MISSOURI COOPERATIVE HIGHWAY RESEARCH PROGRAM

FINAL REPORT

78-1

# INVESTIGATION OF ROADWAY DESIGN VARIABLES TO REDUCE D-CRACKING

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT

TECHNICAL REPORT STANDARD TITLE PAGE

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| MCHRP 78-1 | | TE278 .I69 1988 |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| Investigation of Roadway Design Variables to Reduce D-Cracking | December, 1987 |
| | 6. Performing Organization Code: 78-1 |
| 7. Author(s): Missouri Highway & Transportation Dept. Division of Materials and Research | 8. Performing Organization Report No.: MCHRP 78-1 |
| 9. Performing Organization Name and Address: Missouri Highway & Transportation Dept. Division of Materials and Research P. O. Box 270 Jefferson City, Missouri 65102 | 10. Work Unit No. |
| | 11. Contract or Grant No. |
| 12. Sponsoring Agency Name and Address: Missouri Highway & Transportation Dept. Division of Materials and Research P. O. Box 270 Jefferson City, Missouri 65102 | 13. Type of Report and Period Covered: Final Report |
| | 14. Sponsoring Agency Code |

15. Supplementary Notes

The investigation was conducted in cooperation with the U. S. Department of Transportation-Federal Highway Administration.

16. Abstract


Eight reinforced portland cement concrete pavement test sections were constructed to determine what effect certain designs would have on the occurrence of D-cracking. Various designs included use of a 3/4 inch and one inch maximum size Bethany Falls limestone paving stone produced locally, use of a two inch maximum size Burlington limestone paving stone produced from a source having no known history of a D-cracking problem, and pavement constructed with and without a polyethylene moisture barrier.

Base variables included impermeable, dense graded Type 3 aggregate, cement treated Type 1 aggregate, plant mix bituminous source, and permeable, open graded plant mix bituminous course.

With nearly ten years of service life, there was no D-cracking observed in any test section.

Observation of the test sections will continue to determine if any of the aggregate or base variables result in improved performance.


| 17. Key Words | 18. Distribution Statement |
|---|---|
| D-crack susceptible aggregate, dense and open graded, design variables, distress features, frost resistant, severity level, staining, transition zone | This document is available to the public through the National Technical Information Service, Springfield, Virginia 22151 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 33 | |

Form DOT F 1700.7 (8-69)

# INVESTIGATION OF ROADWAY DESIGN VARIABLES TO REDUCE D-CRACKING

FINAL REPORT

STUDY NO. 78-1

Prepared By

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT

DIVISION OF MATERIALS AND RESEARCH

SEPTEMBER 1988

In Cooperation With

U. S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

The opinions, findings, and conclusions expressed in this publication are not necessarily those of the Department of Transportation, Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

TABLE OF CONTENTS

List of Tables . . . . . iii

List of Figures and Appendices . . . . . iv

Introduction . . . . . 1

Conclusions . . . . . 5

Implementation . . . . . 6

Discussion . . . . . 7

Reference . . . . . 13

## LIST OF TABLES


| Table No. | Title | Page No. |
|---|---|---|
| 1 | Annual Rainfall and Temperature Extremes . . . | 14 |
| 2 | Summary of Distress Features . . . . . | 15 |
| 3 | Sonic Tests of Concrete Cores . . . . . | 16 |
| 4 | Summary of Strain Gage Measurements And Resulting PSI . . . . . | 17 |
| 5 | Microscopic Examination of Core Sections . . . | 18 |

## LIST OF FIGURES


| Figure No. | Title | Page No. |
|---|---|---|
| 1 | General Location Map For Test Sections . . . . | 20 |
| 2 | Detailed Location Map For Test Sections . . . | 21 |
| 3 | Layout and Description of Test Sections . . . | 22 |
| 4 | Typical Cross Section of Sections . . . . . | 23 |


## LIST OF APPENDICES


| Appendix No. | Title | Page No. |
|---|---|---|
| 1 | Materials . . . . . | 24 |
| 2 | Aggregate for Portland Cement Concrete . . . . | 26 |
| 3 | Physical Characteristics of Paving Aggregates . . . . . | 27 |
| 4 | Composition and Gradation of Plant Mix Bituminous Base Mixture . . . . . | 28 |
| 5 | Composition and Gradation of Plant Mix Bituminous Open Graded Base Mixture . . . . . | 29 |

# INTRODUCTION

For many years, the durability of concrete pavements located in Northern and Western Missouri have often been reduced by a distress identified as D-cracking. In an attempt to eliminate or reduce pavement D-cracking, several changes in pavement design were made in 1967. These changes provided for (a) higher quality aggregate than had previously been required, (b) reduced the maximum size of marginally frost resistant paving stone from two to one inch, (c) increased the percent fine aggregate, and (d) required a four mil thick polyethylene moisture barrier placed between the pavement and the aggregate base. These changes were evaluated and all except the use of a polyethylene moisture barrier were found to be beneficial. However, the first observation of significant D-cracking of pavements was generally at an age of 5 1/2 to 6 years.

While the changes made in 1967 were found to be beneficial, the problem of D-cracking was of sufficient magnitude to continue to investigate other design criterion to improve pavement service life. In 1975, a field study was initiated to determine the effectiveness of certain design variables. The project selected for incorporating various design variables was constructed in 1977 in the northbound lanes on Interstate Route I-35, Daviess County (See Figures 1 and 2). There were eight test sections (See Figure 3), each being 922.5 feet in length. A test section consisted of 15 pavement sections, each 61.5 feet in length, with 16 contraction joints. Contraction joints were dowelled for load transfer. Each test

section had the following common factors: (a) 9" reinforced portland cement concrete pavement, (b) same type and source of cement, (c) same source of fine aggregate, (d) 4" thickness of base course, and (e) shoulder design. Shoulder design throughout the project limits included a Type 4, permeable, open graded aggregate for drainage (See Figure 4). The variables for each of the test sections were as follows:

Test Section 1

PCCP - Coarse Aggregate; Burlington Limestone, 100 percent passing 2 inch sieve (having no known history of a D-cracking problem).

