leading to definite failures. Scaling has been common in most parts of the state, but on a whole the concrete is predominantly good. But, even so, the unsightliness of scaled areas and subsequent maintenance and the added possibility of further deterioration is of immediate concern to the highway engineer.

The performance of concrete under the severity of service cannot be predicated upon laboratory studies. Although laboratory studies will aid in the discovery of factors affecting the deterioration and scaling of concrete pavements, the combined physical, chemical and mechanical action as experienced in actual use cannot be predicted.

In order to make observations under service conditions on controlled factors which have been determined to be of importance in the durability of concrete, a portion of the Michigan Test Road was constructed to this end. The purpose in constructing this section was not only to make observations under service conditions, but to afford a field laboratory to obtain accelerated action of chloride salts or ice on concrete pavements and the study of resultant action.

The durability project includes an evaluation of the effect of variation of factors relative to the construction and materials used in concrete pavements. Embodied in these considerations are; the proportioning and grading of aggregates with definite recognition of the material passing 200 mesh; the comparative effect of various types of additives including physical and chemical varieties as well as cement blends and cements produced with grinding aids. Consideration has been given to crushed limestone aggregates with special attention to the finer fractions. The effect of various curing methods is being studied including the use of asphaltic curing agents. In connection with the study of these phases of the problem, it was necessary to obtain certain pertinent incidental data on construction for proper evaluation of each variable factor. Also, it was necessary, in order to obtain quick and reliable information regarding the value of these means in controlling scaling, to set up a special scaling study for this purpose.

In planning the durability project an effort was made in all phases of the work to have only one factor varied at a time. In order to do this the project was divided into a number of test areas, in the manner of the design project. Each test area is designated as a series. A series has been further divided into divisions and sections appropriately marked with letters and numerals respectively. On the durability project there are eight series, each series being devoted to a study of one particular durability factor. A description of the various test areas will be found in table II, entitled "Summary of Test Areas on Durability Project". In addition to table II, a "Schematic Diagram of the Durability Project" has been prepared to further illustrate the various test areas with respect to the entire durability project. This diagram is presented in figure 45.

In the construction of the durability project, no special consideration was given to the design or construction features of the project, except only in those cases expressly mentioned in the description of the durability project. All work was done in accordance with Michigan State Highway Department standard practice.

The expansion joints throughout the durability project were constructed 1 inch wide and spaced 120 feet apart in accordance with the standard practice of the Michigan State Highway Department. In series 7D and 7E of the durability project, all contraction and dummy joints were omitted and the expansion joints were spaced at 90, 120, 360 and 600 foot intervals to be studied in conjunction with the design project as explained in "Summary of Durability Project", table II. The Translode Angle-Unit with continuous base was used as load transfer device at expansion joints throughout the durability project. The joint filler consisted of 1 inch Flexcell fiber filler sealed with asphalt joint seal material SOA.

The contraction joints were constructed in accordance with standard practice, consisting of ¾ inch by 15 inch dowel bars, spaced 15 inches center to center, and held in place by an approved installing device. This is the same type of contraction joint as used on the design project and illustrated in figures 13 and 14 under design project, part II.

The "dummy" plane of weakness joints were constructed in accordance with standard practice.

Steel reinforcement was used throughout the durability project in accordance with standard practice.

Prior to the construction of the durability project of the Michigan Test Road, it was necessary to make preliminary studies of proper proportioning and grading of aggregates to comply with the characteristic requirements of each material added. In the final concrete mixtures used in the test sections of the durability project, natural fine sand and mineral fillers were incorporated in the mixture to improve the grading.

PROPORTIONING AND GRADING OF AGGREGATES

Poorly graded aggregates are inducive to poor workability, segregation, difficult finishing, bleeding and laitance. These properties are contributory in a certain degree to inferior concrete with subsequent scaling and disintegration of the surface of pavements.

Mix designs used on the Michigan Test Road included the regular proportioning as provided for in the Michigan State Highway Department material specifications and determined by the mortar void design method. The standard design method was supplemented by incorporating fines with the fine aggregates. These fines were added to increase the density and workability of the mix and a possible resultant reduction of scaling. The fines included natural sand and mineral fillers.

MODIFIED SAND. In this connection, one phase of the durability study was to design a practical and economical dense concrete mix that would show improvement in resistance to scaling. In the grading of the sand and coarse aggregate, it was attempted to approach an ideal gradation and still be conservative as to cost. A study of the general characteristics of available concrete aggregates meeting Michigan State Highway Department 1940 specifications, showed that it was desirable to improve the gradation of the fine aggregate 2NS, particularly the material passing the No. 50, 100 and 200 sieves. Consequently, in series 7E of the durability project, 175 pounds of special fine sand, obtained from a local natural deposit, was blended with one cubic yard of concrete. The grading of the respective materials is given in appendix II, tables 8 and 9. The combined mixture of fine aggregates is designated as Modified Sand 2NS.

MINERAL FILLERS. Another phase of the study of grading improvement, series 7A, 7C and 8A, included two types of mineral fillers which were added to the concrete to provide additional fines. These materials were silica dust and limestone dust meeting Michigan State Highway Department gradation requirements for Mineral Filler 3MF. See appendix II, table 10.

The mineral filler was added to each batch in the amount of 85 pounds per cubic yard of concrete. The quantity of mineral filler to be added to the concrete mixture was determined from laboratory analysis, taking into consideration the amount of fines in the fine aggregate, the fineness of the Portland cement and the gradation of the mineral filler.

The natural sand and mineral filler admixtures are inert and act wholly as a physical addition to produce a workable and anticipated durable concrete. To obtain the same end, concrete mixes were designed incorporating chemical additives.

EVALUATION OF ADDITIVES IN CONCRETE MIXTURES

Incidental to the construction of the durability project, a preliminary laboratory investigation was necessary in order to evaluate the various additives for the purpose of determining the most beneficial materials and the affect these additives would have upon the design and physical characteristics of their respective concrete mixtures.

The proprietary additives selected for use on the durability project were of the powder and liquid types which included Pozzolith, Plastiment, Orvus, Vinsol Resin and Calcium Chloride. A blend of natural cement was also included which was ground with and without the use of calcium stearate.

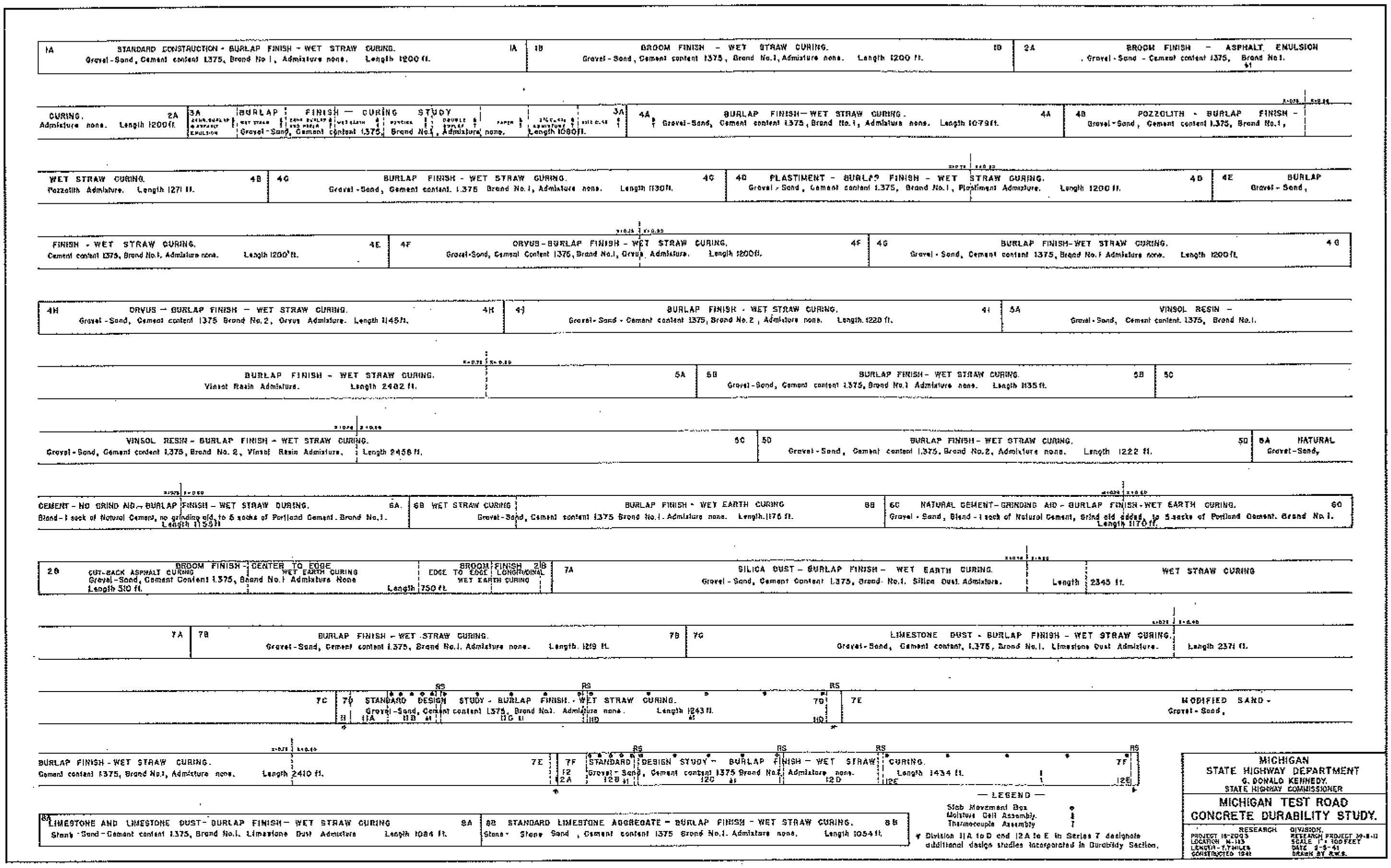


FIG. 45. SCHEMATIC DIAGRAM OF DURABILITY SECTION

Using the mortar-void principle of concrete mix design, various quantities of sand, cement, water and additives were combined in varying amounts to determine the most desirable mortar from the standpoint of density and consequently the most desirable amount of admixture to use. In all cases, the quantity of sand and cement were kept constant in accordance with standard practice but the quantity of admixture varied. The liquid admixtures were added to the predesigned mortars in varying amounts to determine the most desirable quantities to use from the standpoint of physical characteristics of the mortar and concrete such as workability, density and durability.

The additives used for study in the test road are described as follows:

POZZOLITH. Pozzolith is a patented plasticizing agent containing ferric alumina silicate and other ingredients. Two pounds of Pozzolith per sack of cement were added to the dry batch at the mixer as recommended by the manufacturer. Pozzolith was used in series 4B of the durability project.

PLASTIMENT. Plastiment is another type of plasticizing agent in which an organic oxy-acid is the active agent. This organic oxy-acid is incorporated with an inert filler to insure even distribution of the acid throughout the concrete.

Plastiment was added to the dry batch at the mixer in the amount of one pound per sack of cement as recommended by the manufacturer and was used in series 4D of the durability project.

