# 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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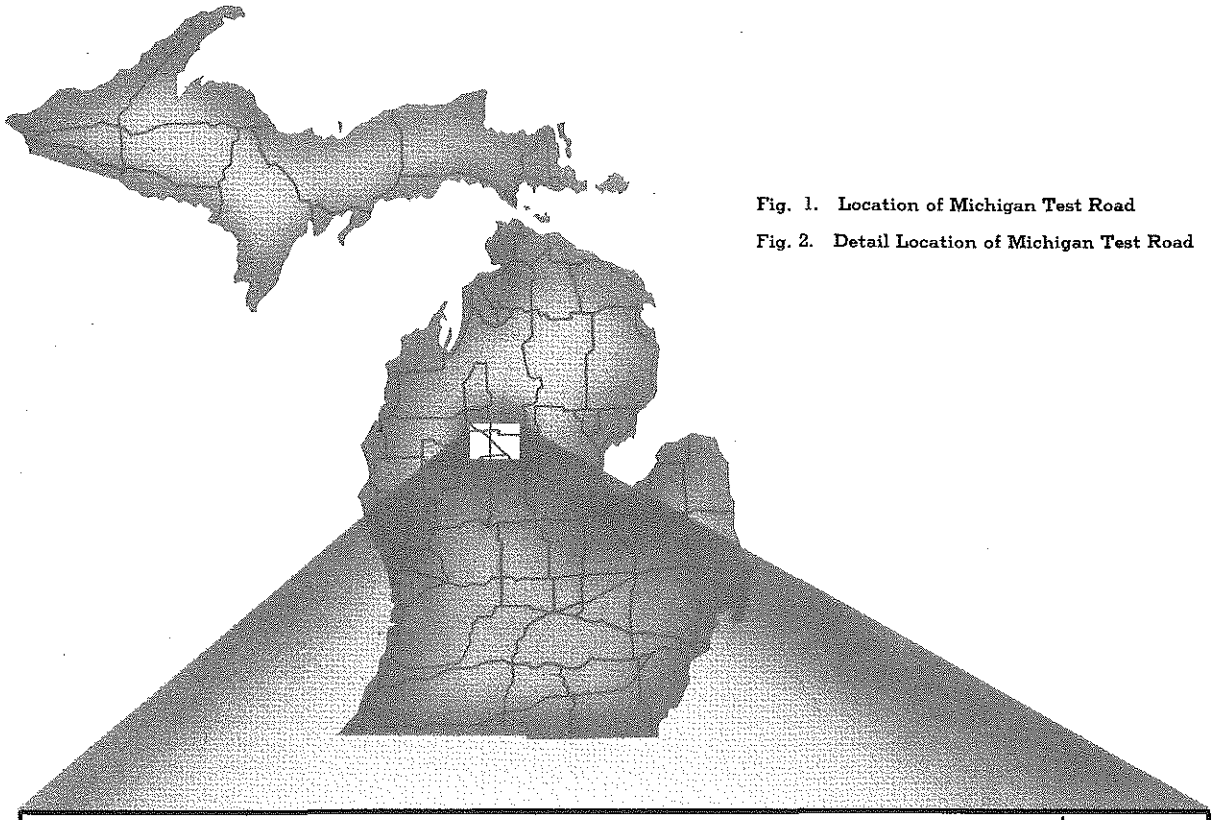
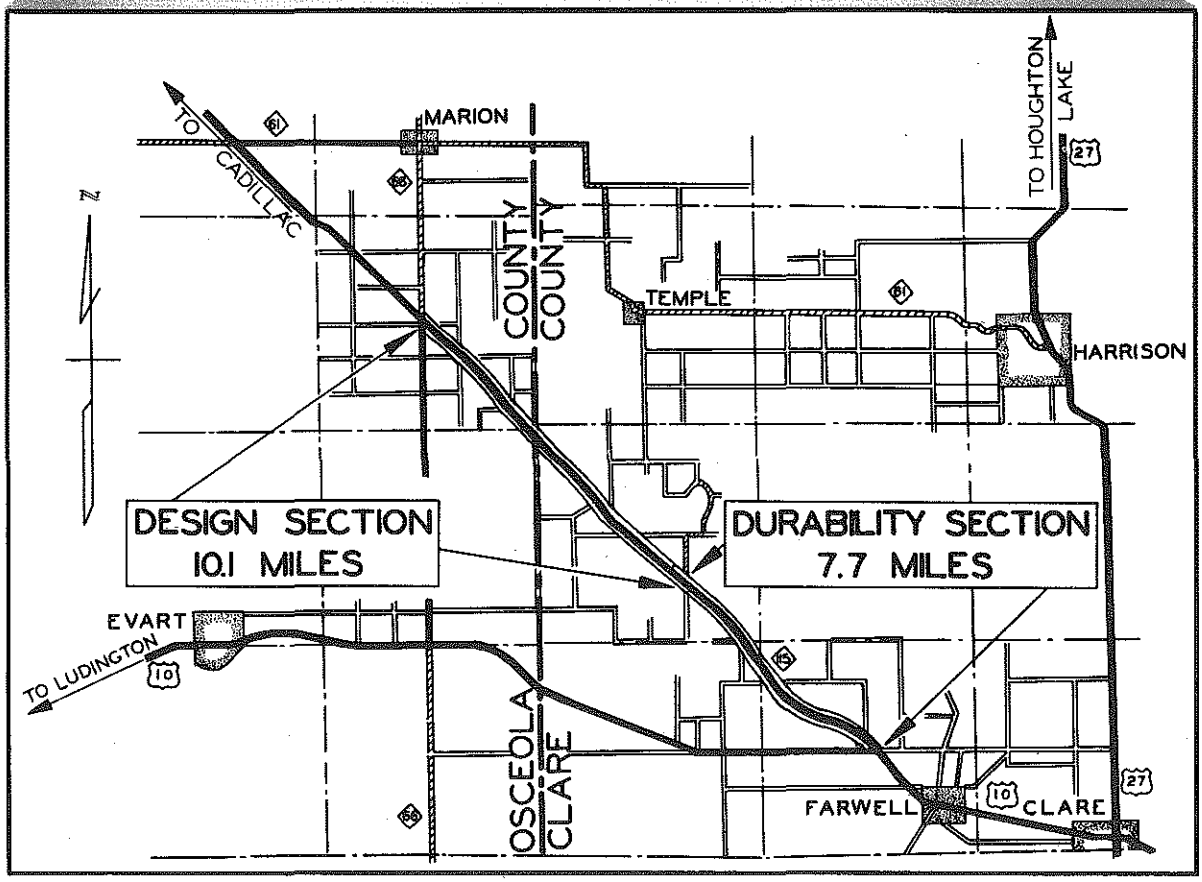


Fig. 1. Location of Michigan Test Road

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

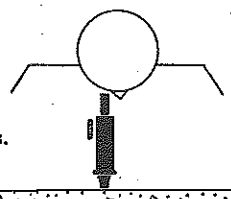
The evaluation of the many factors included in the Michigan Test Road will be determined from these subsequent studies which will be carried on over a period of years or until such time that sufficient data will be obtained to warrant drawing ultimate conclusions. These subsequent studies include pavement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