% Fine Aggregate - 38

Moisture Barrier - No

Base - Type 3 Aggregate (impermeable, dense graded)

Test Section 2

PCCP - Coarse Aggregate; Bethany Falls Limestone, 100 percent passing 3/4 inch sieve (assumed to be D-crack susceptible)

% Fine Aggregate - 45

Moisture Barrier - 4 mil thickness polyethylene

Base - Type 3 Aggregate (impermeable, dense graded)

Test Section 3

PCCP - Coarse Aggregate; Bethany Falls Limestone, 100 percent passing 3/4 inch sieve (assumed to be D-crack susceptible)

% Fine Aggregate - 45

Moisture Barrier - No

Base - Type 3 Aggregate (impermeable, dense graded)

Test Section 4

PCCP - Coarse Aggregate; Bethany Falls Limestone, 100 percent passing 1 inch sieve (assumed to be D-crack susceptible)

% Fine Aggregate - 45

Moisture Barrier - No

Base - Type 3 Aggregate (impermeable, dense graded)

Test Section 5

PCCP - Coarse Aggregate; Bethany Falls Limestone, 100 percent passing 1 inch sieve (assumed to be D-crack susceptible)

Moisture Barrier - No

Base - Plant Mix Bituminous Base (impermeable, dense graded)

Test Section 6

PCCP - Coarse Aggregate; Bethany Falls Limestone, 100 percent passing 1 inch sieve (assumed to be D-crack susceptible)

% Fine Aggregate - 45

Moisture Barrier - No

Base - Plant Mix Bituminous Base (permeable, open graded)

Test Section 7

PCCP - Coarse Aggregate; Bethany Falls Limestone, 100 percent passing 1 inch sieve (assumed to be D-crack susceptible)

% Fine Aggregate - 45

Moisture Barrier - No

Base - Portland Cement Treated Aggregate (impermeable, dense graded)

Test Section 8

PCCP - Coarse Aggregate; Bethany Falls Limestone, 100 percent passing 1 inch sieve (assumed to be D-crack susceptible)

% Fine Aggregate - 45

Moisture Barrier - 4 mil thickness polyethylene

Base - Type 3 Aggregate (impermeable, dense graded)

A typical cross section of the test sections may be seen in Figure 4. Also, various material specifications, results of aggregate physical characteristics, and job mixes may be seen in the appendices.

## CONCLUSIONS

Major conclusions obtained from this study were as follows:

1. The objectives were not achieved during the time frame of this study.

2. No D-cracking was observed on the surface of the portland cement concrete pavement regardless of maximum size of coarse aggregate used in the concrete or the various base variables.

3. Microscopic examination of slabs sawed from concrete cores in each test section indicated little or no cracking of mortar or aggregates.

4. No evidence of pumping was observed at those sections having a special treated base.

5. Evidence of pumping was observed at each of the sections having a Type 3 aggregate base.

## IMPLEMENTATION

Objectives of this study were not achieved since no difference in performance of any section was observed with respect to D-cracking.

Observation of the test sections will continue to determine if any of the aggregate or base variable resulted in improved pavement performance.

## DISCUSSION

### General

The study was initiated with the beginning of construction on July 1, 1977. The completed project was open to traffic in December, 1977. At the end of the study time, 1984, no D-cracking was observed and a three year extension was approved.

Visual surveys of the pavement surface for each of eight test sections were made annually. Pavement edge strain and Present Serviceability Index were determined in 1982, 1983, and 1985. Cores were drilled from each test section in early 1987 to substantiate the condition of the concrete.

Each test section was 922.5 feet in length with a transition zone between each section to allow for changes in construction of the different design variables. A test section consisted of 15 pavement sections, each 61.5 feet in length, with 16 contraction joints. Each contraction joint had dowel supporting units for load transfer. Sawed longitudinal and transverse joints were sealed with a hot-poured elastic type sealer.

### Study Finding

The results of this study are based on nearly 10 years of observation of the concrete pavement. Types of pavement distress and severity level of each type of distress noted in Table 2 was obtained from "Highway Pavement Distress Identification Manual", Department of Civil Engineering, University of Illinois, the Federal Highway Administration, and National Cooperative Highway Research Program, Transportation

Research Board.(1) In addition to those distress features rated and shown in Table 2, other signs of distress surveyed for and not found were (a) Diagonal Cracks, (b) Joint Load Transfer System Associated Deterioration (Second Stage Cracking), and (c) Durability ("D") Cracking.

1. Staining and D-Cracking

A discoloration of the concrete surface (possibly staining or moisture) was noted as one approached some transverse joints and cracks. However, discoloration was not observed when viewed directly down on joints or cracks. No discoloration was observed at the longitudinal joint.

Based on the "Highway Pavement Distress Identification Manual" no D-cracking was observed at any joint or crack in any of the test sections. There were seven joints which exhibited very minor cracking and may, with time, develop the characteristic crack pattern of D-cracking.

In the spring of 1987, three cores were drilled from each test section. Each core was drilled approximately two feet from a longitudinal joint and one foot from a transverse joint. This area would generally be expected to exhibit the earliest signs of D-cracking. Each core was tested for dynamic modulus of elasticity prior to sawing into full length slabs (See Table 3). Microscopic examination of the concrete indicated minor to no cracking of the coarse aggregate, however, some reaction rings were observed with Bethany Falls Limestone (See Table 5).