ORVUS, W. A. PASTE. Orvus is a patented wetting agent manufactured for industrial use. It is a sulphated fatty alcohol containing sodium lauryl sulfate as the active ingredient. Orvus may be obtained in flake or paste form. Sufficient Orvus was added to the mix to produce a drop in weight of 4 to 6 pounds per cubic foot of concrete of a specified consistency and cement content as compared with concrete of the same consistency and cement content without the addition of Orvus. Since this requirement will vary in accordance with materials used, the approximate quantity of Orvus will be between 0.02 and 0.10 pound per barrel of cement. It was found that for the particular materials used on this project that 0.06 pound of Orvus per barrel of cement gave a reduction in weight of approximately 5 pounds per cubic foot.

The Orvus paste was dissolved in water to form a solution of known concentration. The required amount of the solution per batch of concrete was added to the dry materials at the skip. Orvus was used in series 4F and 4H of the durability project.

VINSOL RESIN PORTLAND CEMENT. This cement consists of standard Portland cement ground with Vinsol Resin. Vinsol Resin is an im-

TABLE II.

SUMMARY OF TEST AREAS ON DURABILITY PROJECTS

Series	Division	STATION Beginning	STATION End	Length	Finish	Curing	Type of Standard Portland Cement	Admixture	b/b_o	Nomenclature Section Markers
1	A	358+50	370+50	1200'	Burlap	Wetted Straw	Brand No. 1	None	0.76	1A
	B	370+50	382+50	1200'	Broom	Wetted Straw	Brand No. 1	None	0.76	1A/1B
2	A	382+50	394+50	1200'	Broom	Asph. Emulsion	Brand No. 1	None	0.76	1B/2A
3	A-1	394+50	395+70	120'	Burlap	Asph. Emulsion [1]Initial curing	Brand No. 1	None	0.76	2A/3A
	A-2	395+70	396+90	120'	Burlap	Wetted Straw	Brand No. 1	None	0.76	
	A-3	396+90	398+10	120'	Burlap	Paper with initial curing	Brand No. 1	None	0.76	
	A-4	398+10	399+30	120'	Burlap	Wetted Earth	Brand No. 1	None	0.76	
	A-5	399+30	400+50	120'	Burlap	Ponding	Brand No. 1	None	0.76	
	A-6	400+50	401+70	120'	Burlap	Double Burlap	Brand No. 1	None	0.76	
	A-7	401+70	402+90	120'	Burlap	Paper	Brand No. 1	None	0.76	
	A-8	402+90	404+10	120'	Burlap	2% $CaCl_2$ Admixture	Brand No. 1	None	0.76	
	A-9	404+10	405+30	120'	Burlap	Ritecure	Brand No. 1	None	0.76	
4	A	405+30	412+50	720'	Burlap	Wetted Earth	Brand No. 1	None	0.76	3A/4A
	A-1	412+50	413+70	120'	Burlap	2% $CaCl_2$ Admix.	Brand No. 1	None	0.76	4A-1
	A	413+70	416+09	239'	Burlap	Wetted Straw	Brand No. 1	None	0.76	
	B	416+09	422+07	598'	Burlap	Wetted Straw	Brand No. 1	Pozzolith	0.76	4A/4B
	B	422+07	428+80	673'	Burlap	Wetted Straw	Brand No. 1	Pozzolith	0.80	
	C	428+80	440+10	1130'	Burlap	Wetted Straw	Brand No. 1	None	0.76	4B/4C
	D	440+10	446+10	600'	Burlap	Wetted Straw	Brand No. 1	Plastiment	0.76	4C/4D
	D	446+10	452+10	600'	Burlap	Wetted Straw	Brand No. 1	Plastiment	0.80	
	E	452+10	464+10	1200'	Burlap	Wetted Straw	Brand No. 1	None	0.76	4D/4E
	F	464+10	466+50	240'	Burlap	Wetted Straw	Brand No. 1	Orvus	0.76	4E/4F
	F-1	466+50	467+70	120'	Burlap	1% $CaCl_2$ Admix.	Brand No. 1	Orvus	0.76	4F-1
	F	467+70	470+28	258'	Burlap	Wetted Straw	Brand No. 1	Orvus	0.76	
	F	470+28	476+10	582'	Burlap	Wetted Straw	Brand No. 1	Orvus	0.80	
	G	476+10	488+10	1200'	Burlap	Wetted Straw	Brand No. 1	None	0.76	4F/4G
	H	488+10	494+10	600'	Burlap	Wetted Straw	Brand No. 2	Orvus	0.76	4G/4H
	H	494+10	499+55	545'	Burlap	Wetted Straw	Brand No. 2	Orvus	0.80	
	I	499+55	511+83	1228'	Burlap	Wetted Straw	Brand No. 2	None	0.76	4H/4I
5	A	511+83	531+45	1962'	Burlap	Wetted Straw	Brand No. 1	[2]Vinsol Resin	0.76	4I/5A
	A	531+45	532+50	105'	Burlap	Wetted Straw	Brand No. 1	[2]Vinsol Resin	0.80	
	A-1	532+50	533+70	120'	Burlap	1% $CaCl_2$ Admix.	Brand No. 1	[2]Vinsol Resin	0.80	5A-1
	A	533+70	536+65	295'	Burlap	Wetted Straw	Brand No. 1	[2]Vinsol Resin	0.80	
	B	536+65	548+00	1135'	Burlap	Wetted Straw	Brand No. 1	None	0.76	5A/5B
	C	548+00	566+09	1809'	Burlap	Wetted Straw	Brand No. 2	[2]Vinsol Resin	0.76	5B/5C
	C	566+09	572+58	649'	Burlap	Wetted Straw	Brand No. 2	Vinsol Resin	0.80	
	D	572+58	584+80	1222'	Burlap	Wetted Straw	Brand No. 2	None	0.76	5C/5D
6	A	584+80	590+75	595'	Burlap	Wetted Straw	[3]Brand No. 1	No grind. aid	0.76	5D/6A
	A	590+75	596+35	560'	Burlap	Wetted Straw	blended nat. cement	in nat. cem.	0.80	
	B	596+35	599+15	280'	Burlap	Wetted Straw	Brand No. 1	None	0.76	6A/6B
	B	599+15	608+10	895'	Burlap	Wetted Earth	Brand No. 1	None	0.76	
	C	608+10	614+00	590'	Burlap	Wetted Earth	[3]Brand No. 1	[2]Beef tallow	0.76	6B/6C
	C	614+00	619+80	580'	Burlap	Wetted Earth	blended nat. cement	in natural cement	0.80	
2	B	619+80	624+90	510'	Broom	Cut-back Asph.	Brand No. 1	None	0.76	6C/2B
	1B-1	624+90	632+40	750'	Broom	Wetted Earth	Brand No. 1	None	0.76	2B/1B-1
7	A	632+40	644+10	1170'	Burlap	Wetted Earth	Brand No. 1	Silica Dust	0.76	1B-1/7A
	A	644+10	645+58	148'	Burlap	Wetted Earth	Brand No. 1	Silica Dust	0.80	
	A	645+58	655+85	1027'	Burlap	Wetted Straw	Brand No. 1	Silica Dust	0.80	
	B	655+85	668+04	1219'	Burlap	Wetted Straw	Brand No. 1	None	0.76	7A/7B
	C	668+04	680+06	1202'	Burlap	Wetted Straw	Brand No. 1	Limestone Dust	0.76	7B/7C
	C	680+06	691+75	1169'	Burlap	Wetted Straw	Brand No. 1	Limestone Dust	0.80	
	*D-11A	691+75	692+10	35'	Burlap	Wetted Straw	Brand No. 1	None	0.76	7C/7D 7C/11A
	D-11A	692+10	693+00	90'	Burlap	Wetted Straw	Brand No. 1	None	0.76	
	D-11B	693+00	694+20	120'	Burlap	Wetted Straw	Brand No. 1	None	0.76	11A/11B
	D-R.S.	694+20	694+30	10'	Burlap	Wetted Straw	Brand No. 1	None	0.76	
	D-11C	694+30	697+92	362'	Burlap	Wetted Straw	Brand No. 1	None	0.76	11B/11C
	D-R.S.	697+92	698+00	8'	Burlap	Wetted Straw	Brand No. 1	None	0.76	
	D-11D	698+00	704+00	600'	Burlap	Wetted Straw	Brand No. 1	None	0.76	11C/11D
	D-R.S.	704+00	704+18	18'	Burlap	Wetted Straw	Brand No. 1	None	0.76	
	E	704+18	721+75	1757'	Burlap	Wetted Straw	Brand No. 1	Modified Sand	0.76	11D/7E 7D/7E
	E	721+75	728+10	635'	Burlap	Wetted Straw	Brand No. 1	Modified Sand	0.80	
	F-12A	728+10	728+28	18'	Burlap	Wetted Straw	Brand No. 1	Modified Sand	0.80	7E/7F 7E/12A
	F-12A	728+28	729+00	72'	Burlap	Wetted Straw	Brand No. 1	None	0.76	
	F-12B	729+00	730+20	120'	Burlap	Wetted Straw	Brand No. 1	None	0.76	12A/12B
	F-R.S.	730+20	730+30	10'	Burlap	Wetted Straw	Brand No. 1	None	0.76	
	F-12C	730+30	733+90	360'	Burlap	Wetted Straw	Brand No. 1	None	0.76	12B/12C
	F-R.S.	733+90	734+00	10'	Burlap	Wetted Straw	Brand No. 1	None	0.76	
	F-12D	734+00	736+42	242'	Burlap	Wetted Straw	Brand No. 1	None	0.76	12C/12D
	F-R.S.	736+42	736+52	10'	Burlap	Wetted Straw	Brand No. 1	None	0.76	
	F-12E	736+52	742+52	600'	Burlap	Wetted Straw	Brand No. 1	None	0.76	12D/12E
	F-R.S.	742+52	742+62	10'	Burlap	Wetted Straw	Brand No. 1	[4]Limestone Dust	0.76	
8	A	742+62	753+46	1084'	Burlap	Wetted Straw	Brand No. 1	[4]Limestone Dust	0.76	12E/8A 7F/8A
	B	753+46 764+00	764+00	1054'	Burlap	Wetted Straw	Brand No. 1	None	0.76	8A/8B 8B/S

NOTES: [1]Initial curing pertains to damp burlap placed on concrete after finishing and removed following morning prior to final curing operations.

[2]As grinding aid.

[3]One sack of natural cement was substituted for one sack of Portland cement per 6-bag batch.

[4]Limestone fine and coarse aggregates.

R.S.=Expansion relief section.

*Divisions D-11A to D-11D and F-12A to F-12E in Series 7 designate additional design studies incorporated in durability project because of insufficient space on design project. See Table 1 for details.