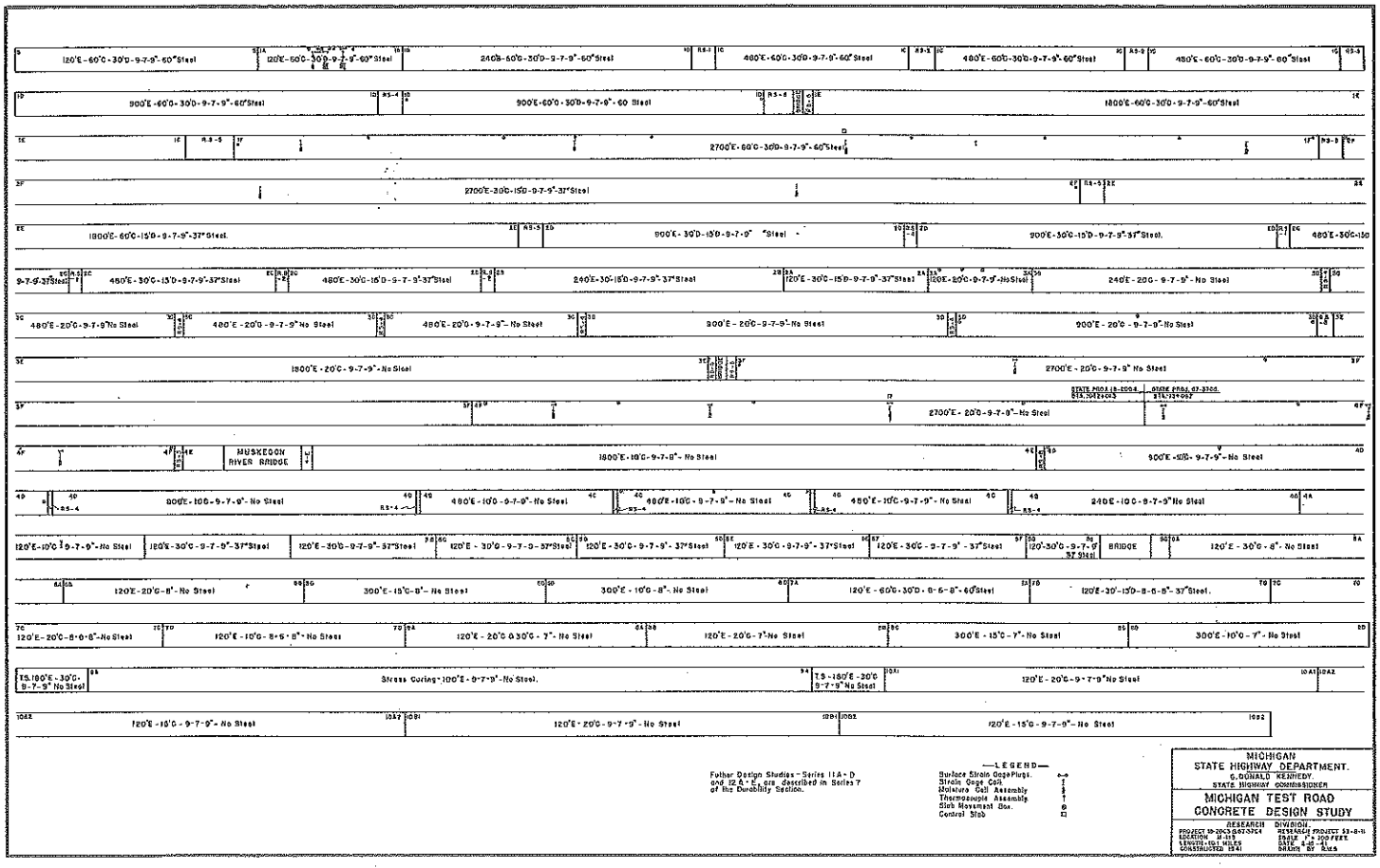



FIG. 3. SCHEMATIC DIAGRAM OF DESIGN PROJECT

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.

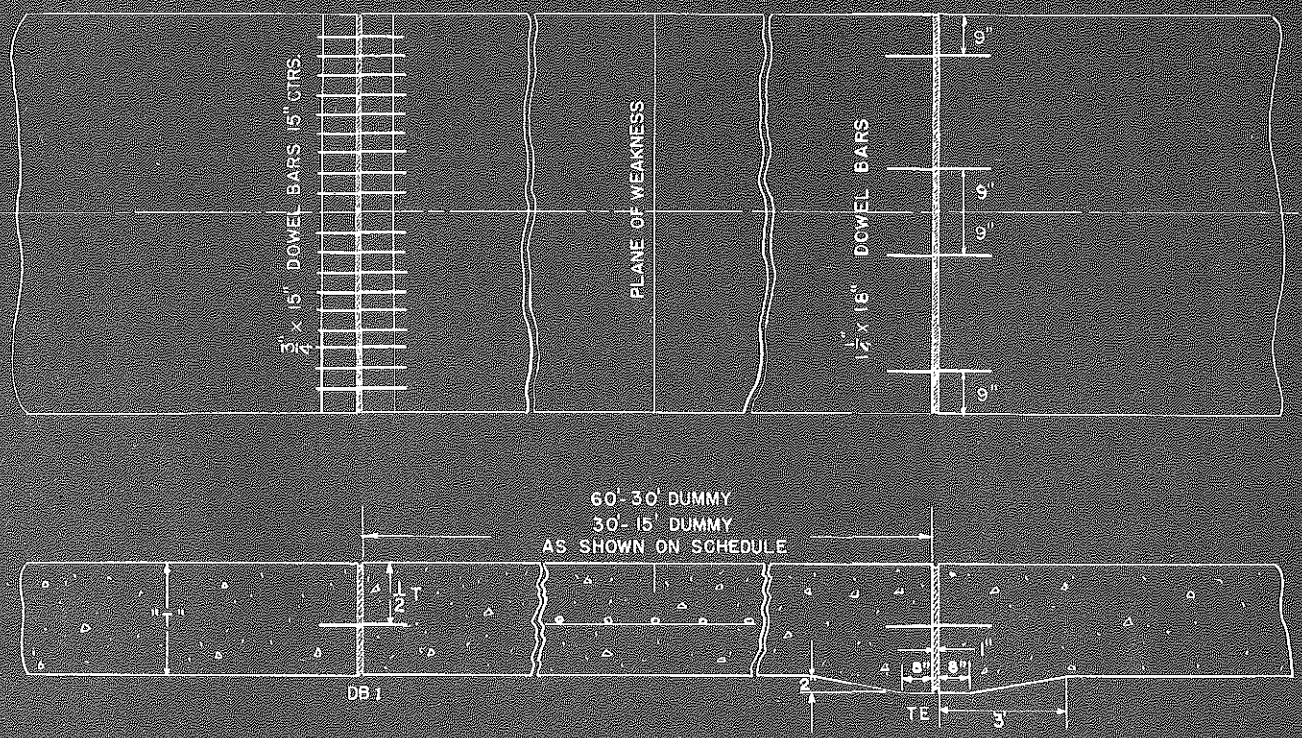
**FURTHER DESIGN STUDIES**—Series 11A-D and Series 12A-E were constructed in conjunction with Series 7 of Durability Project because of insufficient space on Design Project.

**JOINT FILLER AND SEAL:**

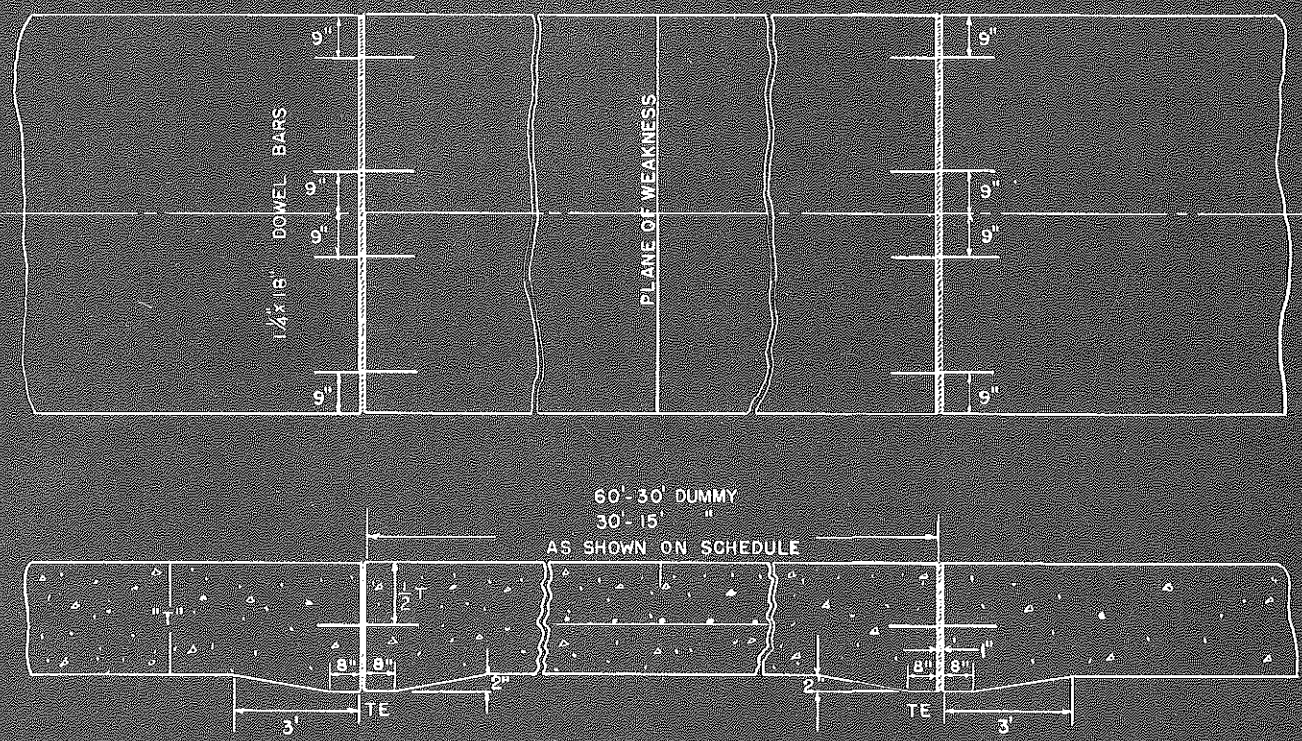
Type 1—Fiber filler with asphalt-latex seal.
Type 2—Fiber filler with asphalt-vultex seal.
Type 3—Special type using removable forms and seal top, bottom and sides with asphalt-latex.
Type 4—Asphalt-latex bottom premolded rubber seal.
Type 5—Fiber filler with thermoplastic seal.
Type 6—Fiber filler with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