2. Corner Break

Two corner breaks were observed throughout the eight test sections each of which was rated at the low severity level.

3. Spalling

A. Corner (Exterior and Interior)

Very minor spalling was observed in each of the eight test sections. Out of 14 corner spalls noted, only one was rated at the medium severity level with the remaining 13 all rated at the low severity level.

B. Transverse Joint

Some degree of spalling was occurring at these joints especially in the three treated base test sections. Parallel cracking followed by spalling was apparently not related to the sawing of these joints as initially there were very few cracks. Progression of cracking generally began to occur between the third and fifth year. Spalling of concrete between the crack and joint (generally two to six inches) usually occurred with time.

Also, with time, some of the smaller spalls extended into each other to form a single longer spall. It is not known why, but there was a substantial increase in joint cracking and spalling on those test sections having special types of bases in lieu of the standard impermeable dense graded aggregate base design. (See Table 2).

C. Longitudinal Joint

Spalling of low severity level was only observed at the centerline longitudinal joint at two locations in test section 7. (See Table 2).

4. Faulting

A. Transverse Joints

Very minor joint faulting was observed and when noted was generally 1/16" or less.

B. Transverse Cracks

Minor amount of crack faulting was observed, though when observed were of a medium severity level and sporadically scattered throughout the various test sections. (See Table 2).

5. Longitudinal and Transverse Cracks

A. Longitudinal Cracks

Very minor longitudinal cracking was observed in the various 61.5 foot PCC pavement panels. Out of a total of five longitudinal cracks for all eight test sections, three were observed in test section 6 having the 1 inch maximum size Bethany Falls limestone with the permeable, open graded plant mix bituminous base.

B. Transverse Cracks

Normally, one or two transverse cracks occur in each panel with 61.5 foot joint spacings. Cracks may extend the full pavement width or may extend only the width of one lane. A summary of transverse panel cracking is shown in Table 2. The amount of transverse cracking for the test sections is scattered. The pavement with the two inch maximum size coarse aggregate and standard base had no transverse cracks. The test section utilizing a permeable, open graded plant mix bituminous base had only two transverse cracks in the concrete pavement. The maximum transverse panel cracking was found to occur in test

section 8 utilizing the impermeable, dense graded Type 3 aggregate base which had 18 cracks.

6. Pavement Edge Strain and Present Serviceability Index

At the time the test sections were built in 1977, no consideration had been given to develop data other than that which would be obtained visually. In 1982, it was decided to include Pavement Edge Strain (PES) and Present Serviceability Index (PSI) to provide additional information which might be of future benefit regarding the base variables. PES and PSI were obtained in 1982, 1983, and 1985 (See Table 4). To date, with the limited data available, no discernible trend has developed. Future tests are planned to determine if any differences occur between any of the eight test sections with time.

7. Pumping

The availability of water will affect the degree of saturation of the concrete pavements which in turn will affect the occurrence of D-cracking. Four different base types were used under a common type of 9" RPCC pavement throughout the project. The shoulder design throughout consisted of a seal coat and a 2 foot by 2 inch thick plant mix bituminous material on an 8 inch Type 1 (impermeable) aggregate base placed over 5 inches of Type 4 (permeable, open graded) aggregate base. See Figure 4.

Pumping was determined by observation of water or water and fines deposited on the surface of the shoulder adjacent to the pavement. When pumping did occur, it was at the interface of the pavement and shoulder at transverse joints, cracks, or along the panels. Some evidence of pumping was observed in each of

the five test sections having a Type 3 aggregate (impermeable, dense graded) base; however, test section 1 had pumping at every transverse joint and along a majority of the panels. The three test sections with treated bases did not exhibit pumping.

## REFERENCE

1. Darter, Michael I., Herrin, Stanley M., and Smith, Roger E., "Highway Pavement Distress Identification Manual" Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, The Federal Highway Administration, and National Cooperative Highway Research Program, Transportation Research Board, March 1979.

Table 1

ANNUAL RAINFALL AND TEMPERATURE EXTREMES

| Calendar Year | Temperature, °F Min. | Max. | Annual Rainfall (Inches) |
|---|---|---|---|
| 1977 | -24 | 99 | 44 |
| 1978 | -16 | 99 | 46 |
| 1979 | -26 | 96 | 30 |
| 1980 | -11 | 107 | 28 |
| 1981 | -16 | 98 | 31+ |
| 1982 | -19 | 97 | 52* |
| 1983 | -19** | 106 | 27 |
| 1984 | -10 | 105 | 33 |
| 1985 | -18 | 100 | 35 |
| 1986 | - 8 | 99** | 30+ |

General: Data taken from available annual official climatological publications for the Bethany Station unless shown otherwise. All three stations are in close proximity to the research project.

* From the Pattonsburg Station
** From the Spickard Station

The test sections are in an area where the freezing index values range between 500 to 600 and expressed in degree-days below 32°F. These degree-days were calculated from the same official source as above and determined for a period in excess of 25 years.