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pure abietic acid in fine powder form. When the acid comes in contact with Portland cement and water it forms a calcium salt of abietic acid which has the characteristic properties of soap, and, as such, favors the entrainment of air during the mixing of the concrete. The Vinsol Resin Portland cement must confrom to the requirements of the current specifications for Portland cement A.S.T.M. Designation C9 with the following exceptions and additions: The cement shall be ground with 0.15 pound (±20 percent) of pulverized Vinsol Resin per barrel, which shall be uniformly added to the clinker at time of grinding. The specific surface as determined in accordance with A.S.T.M. C 115-38T shall not be less than 1750 nor more than 2100 square centimeters per gram. The Vinsol Resin requirements are given in appendix II, table 11. Two brands of Portland cement were used on the durability project. The two brands of Vinsol Resin Portland cement were milled of the same clinker used in the manufacture of the standard Portland cement used in the durability project. Specifications required the manufacturers of these cements to furnish acceptable evidence that they had had previous experience in the production of Vinsol Resin Portland cement in quantity and that the standard and special cements to be furnished would be uniform in quality, fineness and chemical composition.

NATURAL CEMENTS. Two types of natural cements were used on the durability project. One type manufactured without grinding aid was used in series 6A, the other type in which grinding aid was employed was included in series 6C. Both natural cements were of the same brand and furnished in sacks containing 75 pounds each, net.

The natural cement without grinding aid was manufactured in accordance with Standard Specification for Natural Cement, A.S.T.M. Designation C 10-37.

The natural cement with grinding aid was manufactured under the same requirements except beef tallow was used as a grinding aid. No requirements were placed upon the grinding aid itself because the natural cement with grinding aid has been a standard product with the manufacturers.

The Portland natural cement blend was made on the basis of a six sack batch comprising one sack (75 pounds) of natural cement and five sacks of Portland cement. The cement content, including both Portland and natural cement was 5.5 sacks (1.375 barrels) per cubic yard of concrete as specified for the entire project.

CALCIUM CHLORIDE ADMIXTURE. Calcium chloride was added to the concrete mixtures in series 4A, 4F and 5A for a distance of 120 feet. The purpose of adding calcium chloride was primarily to determine its effect as a curing agent, However, a study was made of its effect upon the physical characteristics of regular concrete and of concrete containing such additives as Plastiment, Orvus, and Vinsol Resin. The calcium chloride in flake form was added to the dry batch at the mixer skip in the amounts shown in the "Schematic Diagram of Durability Project", figure 45.

In addition to the studies on aggregates and additives previously described, a portion of the durability project has been set aside for the study of limestone aggregates with and without added fines.

LIMESTONE AGGREGATES

The use of manufactured limestone sand as a fine aggregate in concrete construction has been in disfavor not only in Michigan, but also in some other states where this material is available. The main objections to its use in concrete is reduced workability, excessive bleeding, difficult finishing and its tendency to excessive scaling of pavement surfaces in which it is used.

On the durability project of the Michigan Test Road there were included two test areas comprised entirely of crushed stone aggregates. These two test areas were constructed for the express purpose of studying the stone sand problem under controlled conditions.

One test area, section 8A, is 1084 feet in length and contains limestone coarse aggregate and stone sand with limestone dust admixture added as a possible method to improve the characteristics of the mixtures. The limestone dust mineral filler was added to the concrete mixture at the rate of 85 pounds per cubic yard of concrete.

For comparative study a second test area, section 8B, 1054 feet in length was established adjacent to test section area 8A and contains a standard limestone aggregate mixture with stone sand but no limestone dust added. Both sections were constructed and cured under similar conditions.

The limestone aggregates and limestone dust mineral filler conformed to Michigan State Highway Department requirements for coarse aggregates 4A, 10A, stone sand 2SS, and mineral filler 3MF, respectively. The grading of the various materials is shown in appendix II, table 12.

During the construction of the limestone test areas, visual observations were made of the concrete mixture including its characteristics and appearance during mixing, placing and finishing operations.

The formation of laitance on the surface of concrete pavements during construction is considered as being one of the factors contributing to scaling. Methods to prevent the formation of laitance such as proper grading of aggregates and by the use of additives have been included for study in the durability project. Another method to overcome the effect of laitance is to remove it from the surface of the fresh concrete by means of special brooms. The use of brooms for final finishing of concrete pavements introduces other factors which affect the characteristics of the finished concrete. In order to obtain more information concerning brooming of concrete surfaces, a test area of the durability project has been provided for a comparative study of finishing methods.

FINISHING STUDIES

The brooming of concrete surfaces with stiff brooms as a final finishing operation has been used by some highway engineers to reduce the amount of fine superficial material. However, some engineers have contended that this method provided grooves for concentration of salt solutions and a resultant unsatisfactory condition of aggravated scaling. Therefore, it was felt that a comparative study should be made between burlap finish and brooming to obtain comparative data relative to the two methods.

Brooming was included on certain sections of bituminous curing, since in the past, this method of curing provided a rather slippery pavement for some time after construction and, it was hoped that a trial section of brooming would show how to overcome this difficulty if bituminous curing were allowed in standard specifications.

Therefore, in series 1A and 1B, 2A and 2B of the durability project, a comparative study is being made of burlap finish versus broom finishing, both with and without wetted straw and bituminous membrane curing. Special consideration will be given to such factors as, scaling of the surface, ice formation, ice removal and skidding properties.

BURLAP FINISHING VERSUS BROOMING, STANDARD CURING. The burlap finish method consists of dragging a strip of damp burlap longitudinally over the full width of the pavement at a time when the excess moisture has disappeared and while it is still possible to produce a uniform surface of gritty texture.

Brooming operations, as illustrated in figure 46, were performed during a period after belting when the excess water and laitance had arisen to the surface, and before the concrete had reached a condition such that it would not be unduly roughened or torn. The brooms were of an approved push broom type not less than 18 inches in width and constructed of bass or bassine fibre not more than 5 inches long. Each brush was equipped with a handle at least one foot longer than one-half the width of the pavement slab. It was required that the brooms be washed and dried at frequent intervals and that a sufficient number of brooms be provided to permit interchanging.

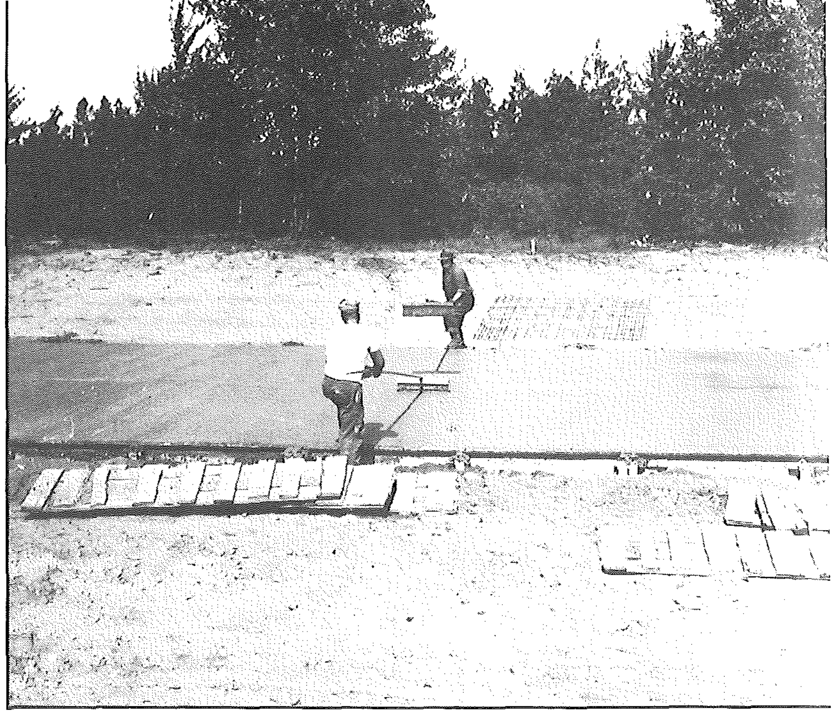
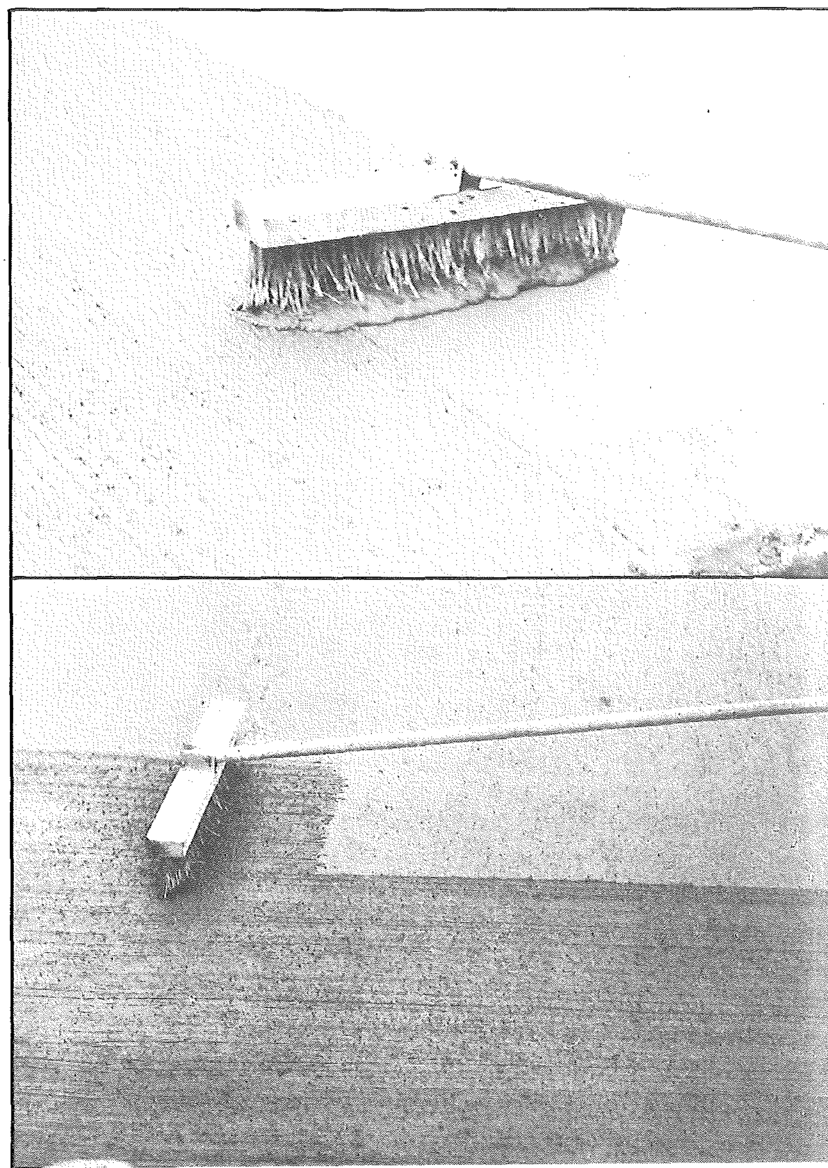


Fig. 46. Views of Brooming Operations



The brooms were drawn across the surface from the center line to each edge with not more than one stroke per width of broom. Each stroke slightly overlapped the adjacent stroke. The brooming operation produced corrugations in the surface of the pavement, uniform in appearance and not more than ⅛ inch in depth.

The curing method consisted of 24 hours wet burlap followed by 6 days of wetted straw.

