STATE OF MINNESOTA
DEPARTMENT OF HIGHWAYS
Materials And Research Section

SPECIAL STUDY NO. 266

ASPHALT EMULSION STABILIZED BASE CONSTRUCTION
T.H. 65, S.P. 0208.18 - NEAR JOHNsville

By Paul G. Velz
Research Engineer

December 1960
DATE: December 9, 1960

DEPARTMENT: Highway

TO: Research Advisory Committee:
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FROM: C. K. Preus, Materials and Research Engineer

SUBJECT: Report on Special Study No. 266
Asphalt Emulsion Stabilized Base Construction
T.H. 65, S.P. 0208-18 - Near Johnsville

We submit herewith the formal report on the evaluation of the stabilization of fine sand with asphalt emulsion as constructed on T.H. 65 near Johnsville. The report covers the design of the project, the costs of the various stabilized and surfacing layers, construction problems and strength evaluations up to October, 1960.

Observations will be made periodically in the future to further evaluate the strength and performance of the project. These findings will be reported when they appear to be significant.

This report is being distributed to county and municipal engineers under the auspices of the Local Road Research Board.

CKP:pgv:or
Attach.
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STATE OF MINNESOTA
DEPARTMENT OF HIGHWAYS

MATERIALS AND RESEARCH SECTION

Special Study No. 266

ASPHALT EMULSION STABILIZED BASE CONSTRUCTION

T.H. 65, S.P. 0208-18 - NEAR JOHNSVILLE

Paul G. Velz,
Research Engineer

December, 1960
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INTRODUCTION

This study was conducted on S.P. 0208-18 (T.H. 65) located between 0.7 miles north of the junction with T.H. 10 and 2.9 miles north of the junction with T.H. 242 at Johnsville. The contract included grading, bituminous stabilized base and bituminous surfacing of 7.5 miles of the north bound roadway paralleling the old concrete pavement. Grading was started in 1958, bituminous stabilization in June, 1959 and surfacing was completed in October, 1959.

The project lies in the Anoka County dune sand area and traverses a number of swamps. Embankments were constructed with sand from adjacent cuts and borrow pits, and the upper 4 inches of the sand subgrade was stabilized by mixing in place with asphalt emulsion. This was covered with 6 inches of plant mixed sand emulsion base and 4.5 inches of plant mixed aggregate-asphalt surfacing mixtures, making a total of 14.5 inches of bituminous treatment.

The primary objective of this study was to evaluate the asphalt emulsion stabilization, both of the subgrade and the 6-inch base. This was accomplished through observations, measurements and tests during and after construction. This progress report includes the data and information collected during the 1959 construction period and during the following year to October, 1960.

GENERAL SUMMATION

The construction of this project was accomplished successfully, but not without certain problems and frustrations centering around the placement and character of the emulsion stabilized sand materials.
The sand and emulsion were mixed with ease both on the road and in
the plant. The dilute SS-1 was readily mixed into the subgrade to a depth
of 4 inches with rotary mixers. And, even though the mixing plant could
not suitably disperse RS-2 emulsion into the sand, it had no trouble pro-
ducing uniform mixtures with MS-2 and SS-1 emulsions. These mixtures were
readily compacted to maximum density by conventional pneumatic rollers.

The accurate placement of the stabilized subgrade and the stabilized
base to grade and crown using motor patrols proved to be very frustrating.
Three factors in particular seemed to be the major causes of concern:
(1) The patrol operators had difficulty visualizing the wide, non-symmetrical
section, (2) The mixed material was difficult to shape, and rolling seemed
to distort the section, (3) The character of the material, low shear re-
sistance and poor re-bonding properties, made it practically impossible
to reshape the base without creating numerous compaction planes which
failed quite readily under load.

After trying several procedures, it was considered necessary to set
blue tops every 50 feet on centerline and on the shoulder lines to control
the crown and grade of the base. Had this practice been used on the stabil-
ized subgrade and the first layer of base, the variations in base thickness
would have been minimized. However, even with this control, further crown
and grade corrections were necessary in the next layer, 2331 hot plant-
mixed base.

Curing of the emulsion stabilized subgrade and base was important to
the strength of these layers. The 4-inch subgrade stabilization cured
quite rapidly, although this layer gained strength for about 6 weeks accord-
ing to plate bearing tests. The material for the first 3-inch layer of
base was hauled over the stabilized subgrade after 8 days of curing, with-
out causing damage. Curing of the base, which contained more emulsion,
was slower and followed a typical pattern over the project. On each layer, a dry, hard, top crust formed in a matter of a couple days which retarded curing of the underlying material. In addition, the upper layer of base reduced the rate of curing in the lower 3-inch layer. Plate bearing tests showed the base to be gaining strength over a period of 3 months. Fortunately, work progressed slowly enough to permit adequate curing of these layers before placement of subsequent layers. Depending on the weather, it was estimated that about 14 days were required for sufficient curing of the 6-inch base to support construction traffic as disclosed by observations and Benkelman beam tests.

In addition to evaluating curing, the Benkelman beam test detected laminations in the upper emulsion stabilized base due to compaction planes and revealed an unexpected softness in the 2331 base. This test also measured the relative strength of the new construction as compared to other roads in the area on the basis of deflection under a 9,000-pound wheel load. For example, deflections on the completed project were .017 to .020 inch as compared to .014 to .017 inch on T.H. 100 west of T.H. 56, indicating a slightly weaker but comparable structure.

The plate bearing tests not only measured curing but were valuable in showing the surcharge effect. The untreated embankment sand, as restrained by the surcharge effect of the overlying material, ultimately had as much supporting capacity as the stabilized layers. This brings up the question of the minimum surcharge thickness needed to develop the full strength of the untreated sand embankment. The plate bearing tests indicate that more than the minimum thickness was provided on this project. By increasing the asphalt content and thickness of the subgrade stabilization, it is possible that the 6-inch plant mixed stabilized base could have been eliminated without sacrificing bearing capacity. The project to the north was designed
along these lines with 6 inches of subgrade stabilization and similar surface courses. This design is estimated to cost $14,000 per mile less than the design used on the project under study.

The loss of strength due to frost action was also determined by the plate bearing tests. In the spring of 1960, the bearing value was 47 percent of that determined the previous fall. However, the spring axle load capacity was 11 tons, adequate for unrestricted traffic.

Detailed cross sections of the wearing course have detected a slight amount of distortion in the wheel tracks which occurred during the summer of 1960. Future measurements will be needed to confirm this indicated possible instability in the road structure.

It is planned to continue tests and observations over a period of several years which will permit a more complete evaluation of the project.

DESIGN AND COST OF THE PROJECT

Since this project is in an area where the natural soils are predominantly sand, it was designed with flexible pavement, utilizing the locally available sand for base through stabilization with asphalt emulsion.