Table 2

Summary of Distress Features

| | | CORNER BREAK | SPALLING | | | FAULTING | | LONGITUDINAL AND TRANSVERSE CRACKS | |
|---|---|---|---|---|---|---|---|---|---|
| Test Section No. | Severity Level | | Corner | Transverse Joint | Longit. Joint | Transverse Joint | Transverse Crack | Longit. | Transverse |
| 1 | L | | 1 | 3 | | 3 | | 1 | |
| | M | | | | | | | | |
| 2 | L | 1 | 2 | 3 | | | | 1 | 7 |
| | M | | | 2 | | 1 | | | |
| 3 | L | | | 1 | | | | | 10 |
| | M | | 1 | | | | 2 | | 3 |
| 4 | L | | 3 | 5 | | | | | 7 |
| | M | | | | | | 1 | | 5 |
| 5 | L | | 3 | 8 | | | | | 7 |
| | M | | | 2 | | | 1 | | 6 |
| 6 | L | | 2 | 10 | | | | 3 | |
| | M | | | 1 | | | | | 2 |
| 7 | L | 1 | 3 | 9 | 2 | | | | 8 |
| | M | | | | | | | | 1 |
| 8 | L | | 2 | 8 | | | | | 11 |
| | M | | | 2 | | | 2 | | 7 |

General: Rating Legend - L = Low Severity; M = Medium Severity
Individual distress features tabulated above were rated in each lane of travel.
Numbers shown are totals for both lanes.

Table 3

SONIC TESTS OF CONCRETE CORES

| Core Number | Section Number | Dynamic Core Modulus (1) | Average Core Modulus By Section |
|---|---|---|---|
| 1-1 | 1 | 5.25 | |
| 1-2 | 1 | 5.75 | 5.73 |
| 1-3 | 1 | 6.20 | |
| 2-1 | 2 | 5.27 | |
| 2-2 | 2 | 5.16 | 5.24 |
| 2-3 | 2 | 5.29 | |
| 3-1 | 3 | 5.11 | |
| 3-2 | 3 | 5.34 | 5.26 |
| 3-3 | 3 | 5.33 | |
| 4-1 | 4 | 5.74 | |
| 4-2 | 4 | 5.01 | 5.35 |
| 4-3 | 4 | 5.31 | |
| 5-1 | 5 | 5.76 | |
| 5-2 | 5 | 5.34 | 5.45 |
| 5-3 | 5 | 5.25 | |
| 6-1 | 6 | 5.27 | |
| 6-2 | 6 | 5.48 | 5.22 |
| 6-3 | 6 | 4.91 | |
| 7-1 | 7 | 4.68 | |
| 7-2 | 7 | 4.85 | 4.90 |
| 7-3 | 7 | 5.18 | |
| 8-1 | 8 | 5.73 | |
| 8-2 | 8 | 5.05 | 5.11 |
| 8-3 | 8 | 4.54 | |

(1) Where: $E \times 10^{-6}$ psi.

Age of pavement approximately 10 years when concrete cores were obtained.

Table 4

SUMMARY OF STRAIN GAGE MEASUREMENTS AND RESULTING PSI
Microstrain (0.000001 In. Per In.) Per Kip Wheel Load (1)

| | Test Section No. | 1982 | 1983 | 1985 |
|---|---|---|---|---|
| Microstrain (2) | 1 | | | |
| at 2 inch | | 4.42 | 4.36 | 4.02 |
| at 10 inch | | 2.51 | 2.47 | 2.29 |
| PSI (3) | | 4.02 | 4.01 | 3.96 |
| Microstrain | 2 | | | |
| at 2 inch | | 4.45 | 3.86 | 4.19 |
| at 10 inch | | 2.52 | 2.18 | 2.41 |
| PSI | | 3.77 | 3.87 | 3.72 |
| Microstrain | 3 | | | |
| at 2 inch | | 4.24 | 4.02 | 4.26 |
| at 10 inch | | 2.46 | 2.28 | 2.46 |
| PSI | | 3.79 | 3.96 | 3.89 |
| Microstrain | 4 | | | |
| at 2 inch | | 5.18 | 4.58 | 4.96 |
| at 10 inch | | 2.94 | 2.60 | 2.85 |
| PSI | | 3.68 | 3.90 | 3.72 |
| Microstrain | 5 | | | |
| at 2 inch | | 4.65 | 4.33 | 4.33 |
| at 10 inch | | 2.66 | 2.50 | 2.48 |
| PSI | | 3.78 | 3.99 | 3.81 |
| Microstrain | 6 | | | |
| at 2 inch | | 3.98 | 3.74 | 3.86 |
| at 10 inch | | 2.23 | 2.11 | 2.18 |
| PSI | | 3.85 | 3.99 | 3.84 |
| Microstrain | 7 | | | |
| at 2 inch | | 3.64 | 3.56 | 3.78 |
| at 10 inch | | 2.08 | 2.04 | 2.15 |
| PSI | | 3.76 | 3.96 | 3.78 |
| Microstrain | 8 | | | |
| at 2 inch | | 4.43 | 4.08 | 4.36 |
| at 10 inch | | 2.50 | 2.29 | 2.44 |
| PSI | | 3.47 | 3.74 | 3.52 |

(1) Values shown for 2 and 10 inches are extrapolated from the data at 9, 18, 27, and 36 inches.
(2) Distance from pavement edge to outer tire tread.
(3) PSI - Present Serviceability Index