TABLE I.
SUMMARY OF TEST AREAS ON DESIGN PROJECT

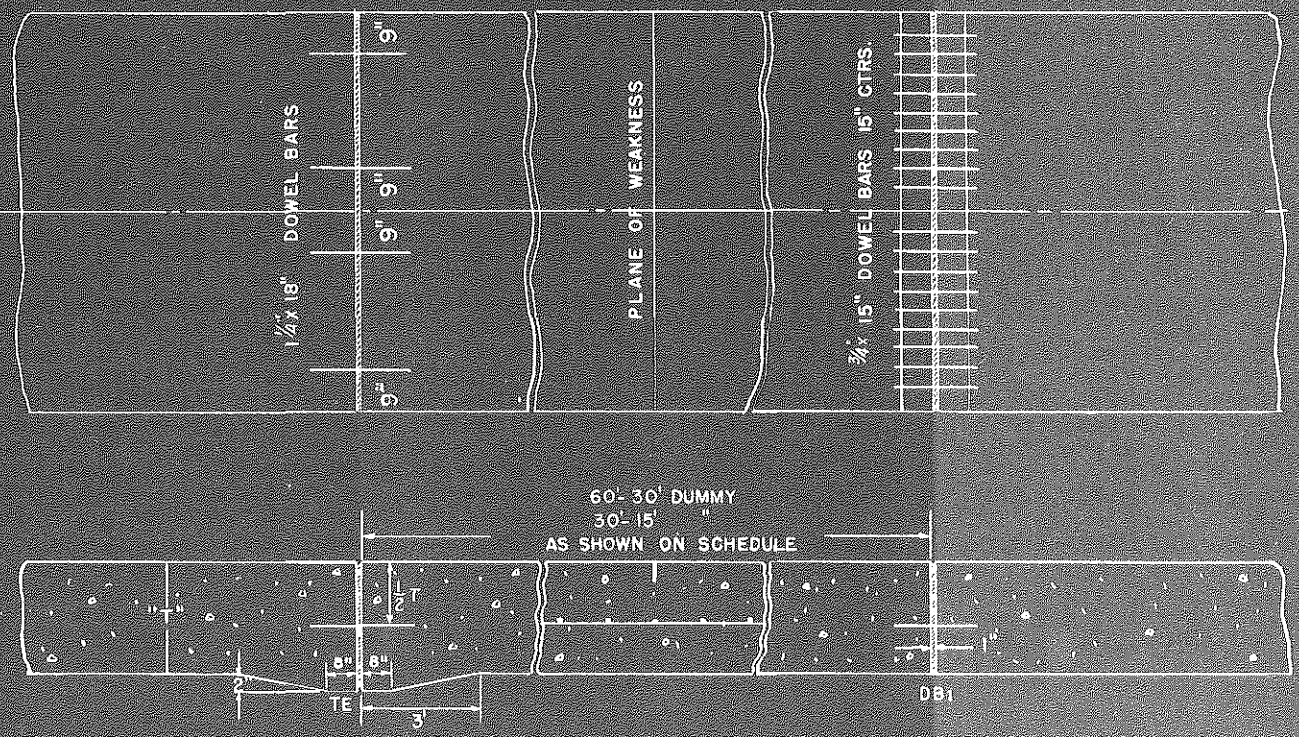
| Series | Division | No. of Sects. | Station Begin | Station End | Pavement Thickness | Steel lbs. per 100 Sq. Ft. | Spacing Exp. | Spacing Contr. | Spacing D'my | Joint Filler and Seal | Type Load Transfer Exp. | Type Load Transfer Contr. | Type Load Transfer D'my | Width of Exp. Joint | Length, in 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' | Typo 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 | 836+40 | 9-7-9 | 60 | 1800' | 60' | 30' | Type 1 | DB-1 | DB | R | 1" | 1800' | RS-5/1E |
| | *RS-5 | 1 | 836+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+60 | 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) | | | | | | | | | | | | | | 9900' | |
| 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 | | | — | — | — | — | 324.69' | |
| | 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) | | | | | | | | | | | | | | 6930' | |
| 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 | BD-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 | 88+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+30 | 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' | |
| | T.S. | 1 | 160+30 | 162+10 | 9-7-9 | None | 180' | 30' | None | Type 4 | Translode** | DB | None | 1" | 180' | 8D/TS |
| 9 | A | 1 | 162+10 | 180+10 | 9-7-9 | None | 180' | None | None | Type 4 | Translode** | DB | None | 1" | 1800' | TS/9A |
| | T.S. | 1 | 180+10 | 181+00 | 9-7-9 | None | 180' | 30' | None | Type 4 | Translode** | 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 | Translode 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 | Translode 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+45 | 9-7-9 | Series 8A of Durability Project | | | | | | | | | 1084' | 12E-7F/8A |



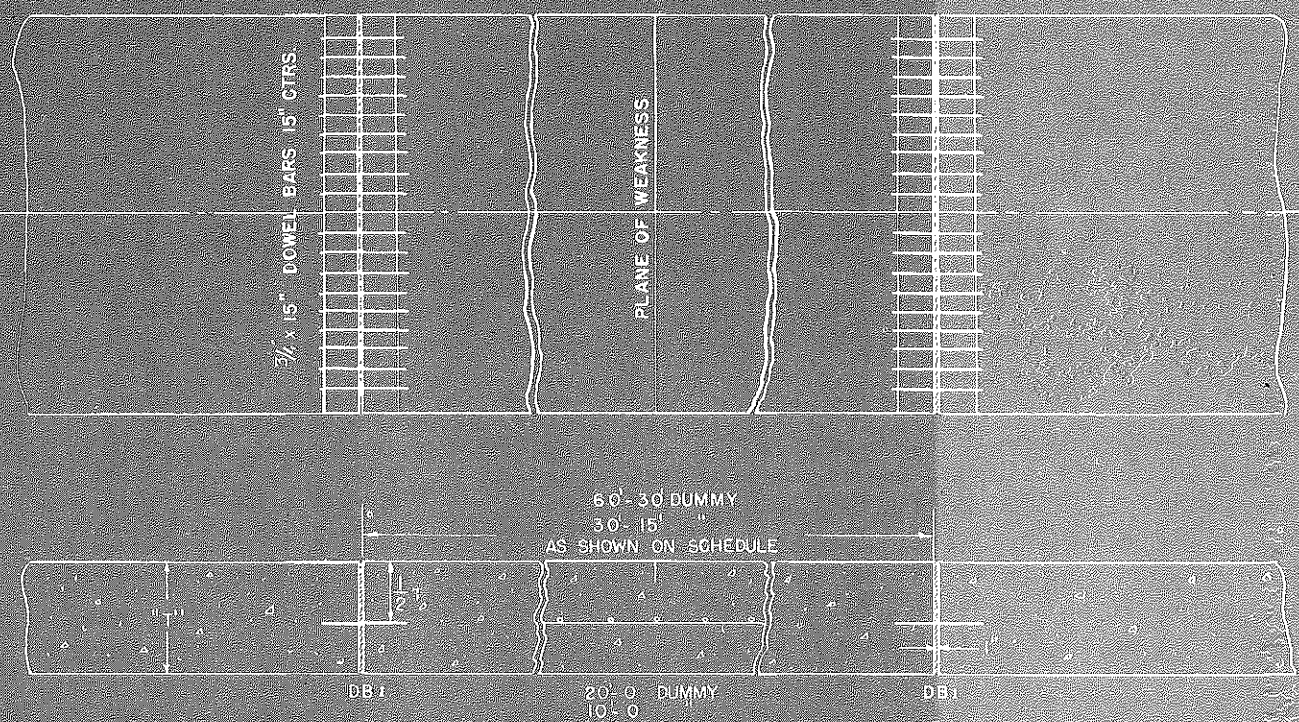

TYPE RS 1
FIG. 4. DETAIL SKETCH OF EXPANSION RELIEF SECTION



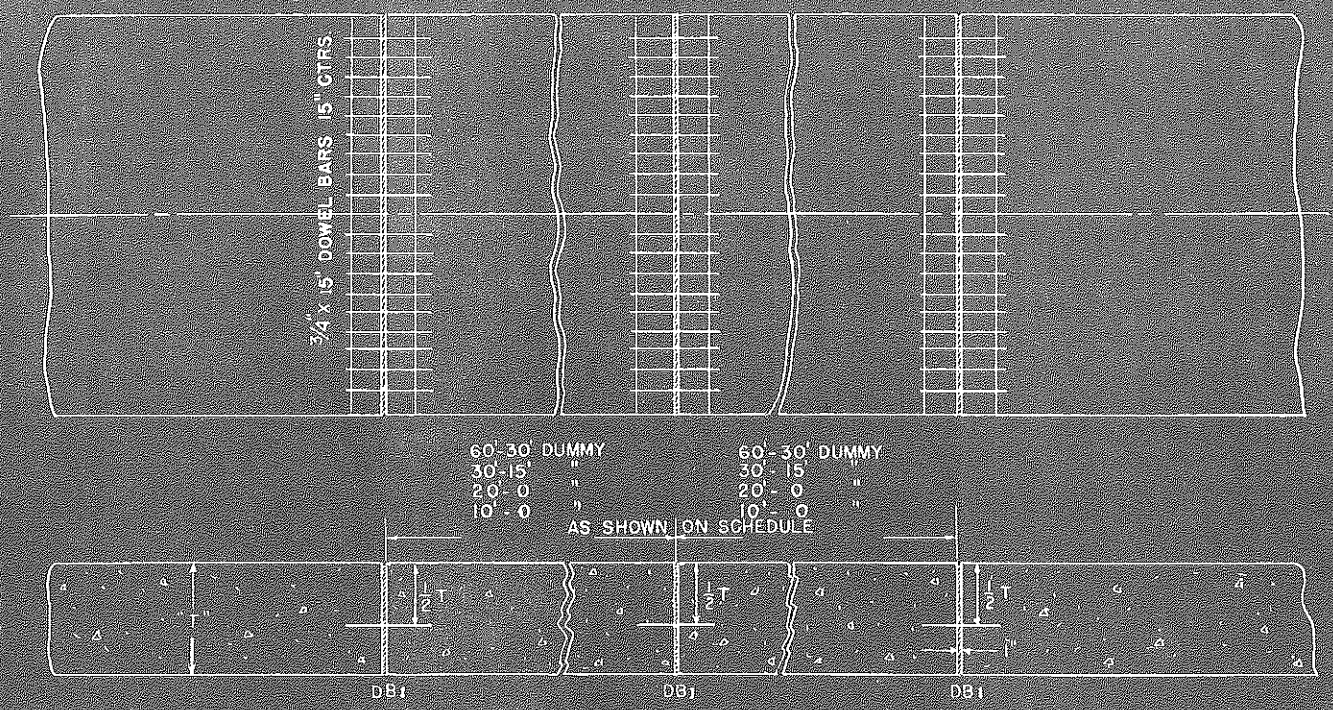

TYPE RS 2
FIG. 5. DETAIL SKETCH OF EXPANSION RELIEF SECTION




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.