The emulsion stabilization was provided in two phases. The first was an in-place treatment of the sand subgrade to a depth of 4 inches with two gallons per square yard of a dilute solution of asphalt emulsion consisting of 30 percent SS-1 and 70 percent water. The second phase was a 6-inch, plant mixed, sand-emulsion base containing 6 percent SS-1 and sand from a local borrow pit.

The surface course structure, consisting of hot plant mixed aggregate-asphalt mixture, was designed in three layers; 1 1/2 inches of 2331 bituminous base, 2 inches of 2341 binder course and 1 inch of 2341 wearing course.

The above items, along with the shoulder details and dimensions, are shown on the typical section in Figure 1.
Figure 1. Typical design section
The cost of the stabilized layers and the surface course structure are itemized in Table I. These cost figures are based on actual job quantities (shoulder to shoulder exclusive of entrances and crossovers) and the bid prices. The total cost per mile on this basis was $52,176.

**TABLE I**

**CONSTRUCTION COSTS**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost Per Sq. Yd.</th>
<th>Cost Per Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wearing Course</td>
<td>$0.30</td>
<td>$4,240</td>
</tr>
<tr>
<td>Binder Course</td>
<td>0.47</td>
<td>6,674</td>
</tr>
<tr>
<td>Bituminous Base</td>
<td>0.36</td>
<td>8,340</td>
</tr>
<tr>
<td>Shoulders (incl. seal)</td>
<td>0.70</td>
<td>5,760</td>
</tr>
<tr>
<td>Bit. Stab. Base</td>
<td>0.90*</td>
<td>21,203*</td>
</tr>
<tr>
<td>Subgrade Stabilization</td>
<td>0.23*</td>
<td>5,959*</td>
</tr>
</tbody>
</table>

Total Cost Per Mile $52,176

*These items adjusted for unbalanced bid.

The entire project was constructed at a total cost of $762,796. This would be an average of $101,706 per mile, which is almost double the cost of the stabilization and surfacing items listed in Table I.
SUBGRADE STABILIZATION

Grading construction was begun on this project in 1958 and was completed to the extent that subgrade stabilization could begin on June 16, 1959.

Just prior to stabilization, the sand subgrade was shaped to blue tops set at centerline and at the shoulder lines. The subgrade was compacted to at least 100 percent of standard maximum density and was quite firm except in a few local areas. The gradation of the sand was very similar to that shown in Table 2 for the stabilized base.

Subgrade stabilization started on the south end of the project (Sta. 358+50) and proceeded in a northerly direction. It was completed, except for two bridge approaches at Sta. 730, on July 14, 1959.

Basically, this work consisted of applying two gallons per square yard of diluted asphalt emulsion (30 percent SS-1 and 70 percent water) to the subgrade with a distributor, mixing it to a depth of 4 inches with rotary mixers, compacting it with pneumatic tired rollers and shaping the surface with a motor patrol. It took two to three passes of the distributor to apply the dilute emulsion, and mixing followed each pass. In some areas, additional water was added to bring the moisture content near optimum. In two areas, only half the width of the road was stabilized at one time.

South of Sta. 379 the surface was rolled after the last mixing pass, and only light blading was used to shape the grade to section. North of Sta. 379 the motor patrol worked up a small windrow after mixing which was relaid as compaction progressed. Grade checks during the early stages of this work showed that a satisfactory section was being obtained, so centerline blue tops were not re-set.
After shaping and compaction, the stabilized subgrade was given a light fog application of about 0.07 gallon per square yard of the dilute emulsion. This was adequate to prevent serious raveling under subsequent hauling of the plant mixed stabilized base.

Field control densities ranged from 111 to 129pcf or from 100 to 115 percent relative density. Moisture contents varied from about 4 to 12 percent or from 39 to 99 percent relative moisture. Measurements made at the time of the density tests showed the thickness of the stabilized layer to be from 3.5 to 5.0 inches.

PLANT MIXED STABILIZED BASE

The stabilized base material consisted of a mixture of sand from a local borrow pit and asphalt emulsion. These materials were mixed in a central plant and hauled to the road in trucks. A typical gradation of the sand is shown in Table 2. The sand stockpile and plant setup in the borrow pit area are shown in Figure 2.

TABLE 2

TYPICAL GRADATION OF SAND FOR PLANT MIXED STABILIZED BASE

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 10</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>99</td>
</tr>
<tr>
<td>40</td>
<td>97</td>
</tr>
<tr>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>100</td>
<td>21</td>
</tr>
<tr>
<td>200</td>
<td>6</td>
</tr>
</tbody>
</table>
Figure 2. Setup for production of plant mixed sand-emulsion base material.
The 6-inch base was constructed in two 3-inch layers. In general, the material for a layer was end-dumped on the road, blade spread and compacted with pneumatic rollers. The emulsion content was held at about 6 percent; except that between the beginning of the project at Sta. 358+50 and Sta. 607 the first layer of base had about 4.6 percent emulsion; and except that in the areas where the three grades of emulsion were used experimentally the emulsion content was about 5 percent. The moisture content at the time of mixing was 9 to 10 percent which amounted to approximately 90 percent of optimum.

THREE GRADERS OF EMULSION TRIED

The special provisions required that, of the first 50,000 gallons of emulsion, at least 10,000 gallons of each of the following grades be used: SS-1, MS-2 and RS-2. Thereafter, the contractor could elect to use any one of the three grades for the remainder of the project.

The SS-1 and MS-2 mixtures were quite similar and appeared to produce a suitable base. The RS-2 emulsion did not mix well with the sand resulting in rich sand-asphalt "pancakes" interspersed in a relatively uncoated sand matrix. This produced an unstable base which was later remixed with additional SS-1. The surface textures of these compacted bases are shown in Figure 3. The emulsion content was about 5 percent in each.

A series of moisture-density and field density tests were performed on the three base mixtures. Maximum densities and optimum moistures were determined in the laboratory on samples from the windrowed mixtures. Field density tests were performed with a special 7-inch diameter cone by the sand method. Moisture contents represent the loss when the samples of mixture were dried to constant weight at 230 F and do not include the residual asphalt.
Figure 3. Surface appearance of compacted bases.
The results of these tests are shown in Table 3. The MS-2 mixture had a slightly higher maximum density, otherwise the data were quite similar. It was interesting to note that the RS-2 section had adequate field densities despite its poor appearance and relatively unstable condition. Thickness of the layers ranged from 2 7/8 to 4 7/8 inches, a considerable deviation from the theoretical 3 inches.

After completion of the trial sections, the contractor used SS-1 emulsion to construct the remaining base.

FIRST LAYER OF BASE

Construction of the first 3-inch layer of plant mixed stabilized base started on June 30 and was completed July 24, 1959 (except for the bridge approaches). This layer was successfully placed over stabilized subgrade which varied in age from 8 to 14 days.