Table 5

MICROSCOPIC EXAMINATION OF CORE SECTIONS

| Core No. | Distress Description |
|---|---|
| 1-1 | One small crack at very top of core associated with tine grooves |
| 1-2 | No cracking noted |
| 1-3 | No cracking noted |
| 2-1 | No cracking noted-some coarse aggregate reaction rims in the lower 2/3 of core |
| 2-2 | No cracking noted-some coarse aggregate reaction rims in the lower 1/2 of core |
| 2-3 | No cracking-some coarse aggregate reaction rims in the lower 2/3 of core |
| 3-1 | No cracking-some coarse aggregate reaction rims in the lower 1/2 of core |
| 3-2 | No cracking-some coarse aggregate reaction rims in the middle 1/2 of core |
| 3-3 | No cracking-some coarse aggregate reaction rims in the lower 7" of core |
| 4-1 | No cracking-some coarse aggregate reaction rims in the lower 2/3 of core |
| 4-2 | No cracking-some coarse aggregate reaction rims in core, various levels |
| 4-3 | No cracking-some coarse aggregate reaction rims in core, various levels |
| 5-1 | Some light cracking top 2"-coarse aggregate reaction rims in the lower 2/3 of core |
| 5-2 | Some light cracking top 3"-some coarse aggregate reaction rims scattered |
| 5-3 | Cracking in top 4 1/2", some very light cracking in bottom 1" coarse aggregate reaction rims throughout |
| 6-1 | No cracking-some coarse aggregate reaction rims in core |
| 6-2 | No cracking-some coarse aggregate reaction rims in core |
| 6-3 | No cracking-some coarse aggregate reaction rims in core |
| 7-1 | Some light cracking top 2", one crack bottom 1" |
| 7-2 | Some light cracking top 1 1/2", some coarse aggregate reaction rims in the bottom 1 1/2" |
| 7-3 | Some light cracking from 1" to 3", some cracking bottom 1"-coarse aggregate reaction rims throughout |

Table 5 (Continued)

| Core No. | Distress Description |
|---|---|
| 8-1 | No cracking-several coarse aggregate reaction rims |
| 8-2 | No cracking-some coarse aggregate reaction rims |
| 8-3 | No cracking-several aggregate particles show fractures but do not appear to go into matrix, some coarse aggregate reaction rims. |

Figure 1

General Location Map
For
Test Sections
I-35, Daviess County

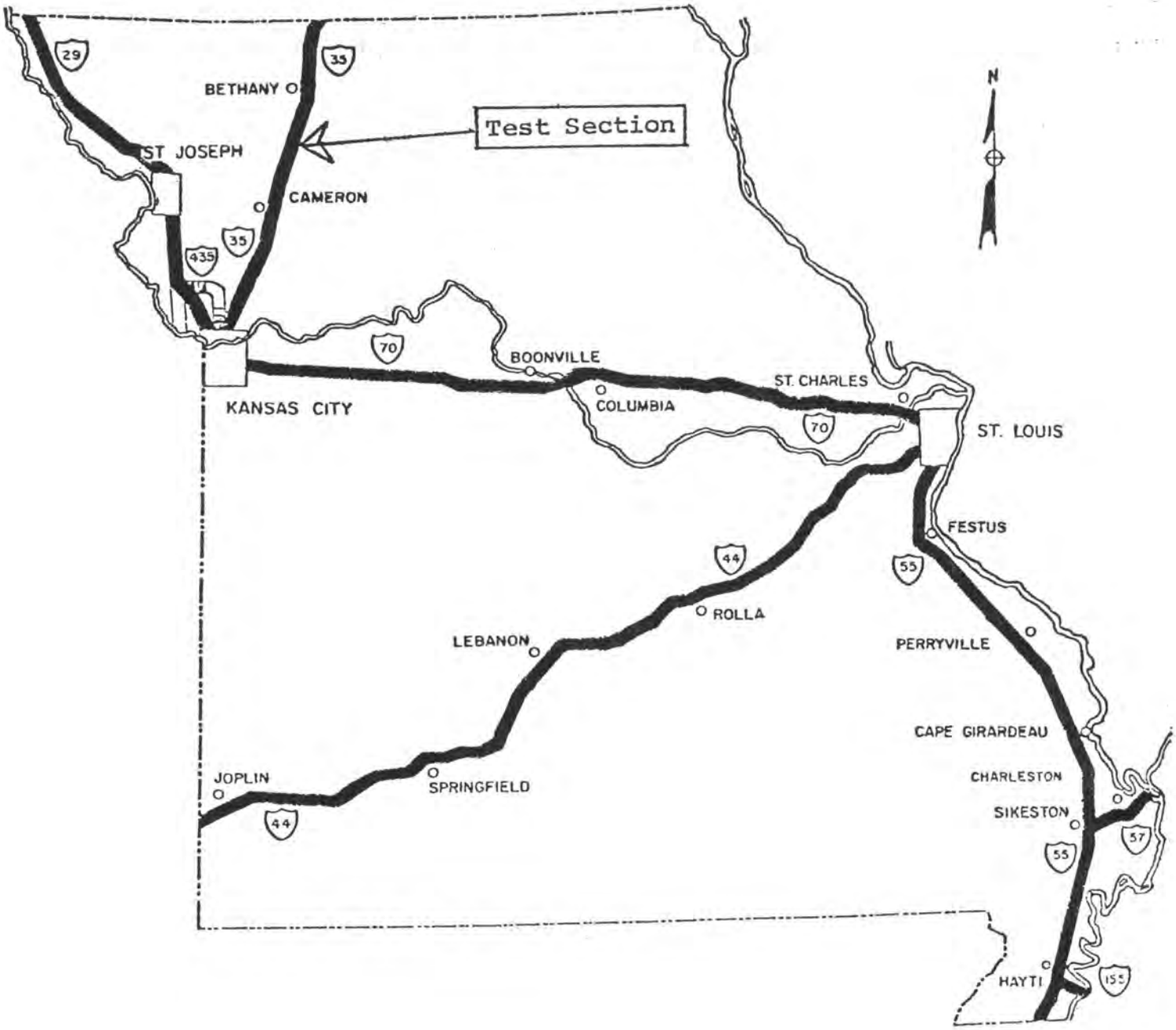
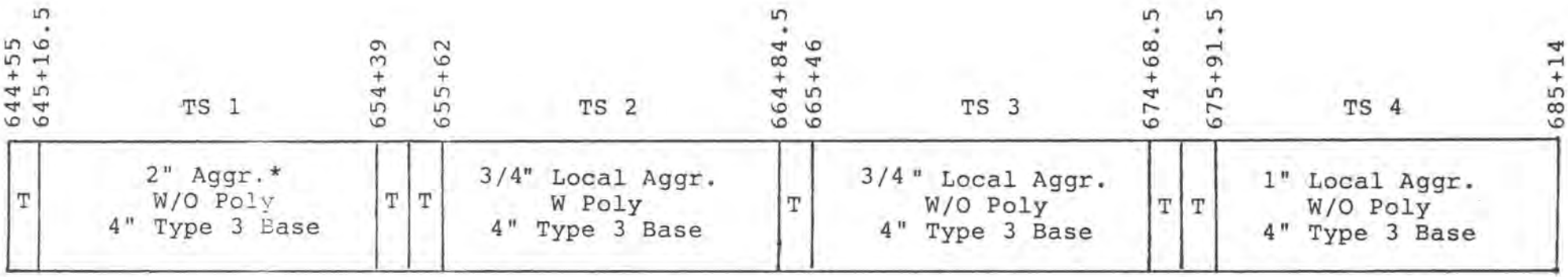