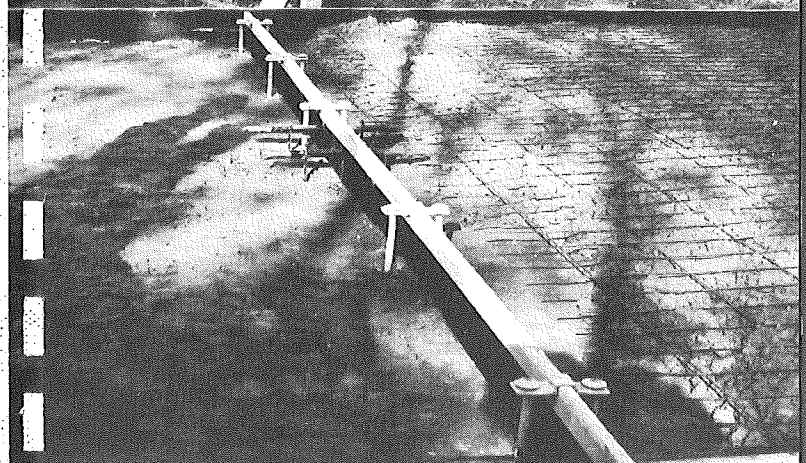
## JOINT SPACING AND DESIGN

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 1/4 inch x 18 inches Corner Bars



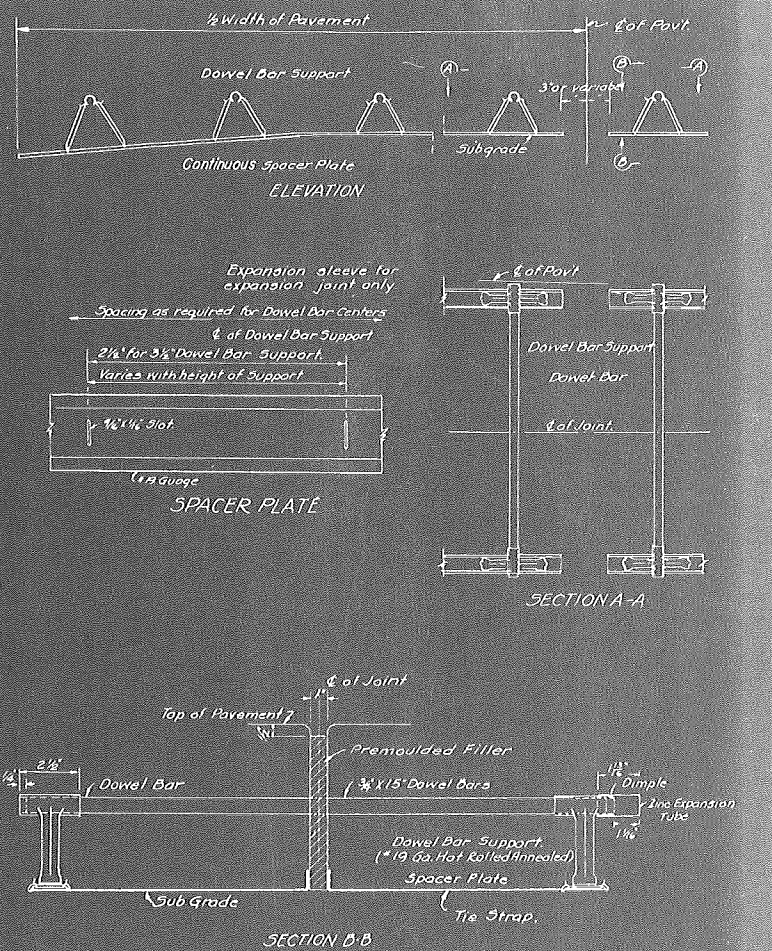



FIG. 9. DETAIL SKETCH OF TRUSS-ASSEMBLY FOR HOLDING DOWEL BARS AT EXPANSION AND CONTRACTION JOINTS

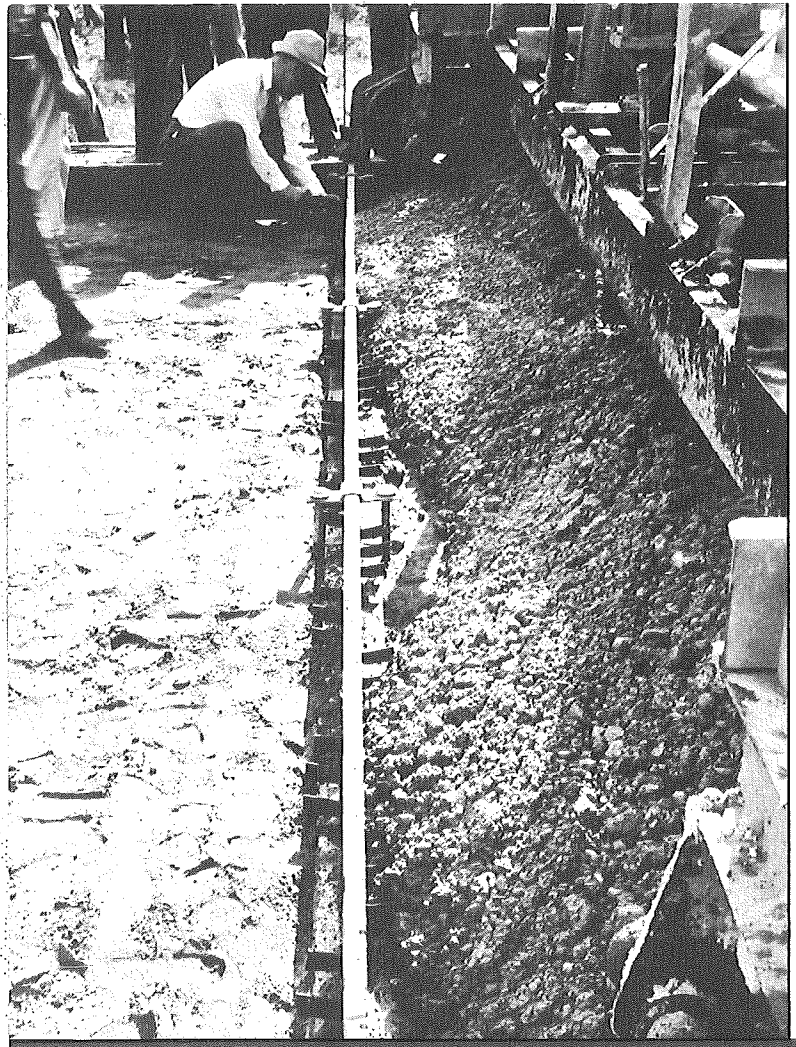
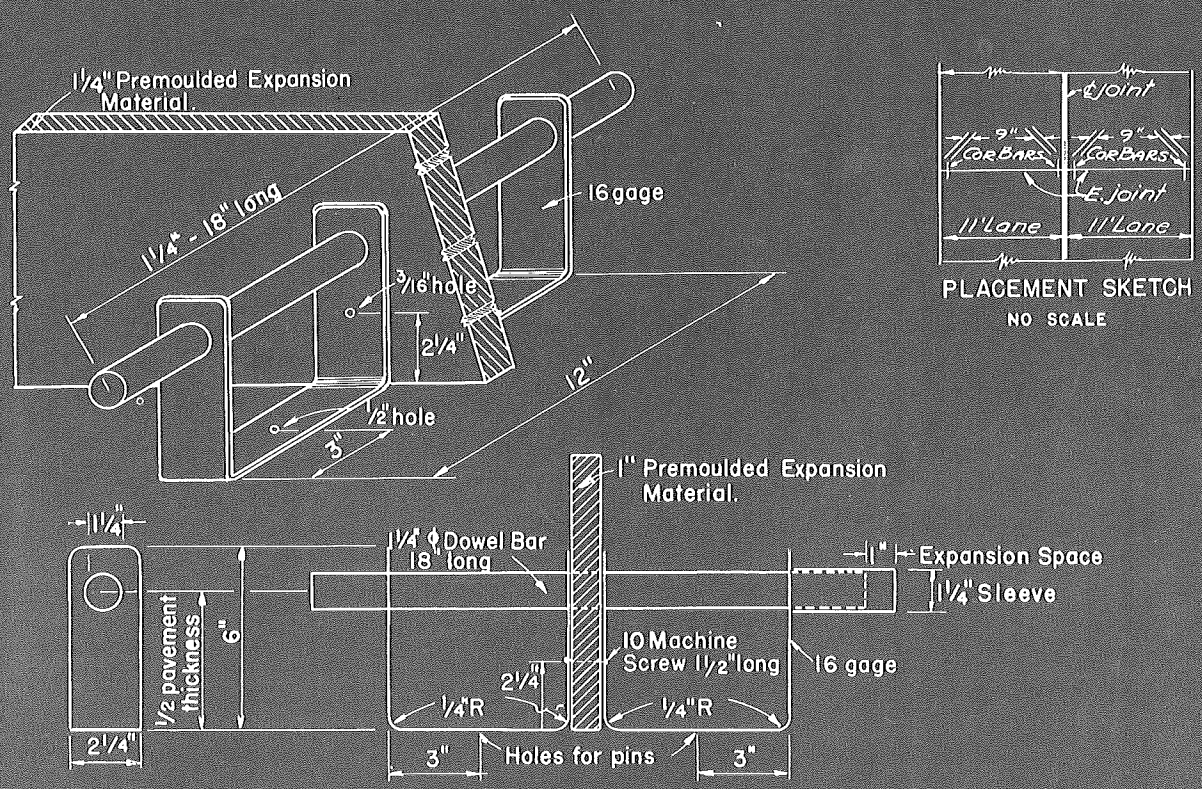


Fig. 12. Translode Expansion Joint Assembly Used on Stress Curing Section

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 1¼ 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.