The field density tests showed the first layer of base to have an average relative density of 108 percent of standard maximum density, with values ranging from 97 to 114 percent.

Observations of the curing of the first layer of base showed that a 1/8 to 1/4-inch top crust formed within a relatively short time, a matter of a couple days or slightly longer depending on the weather. This crust and the underlying stabilized subgrade tended to seal the moisture in the remaining portions of the base layer and retarded curing. Moisture samples taken on July 15 showed that the upper crust, some of which was 1/2 inch thick by this time, had less than 0.9 percent moisture (0.55 percent average) at ages of 5 days or more, and moisture contents of 1.7 percent or less at ages of 1 day to 5 days. Compared to this, the material below the crust had moisture contents ranging from 1 to 4.5 percent at ages of 9 days or older, and 5 to 9 percent where the base had been in place less than 9 days.
<table>
<thead>
<tr>
<th>Emulsion Grade</th>
<th>Station</th>
<th>Location</th>
<th>Age Days</th>
<th>Maximum Density pcf</th>
<th>Optimum Moisture %</th>
<th>Field Density pcf</th>
<th>Field Moisture %</th>
<th>Relative Density %</th>
<th>Layer Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS-1</td>
<td>371+60</td>
<td>10' Rt.</td>
<td>3</td>
<td>107.9</td>
<td>12.3</td>
<td>107.2</td>
<td>3.1</td>
<td>99.4</td>
<td>3&quot;</td>
</tr>
<tr>
<td>SS-1</td>
<td>371+60</td>
<td>10' Lt.</td>
<td>3</td>
<td>&quot;</td>
<td>&quot;</td>
<td>116.4</td>
<td>3.4</td>
<td>107.9</td>
<td>3 1/8</td>
</tr>
<tr>
<td>SS-1</td>
<td>383+90</td>
<td>8' Lt.</td>
<td>2</td>
<td>&quot;</td>
<td>&quot;</td>
<td>102.5*</td>
<td>4.2</td>
<td>95.0*</td>
<td>2 7/8</td>
</tr>
<tr>
<td>SS-1</td>
<td>383+90</td>
<td>10' Rt.</td>
<td>2</td>
<td>&quot;</td>
<td>&quot;</td>
<td>112.4</td>
<td>4.7</td>
<td>104.2</td>
<td>4 1/2</td>
</tr>
<tr>
<td>RS-2</td>
<td>389+25</td>
<td>7' Rt.</td>
<td>2</td>
<td>107.4</td>
<td>12.3</td>
<td>108.8</td>
<td>3.7</td>
<td>101.3</td>
<td>3</td>
</tr>
<tr>
<td>RS-2</td>
<td>389+25</td>
<td>7' Lt.</td>
<td>2</td>
<td>&quot;</td>
<td>&quot;</td>
<td>123.0*</td>
<td>3.9</td>
<td>114.5*</td>
<td>3 1/8</td>
</tr>
<tr>
<td>RS-2</td>
<td>395+70</td>
<td>12' Lt.</td>
<td>2</td>
<td>&quot;</td>
<td>&quot;</td>
<td>107.4</td>
<td>4.1</td>
<td>100.0</td>
<td>3 5/8</td>
</tr>
<tr>
<td>RS-2</td>
<td>395+70</td>
<td>10' Rt.</td>
<td>2</td>
<td>&quot;</td>
<td>&quot;</td>
<td>108.4</td>
<td>4.8</td>
<td>100.9</td>
<td>4 7/8</td>
</tr>
<tr>
<td>MS-2</td>
<td>403+90</td>
<td>10' Lt.</td>
<td>1</td>
<td>109.0</td>
<td>11.8</td>
<td>114.4</td>
<td>4.4</td>
<td>105.0</td>
<td>2 7/8</td>
</tr>
<tr>
<td>MS-2</td>
<td>403+90</td>
<td>7' Rt.</td>
<td>1</td>
<td>&quot;</td>
<td>&quot;</td>
<td>115.5</td>
<td>4.2</td>
<td>106.0</td>
<td>3 5/8</td>
</tr>
<tr>
<td>MS-2</td>
<td>409+50</td>
<td>9' Lt.</td>
<td>1</td>
<td>&quot;</td>
<td>&quot;</td>
<td>106.5</td>
<td>3.9</td>
<td>97.7</td>
<td>2 7/8</td>
</tr>
<tr>
<td>MS-2</td>
<td>409+50</td>
<td>10' Lt.</td>
<td>1</td>
<td>&quot;</td>
<td>&quot;</td>
<td>112.3</td>
<td>4.7</td>
<td>103.0</td>
<td>3 1/4</td>
</tr>
</tbody>
</table>

* Appears to be unusual densities - values questionable
Additional moisture tests, taken on July 27 on the first layer of base which had been in place from 4 days to 18 days, showed the upper 1-inch crust to have less than 0.8 percent moisture and the underlying layer from 2.7 to 5.5 percent moisture. The moist uncured material was soft and mealy. These data show the general trend of moisture contents and curing in the first layer of base, the variations being associated with the weather.

SECOND LAYER OF BASE

Construction of the second 3-inch layer of base was begun on the south end of the project on July 15 and was completed on August 5, 1959. The age of the lower layer ranged from 10 to 18 days at this time.

Placement of this layer proceeded in the usual manner until grade checks in the first mile showed variances of plus and minus 0.33 foot from true grade and cross section. Several procedures were attempted to correct the variations; grades were painted on the base, string-lining, and finally blue tops every 50 feet. The latter seemed to produce the best results, but the blade men had difficulty visualizing the grade and the non-symmetrical section. The base material was very difficult to shape, and rolling seemed to distort the section.

The portion of the second layer of base south of Sta. 432 was relaid one or more times in an attempt to improve the section. From Sta. 432 to Sta. 585, other smaller portions were similarly relaid, and the upper base was shaven with the motor patrol in an attempt to establish true crown and grade. This work proved only partially successful as evidenced by thickness measurements and cross sections which are discussed in a later section of this report.

Reworking the base produced a number of compaction planes. Many of these were evident and were removed immediately. Others did not show up until the next layer of 2331 base was placed. However, it was apparent that
reworking the base was generally creating an undesirable condition, so it was discontinued in favor of setting blue tops every 50 feet for the remaining upper layer. The extent of the distress due to compaction planes is discussed more fully in conjunction with the construction of the 2331 base later in this report.

The second layer of base was compacted to an average density of 105 percent of standard maximum density according to the field density tests. The range in relative densities varied from 100 to 110 percent.

Moisture tests made on July 27 on the second layer of base, which had been in place for 6 to 12 days, showed the upper \( \frac{1}{4} \)-inch crust to have moisture contents of 0.3 to 1.8 percent and the underlying material to have moisture contents of 0.4 to 6.4 percent. Generally, only the crust was fully cured at this time.