Figure 2

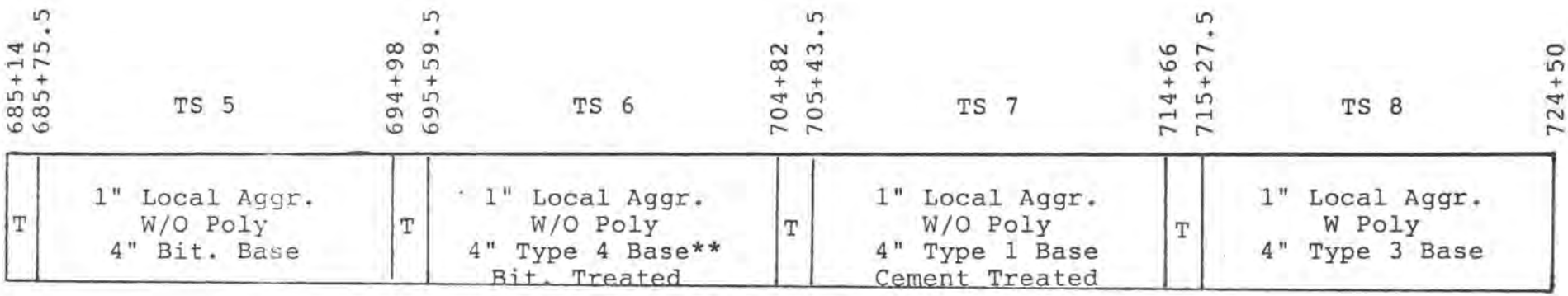
Detailed Location Map
For
Test Sections
I-35 (Northbound), Daviess County