The dowel bar chair assembly shall be installed in such a manner as to secure proper alignment and position of dowel bars in the completed pavement

DETAIL OF DOWEL BAR CHAIR TO BE USED WHERE CORNER BARS ARE CALLED FOR. No Scale.

FIG. 11. DETAIL SKETCH OF 1¼" x 18" DOWEL CORNER BAR ASSEMBLY

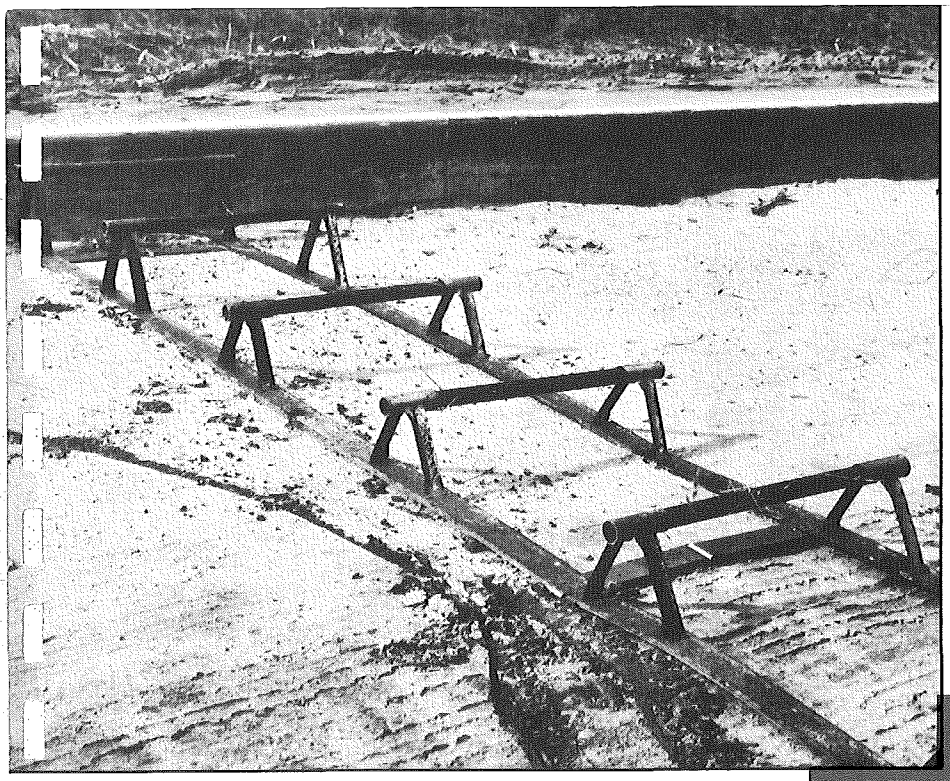
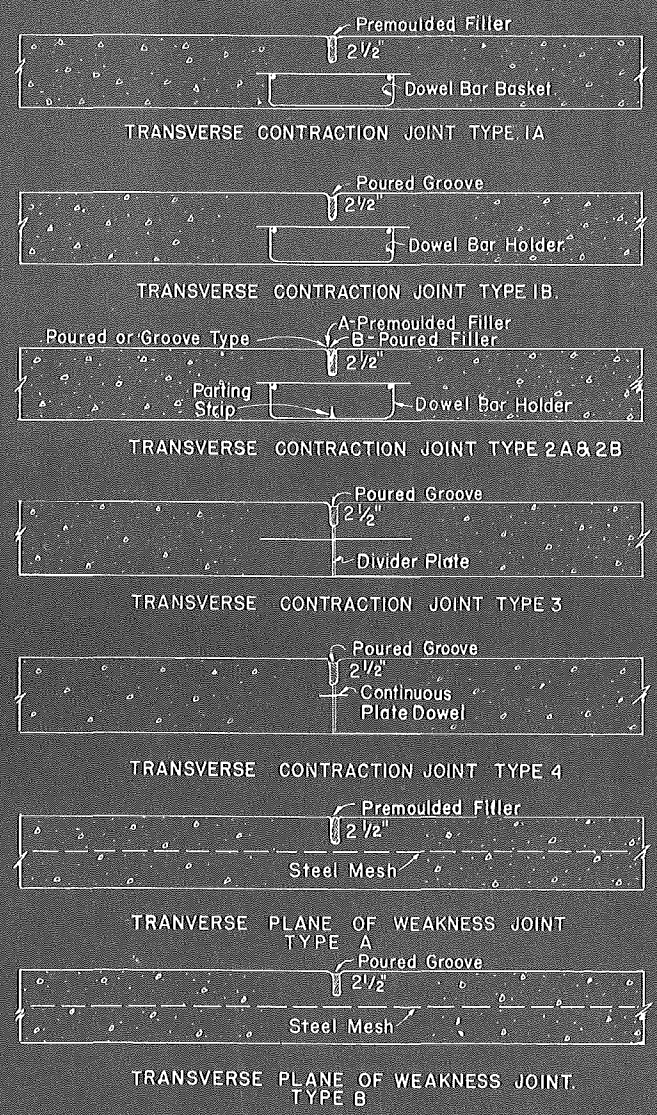