**GENERAL DENSITY AND CURING DATA**

Beginning August 10, five days after completion of the second layer of base, a series of moisture and density tests was made in each layer of the road structure at the five plate bearing test locations. These data are shown in Table 4.

At this time, the upper layer of base was 12 to 20 days old, and it was generally cured to its full depth at these locations. At Sta. 621+00 there appeared to be a slight hardness differential between the upper and lower portions of the layer. However, moisture contents ranged from 0.5 to 1.6 percent indicating a dried out and cured condition at this location.

In contrast, the lower 3 inches of base (first layer) had moisture contents ranging from 0.7 percent in the crust to 5.9 percent overall, indicating a less cured condition. However, the bottom portions of this lower layer of base were much firmer than previously observed, being sort of
### TABLE 4

**MOISTURE AND DENSITY TESTS**

Aug. 10-13, 1959

<table>
<thead>
<tr>
<th>STATION</th>
<th>BITUMINOUS BASE</th>
<th>SUBGRADE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2nd Layer</td>
<td>1st Layer</td>
</tr>
<tr>
<td>465+42</td>
<td>Den. (pcf)</td>
<td>112.9</td>
</tr>
<tr>
<td></td>
<td>Moist. (%)</td>
<td>0.6</td>
</tr>
<tr>
<td>490+00</td>
<td>Den.</td>
<td>116.7</td>
</tr>
<tr>
<td></td>
<td>Moist.</td>
<td>1.2</td>
</tr>
<tr>
<td>527+00</td>
<td>Den.</td>
<td>113.0</td>
</tr>
<tr>
<td></td>
<td>Moist.</td>
<td>0.5</td>
</tr>
<tr>
<td>572+00</td>
<td>Den.</td>
<td>106.2*</td>
</tr>
<tr>
<td></td>
<td>Moist.</td>
<td>0.7</td>
</tr>
<tr>
<td>621+00</td>
<td>Den.</td>
<td>112.8</td>
</tr>
<tr>
<td></td>
<td>Moist.</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Den.</td>
<td>112.9</td>
</tr>
<tr>
<td></td>
<td>Moist.</td>
<td>1.6</td>
</tr>
</tbody>
</table>

*Appears to be unusually low density - value is questionable.*
crisp feeling as opposed to soft or mealy, indicating that a certain amount of curing had taken place in the 27 or more days since it was placed. Figure 4 shows density and moisture tests in progress.

Curing of the upper and lower layers of base was also observed at a considerable number of places in connection with thickness measurements. These observations were made August 12-17 at 10 locations scattered over the project. At each location borings were made at centerline, 6 feet and 12 feet right and left, and at the shoulder lines for five consecutive stations, making a total of 350 observations. This information on curing can be summarized as follows:

**Upper Layer of Base**

The upper layer of base was almost entirely cured for its full depth, except at scattered points, from the beginning of the project to approximately Sta. 705. In this area the upper layer of base was 16 to 28 days old.

Beyond approximately Sta. 705, nearly all the borings showed a 1 to 2-inch top crust with looser and more moist material below. This section of upper base was 12 to 13 days old at the time these observations were made. The Benkelman Beam tests, performed about a week earlier, also showed this area to be inadequately cured.

**Lower Layer of Base**

There was a 1 to 2-inch crust on the lower layer of the base generally over the entire project. The underlying material was less firm than the crust, but showed some stability or curing in that it had a crisp feel when scraped. It was grey as compared to the brownish-black color of the crusted layer. The lower layer of base was 24 to 43 days old when these observations were made.
Figure 4. Density and moisture tests in the 6-inch plant mixed stabilized base
The observations point out the need for curing a sand-emulsion base mixture. Obviously, the compacted base cured slowly on this project. Fortunately construction proceeded in such a manner that the base had time to cure enough to support construction loads without damage. However, had construction proceeded at a more rapid rate, there may have been delays due to uncured base.

CROSS SECTION AND THICKNESS

Crown checks and thickness measurements taken during the construction of the stabilized base showed variations from the planned section which indicated that a more thorough study should be made of these features.

Reviewing the construction, the sand subgrade was finished to blue tops set at centerline and the shoulder lines. The subgrade stabilization was performed, and the section was shaped by motor patrol. Crown checks taken during the early stages of this work indicated that a satisfactory section was being obtained, and no centerline blue tops were reset. The first 3-inch layer of plant mixed stabilized base was hauled to the road and laid by motor patrol. The second 3-inch layer of base was similarly placed and shaped. However, crown checks showed a distorted section at this time. Considerable reshaping was done on the south end of the project, and extra effort was made to get the proper section and grade on the remainder of the base. However, these efforts were only partially successful.

Beginning on July 20, after the upper base had been relaid on the south end of the project and continuing on to the completion of the upper base, thickness measurements were made at intervals of 500 feet or less over the entire project. The thicknesses of the first layer and the second layer of base were determined at centerline and at 12 feet right and left. These values and the total thickness of the base are shown in Table 5. The
extremes for the layers range from 1.25 to 4.75 inches, whereas the averages range from 2.66 to 3.39 inches, with the overall thickness of both layers averaging 6.28 inches.

TABLE 5
BASE THICKNESS

<table>
<thead>
<tr>
<th>Layer</th>
<th>12 ft. Left</th>
<th>Centerline</th>
<th>12 ft. Right</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top</td>
<td>Bot.</td>
<td>Total</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.75</td>
<td>2.00</td>
<td>4.75</td>
</tr>
<tr>
<td>Maximum</td>
<td>4.50</td>
<td>4.75</td>
<td>9.25</td>
</tr>
<tr>
<td>Average</td>
<td>3.18</td>
<td>3.18</td>
<td>6.35</td>
</tr>
</tbody>
</table>

Overall average total thickness = 6.28 inches

Between August 12 and 17, additional thickness measurements, along with cross sections, were taken at ten locations scattered over the project. At each location, elevations were determined and borings were made at five consecutive stations at points located at centerline, 6 and 12 feet right and left, and at the shoulder lines, making a total of 350 points. It was thought that by averaging the measurements for the five stations at a location, the localized variations would be compensated for, and a truer evaluation of the section and the thickness of the base could be made. The results of the thickness evaluation are summarized in Table 6 where the maximum, minimum and average thicknesses are shown for the base layers. Each maximum and minimum value is an average of five consecutive stations.

The data in Table 4 is probably more representative and presents a clearer picture of the thickness pattern than that in Table 3. The section
averages show that the lower or first layer of base was thicker than the second layer, 3.23 inches as compared to 2.92 inches. The layer averages show that both layers of base are thicker on centerline, and that the upper base is considerably thicker on the left than on the right. This could indicate that the crown point was flat after the subgrade was stabilized and that the left side was low or the right side high. It is also probable that the crown point in the lower layer of base was slightly right of centerline. Some of these indications are borne out by the cross sections.