FIGURE 3

Layout and Description of Test Sections




Northbound Lane, I-35, Daviess County



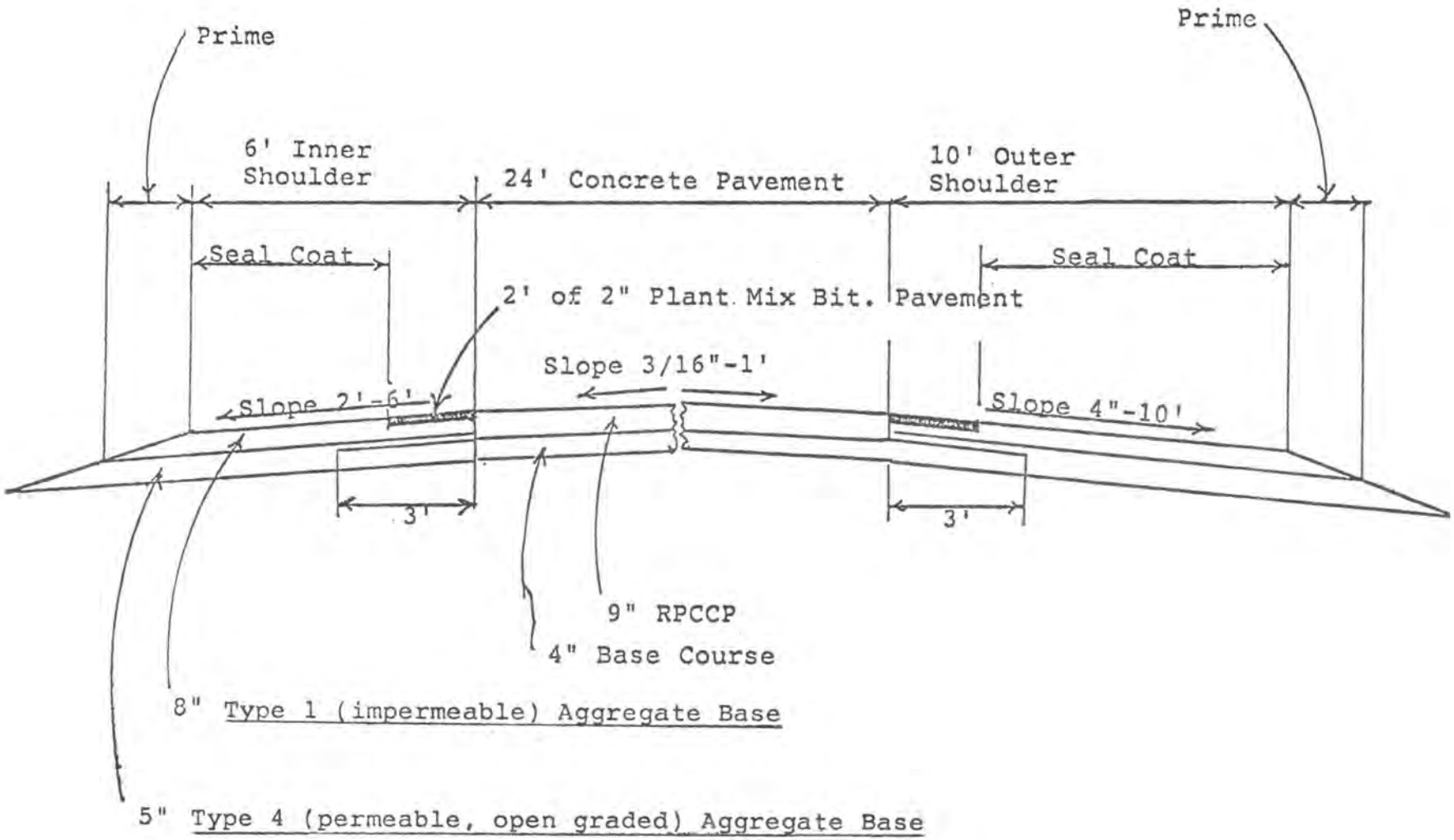

Northbound Lane, I-35, Daviess County

LEGEND:

* Aggregate with no known history of "D" Cracking (Burlington Limestone)
** Open graded aggregate base.
T = Transition Slab
NOTE: Stationing shown is for centerline of northbound lane.

Figure 4

Typical Cross Section of Test Sections



Appendix 1

## 2.0 Materials

Subgrade materials throughout all test sections shall be of uniform character and condition.

Type 3 Aggregate Base shall meet the requirements of Section 1007.3* and all Type 3 aggregate used within the test sections shall be obtained from the same source and ledges.

Plant Mix Bituminous Base shall meet the requirements of Section 301 except the same job mix formula shall be used throughout the test section and substitution of mixtures, as specified in Section 301.3.3 will not be allowed.

Open Graded Plant Mix Bituminous Base shall meet the requirements of Section 308.10. The aggregate used shall meet the requirements of Section 1007.1 and all Type 1 aggregate based used within the test sections shall be obtained from the same source and ledges.

Cement used in portland cement concrete pavement and cement treated Type 1 aggregate base shall be Type 1 cement meeting the requirements of Section 1005.2 and the same source shall be used throughout all test sections.

Two-Inch Maximum Size Coarse Aggregate, all fractions, used in portland cement concrete pavement shall be Burlington Limestone and shall meet the requirements of Section 1005 and the gradation requirements of Section 1005.1.4.1 Gradation A. It shall be obtained from a source which has previously furnished aggregate for use in portland cement concrete pavement on a Missouri State Highway Department project and meets the approval of the engineer. All two-inch aggregate used in the test section shall come from the same source and ledges.

Three-Quarter Inch and One-Inch Maximum Size Coarse Aggregate used in portland cement concrete pavement shall be Bethany Falls Limestone and shall meet the requirements of Section 1005 for concrete pavement. The 3/4-inch aggregate shall meet the gradation requirements of Section 1005.1.6, Gradation E. The 1-inch aggregate shall meet the gradation requirements of Section 1005.1.5, Gradation D. All 3/4-inch and one-inch aggregates used in the test sections shall be obtained from the same source and ledges.

Air Entraining Agent and Curing Compound shall be of the same type, from the same source throughout all test sections. These materials shall meet the requirements of Standard Specifications, 1973 Edition.

The plastic concrete shall be cured in the same manner for all test sections.

All other materials and the construction procedures shall meet the applicable Section of the Standard Specifications, 1973 Edition, and its supplements.

---

*This and other Section (or Division) references in Appendix 1 refer to "Missouri Standard Specifications for Highway Construction, 1973."

## Appendix 2

## AGGREGATE FOR PORTLAND CEMENT CONCRETE

Specified gradation requirements for the different sizes of paving stone used in the test sections and the applicable specification for each are as follows:

### 2" Paving Stone (1005.1.4.1 - Gradation A)

| | Percent |
|---|---|
| Passing 2-inch sieve | 100 |
| Passing 1 1/2-inch sieve | 95-100 |
| Passing 3/4-inch sieve | 35-70 |
| Passing 3/8-inch sieve | 10-30 |
| Passing No. 4 sieve | 0-5 |
| Passing No. 200 sieve | 0-1.5 |

### 1" Paving Stone (1005.1.5 - Gradation D)

| | Percent |
|---|---|
| Passing 1-inch sieve | 100 |
| Passing 3/4-inch sieve | 90-100 |
| Passing 3/8-inch sieve | 15-45 |
| Passing No. 4 sieve | 0-5 |
| Passing No. 200 sieve | 0-2 |

### 3/4" Paving Stone (1005.1.6 - Gradation E)

| | Percent |
|---|---|
| Passing 3/4-inch sieve | 100 |
| Passing 1/2-inch sieve | 80-100 |
| Passing 3/8-inch sieve | 40-70 |
| Passing No. 4 sieve | 0-10 |
| Passing No. 10 sieve | 0-3 |
| Passing No. 200 sieve | 0-2 |

Fine aggregate used for paving was Class B* sand produced from the Grand River at Pattonsburg, Missouri.

*Class B sand includes all river sand weighing from 106 pounds to 108 pounds inclusive per cubic foot when tested in accordance with AASHTO T 19.