Fig. 14. Type I Contraction Joint Assembly

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

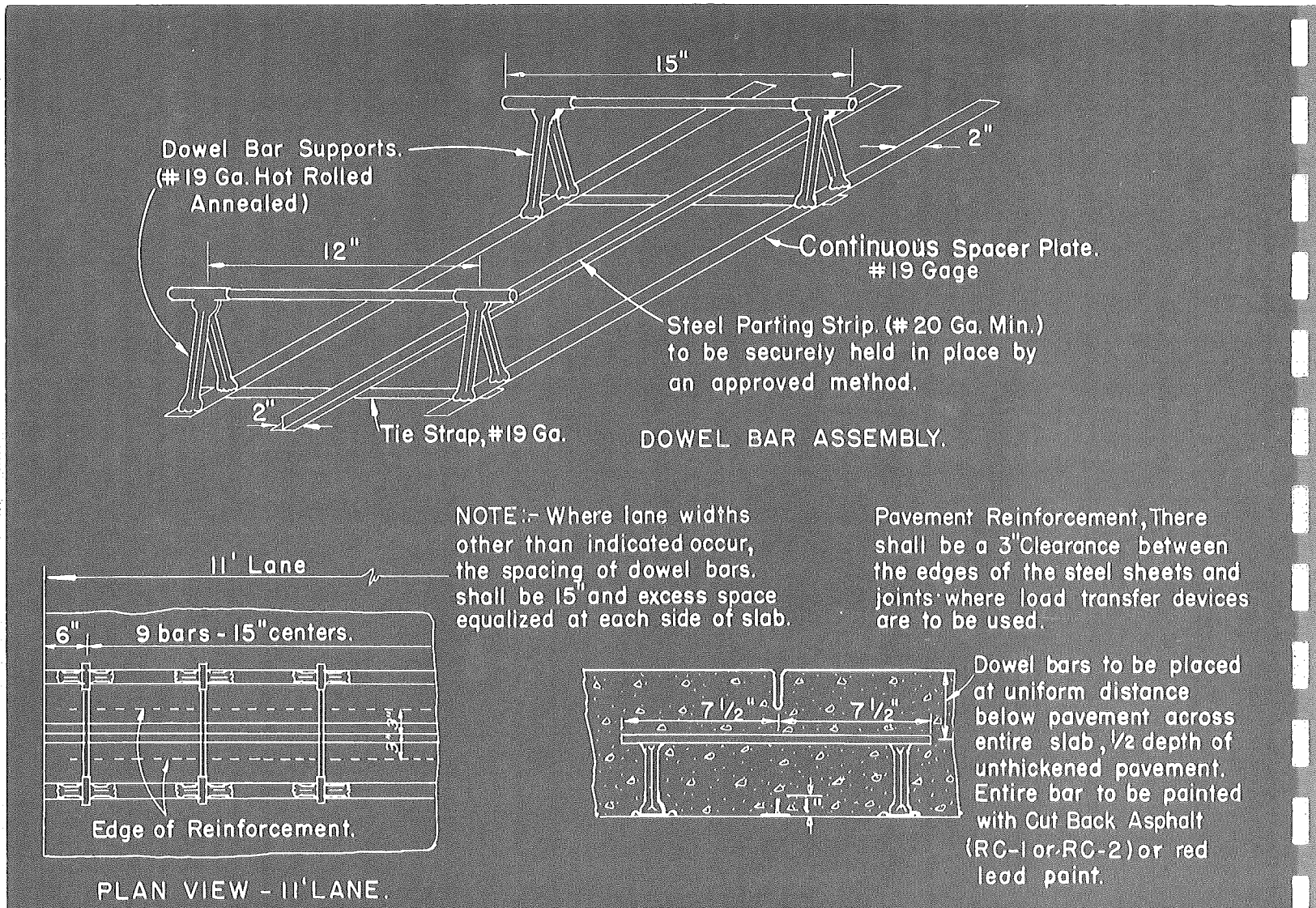



FIG. 15. DETAIL SKETCH OF TYPES 2A AND 2B CONTRACTION JOINT WITH LOAD TRANSFER DEVICE AND PARTING STRIP

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

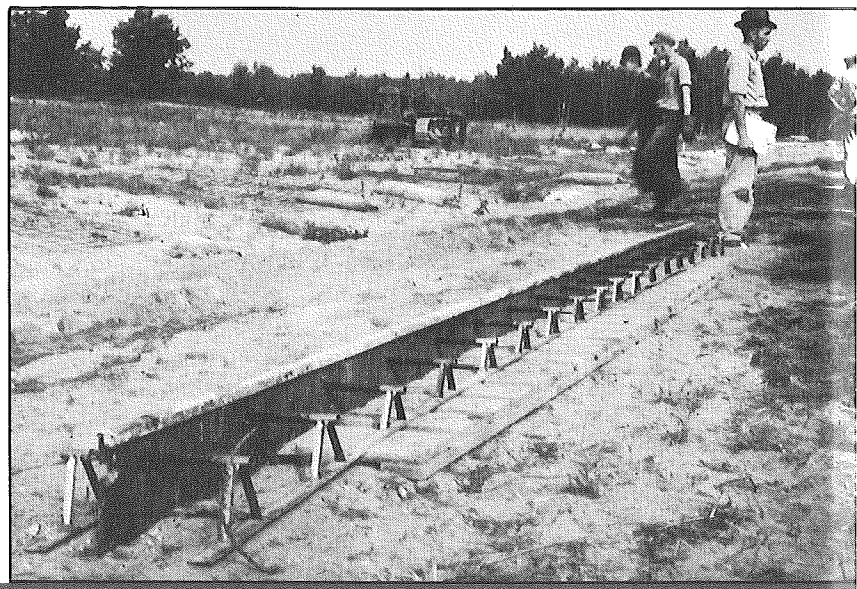
Consistent with the spacing of expansion joints at specified intervals and amount of reinforcing steel, contraction joints have been constructed at 10, 15, 20, 30 and 60 foot intervals. These various spacings have been included in the construction of the various cross sections and expansion joint spacing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

**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



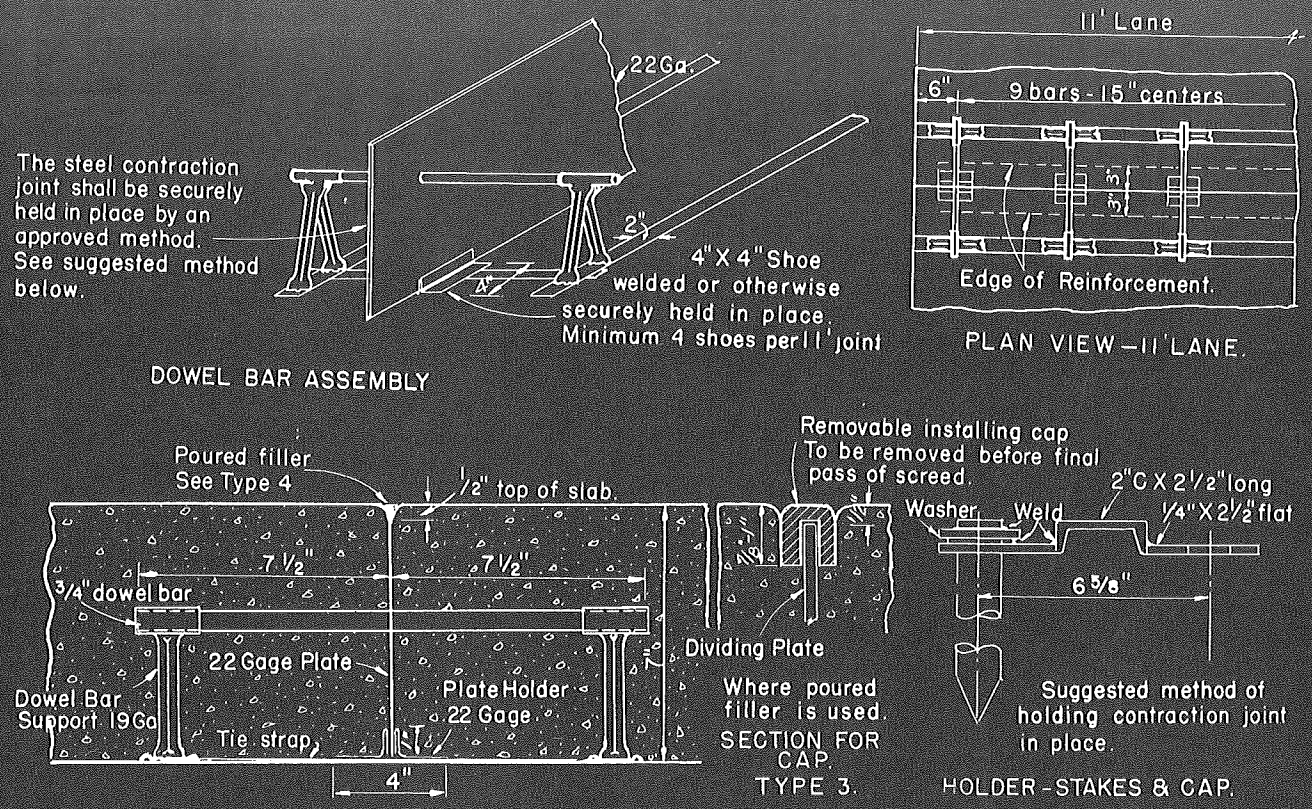



FIG. 17. DETAIL SKETCH OF TYPE 3 CONTRACTION JOINT WITH LOAD TRANSFER DEVICE AND STEEL DIVIDING PLATE

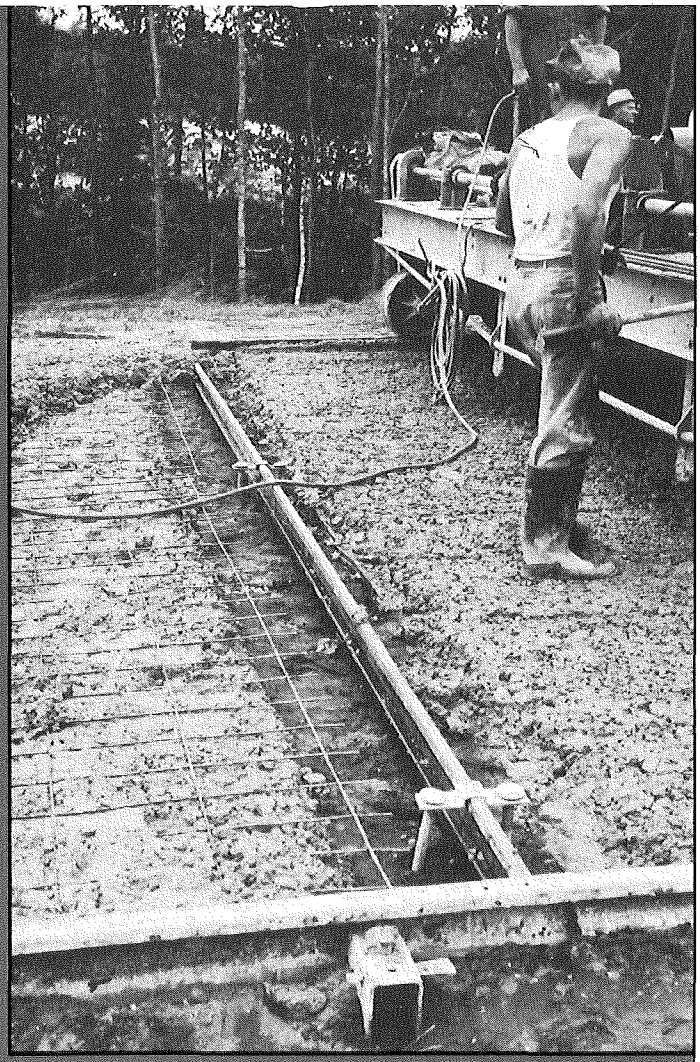


Fig. 19A. Continuous Plate Dowel Contraction Joint Assembly

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.

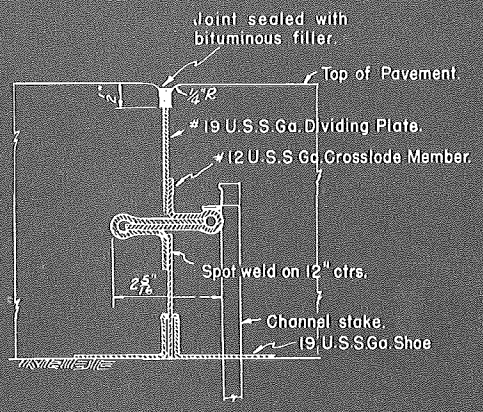
CONTINUOUS DOWEL PLATE — Type 4. The continuous plate dowel illustrated in figures 18 and 19A consists of a continuous No. 10 gage metal plate running the entire length of the joint and supported in proper position by two vertical web members.