**TABLE 6**

**AVERAGE BASE THICKNESS**

<table>
<thead>
<tr>
<th>Section</th>
<th>Left 16'</th>
<th>Left 12'</th>
<th>Left 6'</th>
<th>Right 6'</th>
<th>Right 12'</th>
<th>Right 22'</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Layer:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>3.53</td>
<td>3.47</td>
<td>3.28</td>
<td>3.50</td>
<td>3.55</td>
<td>3.08</td>
<td>3.78</td>
</tr>
<tr>
<td>Minimum</td>
<td>2.42</td>
<td>2.68</td>
<td>2.60</td>
<td>2.13</td>
<td>1.87</td>
<td>1.87</td>
<td>2.14</td>
</tr>
<tr>
<td>Average</td>
<td>3.08</td>
<td>3.07</td>
<td>3.03</td>
<td>3.14</td>
<td>2.65</td>
<td>2.64</td>
<td>2.83</td>
</tr>
<tr>
<td>Bottom Layer:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>3.73</td>
<td>3.60</td>
<td>3.43</td>
<td>4.03</td>
<td>4.13</td>
<td>3.68</td>
<td>3.92</td>
</tr>
<tr>
<td>Minimum</td>
<td>2.53</td>
<td>2.58</td>
<td>2.70</td>
<td>2.80</td>
<td>2.73</td>
<td>2.65</td>
<td>2.78</td>
</tr>
<tr>
<td>Average</td>
<td>3.22</td>
<td>3.10</td>
<td>3.09</td>
<td>3.48</td>
<td>3.43</td>
<td>3.05</td>
<td>3.25</td>
</tr>
<tr>
<td>Total Base:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>7.05</td>
<td>6.67</td>
<td>6.60</td>
<td>7.32</td>
<td>6.58</td>
<td>6.76</td>
<td>6.78</td>
</tr>
<tr>
<td>Minimum</td>
<td>5.70</td>
<td>5.70</td>
<td>5.46</td>
<td>5.58</td>
<td>5.66</td>
<td>4.97</td>
<td>4.92</td>
</tr>
<tr>
<td>Average</td>
<td>6.30</td>
<td>6.17</td>
<td>6.12</td>
<td>6.52</td>
<td>6.08</td>
<td>5.69</td>
<td>6.08</td>
</tr>
</tbody>
</table>

Overall Average Thickness of the Base = 6.15 inches

Maximum and Minimum Values in the Table are Underlined.
The elevations taken on top of the base at the same stations as the borings permitted plotting cross sections of the layers. These generally show that the stabilized subgrade was shaped with curved crown resulting in a flattened shape at centerline. This was continued somewhat through the first layer of base which consequently showed the least thickness variation. The cross sections of the second layer show, in many cases, the attempts to correct to the straight sloping crown called for in the plans, which resulted in larger thickness variations.

From studying the cross sections, it appears that much of the cause for the variations in base thickness and crown goes back to the shape of the stabilized subgrade. Had this material been shaped to blue tops and the crown checked and controlled to a greater degree, it is quite probable that the base would have been more uniform and better shaped. It is also quite probable that this type of base material should be placed on the road by spreaders or laying machines rather than blade spread, particularly when being placed 38 to 40 feet wide and to an offset centerline. This procedure would also tend to minimize compaction planes which were in evidence on this project at a number of locations.

This study did not include a check on the conformance of the base to true grade. However, field records showed the top of the base to have average deviations of almost 0.1 foot from true grade with maximum deviations up to 0.31 foot. These measurements were made at centerline and 12 feet right and left.

THE SURFACING COURSES

For the purpose of this report, all the bituminous courses above the plant mixed stabilized base are included in this general category of surfacing courses. They include the 2331 bituminous base, the 2341 binder course
and the 234L wearing course. The aggregates for these mixtures were obtained
from the gravel deposit located in the area of the New Brighton Arsenal.
The asphaltic material was AC-1, 120 to 150 penetration, and all the mix-
tures were hot plant mixed according to the specifications.

PLANT MIXED BITUMINOUS BASE (233L)

Construction of this 1\(\frac{1}{2}\)\-inch base course 40 ft. wide started on August
17 and was completed on September 8, 1959. At this time the upper layer of
stabilized base was 22 days old or older.

The asphalt content of the mixture was approximately 3.5 percent.

Two problems of particular interest were involved in this work; (1) the
procedure to use to most effectively obtain a true crown and grade, and (2)
the determination of the need to remove areas showing rippling, cracking or
shoving due to slippage at compaction planes in the underlying stabilized
base. Both of these problems were solved through the diligent efforts of
the Project Engineer and his assistants and through the cooperation of the
contractor.

True Crown and Grade

South of Sta. 571, the plant mixed base was placed in one layer averag-
ing about 1\(\frac{1}{2}\) inches thick. The actual thickness was varied by adjustment
of the paver screws to produce the best crown and grade possible within the
ability of the inspectors and operators. The construction procedure was to
pave the outer lanes (11 feet on the right and 8.5 feet on the left) first,
checking the grade from the blue tops and using a bubble-board as a template
to check the crown. Then the two inner lanes (12 feet right and 8.5 feet
left) were paved using the previously laid material as a guide for grade line
and continuing to check the crown. This procedure required a great deal of
screed adjustment and it was felt that still better results could be obtained.
Consequently, a supplemental agreement was made which provided for placing the bituminous base in more than one layer. The idea was to adjust for crown and grade with a wedge course and then pave a more uniform layer over the top. Cross sections were taken every 50 feet at five points located at the edges of the paver passes, and a grade line was laid to best fit the profile of the road and allow for placement of a continuous correction wedge course averaging 1/2 to 3/4 inch thick. The amounts of fill to the top of the wedge course were painted on the road every 50 feet as a guide for the paver. The center 24 feet were paved first with every effort being made to meet the required thicknesses through adjustment of the paver screws. The outer lanes were similarly corrected, and then a uniform layer of about 3/4 to 1 inch was placed over the entire width of the road. This procedure was used between Sta. 571 and 583 and between Sta. 600 and the end of the project.

Between Sta. 583 and Sta. 600 the fills to the top of the entire 1 1/2-inch bituminous base were painted on the road. It was thought that possibly the correction and adequate thickness could be accomplished in one pass of the paver. However, this was not successful because of the difficulty of compacting mixture of such variable thickness.

Lastly, a correction wedge course was laid from the beginning of the project to Sta. 571 over the previously laid 1 1/2-inch base course. Thus, the entire project was covered with a correction course in one way or another.

The procedures used in constructing the bituminous base (2331) were found to be successful in bringing the crown and grade very close to the theoretical section. Only minor deviations could be measured, and no major difficulties were experienced in maintaining the crown and grade when placing the binder and wearing courses.