BURLAP FINISHING VERSUS BROOMING WITH BITUMINOUS CURING. Immediately after completion of burlap finishing or brooming operations as previously described, a coat of asphalt emulsion was applied to the finished surface at the rate of not less than 1/15 gallon per square yard. The type of emulsion and method of application is described fully under Curing Studies.

Studies of this subject will give special consideration to such factors as, the relative skidding properties of each surface with bituminous treatment both dry and wet, effect of bituminous treatment in curing and scaling, effect of bituminous treatment on ice formation and ice removal. Also, a comparative study will be made of bituminous emulsion versus cut-back asphalt as a curing agent, as well as other types of curing.

CONCRETE CURING STUDY

In general, it is the theory that the function of curing is to keep the concrete from drying out until the maximum proportions of the total water originally used in the mixture have combined with the cement. To produce this condition several different types of curing methods have been employed for this purpose. During the last fifteen years, intensive researches have been conducted by the Public Roads Administration[7], the Portland Cement Association[8], and various state highway departments[9] to determine the relative merit of the various curing methods with respect to strength, temperature, volume change, checking and cracking, surface defects and moisture content during curing period.

The relative merit of the various curing methods have been based, in general, on laboratory strength tests. Very little information is available on the subject of curing methods in relation to durability of concrete. Therefore, a study of curing methods under actual field conditions were included in the durability project. Embodied in the curing study are such factors as moisture movement in the slab, relative thermo insulation value of various curing methods, membrane curing versus wetted coverings and relative durability of the slab surface.

Series 3, of the durability project, was set up for the curing study. The various curing methods studied are asphalt emulsion, cut-back asphalt, wetted straw, paper curing with and without initial curing, wetted earth, ponding, double burlap, calcium chloride integral mixed, and a transparent membrane called Rite-Cure. The various curing methods are illustrated in figure 47. A slab 120 feet in length was devoted to each type of curing. In order to study temperature and moisture conditions a unit consisting of three moisture cells and three thermocouples were installed in the center of each 120 foot test area as illustrated in figure 28. Readings were taken at six hour intervals throughout the entire curing period of seven days. A moisture and temperature reading was obtained at the top, center and bottom of the slab for the purpose of studying moisture movement and temperature under various curing methods and climatic conditions.

Further studies pertaining to the desirability of the differently cured concrete surfaces were carried on in conjunction with the incidental scaling study conducted during the winter of 1940 and described under Subsequent Studies, part IV.

In most cases curing may be divided into two phases, specifically initial curing and final curing. Initial curing which is referred to frequently in the discussion of curing methods is described as follows: After finishing operations and when the surface has hardened sufficiently to prevent marring, strips of burlap are laid on the surface to overlap not less than 3 inches and shall be kept thoroughly wet until removed. The burlap must remain at least 6 hours after concrete is placed but not later than 10 a. m. on the day following the placing of the concrete. Upon removal of the burlap, the surface is thoroughly wetted and the regular curing method applied. On the durability project initial curing was used in connection with the curing described below with the exceptions noted.

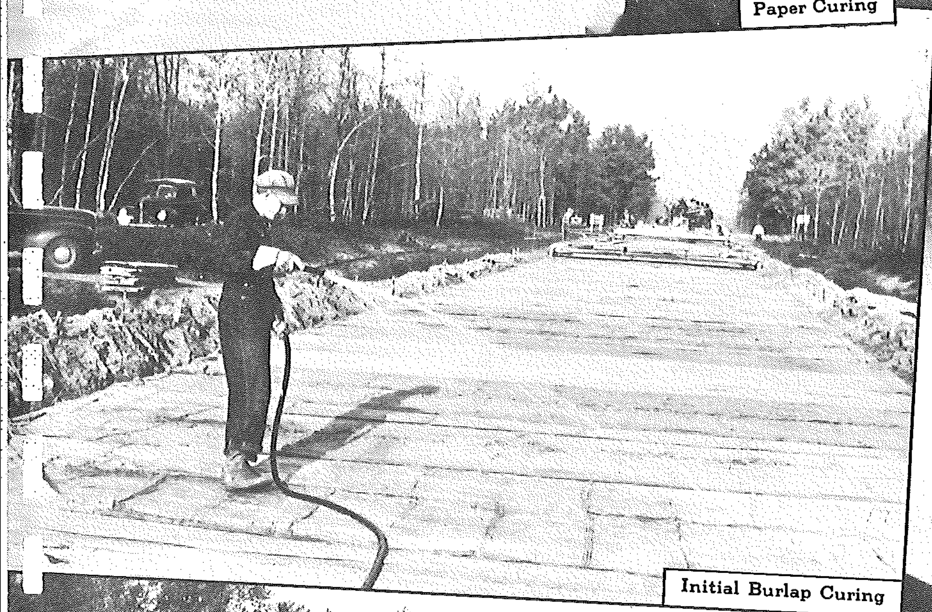
ASPHALT EMULSION CURING. Test area series 3A consists of initial curing with wet burlap followed by an application of asphalt emulsion AE-1A. Immediately after finishing operation, wet burlap was applied, after which the burlap was removed and the surface coated and sealed with a uniform layer of asphalt emulsion. The emulsion was applied at the rate of not less than 1/20 gallon per square yard by means of a suitable pressure outfit. It was applied as illustrated in figure 47 in a fine spray from a nozzle adapted for this particular work. The characteristics of the asphalt emulsion are given in appendix II, table 13.

CUT-BACK ASPHALT CURING. In connection with the study of brooming versus burlap finishing with and without bituminous curing, previously discussed under "Finishing Studies", cut-back asphalt was included for comparative study with asphalt emulsion as a curing agent in series 2B. The cut-back asphalt was applied immediately after finishing operations in the same manner as for the asphalt emulsion except the rate of application was not less than 1/15 gallon per square yard. The application of cut-back asphalt

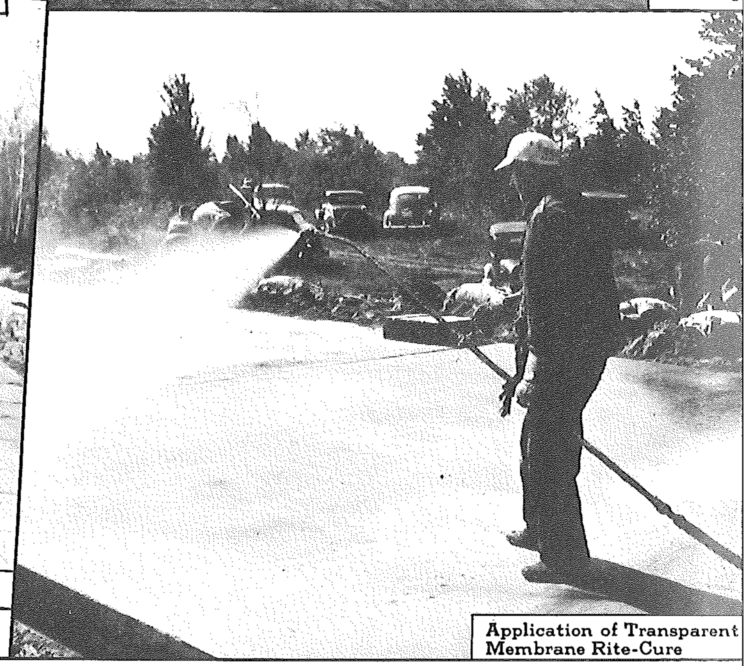
([7]), ([8]) and ([9]) — See Appendix IV.)

Paper Curing

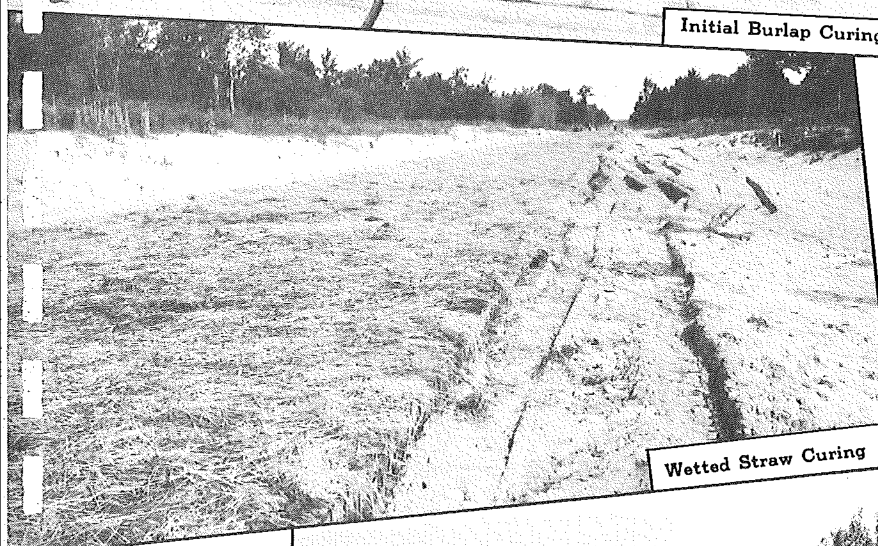
Ponding



Initial Burlap Curing

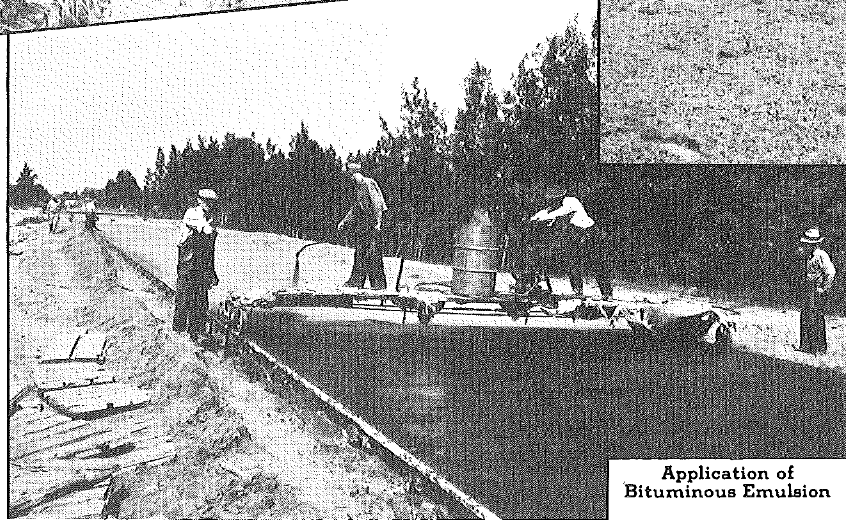


Application of Transparent
Membrane Rite-Cure



Wetted Straw Curing

Wetted Earth



Application of
Bituminous Emulsion

FIG. 47. CURING METHODS

on a concrete surface immediately after finishing is a patented method. The characteristics of the cut-back asphalt is described in table 14, appendix II.

WETTED STRAW. The wetted straw method used in series 3B consists of spreading hay or straw over the entire surface immediately upon removal of the burlap at the end of the initial curing period. The hay or straw is applied at the rate of not less than 4 pounds per square yard. The material is thoroughly wetted as soon as placed and kept saturated for 6 days.