Appendix 3

## PHYSICAL CHARACTERISTICS OF PAVING AGGREGATES

Fine Aggregate: (Used for all paving)

| | | |
|---|---|---|
| (1) | Specific Gravity | 2.59 |
| (1) | Absorption | 0.6 |
| (2) | Weight (lbs per cu ft) | 106 |

| Coarse Aggregate: | | Size of Paving Aggregate 2 Inch* | 3/4 Inch** | 1 Inch** |
|---|---|---|---|---|
| (3) | Specific Gravity | 2.62 | 2.62 | 2.60 |
| (3) | Absorption (%) | 1.1 | 1.6 | 1.7 |
| (2) | Weight (lbs per cu ft) | 100 | 100 | 100 |
| (4) | Los Angeles Abrasion (% Loss) | 37 | 22 | 24 |
| | Deleterious Rock (%) | 1.7 | 2.1 | 1.2 |
| | Shale (%) | 0 | 0 | 0 |
| | Chert (%) | 0.3 | 0 | 0 |

*Burlington Limestone (Test Section 1)
**Bethany Falls Limestone (3/4 Inch: Test Sections 2 and 3)
(1 Inch: Test Sections 4, 5, 6, 7 and 8)

The above tests were run in accordance with the following test method.

(1) AASHTO T84-73I
(2) AASHTO T19
(3) AASHTO T85-70
(4) AASHTO T96

Appendix 4

COMPOSITION AND GRADATION OF
PLANT MIX BITUMINOUS BASE MIXTURE NO. BB77-33

PROJECT I-35-2(35)68 I-IG-35-2(2)72 SECTION

ROUTE I-35 COUNTY Daviess DATE 6/22/77

| TYPE MATERIAL | SOURCE OF MATERIAL | IDENT. NO. | SP. GR. | % ABS. | FORMATION |
|---|---|---|---|---|---|
| Crushed Stone | Raid Quarries, Inc. Pattonsburg, Mo. | 77-6065 | 2.667 | 2.0 | Bethany Falls Ls. Ledges 2-5 |
| Limestone Screenings | Raid Quarries, Inc. Pattonsburg, Mo. | 77-6066 | 2.715 | | Bethany Falls Ls. Ledges 2-5 |
| Asphalt (60-70) | Phillips Pet. Co. Kansas City, Kansas | 77-3808 | 1.017 | | |
| | | | | | |

Theoretical Maximum Specific Gravity of the Mixture -- 2.482

AGGREGATE GRADATIONS - PERCENT PASSING

| Ident. No. | 77-6065 | 77-6066 | | 77-6065 | 77-6066 | | | |
|---|---|---|---|---|---|---|---|---|
| Percent Used | | | | 85.0 | 15.0 | | Combined Gradation | Spec. Limits |
| 1-1/2" | 100 | 100 | | 85.0 | 15.0 | | 100 | |
| 1/2" | 77 | 100 | | 65.4 | 15.0 | | 80.4 | |
| 4 | 36 | 100 | | 30.6 | 15.0 | | 45.6 | |
| 10 | 21 | 82 | | 17.8 | 12.3 | | 30.1 | |
| 40 | 10 | 36 | | 8.5 | 5.4 | | 13.9 | |
| 200 | 6 | 20 | | 5.1 | 3.0 | | 8.1 | |
| | | | | | % Asphalt | | 5.0 | |

Composition of mixture, based on weight of total mix, is 95.2 % mineral aggregate and 4.8 % asphalt.

CHARACTERISTICS OF LABORATORY COMPACTED MIXTURES

| Specific Gravity | Percent Voids | Stability | Percent of Voids in M.A. Filled |
|---|---|---|---|
| 2.372 | 4.43 | 787 | |

Appendix 5

COMPOSITION AND GRADATION OF PLANT
MIX BITUMINOUS OPEN GRADED BASE MIXTURE NO. OGB77-20

PROJECT I-35-2(35)68 I-IG-35-2(72) SECTION

ROUTE I-35 COUNTY Daviess DATE 5/5/77

| TYPE MATERIAL | SOURCE OF MATERIAL | IDENT. NO. | SP. GR. | % ABS. | FORMATION |
|---|---|---|---|---|---|
| Crushed Stone | Raid Quarries, Inc. Pattonsburg, Mo. | 77-1651 | 2.640 | 2.5 | Winterset Ls. Ledges 1-3 |
| Asphalt (60-70) | Phillips Pet. Co. Kansas City, Kansas | 77-92 | 1.020 | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Theoretical Maximum Specific Gravity of the Mixture -- 2.523 | | | | | |

AGGREGATE GRADATIONS - PERCENT PASSING

| Ident. No. | 77-1651 | | | | 77-1651 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Percent Used | | | | | 100 | | | | Combined Grad. |
| 1" | 100 | | | | 100 | | | | 100 |
| 1/2" | 57 | | | | 57.0 | | | | 57.0 |
| 4 | 11 | | | | 11.0 | | | | 11.0 |
| 10 | 4 | | | | 4.0 | | | | 4.0 |
| 40 | | | | | | | | | |
| 200 | 3 | | | | 3.0 | | | | 3.0 |
| | | | | | | | % Asphalt | | 3.0 |

Composition of mixture, based on weight of total mix, is 97.1 % mineral aggregate and 2.9 % asphalt.

CHARACTERISTICS OF LABORATORY COMPACTED MIXTURES

| Specific Gravity | Percent Voids | Stability | Percent of Voids in M.A. Filled |
|---|---|---|---|
| 2.161 | 14.35 | 188 | |

MoDOT Library
RD0019614