Effects of Compaction Planes

Early in the placement of the 2331 bituminous base, a considerable number of areas showed signs of rippling, cracking or actual shoving under the rolling. Between Sta. 358+50 and Sta. 592 there were 35 such areas, whereas north of Sta. 592 there was only one questionable area. It was in the southern portion of the project, south of Sta. 505, that most of the reworking of the upper layer of the emulsion base took place. This undoubtedly was responsible for a great deal of the observed distress.

The areas varied in size from only a few feet in length and width to areas 4 to 8 feet wide and 600 feet long. Oddly, most were located right of centerline which is the wide side. Probably the blade men had the most difficulty shaping this side.

Investigation of these areas disclosed movement or slippage at compaction plane s located 0.5 to 1.5 inches below the surface of the plant mixed emulsion base. In one case it appeared that the plane was at the top of the lower layer. In nearly all cases, there were uncoated sand particles at the plane of slippage. Whether these particles were brought in by the wind or the asphalt was stripped off by water applied for compaction is not known. However, it is significant to note their presence even though the compaction plane may be the prime cause of failure.

Figure 5 shows a typical area at Sta. 363+50 where the material above the compaction plane has been removed. The upper picture is a general view of the area which was 45 feet long and 5 to 6 feet wide. The center picture shows gouges into the lower base made by the front and loader used for removing the loose material. Subsequently, these areas were removed by hand. The lower picture shows a close-up of the layers. The compaction plane (where the stationing is written) lies about 1/2 to 1 inch below the top of the emulsion base which extends down to the end of the knife handle. The blade of the
Figure 5. Repair of bituminous stabilized base necessitated by slippage at compaction plane.
knife covers the stabilized subgrade, and untreated sand subgrade lies below the point of the knife blade. It is very likely that the slippage plane was at the top of the first 3-inch layer of plant mixed stabilized base at this location. The upper layer was so thin because of the numerous reworkings in this area.

Of the 36 questionable areas, 15 were shoving or badly cracked and were excavated and patched with 2331 base mixture or 2341 binder course mixture. The remaining rippled or slightly cracked sections showed no further distress when the leveling, binder and wearing courses were placed. It is assumed that they became stable when adequately confined by the upper layers. Many of the 15 treated areas were in the outer 4 to 5 feet of the right shoulder and were corrected when the 2-inch shoulder paving was placed.

**BINDER COURSE (2341)**

The 2-inch binder course was constructed between September 9 and September 21, 1959. The bitumen content was approximately 4.5 percent of AC-1 (120-150 penetration).

Very little difficulty was experienced in placing the binder course. Rough areas of the 2331 base were shaved with a motor patrol in an attempt to improve the surface upon which the binder course was to be laid. The blade tore into the base at one location, and this area had to be patched.

**WEARING COURSE (2341)**

The 1-inch wearing course mixture contained mineral filler, and the bitumen content was about 5.3 percent AC-1 (120-150 penetration). Some difficulties in the form of tearing, open texture and minor thickness variations were experienced during placement of the wearing course. These were attributed to the thinness of the layer and the cool weather, as they could not be eliminated by paver adjustment. The wearing course was placed during
the period from October 10 to October 20, 1959, and the road was opened to
traffic the next day.

Cross sections were developed at 50 stations for points at centerline
and 12 feet right and left to evaluate the grade and section of the finished
road. The average deviations were no greater than 0.02 foot from true crown
and 0.04 foot from true grade, with the maximum deviation from grade being
0.14 foot. The significance of these values can be more fully appreciated
when they are compared to the grade deviations of the underlying layers as
shown in Table 7. The reduction in maximum deviation from 1/3 foot to about
1/10 foot shows the desire and concerted cooperative effort of the construc-
tion and engineering personnel to build a good road.

TABLE 7
COMPARISON OF DEVIATIONS FROM TRUE GRADE

<table>
<thead>
<tr>
<th></th>
<th>Stab. Subgrade</th>
<th>Stab. Bit. Base</th>
<th>Wearing Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>0.33 0.30 0.32</td>
<td>0.31 0.26 0.26</td>
<td>0.14 0.10 0.12</td>
</tr>
<tr>
<td>Minimum</td>
<td>0 0 0.01</td>
<td>0 0 0</td>
<td>0 0 0</td>
</tr>
<tr>
<td>Average</td>
<td>0.09 0.06 0.11</td>
<td>0.10 0.08 0.09</td>
<td>0.04 0.03 0.03</td>
</tr>
</tbody>
</table>

The roughness of the binder and wearing courses was determined with
the Road Roughness Recorder. On September 30, 1959, the binder course had
an average roughness index of ¼ inches per mile. On October 20, the wear-
ing course had an average index of ¾ inches per mile, an improvement of
ten points over the binder course and a very low roughness value. Apparently
the open surface texture of the wearing course was not of the nature to cause roughness.

BENKELMAN BEAM DEFLECTION TESTS

The Benkelman Beam is used to measure deflection of the road surface caused by the slowly moving dual tires of a loaded truck. On this project, the truck was loaded to produce 9,000-pound wheel loads on the rear axle, and two beams were used. Figure 6 shows the beams in starting position with the probes extending through the dual wheels to a point about 5 feet in front of the tires, and in the final position after the truck has moved ahead. The initial dial readings are made, the truck pulls ahead at "creep" speed, the dials are read at maximum deflection when the wheels pass the probe, and, after the truck pulls ahead and the road rebounds, the final dial readings are made. From these measurements, the maximum and final residual deflections of the road surface are calculated. The deflections are a source of information about the strength and characteristics of the road structure.

Benkelman Beam tests were made at three different times on this project. On August 10-11 the tests were made on top of the second layer of bituminous stabilized base. On August 31 tests were made on the 2231 bituminous base and also on a portion of the bituminous stabilized base near the end of the project. And, on July 6, 1960, tests were made on the wearing course. Each of these sets of tests will be discussed separately.

Sixteen test locations were selected on the project. At each, 200 to 500 feet of road was tested at 50-foot intervals. For comparison, deflections were measured on a bituminous surfaced side road adjacent to the beginning of the project and on T.H. 100 west of T.H. 56. All deflection values were measured in thousandths of an inch.
Benkelman beams in starting position.

Taking final dial readings after truck has moved ahead.

Figure 6. Making Benkelman beam tests on the bituminous stabilized base.
DEFLECTION OF THE STABILIZED BASE

The maximum and residual deflections varied greatly for the tests made on top of the bituminous stabilized base. Much of this variation was due to the base squeezing up between the truck tires, and the uncured condition of portions of the base. The data can be evaluated best by dividing the project into sections.

Between the beginning of the project (Sta. 358+50) and approximately Sta. 445, four areas were tested. The average maximum deflections ranged from .006 to .028 with individual readings ranging from .002 to .040. Residual deflections averaged from -.002 to -.028, minus indicating that the road surface at the probe (between the tires) was higher after the test. Nearly always, the low maximum deflections were associated with high negative residual deflections, indicating that the base was being squeezed up between the tires almost as much as the total structure was being depressed by the load. Observations of the base showed it to be quite well cured through this area, but also disclosed a definitely laminated structure with horizontal planes of poor bond scattered through the upper portion of the base, undoubtedly a result of reworking the base. The poorly bonded material sheared under the wheel load and caused the upheaval between the tires.