PAPER CURING WITH AND WITHOUT INITIAL CURING. In series 3C, the concrete received an initial curing of wet burlap. After the burlap was removed, the surface was wetted and immediately covered with an impermeable paper covering for final cure. The paper blankets were composed of an approved moisture-proof paper of sufficient strength and thoroughness to permit handling without becoming unfit to provide a sealed covering during the entire curing section. The paper blankets were of sufficient width to cover the top and edges of the slab to within 2 inches of the bottom with adequate provision for shrinkage.

In series 3G, the paper was applied to the surface immediately after finishing operations omitting the initial curing period with wet burlap. The paper and method of application was the same as for series 3C.

WETTED EARTH. The wetted earth method as used in series 3D consisted of covering the entire surface of the pavement with earth to a minimum depth of 2 inches after the initial curing period. The earth covering was thoroughly wetted after it was placed and kept saturated for a period of 6 days.

PONDING. After initial curing in series 3E, the entire surface of the pavement was flooded with water which was held in place by a system of transverse and longitudinal dykes of earth. The surface was completely submerged for a period of 6 days.

DOUBLE BURLAP. After initial curing, an additional layer of burlap was added to the surface in series 3F and the double layer of burlap was kept saturated for a period of 6 days.

CALCIUM CHLORIDE INTEGRAL MIXED. In series 3H, the calcium chloride in flake form was added to the dry materials in the skip at the rate of 2 pounds of calcium chloride per sack of cement. Immediately after finishing, the concrete was covered with a single thickness of wet burlap. No subsequent curing treatment was applied to the surface after removal of burlap the following morning.

TRANSPARENT MEMBRANE — RITE-CURE. In series 3I, immediately after finishing operations, Rite-Cure a patented transparent membrane curing agent was applied to the surface of the pavement by the method described for asphalt emulsion except that the rate of application was 1/20 gallon per square yard.

In conjunction with the five durability studies including grading, and proportioning of aggregates, the evaluation of additives, limestone aggregates, finishing studies and concrete curing studies, it was necessary to make special observations. These observations are described under incidental studies.

INCIDENTAL STUDIES

The incidental studies were essentially a visual and physical evaluation of the physical characteristics of the various concrete mixtures.

PHYSICAL CHARACTERISTICS

The following factors were considered with respect to each concrete mixture.

SUBGRADE CONDITION, including surface grade, soil type and condition of compaction.

GENERAL APPEARANCE OF CONCRETE, such as consistency of mixture and workability when deposited on the subgrade, when manipulated by workmen and when struck off by the finishing machine.

WORKABILITY of the various concrete mixtures containing admixtures as compared with standard concrete mixtures.

SEGREGATION, the ability of the various concrete mixtures to resist segregation of the coarse from fine aggregates.

CONSISTENCY of concrete mixtures as determined by the slump cone method.

BLEEDING. The free water appearing upon the surface was noted as to time of appearance, duration, apparent quantity and amount of fines remaining on the surface of the concrete.

FINISHING. Particular attention was paid to the number of passes of the finishing machine, the ease of hand floating and surface appearance of finished concrete. Also, the time interval between mixing and finishing observations were observed as well as the amount of mortar present during this period.

LAITANCE. The various concrete mixtures were carefully watched for the formation of laitance and the location of such areas were recorded by stations.

CURING. General observations were made on curing operations and any irregularities noted.

JOINTS. Irregularities in joint installation and final finishing were recorded by stations, including assembly, alignment, placing of concrete adjacent to joints, finishing and edging, the filling of low areas adjacent to joints with fine mortar and laitance. From time to time the position of dowels were checked after finishing operations.

FORMS. After removal of forms, the condition of the concrete was observed and recorded.

TIME-TEMPERATURE OF PLACING CONCRETE. Time and temperature readings were taken each time the batch quantities were changed. Also, observations were made during the day at maximum and minimum temperature conditions.

MECHANICAL ANALYSIS OF CONCRETE

To determine the effectiveness of the various admixtures to prevent segregation of the aggregates during placement of the concrete, representative samples were taken from the top, center and bottom of the slab and analysed by Dunagans' "Method for Determining Constitutents of Fresh Concrete"[10].

SETTING TIME OF CONCRETE

At certain locations throughout the durability project, a comparative study was made of setting rates of concrete with and without calcium chloride, particularly in those sections containing it as an admixture. The test procedure consists of a series of time-penetrations and load observations on a one-pound sample of fresh concrete mortar obtained by removing all material retained on a No. 4 sieve. The tests were conducted under similar climatic conditions. The test equipment and procedure were designed and developed by Mr. F. Burggraf. The test equipment is illustrated in figure 48.

CONCRETE TEST SPECIMENS

Concrete test specimens were molded in accordance with current standard practice and cured adjacent to the pavement in the same manner as the structure. See figure 49. For each type of mixture, sufficient 6 by 12 inch cylinders and 6 by 8 by 24 inch beams were prepared for 7 and 28 day compression and flexural tests respectively.

Also, 3 by 6 by 15 inch beams and 4 by 16 inch cylinders were prepared for laboratory freezing and thawing tests and modulus of elasticity determination in relation to durability. This determination being made by the sonic method illustrated in figure 50.

Six inch concrete cores have been obtained from the entire project for further laboratory study relative to durability of concrete.

During the actual service life of the pavement and for a period of 3 to 5 years, it is planned to study or observe certain sections of the project under the action of ice and salts in accelerated manner. This study is discussed in Part IV under Special Scaling Studies.

([10]) — See Appendix IV.)

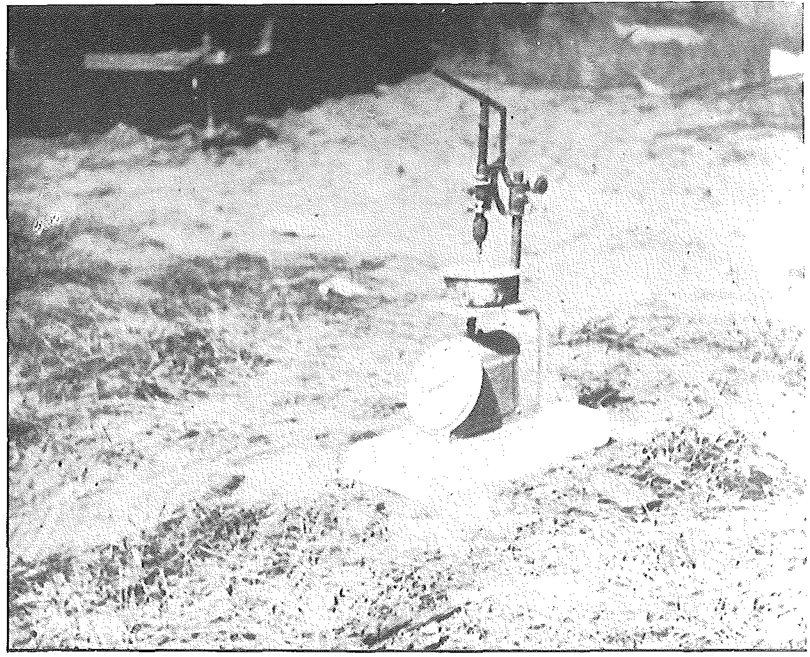


Fig. 48. Burggraf Test Equipment for Measuring Time of Set of Concrete

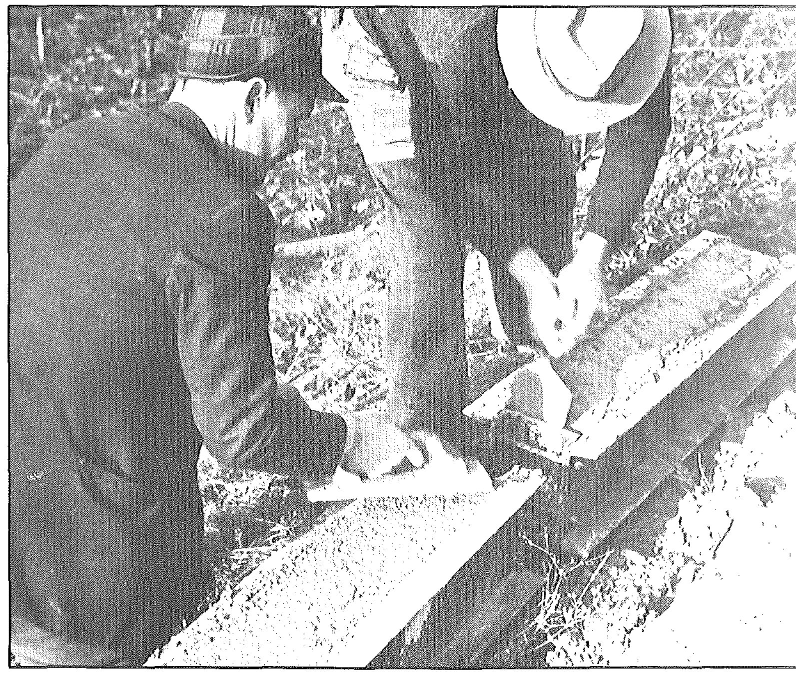


Fig. 49A. Molding Modulus of Rupture Specimens

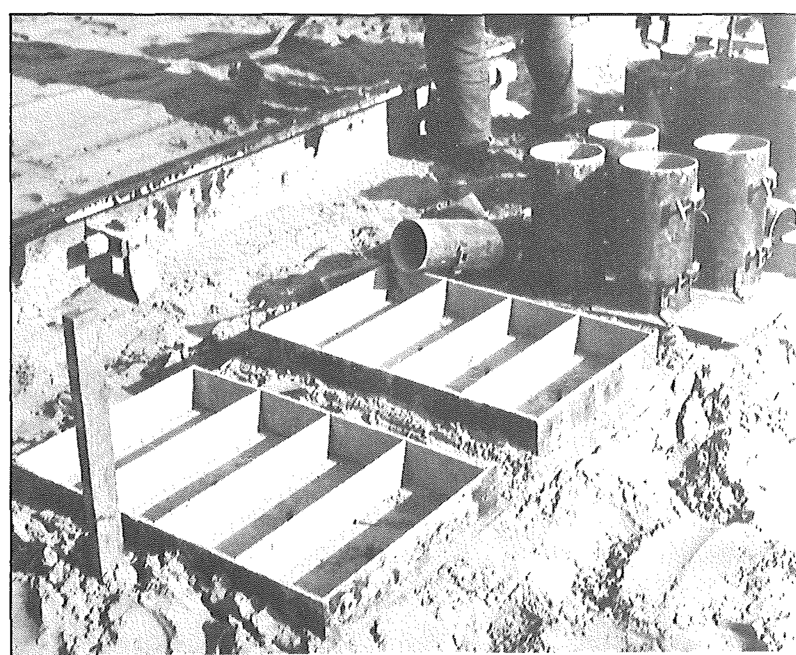


Fig. 49B. Molds for Casting, Freezing and Thawing Specimens and Compression Cylinders