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.



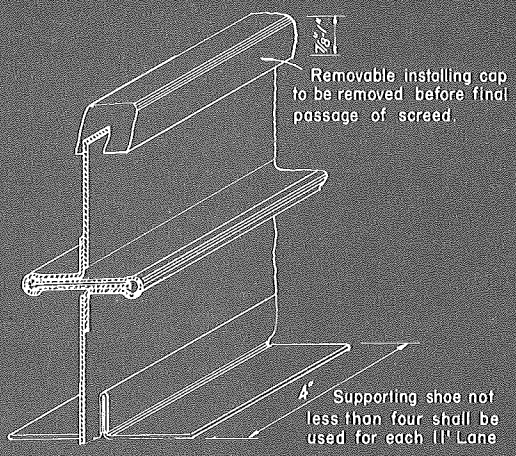
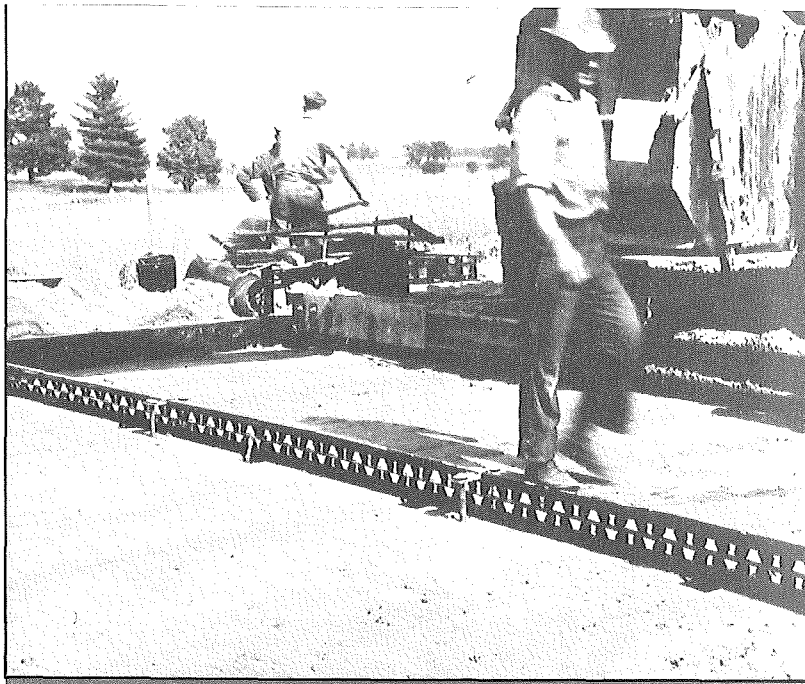




Fig. 18. Detail Sketch of Type 4, Contraction Joint with Continuous Plate Dowel Load Transfer Device

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.

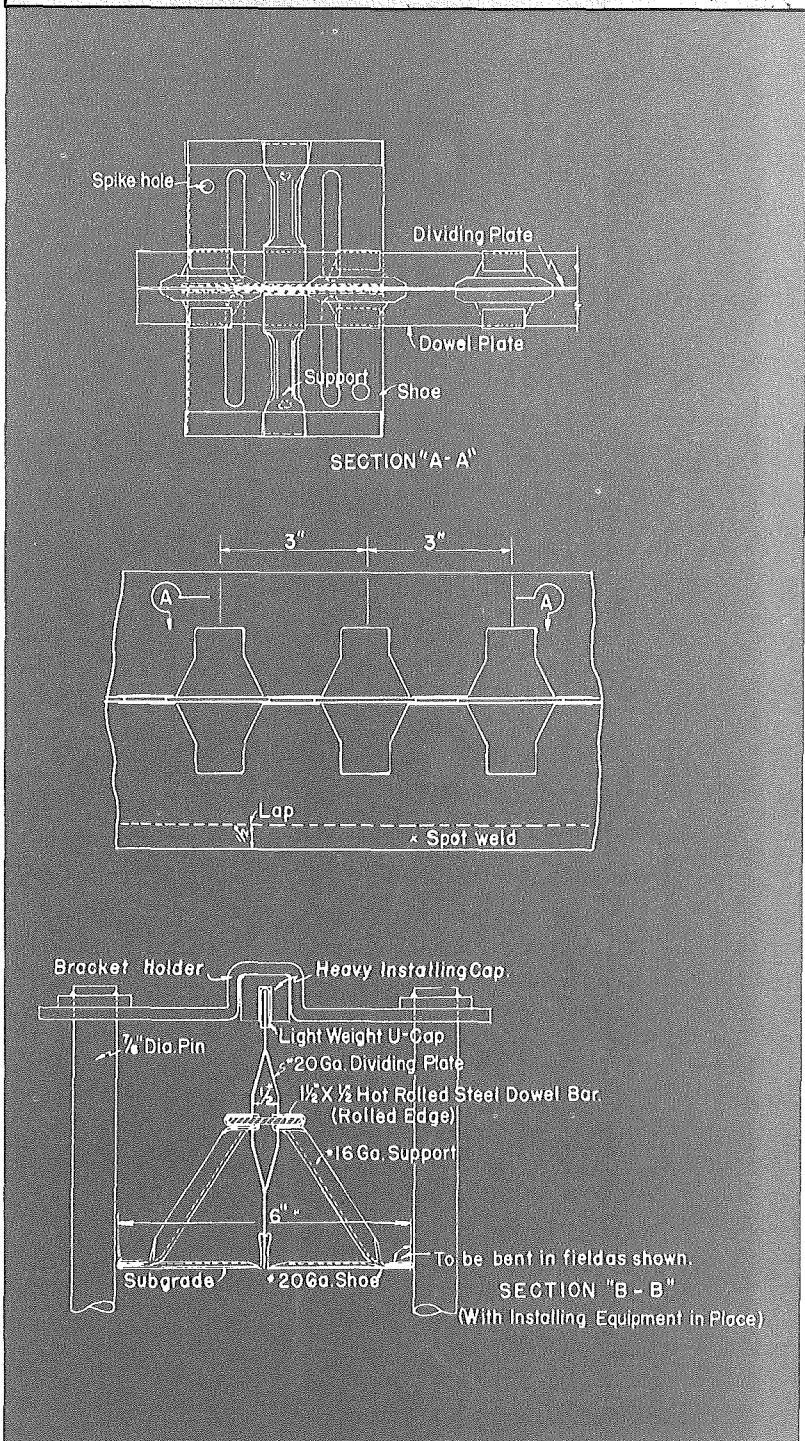



Fig. 20. Detail Sketch of Keylode Contraction Joint Assembly, Type 5

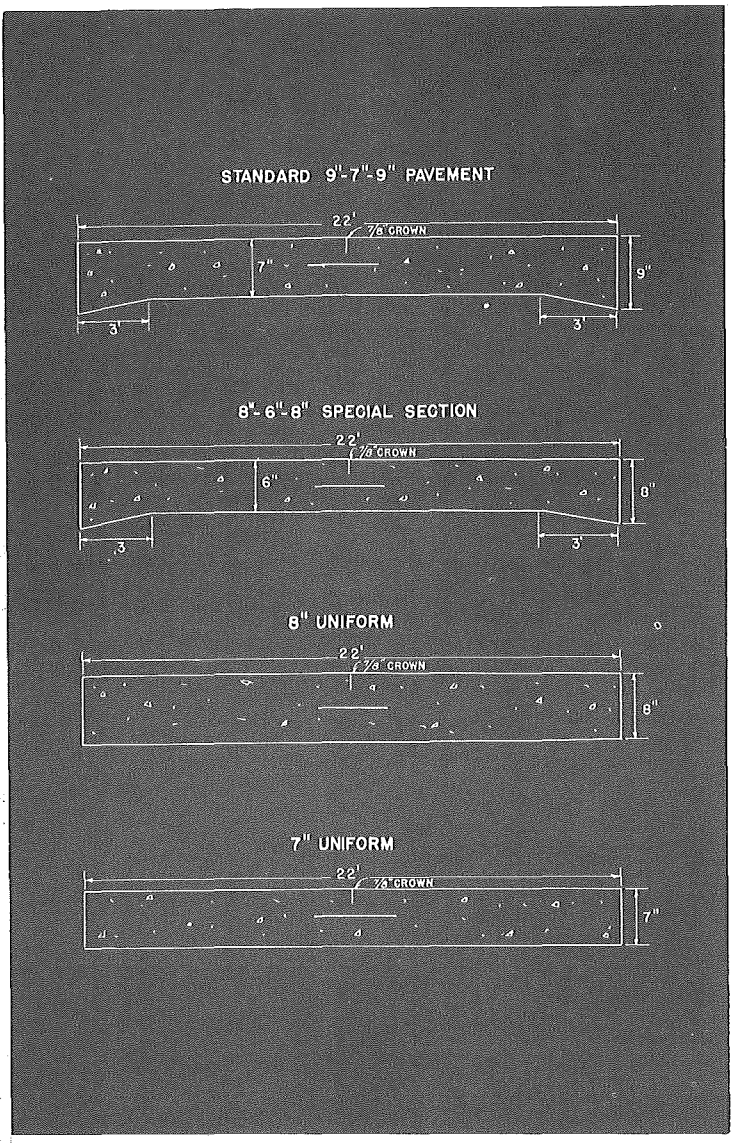



Fig. 21. Detail Sketch of Pavement Cross-Sections

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.