Between Sta. 445 and 625 (approximate) the base carried the test load without significant squeezing up between the tires. Average maximum deflections on eight areas ranged from .022 to .032, and residual deflections averaged from .000 to .004. It is believed that these values gave a relatively true strength evaluation of the road structure which could be compared to the deflections on the side road and T.H. 100. Maximum deflections averaged .016 on T.H. 100 and .025 on the side road. The deflections on the stabilized base compare favorably with these values. The base was 13 to 21 days old at this time.
Between approximately Sta. 625 and 705, a weaker transition zone was indicated by variable deflections. Maximum deflections averaged from .000 to .032 and residual deflections from .002 to -.024. Here the upper base was 11 to 13 days old and the lower 3 inches was 21 to 26 days old. Apparently this section of road was in various stages of curing with many areas still soft and yielding.

Beyond Sta. 705 to the end of the project at Sta. 753, a noticeably weak condition was evidenced by the base squeezing up between the truck tires. Average maximum deflections ranged from .004 to .008 and residual deflections averaged from -.032 to -.060 showing how the base was being displaced. This weakness was general at all test sites, and further examination indicated that the weakness was due to moist uncured layers in the stabilized base. At this time (August 11), the upper 3 inches of the base was 6 to 7 days old and the lower base was 18 to 19 days old. It was doubtful whether the next layer of plant mixed base could have been placed successfully on this section under these conditions. However, it was some time later before these operations reached this area.

Benkelman Beam tests were repeated on August 31 on the stabilized base north of Sta. 619 just before the 1½-inch plant mixed base was placed. At this time the maximum deflections averaged .026 to .032 and the residual deflections averaged .000 to .006 with only a very few individual readings showing slight squeezing up between the tires. These deflections reflect a well cured base and are about the same as the data previously obtained between Sta. 445 and 625. The upper base was 26 to 27 days old at this time as compared to 13 to 21 days when the tests were made between Sta. 445 and 625.

Considering all the deflection data, it seems that a period of at least two weeks was required after placement of the upper layer to achieve satisfactory curing of the 6-inch bituminous stabilized base.
DEFLECTION OF THE PLANT MIXED BASE (2331).

On August 31, Benkelman Beam tests were made on the 1\(\frac{1}{2}\)-inch 2331 base at eleven locations between the beginning of the project and Sta. 575. This layer varied in age from 14 days to freshly laid, and the results of the tests were most disappointing. Practically every test showed squeezing up between the tires, the residual deflections being as much as -.048 and averaging about -.010. Obviously the maximum deflections were of no value under these circumstances. It seemed odd that 2331 hot plant mixed material with only 3.5 percent asphalt (120-150 penetration) would be so yielding at ages up to 14 days. However, there is no background information on other fresh mixtures for comparison.

DEFLECTION OF THE FINISHED ROAD

Deflection tests on top of the finished wearing course were postponed until July 1960, due to the lack of time to take them in the fall of 1959 and to permit the road to recover from the loss of strength caused by frost action in the spring. At this time there were only a few points showing squeezing up between the truck tires, except at the extreme north end of the project where quite a few points in the outer wheel track showed upheaval amounting to .002. However, the results of the tests were quite satisfactory, and they are shown in Table 8.

At this same time (July, 1960) the side road near the beginning of the project and T.H. 100 west of T.H. 56 were also tested. The comparison between the average maximum deflections and average residual deflections for these two roads and the newly constructed NBL of T.H. 65 are shown in Table 9. The road covered in this report (T.H. 65) shows considerably less deflection than the side road, but only slightly more than T.H. 100. These values are an indication of the relative strengths of the roads, the smaller the deflections the stronger the road.

-33-
### TABLE 8
BENKELMAN BEAM DEFLECTIONS ON THE FINISHED ROAD

<table>
<thead>
<tr>
<th></th>
<th>Maximum Deflection</th>
<th>Residual Deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IWT*</td>
<td>OWT*</td>
</tr>
<tr>
<td>Maximum</td>
<td>.024</td>
<td>.028</td>
</tr>
<tr>
<td>Minimum</td>
<td>.010</td>
<td>.012</td>
</tr>
<tr>
<td>Average</td>
<td>.017</td>
<td>.020</td>
</tr>
</tbody>
</table>

*IWT = Inner Wheel Track; OWT = Outer Wheel Track

### TABLE 9
COMPARISON OF DEFLECTIONS OF THREE ROADS

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IWT</td>
<td>OWT</td>
</tr>
<tr>
<td>T.H. 65</td>
<td>.017</td>
<td>.020</td>
</tr>
<tr>
<td>Side Road</td>
<td>.026</td>
<td>.035</td>
</tr>
<tr>
<td>T.H. 100</td>
<td>.014</td>
<td>.017</td>
</tr>
</tbody>
</table>

Another significant fact pointed out by the deflection tests is that the outer wheel track is weaker (deflects more under load) than the inner wheel track. This has been known for sometime and is borne out by the visual failures or distress which occur first in the outer wheel track of roads. The Benkelman Beam deflections provide a relative measure of this difference in strength.
Plate bearing tests, using both the 6 and 12-inch plates, were performed a number of times on various layers of the subgrade, base and surfacing. The first tests were made on the untreated sand subgrade in June of 1959 and the last tests were made on the completed surface in June of 1960, covering a span of just one year and involving 211 individual tests. The equipment used for making plate tests is shown in Figure 7.

Five test sections were selected over the project. Each section had three test points spaced at approximately 100-foot intervals, making a total of 15 test points. Whenever possible, plate tests were made at all 15 test points, but sometimes only one point was tested in each of the five sections. Tests were made on underlying layers by making excavations just adequate to accommodate the plates. This made it possible to observe the surcharge effect as well as the effect of extended curing on the strength of the road.

The plate test data are summarized in Table 10. The first group of bearing values shows the average strength of the untreated sand in relation to the stabilized subgrade and also the increase in strength with the age (curing) of the stabilized material.