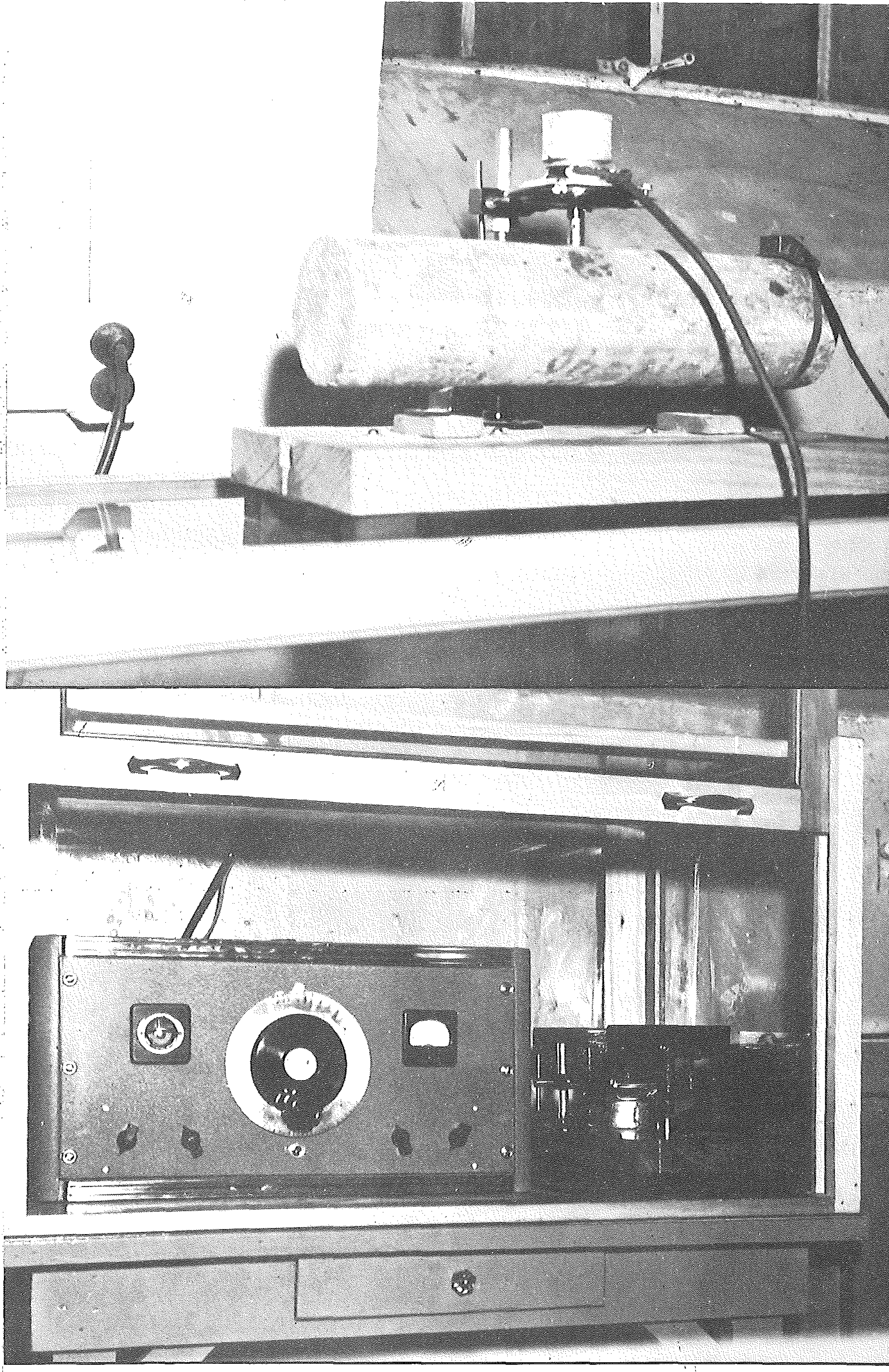


Fig. 50. Sonic Apparatus for Determining Modulus of Elasticity of Concrete Test Specimens

Upper—Concrete Specimen in Position for Test

Lower—Sonic Apparatus

PART IV

SUBSEQUENT STUDIES

The relative value of the various factors studied in the design and durability projects may be prophesied by laboratory tests and observations during construction, but the ultimate conclusions must be determined by observations made under actual service conditions. Therefore, it is planned to make periodic visual examinations together with measurement of physical conditions as discussed in this bulletin. These observations throughout both projects will include continuation of measurements of moisture content, slab temperature, slab movement, joint width, joint elevation, concrete stresses and surface condition surveys. Special consideration will be given to a study of surface scaling due to accelerated weathering tests with calcium chloride and ice.

SUBSEQUENT OBSERVATIONS

A survey of the general condition of the pavement will be made twice a year, spring and fall. In addition to the regular condition survey, general observations will be made by the Research Division personnel during measurement observations. The condition survey will include such factors as the appearance and location of cracking, condition of joints, condition of pavement surface and the occurrence of any irregularities pertinent to the design and durability studies.

PAVEMENT MEASUREMENTS

Measurement observations will be conducted four times a year during the winter (January or February), spring (April or May), summer (July or August) and fall (October or November).

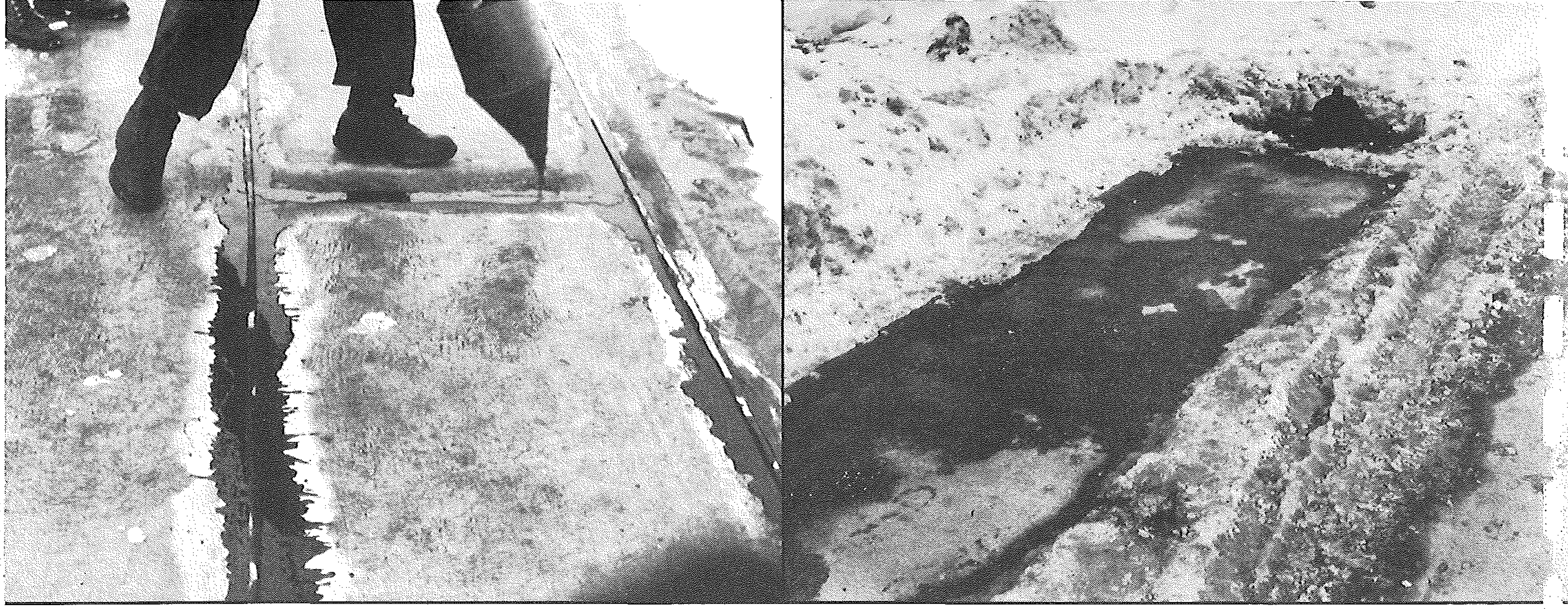
Measurements will be made of daily changes in the width of joints on selected days at each of the four seasons of the year. A set of measurements will be made at various joints selected for studying the permanent changes in joint width.

Elevation measurements at joints will be made one year after construction of pavement and thereafter at two year intervals.

SPECIAL SCALING STUDY

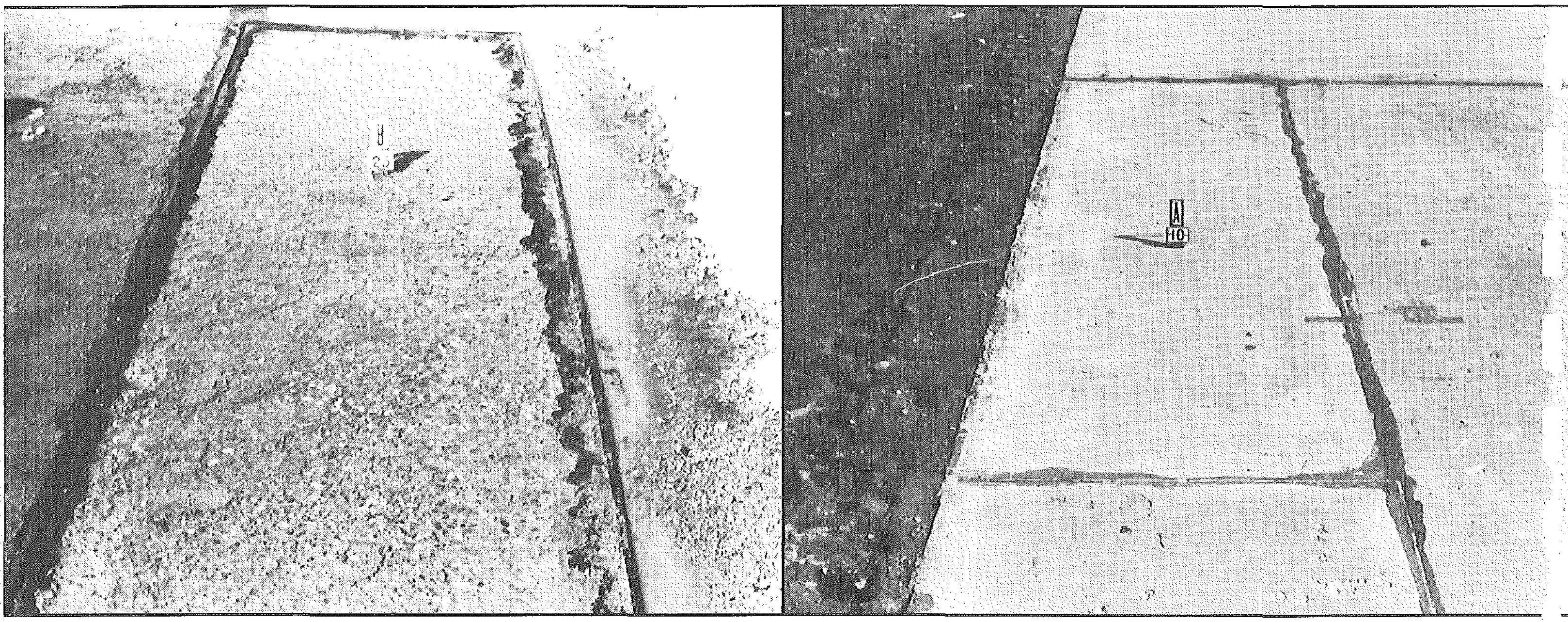
During the actual service life of the pavement and for a period of 3 to 5 years, it is planned to study or observe certain sections of the durability project under the action of ice and salts in an accelerated manner.