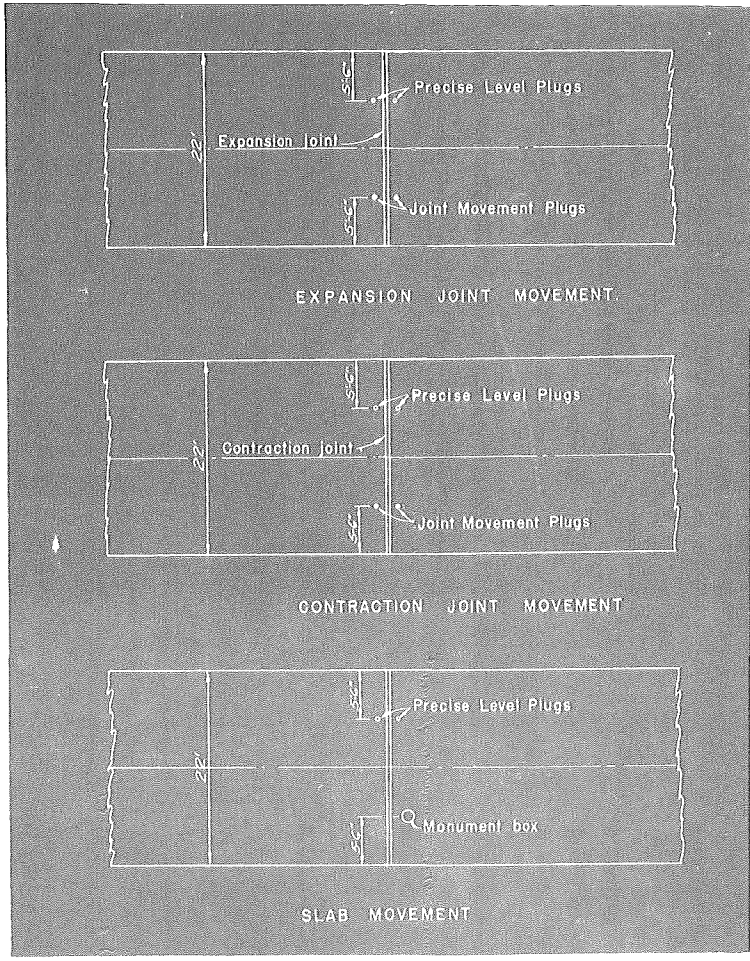



Fig. 22. Detail Sketch Showing Relative Location of Reference Points

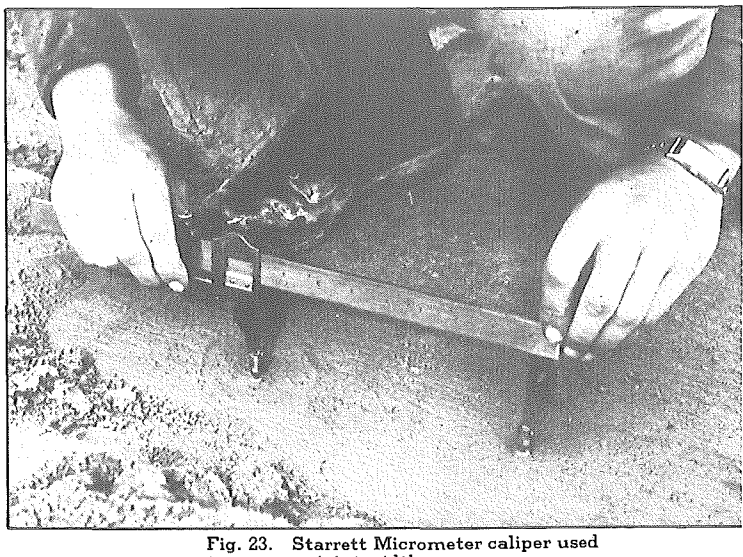


Fig. 23. Starrett Micrometer caliper used to measure joint widths

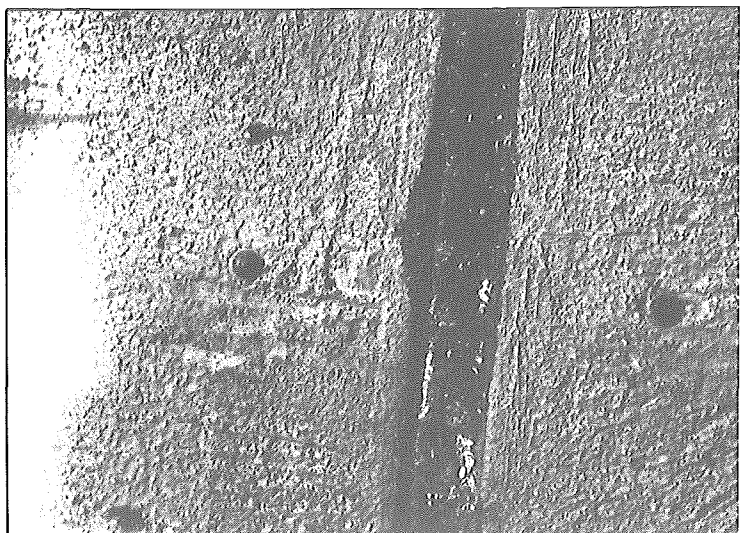


Fig. 24. Elevation points to determine vertical displacement of pavement at the joint

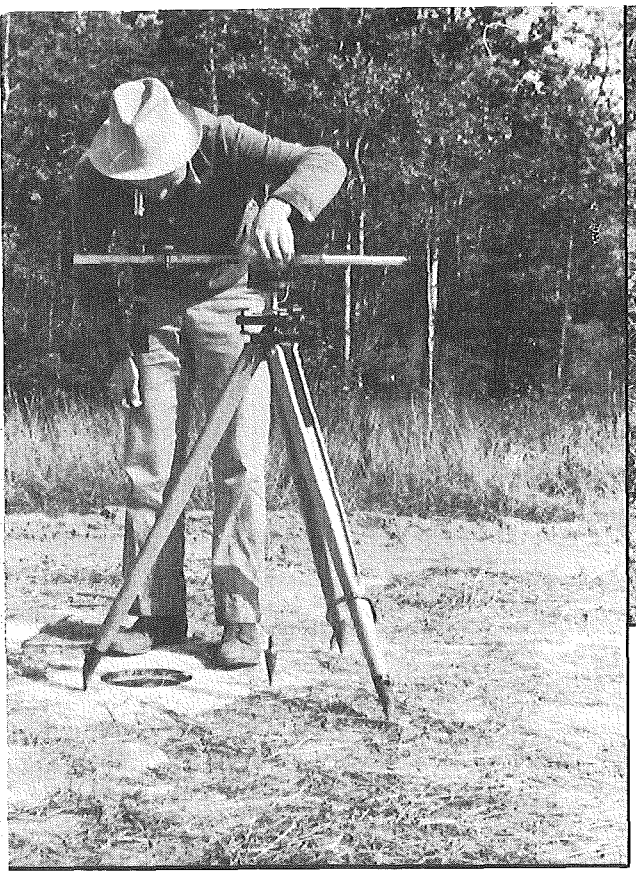


Fig. 25A. View of telescopic measuring device

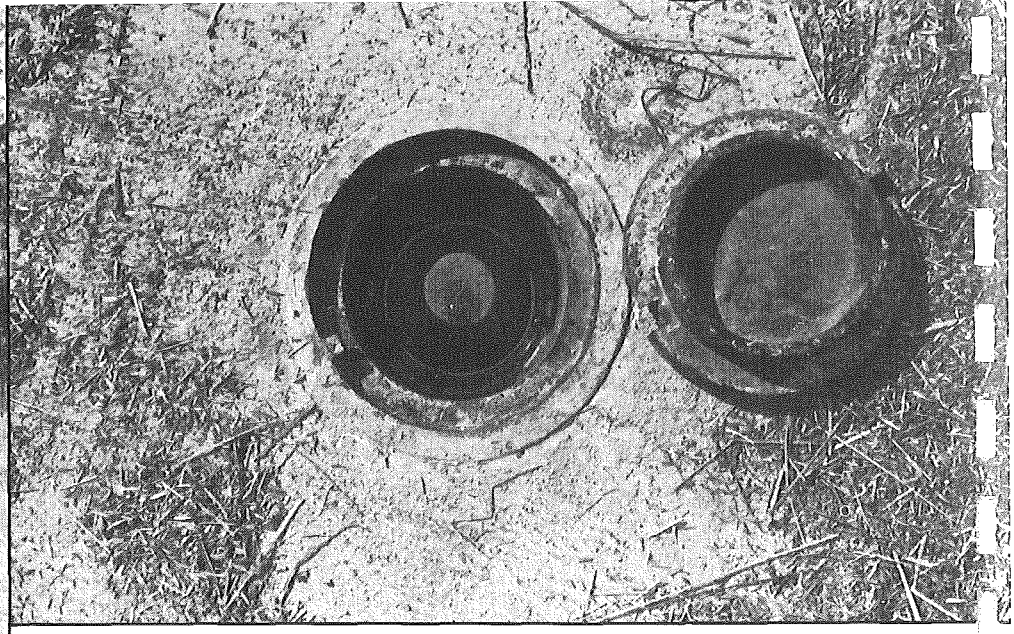


Fig. 25B. View of reference monument

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.