The untreated sand subgrade approximately doubled in strength due to the surcharge effect. The maximum bearing values (646 and 348 psi) for the two plate sizes (6 and 12-inch) were obtained with a surcharge of 10 inches which included 4 inches of stabilized subgrade and 6 inches of stabilized base. There was no increase in bearing due to the additional 4.5 inches of surfacing courses as shown by the tests on the untreated subgrade in November. Thus it might be concluded that more surcharge was provided on this project than needed to develop the full strength of the sand subgrade.
Figure 7. Plate bearing test equipment.
TABLE 10
AVERAGE PLATE BEARING TEST VALUES

<table>
<thead>
<tr>
<th>Condition Age or Date</th>
<th>PSI on 6&quot; Plate</th>
<th></th>
<th>PSI on 12&quot; Plate</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PSI on 6&quot; Plate</td>
<td>PSI on 12&quot; Plate</td>
<td>PSI on 6&quot; Plate</td>
<td>PSI on 12&quot; Plate</td>
</tr>
<tr>
<td></td>
<td>Subgrade Base Surface</td>
<td>Subgrade Base Surface</td>
<td>Subgrade Base Surface</td>
<td></td>
</tr>
<tr>
<td>Prior to Stab.</td>
<td>262</td>
<td>193</td>
<td>222</td>
<td>201</td>
</tr>
<tr>
<td>2 to 6 Days</td>
<td>222</td>
<td>266</td>
<td>393</td>
<td>266</td>
</tr>
<tr>
<td>9 to 10 Days</td>
<td>393</td>
<td>348*</td>
<td>646*</td>
<td>357*</td>
</tr>
<tr>
<td>42 to 49 Days</td>
<td>646*</td>
<td>348*</td>
<td>600*</td>
<td>357*</td>
</tr>
<tr>
<td>5 to 14 Days</td>
<td>265</td>
<td>248</td>
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<td>248</td>
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<tr>
<td>15 to 21 Days</td>
<td>304</td>
<td>277</td>
<td>304</td>
<td>277</td>
</tr>
<tr>
<td>30 to 36 Days</td>
<td>419*</td>
<td>313*</td>
<td>419*</td>
<td>313*</td>
</tr>
<tr>
<td>Nov., 1959</td>
<td>570*</td>
<td>596*</td>
<td>732</td>
<td>330*</td>
</tr>
<tr>
<td></td>
<td>622*</td>
<td>333*</td>
<td>732</td>
<td>333*</td>
</tr>
<tr>
<td></td>
<td>596*</td>
<td>330*</td>
<td>732</td>
<td>333*</td>
</tr>
<tr>
<td></td>
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<td>330*</td>
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<td>333*</td>
</tr>
<tr>
<td></td>
<td>596*</td>
<td>333*</td>
<td>732</td>
<td>333*</td>
</tr>
<tr>
<td></td>
<td>732</td>
<td>330*</td>
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<td></td>
<td>330*</td>
<td>732</td>
<td>333*</td>
<td>333*</td>
</tr>
<tr>
<td>April, 1960</td>
<td>(47% of the Nov. '59 Value) 173</td>
<td>247</td>
<td>(47% of the Nov. '59 Value) 173</td>
<td>247</td>
</tr>
<tr>
<td>June, 1960</td>
<td>283(67% of the Nov. '59 Value) 247</td>
<td>283(67% of the Nov. '59 Value) 247</td>
<td>283(67% of the Nov. '59 Value) 247</td>
<td></td>
</tr>
</tbody>
</table>

Tests made through overlying layers

Tests on the stabilized subgrade at various ages up to 49 days show progressively higher bearing values, reaching maximums of 600 and 357 for the two plate sizes at 42 to 49 days. These values are nearly equal to those on the raw sand subgrade, indicating that the incorporation of the bituminous material, though beneficial in other respects, did not increase the final bearing values on this project. The maximum bearing values stated above included the surcharge effect of the 6-inch stabilized base. Later in November, the bearing values on the stabilized subgrade showed practically
no change due to the additional surcharge of the surface courses. Here the indications are that a 6-inch surcharge is adequate to develop the full bearing of the stabilized subgrade material.

The next set of data in Table 10 shows the results of tests made on the stabilized base at ages ranging from 9 to 36 days. The tests at 30 to 36 days were made on top of the first 3-inch layer of base with the second layer acting as a 3-inch surcharge. Here again, curing and surcharge increased the bearing of the stabilized mixtures. The November tests on top of the base show the increase in strength due to additional curing of the base and the surcharge of the surface layers.

The results of the tests in November for the untreated subgrade and the emulsion stabilized layers are very similar, being on the order of 600 psi for the 6-inch plate and 300 psi for the 12-inch plate. The bearing values on the surface were somewhat higher, 732 and 370 psi, reflecting the strength added by the surfacing courses.

Based on the tests made on the various layers, it appears that the designed thickness (14.5 inches) of bituminous treatment was more than adequate. It seems very probable that the 6-inch stabilized base could have been eliminated, provided the subgrade stabilization was upgraded both as to asphalt content and thickness. This could have effected a saving of about $14,000 per mile on this project. The project to the north was designed along these lines with 6 inches of subgrade stabilization using asphalt cement and similar surface courses. The comparable cost of this project has been estimated at $38,000 per mile, $14,000 per mile less than the project under study. This price differential reflects the cost of the 4-inch subgrade stabilization, the cost of plant mixing over inplace mixing, the cost of hauling the 6 inches of plant mixed base material over the entire project from one source as compared to the short hauls during grading, the cost of asphalt emulsion
as compared to asphalt cement, and probably other differences between the two projects. However, it remains to be seen whether the load carrying capacities are equivalent.

Surface tests in April and June of 1960 show the effects of frost action on the strength of the road. In April, the 12-inch plate bearing values dropped to only 47 percent of those in November, 1959. This is a very serious loss in strength, however, the spring capacity was about 11 tons axle load, adequate to carry unrestricted traffic. The June test results show the recovery of strength back to 67 percent of the November strength, and the road will continue to recover until maximum strength is again attained in the fall.

On this project, more than on others, the bearing plates left noticeable impressions in the bituminous surface after the plate tests. As previously mentioned, the Benkelman beam tests disclosed the 2331 plant mixed base to be so soft that it squeezed up between the tires of the loading truck. These observations indicate that the surface courses may be somewhat soft or unstable. This was also indicated by the laboratory trail mixes which had Hveem and Marshall stabilities on the low side. In addition, the gradation of the aggregates was on the fine side of the specification range. All these items point toward the possibility that the bituminous surface courses may be "tender".

Detailed cross sections of the wearing course were taken shortly after construction, in the spring of 1960, and again in October, 1960 as a check on displacement in the wheel tracks. From the October data, a slight amount of displacement can be detected in the wheel tracks. Since there were no indications of this in the spring of 1960, it is assumed that what displacement occurred happened during the warm summer months. Future measurements will be needed to further confirm the displacement which is very minor at
this time. It is expected that this feature and others will be re-evaluated over a period of several years.

ACKNOWLEDGMENTS

The Materials and Research Section and the Research Unit in particular gratefully acknowledge the cooperation and assistance of the personnel of District 9 who provided the engineering supervision for this project. These employees took cross sections, made thickness measurements, provided construction data and generously contributed information useful in the analysis of the project. We wish to thank Mr. C. F. Welch, District Engineer, and Mr. K. A. Madole, Project Engineer, for their cooperation in arranging for this assistance.