The correlation of the observations made during construction and actual service together with the test information of the special scaling study should enable the Michigan State Highway Department Research Division to evaluate the many factors and determine their relative importance under the conditions imposed.



Constructing Dykes — Dyked Area Under Winter Conditions

FIG. 51. DYKED AREAS FOR SCALING STUDY



Dyked Area Showing Escessive Scaling — Dyked Area Showing Slight Scale

FIG. 52. SUBSEQUENT RESULTS OF SCALING STUDY

In conducting the scaling study, definite pavement sections 120 feet in length were chosen with respect to the various concrete mixtures and surface treatments involved in the construction of the pavement. In each section two areas were dyked off, each area being 3 feet wide and 12 feet long. The dyked areas were established along the east edge of the pavement and parallel to it. The dyked areas are illustrated in figures 51 and 52. Safety precautions were maintained day and night to warn traffic of the presence of the test areas and to prevent accidents.

Two different types of accelerated test methods were employed. In test area "A", a 10 percent solution of calcium chloride of ¼ inch minimum depth was applied and allowed to remain in place 5 days. At the end of this period, the solution was removed, the panel flushed and water applied to a depth of ¼ inch. After the water had frozen, it remained in this condition over the week end weather permitting. The ice was melted by an application of 5 pounds of flake calcium chloride per test area. When the ice was decomposed, it was removed from the test area, the surface was flushed and the next cycle started.

Test area "B", adjacent to test area "A", received a different type of treatment. Water was applied to the test area and allowed to freeze over night. The following morning the ice was melted by distributing calcium chloride over the area at the rate of 5 pounds per test area. When the ice was decomposed, it was removed from the test area and the surface was flushed. Fresh water was applied to the test area and the freezing and thawing cycle repeated. On the basis of the quantity of water resulting from the melted ice in each test area, it was calculated that 5 pounds of flake calcium chloride would be sufficient to produce a 10 percent solution.

It is proposed to carry on these tests for several years, on certain sections, to determine what effect age has on the ability of the various concretes to resist freezing, thawing and calcium chloride treatments. To this end, no calcium chloride has been applied to the durability project of the Test Road, except in the test areas. Each winter the test areas on certain sections will be established adjacent to the previous test areas.

It is hoped that the correlation of the observations made during construction and actual service together with the test information of the special scaling study should enable the Michigan State Highway Department to evaluate the many factors and determine their relative importance under the conditions imposed.

CONCLUSIONS

As soon as definite conclusions are obtained they will be transmitted to the various divisions of the Michigan State Highway Department who are concerned and, if feasible, will be incorporated in the specifications. In some cases, it will be necessary to construct only a few projects including these changes to obtain further substantiating data as to the effectiveness of the newer practice. It is hoped that the facts and relationships finally obtained from both the design and durability projects will assist in obtaining the whole answer to many controversial issues and will serve to aid the highway industry in the development and improvement of concrete pavements.

APPENDICES

I Public Roads Administration Outline of Proposed Experimental Concrete Pavement Construction.

II Characteristics of Materials Used in Michigan Test Road.

III Miscellaneous Information.

IV Bibliography.

APPENDIX No. I

PUBLIC ROADS ADMINISTRATION OUTLINE OF PROPOSED EXPERIMENTAL CONCRETE PAVEMENT CONSTRUCTION

OBJECT

The purpose of this proposed experimental work is to study the desirable spacing of transverse expansion joints in concrete pavements and the amount of expansion space required per unit of pavement length, and to study the efficiency of dummy contraction joints with and without dowels or other devices for the transfer of load.

PROCEDURE

The investigation divides itself naturally into two parts as follows:

1. EFFICIENCY OF DUMMY CONTRACTION JOINTS

(A) It has been shown by previous investigations of the Public Roads Administration that the efficiency of tranverse joints, from the standpoint of stress reduction, cannot be determined by measurements of maximum deflections under load. For example, when a load is applied on one side of a joint the maximum deflections of the two joint edges may be identical but the maximum stress in the loaded edge may be more than twice as great as in the unoaded edge (see figure 32, PUBLIC ROADS, October 1936). The efficiency of joints in pavements can be determined only by accurate and time-consuming measurements of stress deformations in the concrete and it is not practicable to make such observations on pavements under traffic. Therefore, it is proposed to study the action of tranverse dummy joints in full-size pavement slabs that will not be subjected to traffic.

This study will be carried on at the laboratories of the Public Roads Administration. The test slabs will be constructed so that the width of joint opening can be controlled and so that the joints can be closed and the slabs subjected to direct compressive stress, thus simulating the condition of a pavement subjected to compressive stress due to expansion. Observations will be made of the efficiency of the joints as affected by the following variables:

(a) Width of joint opening.
(b) Restraint due to direct compressive.
stress in the slab.
(c) Type of aggregate.
(d) Maximum size of aggregate.
(e) Doweled vs. undoweled joints.

(B) In addition to this laboratory study, periodic condition surveys will be made of the actual performance of doweled and undoweled dummy joints in the experimental pavements that are hereinafter described.

2. SPACING OF EXPANSION JOINTS

A study of the required expansion space and the desirable spacing of expansion joints can be made only in relatively long sections of pavement and therefore it is proposed to enlist the cooperation of interested State Highway Departments in including the desired experimental sections in new projects that are to be built in the near future.

The details of the proposed experiment are as follows:

SELECTION OF PROJECT. The project selected should have no steep grades, a minimum of curvature, and the subgrade and drainage conditions should be as nearly uniform as possible throughout its length.

CROSS SECTION. With the exception of section 7, the pavement is to be of the thickened-edge type and the cross section is to be the standard of the State in which the project is built.

CONCRETE. The mix shall be the standard of the State in which the project is built and shall be made from coarse aggregate having a maximum size of not less than 1½ inches.

EXPANSION JOINTS. All expansion joints are to be ¾ inch wide with a non-extruding filler and, except in section 7, are to be provided with approved load transfer devices.

CONTRACTION JOINTS. Contraction joints are to be of the grooved-dummy type and the spacing in the unreinforced sections is to be 15, 20 or 25 feet, depending on the type of aggregate and other local conditions.

REINFORCEMENT. With the exception of section 6, the pavement is not to be reinforced.

DESCRIPTION OF SECTIONS.

Section 1.

(a) Length — approximately 1 mile.
(b) No expansion joints.
(c) Contraction joints without dowels.

Section 2.

(a) Length — approximately ½ mile.
(b) Expansion joints at intervals of approximately 800 feet.
(c) Contraction joints without dowels.

Section 3.

(a) Length — approximately ½ mile.
(b) Expansion joints at intervals of approximately 400 feet.
(c) Contraction joints without dowels.

Section 4.

(a) Length — approximately ¼ mile.

(b) Expansion joints at intervals of 120 or 125 feet, depending on spacing of contraction joints.

(c) Contraction joints without dowels.

Section 5.

(a) Length — approximately ¼ mile.

(b) Expansion joints at intervals of 120 or 125 feet depending on the spacing of contraction joints.

(c) Contraction joints with dowels.

Section 6.

(a) Length — approximately ¼ mile.

(b) Expansion joints at intervals of 120 feet.

(c) One contraction joint with dowels midway between each pair of expansion joints.

(d) Reinforcement. The amount of reinforcement will depend on the thickness of the slab, but, if of wire fabric, it will weigh approximately 70 pounds per 100 square foot.

Section 7.

(a) Length — approximately ¼ mile.

(b) Expansion joints without dowels at intervals of 120 or 125 feet, depending on the spacing of contraction joints.

(c) Contraction joints without dowels.

(d) Cross-section — uniform thickness. The thickness is to be such that, with respect to maximum computed stresses, the slabs will be approximately comparable with the thickened-edge slabs used in the other sections.

NUMBER OF SECTIONS. Each experimental project will have only one section 1 but preferably there should be at least two each of the other sections, and two sections that are alike should be separated from each other by an appreciable distance. For example, the sections might be arranged in the order 7-6-5-4-3-2-1-2-3-4-5-6-7. This number of sections would occupy a total length of approximately 5 miles.

OBSERVATIONS. Careful observations will be made during construction so that a complete history of the project will be available. Periodic inspections will be made subsequently to determine behavior in service, particularly with respect to cracking that may develop.

Measurements of pavement temperature and the longitudinal movement at expansion and contraction joints will be made at a number of selected points on the project. These measurements will be sufficiently comprehensive to establish the range of the daily and annual cycle of temperature change and slab movement.

HISTORY

Since early in 1934 the Public Roads Administration has placed a limitation on the maximum spacing of expansion joints (originally 100 feet, now 120 feet) and has required the use of load transfer devices in both expansion and contraction joints in thickened-edge pavements. This limit on the spacing of expansion joints and the required use of dowels in transverse dummy contraction joints, irrespective of other design details, have been questioned by a number of State Highway Departments and by the Portland Cement Association.

These criticisms are based on theoretical analysis and experience in certain localities, both of which indicate that

1. Little or no provision for expansion is required in concrete pavements that have normal expansion characteristics provided that contraction joints are so spaced as to control cracking and are so maintained as to prevent the infiltration of solid materials.

2. When expansion joints are used it is not necessary to provide enough expansion space to effect complete relief of restraint but, on the contrary, it is desirable from a structural standpoint to provide only enough space to keep compressive stresses within safe limits.

3. In dummy-groove contraction joints, so spaced as to control cracking, it is unnecessary to use dowels or other load transfer devices, particularly when expansion joints are omitted or used only at long spacings.

Recently the Portland Cement Association has presented a brief on the subject of jointing to the Public Roads Administration. As a result of study and discussion of this brief, the Public Roads Administration feels that further experimental work is needed to study some of the questions at issue.

The Public Roads Administration is of the opinion that its past experimental work has amply demonstrated the need for efficient load transfer devices in dummy contraction joints in thickened-edge slabs if these joints are not to be a source of potential weakness (see PUBLIC ROADS, October 1936). However, it is not averse to conducting a more comprehensive study of this subject than it has done previously.

It will be generally agreed by highway engineers that it would be advantageous to omit expansion joints entirely in concrete pavements if this could be done without detriment to the pavement. However, the desirability of this practice, or the proper spacing of joints if they are used, are still moot questions and further experimental work is required before they can be answered definitely. Additional information should be developed by the program of experimental construction that has been described.

APPENDIX No. II

CHARACTERISTICS OF MATERIALS USED IN MICHIGAN TEST ROAD

TABLE No. 3

Characteristics of Portland Cement Used on Design Project

Surface area, specific surface, square centimeters per gram	1800
Specific gravity	3.13
Normal consistency, percent	27.4
Initial setting time	4 hours
Final setting time	6 hours
Passing 100 mesh, percent	100
Passing 200 mesh, percent	98
Loss on ignition, percent	1.06
Insoluble matter, percent	0.20
Sulphuric anhydride (SO_3), percent	1.65
Silica (SiO_2), percent	22.67
Ferric oxide (Fe_2O_3), percent	2.09
Aluminum oxide (Al_2O_3), percent	4.68
Lime (CaO), percent	64.52
Magnesia (MgO), percent	3.16

TABLE No. 4

Characteristics of Coarse Aggregates Used on Design Project

Material	4A	10A
Passing 2¼″ sieve . . . . . percent	....	....
Passing 2″ sieve . . . . . percent	100	....
Passing 1½″ sieve . . . . . percent	74	....
Passing 1″ sieve . . . . . percent	20	100
Passing ½″ sieve . . . . . percent	....	50
Passing ⅜″ sieve . . . . . percent	0.1	29
Passing No. 4 sieve . . . . . percent	....	3.1
Loss by washing . . . . . percent	0.1	0.1
1. Soft and non-durable particles . . . . . percent	0.7	1.1
2. Chert particles . . . . . percent	2.6	5.8
3. Hard absorbent sandstone . . . . . percent	0.0	1.1
Sum of 1, 2 and 3 . . . . . percent	3.3	8.0
Thin elongated particles . . . . . percent	3.4	0.8
Incrusted particles (greater than 1/3 surface area) . . . . . percent	1.7	0.7
Incrusted particles (1/3 surface area or less) . . . . . percent	15.7	6.5
Crushed material in abrasion . . . . . percent	33.5	....
Percent of wear modified "B" abrasion	3.5	....
Specific gravity	2.65	2.59
Absorption . . . . . percent	1.40	2.32

TABLE No. 5

Typical Grading of Fine Aggregate Used on Design Project

Material	2 NS
Passing ¾" sieve . . . . percent	100
Passing No. 4 sieve . . . . percent	99
Passing No. 8 sieve . . . . percent	66
Passing No. 16 sieve . . . . percent	37
Passing No. 30 sieve . . . . percent	22
Passing No. 50 sieve . . . . percent	7
Passing No. 100 sieve . . . . percent	1.6
Loss by washing . . . . percent	0.7
Fineness modulus . . . . percent	3.67
Organic matter	Plate No. 2
Specific gravity	2.60
Absorption . . . . percent	1.78

TABLE No. 6

Characteristics of Steel Reinforcing Bars Used on Design Project

	Tie Bars			Dowel Bars		
Laboratory No.	40A—1919 St.	40A–1920 St.	40A–1921 St.	40A–1922 St.	40A–2170 St.	40A–2171 St.
Size of specimen, inches	½ Rd. Def.	½ Rd. Def.	¾ Rd. Def.	¾ Rd. Pl.	1 Rd. Plain	1¼ Rd. Pl.
Yield point, lbs. per sq. in.	49,650	51,600	44,950	52,450	45,000	45,800
Tensile strength, lbs. per sq. in.	75,650	77,950	76,300	89,200	72,250	80,400
Elongation, percent	23.78	21.85	21.4	18.0	21.0	26.9
Diameter of pin, inches	1½	1½	2¼	2¼	2	2½
Angle, degrees	180	180	90	90	90	90
Quantity represented, lbs.	40,474	....	131	5,633	4,926	510
Grade of steel	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate
Cold bend test	OK	OK	OK	OK	OK	OK

Reinforcement

TABLE No. 7

Characteristics of Portland Cement Used on Durability Project

Characteristics	Portland Cement			
	Standard		With Vinsol Resin	
	Brand No. 1	Brand No. 2	Brand No. 1	Brand No. 2
Surface area, specific surface square centimeters, per gram	1,650	1,800	1,745	2,001
Specific gravity	3.12	3.07	3.13	3.11
Normal consistency	24.8	27.4	26.4	27.0
Initial setting time	3–40	3–35	4–10	3–35
Final setting time	5–40	5–20	6–40	5–35
Passing No. 100 sieve, percent	100	100	100	100
Passing No. 200 sieve, percent	95	98	96	98.5
Vinsol Resin, percent	......	......	.050	.038
Loss on ignition, percent	1.25	1.06	1.30	1.17
Insoluble matter, percent	0.19	0.20	0.22	0.21
Sulphuric anhydride (SO_3), percent	1.74	1.65	1.80	1.58
Silica (SiO_2), percent	20.88	22.67	21.11	22.73
Ferric oxide (Fe_2O_3), percent	2.70	2.09	2.68	2.10
Aluminum oxide (Al_2O_3), percent	6.62	4.68	6.71	4.59
Lime (CaO), percent	62.83	64.52	63.01	64.12
Magnesia (MgO), percent	3.17	3.16	3.00	2.98

TABLE No. 8

Characteristics of Coarse Aggregates Used on Durability Project

Material	4A	10A
Passing $2\frac{1}{4}''$ sieve ......percent	....	....
Passing $2''$ sieve ......percent	100	....
Passing $1\frac{1}{2}''$ sieve ......percent	84	....
Passing $1''$ sieve ......percent	23	100
Passing $\frac{1}{2}''$ sieve ......percent	....	55
Passing $\frac{3}{8}''$ sieve ......percent	1.7	25
Passing No. 4 sieve ......percent	....	1.1
Loss by washing ......percent	0.2	0.1
1. Soft and non-durable particles ......percent	1.2	0.6
2. Chert particles, percent ......percent	0.7	9.0
3. Hard absorbent sandstone ......percent	1.8	0.7
Sum of 1, 2 and 3 ......percent	3.7	10.3
Thin elongated particles ......percent	0.7	0.5
Incrusted particles (greater than 1/3 surface area) percent	1.4	0.3
Incrusted particles (1/3 surface area or less) ......percent	1.7	1.8
Crushed material in abrasion ......percent	29.1	....
Percent of wear modified "A" abrasion ......percent	3.7	....
Specific gravity	2.65	2.62
Absorption ......percent	1.09	1.73

TABLE No. 9

Typical Grading of Fine Aggregates Used on Durability Project

	Nat. Sand 2 NS	Blend Sand
Passing 3/8″ sieve..............percent	100	....
Passing No. 4 sieve............percent	98	99
Passing No. 10 sieve...........percent	75	....
Passing No. 20 sieve...........percent	45	....
Passing No. 40 sieve...........percent	....	99
Passing No. 50 sieve...........percent	16	....
Passing No. 100 sieve..........percent	3	69
Passing No. 200 sieve..........percent	....	51
Silt and clay (0.005 mm.).......percent	....	40
Clay (0.001 mm.)...............percent	....	5
Organic matter......................		Plate 2

TABLE No. 10

Grading Characteristics of Mineral Fillers Used on Durability Project

	MSHD Spec.	Silica Dust	Limestone Dust
Passing No. 40 sieve, percent	100	100	100
Passing No. 80 sieve, percent	....	98.8	99.4
Passing No. 100 sieve, percent	....	98.4	99.2
Passing No. 200 sieve, percent	75+	78.4	89.8

TABLE No. 11

Specifications for Vinsol Resin Admixture

	Maximum	Minimum
Melting Point, Hercules Drop Method.....	125°C	110°C
Acid Number...........................	105°C	85°C
Gasoline Insoluble...............percent	....	85
Toluene Insoluble................percent	30	15
Acetone Insoluble................percent	2	....
Ash...........................percent	0.3	....
Passing No. 30 sieve..............percent	....	100
Passing No. 80 sieve..............percent	100	90
Passing No. 200 sieve.............percent	80	60

TABLE No. 12

Characteristics of Limestone Materials Used on Durability Project

	Coarse Aggregate		Fine Aggregate
	4A	10A	2SS
Passing 2″ sieve.................percent	100	....	....
Passing 1½″ sieve...............percent	67	....	....
Passing 1″ sieve.................percent	13	100	....
Passing ½″ sieve................percent	....	53	....
Passing ⅜″ sieve................percent	1.1	37	100
Passing No. 4 sieve..............percent	....	7.3	99
Passing No. 8 sieve..............percent	....	....	88
Passing No. 16 sieve.............percent	....	....	52
Passing No. 30 sieve.............percent	....	....	28
Passing No. 50 sieve.............percent	....	....	13
Passing No. 80 sieve.............percent	....	....	....
Passing No. 100 sieve............percent	....	....	4.3
Passing No. 200 sieve............percent	....	....	....
Loss by washing................percent	0.3	0.7	2.0
Soft and non-durable particles...percent	0.0	0.0	....
Thin elongated particles.........percent	....	7.7	....
Crushed material...............percent	100	....	....
Percent of wear modified "A" abrasion.....................percent	11.9	....	....
Absorption......................percent	0.58	0.66	1.47
Specific gravity..........................	2.66	2.66	2.62

TABLE No. 13

Asphalt Emulsion Characteristics
Michigan State Highway Department Specification AE-1-A

Viscosity, Saybolt Furol at 25°C, sec.	20
*Test for break on fresh concrete	Passes
Distillation at 500°F. (250°C.)	
Total distillate, percent	46.0
Oil distillate, percent	Trace
Asphaltic residue from distillation	
Penetration at 25°C., 100 g., 5 sec.	161
Ductility at 25°C., cm.	110+
Solubility in CS_2, percent	99.43
Specific gravity, 25°/25°C	1.008
Ash content, percent	0.55

*The asphalt emulsion shall commence to break in not less than 15 seconds and not more than 5 minutes after applied to fresh concrete.

TABLE No. 14

Cut-Back Asphalt Characteristics

Specific Gravity, 15.5°C./15.5°C.	0.901
Water, percent volume	Trace
Flash point, Tagliabue, open cup	34.4°C
Viscosity, Saybolt Furol, sec. 38°C.	59
Viscosity, Saybolt Furol, sec. 25°C.	97
Distillation Test, percent by volume	
To 190°C.	39.0
To 225°C.	47.5
To 315.5°C.	52.5
To 360°C.	54.5
Tests on distillation residue	
Specific gravity 25°/25°C.	1.043
Penetration at 25°C./100 g., 5 sec.	5
Ductility at 25°C., cm.	1
Solubility in CCl_4, percent	99.83
Oliensis spot test	Negative
Fixed carbon, percent	20.7

APPENDIX No. III

MISCELLANEOUS INFORMATION

TABLE No. 15

Average Traffic Record of Michigan Test Road 1941

Month	Period					
	Week Day			Sunday		
	Low	High	Aver.	Low	High	Aver.
March	262	876	584	702	1062	925
April	539	1367	789	1064	1637	1292
May	565	1286	839	1412	1907	1698
June	642	1610	980	1389	1885	1705
July	918	2514	1398	1885	2526	2205
August	1088	2544	1811	2607	3347	2977
September	698	1481	1089	1641	2456	2048
October	645	1225	935	1626	1772	1699

TABLE No. 16

Classification of Traffic on Michigan Test Road
Average Summer Daily Traffic

	Amount	Percent
Total traffic	1590	100
Passenger cars	1361	85.6
Passenger cars with trailers	76	4.8
Total passenger cars	1437	90.4
Light trucks, (¾ ton and under)	43	2.7
Medium trucks, (1 to 2½ tons)	26	1.6
Heavy trucks, (3 tons and over)	43	2.7
Trailer combinations	41	2.6
Busses	0	0.0
Total commercial	153	9.6

APPENDIX IV

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